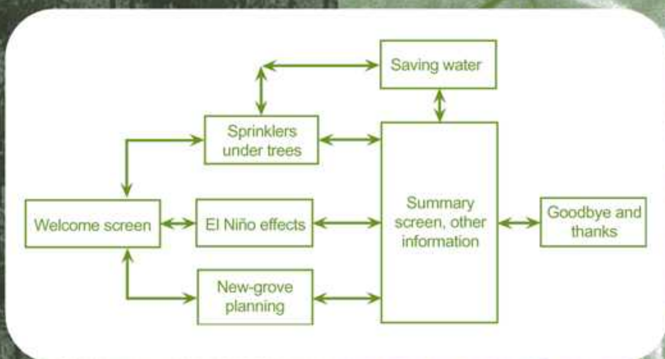
Dekker Media

Media Included

Agricultural Systems Management

Optimizing Efficiency and Performance



Robert M. Peart
W. David Shoup

Agricultural Systems Management

Optimizing Efficiency and Performance

Robert M. Peart
University of Florida
Gainesville, Florida, U.S.A.

W. David Shoup
Southern Illinois University
Carbondale, Illinois, U.S.A.

MARCEL DEKKER, INC. NEW YORK • BASEL

Marcel Dekker, Inc., and the author(s) make no warranty with regard to the accompanying software, its accuracy, or its suitability for any purpose other than as described in the book. This software is licensed solely on an “as is” basis. The only warranty made is that the medium on which the software is recorded is free of defects. Marcel Dekker, Inc., will replace a diskette or CD-ROM found to be defective if such defect is not attributable to misuse by the purchaser or his agent. The defective diskette or CD-ROM must be returned within 10 days to: Customer Service, Marcel Dekker, Inc., Cimarron Road, Monticello, NY 12701.

Although great care has been taken to provide accurate and current information, neither the author(s) nor the publisher, nor anyone else associated with this publication, shall be liable for any loss, damage, or liability directly or indirectly caused or alleged to be caused by this book. The material contained herein is not intended to provide specific advice or recommendations for any specific situation.

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress.

ISBN: 0-8247-4783-6

This book is printed on acid-free paper.

Headquarters
Marcel Dekker, Inc., 270 Madison Avenue, New York, NY 10016, U.S.A.
tel: 212-696-9000; fax: 212-685-4540

Distribution and Customer Service
Marcel Dekker, Inc., Cimarron Road, Monticello, New York 12701, U.S.A.
tel: 800-228-1160; fax: 845-796-1772

World Wide Web
http://www.dekker.com

The publisher offers discounts on this book when ordered in bulk quantities. For more information, write to Special Sales/Professional Marketing at the headquarters address above.

Copyright © 2004 by Marcel Dekker, Inc. All Rights Reserved.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage and retrieval system, without permission in writing from the publisher.

Current printing (last digit):

10 9 8 7 6 5 4 3 2 1

PRINTED IN THE UNITED STATES OF AMERICA

BOOKS IN SOILS, PLANTS, AND THE ENVIRONMENT

Editorial Board

Agricultural Engineering	Robert M. Peart, University of Florida, Gainesville
Animal Science	Harold Hafs, Rutgers University, New Brunswick, New Jersey
Crops	Mohammad Pessarakli, University of Arizona, Tucson
Environment	Kenneth G. Cassman, University of Nebraska, Lincoln
Irrigation and Hydrology	Donald R. Nielsen, University of California, Davis
Microbiology	Jan Dirk van Elsas, Research Institute for Plant Protection, Wageningen, The Netherlands
Plants	L. David Kuykendall, U.S. Department of Agriculture, Beltsville, Maryland
	Kenneth B. Marcum, Arizona State University, Mesa, Arizona
Soils	Jean-Marc Bollag, Pennsylvania State University, University Park, Pennsylvania
	Tsuyoshi Miyazaki, University of Tokyo

Soil Biochemistry, Volume 1, edited by A. D. McLaren and G. H. Peterson
Soil Biochemistry, Volume 2, edited by A. D. McLaren and J. Skujiņš
Soil Biochemistry, Volume 3, edited by E. A. Paul and A. D. McLaren
Soil Biochemistry, Volume 4, edited by E. A. Paul and A. D. McLaren
Soil Biochemistry, Volume 5, edited by E. A. Paul and J. N. Ladd
Soil Biochemistry, Volume 6, edited by Jean-Marc Bollag and G. Stotzky
Soil Biochemistry, Volume 7, edited by G. Stotzky and Jean-Marc Bollag
Soil Biochemistry, Volume 8, edited by Jean-Marc Bollag and G. Stotzky
Soil Biochemistry, Volume 9, edited by G. Stotzky and Jean-Marc Bollag
Soil Biochemistry, Volume 10, edited by Jean-Marc Bollag and G. Stotzky

Organic Chemicals in the Soil Environment, Volumes 1 and 2, edited by C. A. I. Goring and J. W. Hamaker
Humic Substances in the Environment, M. Schnitzer and S. U. Khan
Microbial Life in the Soil: An Introduction, T. Hattori
Principles of Soil Chemistry, Kim H. Tan
Soil Analysis: Instrumental Techniques and Related Procedures, edited by Keith A. Smith
Soil Reclamation Processes: Microbiological Analyses and Applications, edited by Robert L. Tate III and Donald A. Klein
Symbiotic Nitrogen Fixation Technology, edited by Gerald H. Elkan

Soil–Water Interactions: Mechanisms and Applications, Shingo Iwata and Toshio Tabuchi with Benno P. Warkentin

Soil Analysis: Modern Instrumental Techniques, Second Edition, edited by Keith A. Smith

Soil Analysis: Physical Methods, edited by Keith A. Smith and Chris E. Mullins

Growth and Mineral Nutrition of Field Crops, N. K. Fageria, V. C. Baligar, and Charles Allan Jones

Semiarid Lands and Deserts: Soil Resource and Reclamation, edited by J. Skujiņš

Plant Roots: The Hidden Half, edited by Yoav Waisel, Amram Eshel, and Uzi Kafkafi

Plant Biochemical Regulators, edited by Harold W. Gausman

Maximizing Crop Yields, N. K. Fageria

Transgenic Plants: Fundamentals and Applications, edited by Andrew Hiatt

Soil Microbial Ecology: Applications in Agricultural and Environmental Management, edited by F. Blaine Metting, Jr.

Principles of Soil Chemistry: Second Edition, Kim H. Tan

Water Flow in Soils, edited by Tsuyoshi Miyazaki

Handbook of Plant and Crop Stress, edited by Mohammad Pessarakli

Genetic Improvement of Field Crops, edited by Gustavo A. Slafer

Agricultural Field Experiments: Design and Analysis, Roger G. Petersen

Environmental Soil Science, Kim H. Tan

Mechanisms of Plant Growth and Improved Productivity: Modern Approaches, edited by Amarjit S. Basra

Selenium in the Environment, edited by W. T. Frankenberger, Jr., and Sally Benson

Plant–Environment Interactions, edited by Robert E. Wilkinson

Handbook of Plant and Crop Physiology, edited by Mohammad Pessarakli

Handbook of Phytoalexin Metabolism and Action, edited by M. Daniel and R. P. Purkayastha

Soil–Water Interactions: Mechanisms and Applications, Second Edition, Revised and Expanded, Shingo Iwata, Toshio Tabuchi, and Benno P. Warkentin

Stored-Grain Ecosystems, edited by Digvir S. Jayas, Noel D. G. White, and William E. Muir

Agrochemicals from Natural Products, edited by C. R. A. Godfrey

Seed Development and Germination, edited by Jaime Kigel and Gad Galili

Nitrogen Fertilization in the Environment, edited by Peter Edward Bacon

Phytohormones in Soils: Microbial Production and Function, William T. Frankenberger, Jr., and Muhammad Arshad

Handbook of Weed Management Systems, edited by Albert E. Smith

Soil Sampling, Preparation, and Analysis, Kim H. Tan

Soil Erosion, Conservation, and Rehabilitation, edited by Menachem Agassi

Plant Roots: The Hidden Half, Second Edition, Revised and Expanded, edited by Yoav Waisel, Amram Eshel, and Uzi Kafkafi

Photoassimilate Distribution in Plants and Crops: Source–Sink Relationships, edited by Eli Zamski and Arthur A. Schaffer

Mass Spectrometry of Soils, edited by Thomas W. Boutton and Shinichi Yamasaki
Handbook of Photosynthesis, edited by Mohammad Pessarakli
Chemical and Isotopic Groundwater Hydrology: The Applied Approach, Second Edition, Revised and Expanded, Emanuel Mazor
Fauna in Soil Ecosystems: Recycling Processes, Nutrient Fluxes, and Agricultural Production, edited by Gero Benckiser
Soil and Plant Analysis in Sustainable Agriculture and Environment, edited by Teresa Hood and J. Benton Jones, Jr.
Seeds Handbook: Biology, Production, Processing, and Storage, B. B. Desai, P. M. Kotecha, and D. K. Salunkhe
Modern Soil Microbiology, edited by J. D. van Elsas, J. T. Trevors, and E. M. H. Wellington
Growth and Mineral Nutrition of Field Crops: Second Edition, N. K. Fageria, V. C. Baligar, and Charles Allan Jones
Fungal Pathogenesis in Plants and Crops: Molecular Biology and Host Defense Mechanisms, P. Vidhyasekaran
Plant Pathogen Detection and Disease Diagnosis, P. Narayanasamy
Agricultural Systems Modeling and Simulation, edited by Robert M. Peart and R. Bruce Curry
Agricultural Biotechnology, edited by Arie Altman
Plant–Microbe Interactions and Biological Control, edited by Greg J. Boland and L. David Kuykendall
Handbook of Soil Conditioners: Substances That Enhance the Physical Properties of Soil, edited by Arthur Wallace and Richard E. Terry
Environmental Chemistry of Selenium, edited by William T. Frankenberger, Jr., and Richard A. Engberg
Principles of Soil Chemistry: Third Edition, Revised and Expanded, Kim H. Tan
Sulfur in the Environment, edited by Douglas G. Maynard
Soil–Machine Interactions: A Finite Element Perspective, edited by Jie Shen and Radhey Lal Kushwaha
Mycotoxins in Agriculture and Food Safety, edited by Kaushal K. Sinha and Deepak Bhatnagar
Plant Amino Acids: Biochemistry and Biotechnology, edited by Bijay K. Singh
Handbook of Functional Plant Ecology, edited by Francisco I. Pugnaire and Fernando Valladares
Handbook of Plant and Crop Stress: Second Edition, Revised and Expanded, edited by Mohammad Pessarakli
Plant Responses to Environmental Stresses: From Phytohormones to Genome Reorganization, edited by H. R. Lerner
Handbook of Pest Management, edited by John R. Ruberson
Environmental Soil Science: Second Edition, Revised and Expanded, Kim H. Tan
Microbial Endophytes, edited by Charles W. Bacon and James F. White, Jr.
Plant–Environment Interactions: Second Edition, edited by Robert E. Wilkinson
Microbial Pest Control, Sushil K. Khetan

Soil and Environmental Analysis: Physical Methods, Second Edition, Revised and Expanded, edited by Keith A. Smith and Chris E. Mullins
The Rhizosphere: Biochemistry and Organic Substances at the Soil–Plant Interface, Roberto Pinton, Zeno Varanini, and Paolo Nannipieri
Woody Plants and Woody Plant Management: Ecology, Safety, and Environmental Impact, Rodney W. Bovey
Metals in the Environment: Analysis by Biodiversity, M. N. V. Prasad
Plant Pathogen Detection and Disease Diagnosis: Second Edition, Revised and Expanded, P. Narayanasamy
Handbook of Plant and Crop Physiology: Second Edition, Revised and Expanded, edited by Mohammad Pessarakli
Environmental Chemistry of Arsenic, edited by William T. Frankenberger, Jr.
Enzymes in the Environment: Activity, Ecology, and Applications, edited by Richard G. Burns and Richard P. Dick
Plant Roots: The Hidden Half, Third Edition, Revised and Expanded, edited by Yoav Waisel, Amram Eshel, and Uzi Kafkafi
Handbook of Plant Growth: pH as the Master Variable, edited by Zdenko Rengel
Biological Control of Crop Diseases, edited by Samuel S. Gnanamanickam
Pesticides in Agriculture and the Environment, edited by Willis B. Wheeler
Mathematical Models of Crop Growth and Yield, Allen R. Overman and Richard V. Scholtz III
Plant Biotechnology and Transgenic Plants, edited by Kirsi-Marja Oksman-Caldentey and Wolfgang H. Barz
Handbook of Postharvest Technology: Cereals, Fruits, Vegetables, Tea, and Spices, edited by Amalendu Chakraverty, Arun S. Mujumdar, G. S. Vijaya Raghavan, and Hosahalli S. Ramaswamy
Handbook of Soil Acidity, edited by Zdenko Rengel
Humic Matter in Soil and the Environment: Principles and Controversies, Kim H. Tan
Molecular Host Resistance to Pests, S. Sadasivam and B. Thayumanavan
Soil and Environmental Analysis: Modern Instrumental Techniques, Third Edition, edited by Keith A. Smith and Malcolm S. Cresser
Chemical and Isotopic Groundwater Hydrology: Third Edition, Emanuel Mazor
Agricultural Systems Management: Optimizing Efficiency and Performance, Robert M. Peart and W. David Shoup
Physiology and Biotechnology Integration for Plant Breeding, edited by Henry T. Nguyen and Abraham Blum
Global Water Inventory: Shallow and Deep Groundwater, Petroleum Hydrology, Hydrothermal Fluids, and Landscaping, Emanuel Mazor

Additional Volumes in Preparation

Seeds Handbook: Biology, Production, Processing, and Storage, Second Edition, Revised and Expanded, Babasaheb B. Desai

Preface

With the publication of this book we are mindful of the ever-changing technology available to agriculture, the oldest industry in the world. While acknowledging the amazing improvements made possible by better hardware agricultural tools we also look forward to the future and the range of sophisticated software tools made possible by modern computer technology. We have taught these concepts at several universities, and our students have related how these tools have been very useful and have kept them in the technological lead in their professions. We believe that these concepts, current and future, can continue to be the basis of improvements in 21st century agriculture.

The emphasis of this book is on system management tools that are helpful in solving problems. For example, selecting the best capacity for an unloading facility that has a line of trucks waiting, scheduling a many-faceted project to complete construction of a facility or a particular research project, using crop growth models to determine the best amount and timing for irrigation and/or fertilizer for various areas of a field with a yield map showing differences, all involve methods and tools that are the result of the latest computer technology.

This book will be valuable to students in the general area of management of agricultural systems, whether their curriculum is specifically in agricultural systems management, agricultural and biological engineering, or another agricultural and food field. Modern technical managers in any field must be familiar with the latest computer methods of solving business problems. The widespread use of the Internet has rapidly increased the need for technological expertise in management, especially in agriculture. These techniques use up-to-date weather data, simulation of crop yields, projected harvesting dates, and market forecasting that give the user an edge in crop management.

Many topics in this book will be valuable for particular courses in agricultural engineering as well as agricultural systems management. Field and crop system simulations will be useful in power and machinery courses, showing the importance of field capacity in critical, time-sensitive operations. Machinery selection decisions should be based on a balance between timeliness and fixed costs.

One chapter focuses on reliability, an important topic in engineering design, and its value to managers as well as engineers. The material on project scheduling has been used in a senior design course for engineers to demonstrate the timing of the various steps in completing a design project. The concepts of a Gannt chart, interactions between tasks, and independence of tasks are invaluable in many real-world jobs for both engineers and agricultural systems managers. The topic of precision management is of interest in power and machinery and in land drainage courses for engineers.

The academic field of agriculture has become so complex, with the need for great depth in subjects from plant pathology to genetic engineering, that studying the system as a whole may be omitted or de-emphasized. However, real problems in agricultural production and processing require a systems view. In cotton production, for example, many weather-related factors influence the final yield. Soil nutrient level can be affected by rainfall, especially on sandy soils. Soil moisture is influenced by rainfall, irrigation, and evapotranspiration. Water costs continue to rise, and efficient use of irrigation is more and more important. Many insect and microorganism crop pests are strongly influenced by weather conditions, relative humidity, temperature, rainfall, and even the intensity and timing of rainfall. Process-based models of a crop, including the root zone and pests, can help the manager time the application of pesticides, irrigation water, and nutrients for the most efficient use of resources.

Livestock operations use modern computer programs for keeping track of animals, feed use, and weight gain. For breeding stock, this information is especially important in maintaining a record of each animal and its ancestors.

Financial record-keeping is less of a problem when computer programs are used to classify data according to various enterprises that may be used in a large agricultural operation. Income tax programs can be integrated with day-to-day operational data collection programs and are ideal for a system in which data is entered only once.

Field operations are a big issue in crop-based agriculture, and determining the size or capacity of equipment is an important decision. The manager must balance the need for timeliness during planting, harvesting, and other operations with concern about the fixed cost of large equipment. Computer programs can be found on the CD accompanying this book comparing total costs, including fixed costs of equipment and the cost of yield losses.

The rapid introduction of precision farming demonstrates another need for the systems approach. Yield monitors on harvesters show deficiencies that call for expertise in plant nutrition, drainage, or irrigation, depending on the particular problem. Computer-based methods such as precision farming raise new questions that only an integrated systems approach can solve. Problems such as these illustrate the need for expertise from agricultural economics, agronomy, animal sciences, soil science, entomology, plant pathology, and especially agricultural systems management to help integrate all these areas.

The systems approach also applies to various professionals working with growers, suppliers, marketing groups, crop consultants, and agricultural extension workers. These people are all part of the agricultural industry and should be recognized as an essential part of the overall production and marketing system.

The agricultural industry has many challenges in the 21st century to increase profitability, make environmental improvements, and choose from a wider range of marketing options, among others. We believe this book will help agricultural systems managers and the agricultural industry achieve their goals.

Robert M. Peart
W. David Shoup

Acknowledgments

We gratefully acknowledge all who have contributed material and editorial assistance. Dr. John C. Siemens, Professor Emeritus of the University of Illinois, Urbana, discusses the machinery selection optimization program in Chapter 5. The S10 program, developed under Dr. Siemens' direction at the Department of Agricultural and Biological Engineering of the University of Illinois, is included on the CD that accompanies this book. We gratefully acknowledge Dr. Siemens and the University of Illinois for their support.

We thank our very good friend and colleague of many years, Dr. Richard C. Fluck, Professor Emeritus of the University of Florida, Gainesville, for his contribution of Chapter 4.

Dr. Fred Royce, Postdoctoral Associate, at the University of Florida, Gainesville, supported us in many ways. Specifically, he edited and added material to Chapter 8, for which we are very grateful.

Dr. Robert Smith, Harare, Zimbabwe, developed Crop-Plan during his doctoral work at Purdue University, and we thank him for the use of his material and the program.

Dr. Wonsuk "Daniel" Lee, Assistant Professor, University of Florida, Gainesville, and Dr. Tony Harrison, Assistant Professor, Southern Illinois University, Carbondale, were coauthors with Dr. W. David Shoup of Chapter 12 and we appreciate and acknowledge their contributions to this important chapter.

We also acknowledge the good Lord, who smiled on us, gave us good wives and families, and inspires our work.

Contents

1

Agricultural Systems: A Managerial Overview

W. David Shoup

AGRICULTURAL SYSTEMS DEFINED

Many groups and individuals today use the term *systems* to describe some group of operational functions. Yet it would be difficult to find any definition of the word *system*, let alone an operational definition of the term *agricultural systems*. Because so much rests on measuring the efficiency or output of an agricultural system, we really need to define and identify components of agricultural systems.

The term *system* in the modern sense gained much popularity during the beginning of the NASA era of the late 1950s. Engineers at NASA needed to clearly define space travel components so they could establish the highest performance standards possible. Agricultural engineers began research in agricultural systems at about the same time. The late 1950s and early 1960s saw great advancements in technology on the farm, in processing, and in agribusiness. Today those great advancements continue at an even faster rate.

In our context, an *agricultural system* is a specified group of components, operational functions, and processes that are integrated to accomplish a well-defined purpose. *Agricultural systems managers* (ASMs) usually plan, evaluate, and adjust a system or some group of components of a system. In a complex agricultural system one can easily identify or envision systems within systems. We might call those systems within systems subsystems, but the main concern is that the system perform to the highest level we can achieve within the parameters or resources at hand. The ASM must learn quickly to manage and evaluate subsystems concurrently.

CHARACTERISTICS OF AGRICULTURAL SYSTEMS

We already stated that each agricultural system has some well-defined purpose. The purpose might be stated simply, or more often it might be stated as a group of objectives. And those objectives might include some very definite specifications or measures of performance. As an example let's consider an agricultural system that produces potato chips. The overall purpose might be to produce six 1/2-ounce bags of chips for the consumer market. However, the *well-defined* purpose for the line technical mangers of the processing plant might be production objectives of 1500 bags per hour, less than 0.05% of bags over 0.675 ounces, with less than 8.00% waste, less than 1% under 0.6355 ounces, with less than 0.5 hours line downtime per shift, less than 1 recorded human accident per 6 months, at a cost of less than $0.233 per bag, and meeting the 2002 EPA guidelines regarding odor control in the community. In real life this specification list could be much longer, involving hours of planning and discussion with managers, engineers, accountants, labor unions, and lawyers.

We could easily identify the same level of complexity in a production farming operation. The overall purpose might simply be to grow hogs for meat processing. The *well-defined* purpose might be to produce 1000 barrows, with weight range limited to 205–215 lb, loin eyes of not less than 4.14 sq in or more than 5.01 sq in, average rates of gain of not less than 1.98 lb/day, at a cost of less than $0.21 per pound, utilizing non-GMO feeds, and meeting all local and federal EPA requirements. And, once again, the real pork producers reading this chapter know that an actual specification list for this agricultural system would be much longer. This discussion of the "well-defined purpose" portion of the definition is well served by the two examples.

Looking back at our potato chip processing plant example, we know that in order to fulfill the well-defined purpose (specifications), numerous operational functions and processes need to be performed. The *operational functions and processes* are key parts of our definition. Some of those operational functions and processes involving our complete definition of the potato chip agricultural system might be:

Purchasing of potatoes
Transportation
Unloading at the plant
Storage
Grading and inspection
Sorting
Chemical wash
Storage
Waste disposal
Purchasing of frying oils
Transportation of oils
Storage of oils
Least-cost formulation of ingredients
Cutting processes
Line movement of product
Frying
Salting

Packaging/weighing
Boxing
Quality control
Pricing
Loading
Distribution and storage
Sales
Transport

In this agricultural system each operation or process might require humans, machine components, or a chemical or biological process. And each process will have management-defined parameters for successful operation. We could construct elaborate diagrams or computer programs to inspect or evaluate each component or operational activity. But our mission is to manage agricultural systems to achieve goals. To do that, we have to fully understand how each component of a system works and the interacting effect its application might have on other components and the outcome of the system. To predict those impacts, we can rely on mathematical models and tools to forecast outcomes of decision alternatives.

EXPECTED OUTCOMES OR "DELIVERABLES" OF AGRICULTURAL SYSTEMS

First, there is a real need for the system to deliver *well-defined* products. Today's consumer-oriented market demands truth and performance. A system often must meet standards either the consumer wants or governments might demand.

Let us consider the challenge a small organic fertilizer bagging plant might have. The manager must meet the desires of the company for profit, of the public for performance, and of the government for truth in packaging. The manager and the company must design a product that meets the specifications that satisfy company upper management for profit, establish product features that entice a certain market share of buyers, and meets state and federal analysis on the package label. Each fertilizer product becomes very well defined, and the agricultural processing system must meet the goals. Many people from many arenas give critical input.

It is expected that the products the production line delivers are *profitable*. Agriculture is a business Every business must in the end meet a profit goal. In this small organic fertilizer bagging business we must set production volume targets, estimate fixed and variable costs, and establish costs per bag, pricing, and target profits. If this was all there was to management of this line, it would be easy. However, agricultural systems have to satisfy many other conditions. Profitability is not enough. The product must be *safe for use*. The manufacturer must also guarantee the safety of the production workers and perhaps meet union work conditions. If the product were edible or a drug it would have to be safe for human consumption Certain aspects of quality control would have to be met and verified.

Our bagging plant would probably produce "secondary" compounds or wastes. They must be managed as well. Those processes and costs become part of the total agricultural system too. The plant is responsible in American society to maintain or enhance the environment. Or at the very least, the product must be produced at environmental costs that society (and the law) deems acceptable. It is not unusual to expect that the bagging plant system also contribute to the general community economic development and well-being.

THE PRIMARY GOALS OF AGRICULTURAL SYSTEMS MANAGERS

An all-too-common mistake of technical management is a failure to identify performance criteria against which the system must be evaluated. These criteria and their measures need to be well established before we "flip the switch" and a system begins to operate. The goals, criteria for success, and performance measurement assessment should be part and parcel of every planning process and evaluation process. These performance criteria should be established up front and agreed upon by all management. It is not unusual to see these measures as part of monthly, quarterly, and annual reports.

Some primary goals agricultural systems managers must attain are:

Optimization of economic costs, profits, and benefits
Production of defined levels of product quality and quantity
Meeting timelines and schedules
Delivery of value-added products and product attributes
Attaining acceptable process reliability
Maximization of efficiencies
Realization of environmental and regulatory guidelines
Optimization of human factors—safety, job satisfaction, performance factors, and perhaps labor union issues

Let's go back for a moment and consider our potato chip processing agricultural system. We know that the primary goal is to make chips. But what kind? How many? At what cost? In real life the plant probably has three or four production lines and four to eight products. The upper management has determined many overall goals, so consider the plight of a single line manager of the "ripple chip" processing line. What would his goals be? And what would be some of the criteria of evaluation needing assessment?

Criteria of Evaluation

Obviously, *production costs per bag* of chips would be a key criterion to evaluate, or maybe the total volume over a week, or total production in bags over the year. So *costs, volumes, and profits* are key criteria. *Efficiency* of the processes can be measured, equipment adjustments made, or replacement of processes effected. Some of the processes included truck unloading, storage, belt movement, cutting, frying, salting, sorting, weighing, bagging, and boxing. *Product quality* must also be assessed. Yes, we all like a beautiful, unbroken chip! The size, color, weight, etc can all be assessed. Storage life and condition of the package itself can be evaluated and goals set No one likes a wrinkled bag or a misprinted label. And who wants a six-ounce bag of chips labeled as seven ounces?

If we forget that the whole system must have a very high *performance reliability,* we cannot achieve any other goals. To achieve this we must *meet timelines and schedules and attain serviceability and machine replacement goals*. In a production plant we are always scrutinizing *resource utilization, waste reduction, risk minimization, performance, stability, environmental impacts, FDA guidelines, food safety guidelines,* and *state and federal regulations*. Today, food processes must meet purity and process standards.

Then there is the human element. Is the plant meeting *union agreements?* Some additional criteria for evaluation would be meeting goals in *plant safety, personnel satisfaction, health, comfort*, and *plant security*. The ASM must approach the system management from a team perspective. Many have input. Many must be informed and empowered.

It becomes quite clear that a good technical manager manages far more than money. Managing means managing *all of the resources*. The good technical manager must also consider machine replacement, new products, new technologies, and training of personnel.

FACTORS AFFECTING THE AGRICULTURAL SYSTEM AND THE ASM'S DECISION MAKING

Many factors can influence the outcome or performance of an agricultural system. The ASM's decisions can always have an impact (hopefully a positive one) that influences the system to perform to its potential. But the manager's decisions are not the only influencing factor. While it could be argued that there is an infinite number of factors, the authors would submit that there are nine other significant areas influencing change in the agricultural system's environment. These ten areas should be constantly researched by the ASM as part of the ongoing updating of the agricultural system. Together with the manager, these nine other areas of informational needs are critical to the managerial success of agricultural systems.

Changes in Weather, Seasonality, or Biological Intrusions

Perhaps the most significant and unique factor in agricultural systems management is dealing with the weather or seasonality of commodity production. In our organic bagging plant example, an unknown or unplanned warm weather span could greatly spur biological activity of stored wood chips or manure. Rising temperatures or microbe levels in the potato storage sheds would cause the potato chip manger to have to adapt to these conditions. Many processed products of agricultural systems are live biological entities requiring heating, cooling, pasteurization, sterilization, fermentation, or even radiation. Seasonal changes or unusual weather patterns can greatly change schedules in field planting of corn or harvesting of soybeans. A meat processor knows that biological processes occur in known time frames. He or she must acknowledge and respond to unusual temperatures. Processing changes must occur, or product quality is lost—or the product itself could be lost entirely. A Florida citrus grower must change processes if an unusual cold snap jeopardizes the life of a young fruit tree Or if a disease such as aflatoxin enters a corn field nearing harvest, an immediate response by the ASM is required. In production agriculture one must always be prepared to alter decisions when plant or animal diseases enter or threaten. The threat of SDS (sudden death syndrome) to a soybean crop would require changes in variety selection, planting dates, and harvest dates. Likewise, a dry year would certainly spur the ASM of a grape vineyard to engage irrigation scheduling.

The same dry year would spur the ASM of a winery to change the formulation of his winemaking process, since the soluble solids count of the grape juice would increase in a dry year. In a wet year, the count may drop and the ASM might actually add sugar to fermentation processes.

Changes in Technology

Every so often dramatic changes in technology or innovations impact the agricultural system so much that the ASM is required to completely change the components, functions, or processes of the systems. In other words, we completely change the way we do things. One dramatic example of this is the impact of biotechnology techniques and nanotechnology equipment on the development of plant seeds. The new technology completely changed how we exchange genetic information to form new varieties. Processes were changed, new skills were required, and old seed technology was rendered noncompetitive. While this new technology changed forever how we promulgate plants, it also changed how we grow them in the field Genetically modified plants are now collegial in being resistant to certain herbicides. Thus, we also have modified the cultivation and pesticide application in the production field systems of agriculture.

Changing a technological process is not the only impact of changing technology. The development of a new product can greatly change an agricultural system. The invention of the large round hay baler is a good example. The introduction of the machine completely revolutionized haymaking in the Midwest, where labor costs are high. The old system of baling hay in small rectangular bales was rendered economically noncompetitive, except in specialty markets. Likewise, another biotechnological breakthrough is allowing us to grow pharmaceutical proteins and compounds in corn. Several billion dollars a year is now generated by growing this new "Pharma" corn product, but the system of growing and handling requires new and unusual techniques in order to ensure biological security of plant growing regions "Pharming" requires many changes in the agricultural system.

Sometimes the breakthroughs can come from other industries or other countries. Agricultural industries and systems were greatly affected when other manufacturing industries began to adopt and develop different sweeteners. Corn growers benefited from high-fructose sweetener, while sugar cane growers were forced to change production methods in order to remain competitive. Better irrigation technology in Israel and Brazil forced growers of citrus in Florida, Arizona, and Texas to completely change irrigation technology to remain competitive. Some examples of technology changes of great impact would be:

- Analog/digital interfacing with microcomputers
- Global positioning systems (GPS)
- Introduction of microcomputers for data handling and controls
- Spreadsheet software
- New plastic extrusion methods
- Ethanol processing from corn
- Rotary threshing mechanisms in combines
- Ergonomic engineering of tractor cabs
- Soil conservation practices
- The cotton gin
- Evaporative cooling for greenhouses
- Hydra cooling of fruits and vegetables
- Irradiation of meats, fruits, and vegetables

The list is very long and continues to grow on a daily basis. One of new technologies having the most impact is the use of the Internet for marketing and purchasing—commonly called e-commerce. E-commerce now allows an ASM to purchase and market worldwide. Top ASMs will need information systems that allow them to be educated rapidly regarding new developments. The Internet itself is a technological addition that has had perhaps the most dramatic effect on 21st century agriculture.

Legal/Political Factors

New laws and regulations can have great impacts on decisions regarding field production, manufacturing and processing, and technical marketing areas of agricultural systems. Even without new laws, new rulings by regulatory agencies can have consequences.

Changes in the tax structure can have significant impacts on management. Throughout the 1970s and early 1980s, farmers enjoyed federal tax exclusions from an investment credit deduction. Farmers could derive great benefits that encouraged buying capital equipment such as tractors, combines, and portable buildings. Federal tax reform removed these advantages, and equipment replacement planning strategies changed greatly. Because many did not know their income status until late in the year, there was a lot of last-minute December purchasing. This last-minute buying ceased. This change affected not only farmer purchasing but the way money was spent. Manufacturing schedules, technical sales programs and activities, and managerial decisions were changed. Even tax accountants had to change their schedules of activity.

Some of the most significant laws now affect the livestock production industry. Some small rural cities now have "influence" up to three miles from their city limits regarding odor control. Many local agencies in counties now control animal unit limits. Changes in fees for grazing on public lands in the West are another example where ranchers are forced to manage differently under different rate structures.

Laws affecting migrant labor, labor camp conditions, and wage rates greatly affect the fruit and vegetable industries. The trade-off between labor and mechanization greatly changes. Likewise, Occupational Safety and Health Administration

(OSHA) regulations and labor laws impact management decisions in processing plants.

On the technical marketing scene, the North American Free Trade Agreement (NAFTA) has changed the playing field considerably. Some industries have greatly benefited, while others have suffered.

Changes in EPA guidelines and standards now have great managerial impact regarding the use of fertilizers and pesticides. Nonpoint and point sources of watershed runoff are now more controlled. The ASM must keep abreast of key local, national, and international issues. Some key governmental agencies are:

Bureau of Land Management
EPA
State Departments of Agriculture
Water management districts
Farm Services
US Forest Service
Zoning commissions
Department of the Interior
Bureau of Indian Affairs
Agricultural Plant Health Inspection Service (APHIS)
Homeland Security

The Economy

Since the events of Sept. 11, 2001, we have learned how catastrophes can send an economy reeling for many months. Numerous factors in the economy can affect agricultural systems decisions. Managers in the manufacturing and processing areas certainly must be in tune with changes in the economy. Some key factors of change include oscillating inventory levels for supplies, available disposable income, new housing starts, changes in gross domestic product (GDP), expansion/failures of businesses, price levels, and changes in exports or imports.

Today, agriculture faces many changes in marketing channels for livestock, increasing mergers of seed and chemical companies, and consolidation of equipment suppliers. Yet new opportunities abound in the emergence of alternative fuel processors and new crop initiatives.

Changing Societal Trends

Society's attitudes are constantly changing and evolving. A number of attitude changes have greatly impacted agricultural systems. Perhaps the most important has been in the attitude toward the environment. A growing spirit of conservation and preservation of wildlife and habitat has spurred numerous changes in agricultural systems management. In the early 1990s, support for the Pacific Northwest's spotted owl changed many lives. The giant logging industry, through public opinion, was forced to change its cultural and harvesting practices. The industry continues, but not until after many systems changes were implemented. Managers must look ahead and be considerate of society's attitudes or perhaps pay a larger price—being forced out of existence. Society as a whole now focuses more keenly on the affects of production practices, including biotechnology, waste disposal, water quality, chemical waste, and odor generation. Other attitude changes during the past decade have included:

Change in attitude toward the use of electronics and computing technologies
Change in attitude toward the use of credit
Change in attitude toward increased leisure time
Change in attitude toward the use of foreign products
Change in attitude toward health and fitness
Change in attitude toward cultural diversity
Change in attitude toward higher education
Change in attitude toward human and animal health
Increased desire for food safety
Increased desire for protection from terrorism

Unfortunately, many of these attitude changes have brought about increased regulation of a system manager's activities. In order for the technical manager to be successful in the long run, he or she must not limit his or her continuing education activities to technical updates alone. One must develop a good "crystal ball" by following and participating in many cross-educational activities, including local, state, federal, and international politics.

Some of these changes in attitudes have encouraged whole "new" industries. The desire for increased leisure and the desire to enjoy the "good life" have generated the new area of agritourism. Industries such as hunting preserves, fishing resorts, bed-and-breakfast inns, grape vineyards and wineries, farmers markets, maple syrup festivals, and equine events now abound.

The Competition

Someone else is always playing the same game. Decisions by the competition sometimes affect the strategy of another ASM's planning and ultimately the outcome of those decisions. Often, we may be affecting one and the same system. Awareness of what others are doing to that system is important. Competitors' decisions or actions can affect the economic well-being of other firms or entities.

The entry of new competitors does not always mean disaster for existing firms, but it can—especially if management does nothing to secure its position. A new competitor may force expansion in order to get lower cost per unit benefits. A new competitor may force the changing of hours of operation, additional investments, review of the product lines, expansion, or closures. Competition may come from foreign markets, such as lower-cost produced pork from Argentina or Brazil.

The competition's addition of a new or improved product often changes the business or management of a system. A seed company may add a new biotechnology-developed seed. A steel building system might have improved life. The introduction of retort packaging or irradiated food could change marketing, processing, or packaging systems.

Competition might introduce new selling or marketing strategies. Promotion of Angus beef might encourage growers to produce more Angus beef and less of other breeds of cattle. New marketing strategies might change how one would package the product. Or sometimes the new package itself creates the need for changes in processing.

Competition might obtain new customers, which gives them either economies of scale or a new niche market. In the late 1980s the Florida corporation Naples Tomato Growers landed the account to supply all tomatoes used by McDonald's Corporation. The security of a contracted major account afforded them a number of new managerial options.

New markets are always being sought. Competitors who might find them first win the opportunity, at least briefly, to attain economies of scale. The adoption of NAFTA opened many doors and opportunities for many agricultural industries. Clearly, irrigation sales, food equipment sales, and aquaculture equipment sales to Mexico were some of those new markets open for a short time. Perhaps one of the most exciting new markets exists in China. Without a doubt China can be America's largest new market for corn, soybeans, and other commodities.

The adoption of new, more efficient processes or management strategies can change cost structure rapidly as well. In the 1970s Japan adopted new steel-making technologies that forever changed the world industrial markets for steel. And in the decade of 2000, the American technological expansion of Internet and software technologies is greatly changing the face of all systems management.

Changes in Clients Needs

The customer is always changing, and so are customers needs. The ASM must develop mechanisms that allow timely interaction as clients develop strategic plans. Regrettably, many ASMs have become so engrossed in their own firm's plan that they simply overlook the changing needs of the customer. And before long another firm is taking care of those changing needs.

Consumer needs change constantly. A good case study is that of the consumer acceptance of genetically modified products (GMs), or products from genetically modified organisms (GMOs). European consumers and those in the United Kingdom are keenly aware of food safety issues. Their perception (right or wrong) is that GMO-developed food products may not be safe. Hence, they do not want GMO products mixed with non-GMO products. ASMs in the United States may have to change many operations, functions, and equipment pieces in order to have a food system that can deliver a 100% non-GMO product.

And Americans have grown, literally. The average American is taller, larger, and overweight. Clothes makers have to make those shirts bigger!

Changes in the ASM's or Firm's Purpose

The ASM and his or her firm is an entity that also changes, grows, adds and drops obligations, and responds to new opportunities and challenges. The agricultural system must change in personnel, functions, purpose, activities, and goals. A self-assessment process is a vital part of ongoing management of the total system.

In summary, the performance of the system is greatly influenced by the ASM's decisions. Success is determined by how well the ASM adjusts for changes in:

Weather
Seasonality
Biological intrusions
Technology
Legal and political regulation
The economy
Societal trends

Competition
Customer or client needs

TOOLS FOR PLANNING, MANAGING, AND EVALUATING

The bottom line as to whether management is good or not is whether the system is meeting performance specifications or improving. Validating that the system is on the upswing can be very difficult. Verification requires measuring and analysis techniques. To do this, a process requires a six-step loop:

1. Sensing
2. Information storage
3. Information processing and analysis
4. Evaluation
5. Decision
6. Action or change
7. And back to sensing, etc

A manager might utilize this testing process to improve the system on a weekly basis or even a daily basis. Imagine the potato chip processing line manager we discussed earlier. The chip process might be sampled and adjusted every few minutes or even seconds.

Improvement requires planning and management tools. Mathematical models are often used for planning and evaluation. Any agricultural system can be analyzed utilizing mathematical tools if it can be described logically. In most cases, approximation, record-keeping, sensing devices, electronic monitors, satellite imaging, or statistical sampling techniques will yield enough accurate data for management to begin planning and evaluation.

Quite a number of today's best technical management tools are mathematical models disguised as computer software packages. Many of those packages will be explored in the upcoming chapters of this book. Good examples are spreadsheets, linear programs, scheduling routines, and simulations. One can begin to see that the skills required to be a successful ASM have a wide range, based on the varied activities this technical manager must oversee. Managerial skills are needed in:

Accounting and finance
Organizational planning
Scheduling
Systems reliability planning
Personnel
Human factors and human safety
Environmental planning
Pricing and costing
Data information and management
Transportation analysis
Biological, chemical, and physical management
Decision systems
Systems integration
Promotion and sales planning
Legal and regulatory planning

Ideally, a strong ASM will have an academic preparation that is strong in engineering technology, the sciences, and business. The use of statistics and computer tools is paramount. Fortunately, there are many good software packages today to assist the ASM And the Internet can be an excellent source of current information The upcoming chapters will tie some of today's common agricultural systems challenges to a problem-solving framework utilizing some of the more popular mathematical models and contemporary software packages available today.

2

Reliability of Agricultural Systems

W. David Shoup

The goal of every agricultural systems manager (ASM) is to develop a total system that functions without fail. We know that this is an unobtainable goal, yet we strive to approach this by setting a goal of some successful percentage, such as 97% of the time the system operates as we need it. In order to obtain a high reliability for a system we must set a reasonable goal and plan for how to get there. The planning involves analysis of each component and function of the system. Then we consider what devices are replaced, which require backup, and how much we can afford to spend on our way to attaining the system reliability goal.

Measuring performance of a system can be done in a number of ways, all depending on which of the criteria we wish to evaluate. The technical manager spends a high proportion of time attempting to evaluate and improve performance–trying to reach those goals that have been agreed upon. As agricultural systems have become more complex, the need for understanding and quantifying a system's performance reliability has increased.

DEFINING RELIABILITY

Every agricultural system can be viewed as a group of processes and components (including humans) that must perform satisfactorily and in a timely fashion in order to achieve the output we have specified. Within our context we shall consider *reliability* to generally mean the probability that our system performs successfully. And we as managers will predetermine what "success" is.

We will now explore some of the management implications of our working definition of *reliability* within the context of agricultural systems. In production management reliability is most often viewed as the probability that the system will perform satisfactorily when called upon under specified conditions. Thus, reliability of a system, a subsystem, a function, or a component is measured in terms of probabilities. Quantitatively, a component or system is expressed as .9999 or .94 or some positive value less than 1.00. It should be noted that not all of the system components necessarily have to perform at the same time, but each component must operate at the proper time for a sufficient period of time to ensure that the system accomplishes its purpose. Operation of the jet propulsion engine on a space shuttle launch is a good example. The engine has to perform for only a few critical minutes in the proper way to be deemed successful.

A critical part of the definition of *reliability* is the "specified conditions" under which a unit or component is to function. Systems that would perform under all extremes of heat, dust, humidity, poor field or manufacturing conditions, vibration, and mismanagement and all possible conditions would be ideal—ideal but not very realistic. *Systems must be evaluated within the limits of their intended use*. These conditions should be explicitly stated or recognized before evaluating the performance reliability of a system. For example, it would not be a fair evaluation to state that the reliability was poor if a citrus harvest system failed because the hydraulic lift truck for moving pallets was stolen, or if a computer designed to operate in an air conditioned working environment failed because it was exposed to 125° temperatures in an incubation chamber. It is the job of the technical or agricultural systems manager to assist in planning and in setting needed, reasonable expectations. Some critical processes may require component performances of extremely high reliability (launching astronauts, embryo incubation, refrigeration, evaporators, etc.).

The words *perform satisfactorily* also carry great signifi cance in the definition and in understanding the performance reliability concept. Tolerances must be specified so as to establish what *acceptable* reliability means. From the very beginning of the existence of a system degradation begins. As each component within the system ages, wears, or depletes with use, the output or system performance begins to vary. For a substantial period the variance may be so minimal that it is not worthy of notice. Eventually the system may continue to function, but not at an acceptable level. A corn harvesting system consisting of a combine, tractor, wagons, augers, bucket elevators, grain drier, and storage bins is a good example. As the combine ages, field losses of grain increase. As the augers and bucket elevators wear, grain kernel damage increases and system flow rates decline. Drying rates may increase and fuel costs rise. There eventually comes a time when the unacceptable level is reached and the system is deemed no longer reliable. One day the value may be .91 and the next day it can be deemed inoperable (zero). The manager can elect to replace components, change the system, get backup units, or even hire another system to perform the task.

Setting the acceptable levels of performance of various components is not always easy. First, one must recognize what criteria are typical. The following criteria often need acceptability levels established in field production agriculture:

Speed of operation
Crop loss acceptability
Quality and condition of crop
Timeliness of completion date or times
Cost–profitability trade-offs
Field efficiency
Capacity of each system needed

To dwell on this topic of acceptability for just a moment, we might consider a farmer evaluating the levels of acceptability regarding capacity of his soybean harvest system. Due to the limited days of good weather in his Midwest fall season, he may know that his harvest system must maintain the overall daily capacity of 55 acres per day. If harvest capacity is less, he does not get all of the crops in before the snow arrives and ends the season. Low reliability or high *downtime*, as he may phrase it, would not be acceptable. Likewise, a corn producer must view the quality of the harvested crop. It would do no good to continue running a combine if the threshing unit had become so worn that the machine produced a crop with 20% of kernels cracked. The crop would be evaluated poorly when graded at the grain terminal and deemed a very low market grade (sample grade would yield a very low price)!

In biological processing, packaging, or food processing, added factors such as the following could be determinants:

Percent loss
Yield
Critical time durations met
Cost per unit
Food quality
Food safety
Contamination
Cost of rework

Let's suppose a pecan processor is making bagged, crushed nuts for a candy manufacturer. The pecan processor delivers several truckloads of nuts. It is found that the nuts contain many pieces of shell. The candy manufacturer rejects the product (they do not want lawsuits from customers who break their teeth). If it is found that the screening devices are no longer capable of use because they are too worn, then the reliability of the processing line becomes zero.

HUMAN INTERACTIONS

Most agricultural systems consist of mechanical equipment and humans. In some cases biological, chemical, or physical processes are components as well. Humans are often required for planning, initiation, maintenance, operation, vigilance, ending operations, or any variety of tasks. They may provide the "backup" to any number of potentially failed components.

If one considers only equipment or process factors in systems planning, then one is assuming operator performance to have the probability of $r = 1.00$. Obviously, the reliability of humans is not perfect, or 1.00. Leaving out the valuation of human elements would give grossly inflated systems reliabilities, as often happens. However, the proper management of human interaction can lead toward exceptionally high systems reliability, as we will see later in this chapter.

Humans are much more complex than any machine or process used in agricultural systems today. The challenge of duplicating higher human functions such as perception, recognition, and decision making has just begun, through artificial intelligence algorithms and electronic circuitry. The field of robotics is still expensive and in its infancy.

Human limitations are numerous. They are less stable than machines and are influenced by and more responsive to the work environment. Human performance is affected by physiological conditions, fatigue, noise, incentives, rewards, previous learning, and conditioning (good and bad). However, thanks to the study of human factors, or *ergonomics*, it is possible to treat human operators mathematically, as one does for other components and processes as we estimate reliability of systems. In terms of inputs and outputs, a common descriptive language exists from empirically derived research. This permits a mathematical treatment that can be applied to man, machine, or processes. We will return to this topic.

ESTIMATING THE SYSTEMS RELIABILITY VALUES

There are many questions for which estimation of reliability can assist in providing technical management answers. Always remember: *The system must work when you need it*. If it doesn't, all other aspects of a system are irrelevant. Here are just a few of the decisions that quantification can help answer:

What percent of the time does this system really work?
Which machine should be replaced to gain reliability?
Should a new machine (or person) be purchased, or can a used machine be utilized?
If other machines are available for "backup," how will this affect performance?
How many "backup" units are needed?
Which is more profitable—renting, buying, or leasing?
Will the system work if a particular unit fails?
How does the human operator or manager in the system affect the probability of success? Do we need more management or less?
How much will I gain in efficiency and capacity by increasing reliability or decreasing it and saving costs?
What level of reliability is economically acceptable?

Production managers, salespersons, service personnel, and design engineers need to fully understand that system reliability is inherently the absolute bottom line in selecting equipment, people, and resources. Granted, selections are often made for other reasons (economic, safety, etc.), but reliability must *always* be at an acceptable level.

Estimating System Reliabilities

Components in Series

Many agricultural systems are arranged in series. The successful operation of a series system depends upon the successful performance of each and every component in the system: man; machine; or process [1]. Two conditions often exist: (1) Failure of any given unit results in a complete system failure, and (2) the component failures are independent of each other. Gordon showed that in series systems the probability that a system operates acceptably is the product of the reliabilities of the individual units or components [2]. If, for example, there are three components in a system, each with a reliability of 0.90, the reliability of the system would be a product of the three, or 0.729. Lusser presented the original formula for sequential events as:

$$R_{\text{system}} = R_1{}^{*}R_2{}^{*}R_3{}^{*}\cdots{}^{*}R_n \qquad (2\text{-}1)$$

where $R_1, R_2, R_3, \cdots, R_n$ are reliabilities of individual units expressed as a probability (fraction) of successful functioning based on history or estimates [3].

The inherent weakness of most agricultural systems is the sequential nature, leading to overall low system performance reliability [4]. Think of a simple wheat harvesting system consisting of a tractor (0.90) to pull a wagon (0.90) that the combine (0.85) unloads into a storage tank (Fig. 2-1). The system reliability is only 0.6885. One unit fails and the whole system stops.

As more units are added to an agricultural system, each unit must be very close to unity (1.00) if the system is to re-

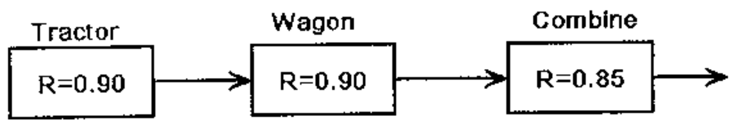


Figure 2-1 Three units in series: R_{system} = 0.90 * 0.90 * 0.85 = 0.6885.

main acceptable. There are three possibilities for improving a system:

1. Replace components of lowest reliability with higher-valued units.
2. Use only components of high reliability (new equipment).
3. Use redundant components (provide dedicated "back-up" units).

Components in Parallel

With parallel units, there are two or more that are performing the same function or are available to perform the same function at any particular time. This is referred to as either "backup" or *redundancy*. NASA missile research showed that parallel system reliability of like units can be estimated by combining the probabilities of unit success (reliabilities) of the individual units using the following formula [2]:

$$R_{\text{system}} = [1 - (1 - r)^m]^n \tag{2-2}$$

where

m = number of components in parallel for each function
n = number of functions the unit must perform
r = unit reliability

In a completely parallel arranged system, identical components would be used independently, either physical machines or human operators, as the case may require. Suppose one were baling hay and a tractor is needed to pull and power the baler. The farmer needs only a single functioning tractor at one time to pull the hay baler. However, if he had two identical tractors, both available 100% of the time if needed and, say, with unit reliabilities of 0.90, the joint probability of having a tractor available to pull the baler would be (Fig. 2-2):

$$\begin{aligned} R_{\text{tractor fuction}} &= [1-(1-0.9)^2]^1 \\ &= 0.99 \end{aligned}$$

Thus, even with relatively low component reliabilities such as 0.70, a system with four units in parallel could achieve a system reliability of 0.992. In some systems the components could be very different types, such as a human backing up a machine unit, or vice versa.

Achieving redundancy, or "backup," in a system can be accomplished in several ways. Some common management alternatives are:

Purchasing another machine
Borrowing a "backup" machine when needed
Using a unit from another operation
Leasing another unit
Renting another unit
Assured availability warranty from manufacturer

Equation (2-2) is very useful because it expresses the real world of agricultural systems fairly well. The equation, how-

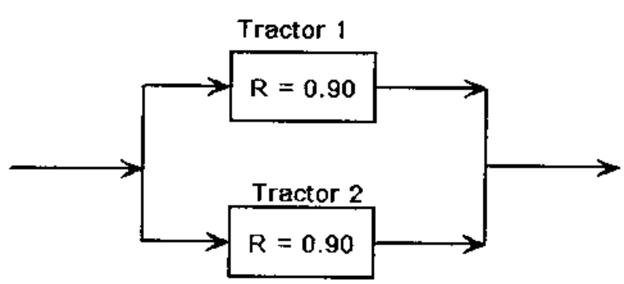


Figure 2-2 Parallel identical units: $R_{\text{sys}} = [1 - (0.1)^2]^1 = 0.99$.

ever, applies only where the components in parallel for each of the n functions is exactly the same and unit reliability of each component is the same. Where these conditions do not apply, the derivation becomes more complex. And in reality it is rare to find two components or processes that are identical. For example, a new tractor may be in use with a reliability value of 0.95; but if the new tractor were to fail, the manager might bring in the old tractor from the shed (0.78) to back the newer unit up. This situation is very typical in field production agriculture and processing. Complexity occurs in deriving a set of equations, since the selection of the first unit is a parameter open to management. An iterative technique is essential.

Heterogeneous Units

Redundant units in parallel possessing different reliability values can be termed *heterogeneous* backup units. An iterative technique would work as follows: For the components in parallel, select the first. If the system only had that one, that subsystem reliability, R_s, would be equal to that of the component, R_1. The reliability of the subsystem that included both components 1 and 2 (call it $R_{s(1,2)}$) would be the probability that the first unit functions (R_1) plus the probability that the first unit fails ($1 - R_1$) and the backup unit functions (R_2). These last two reliabilities are multiplied to get the reliability of the backup system's functioning. Therefore, the reliability of the the subsystem with a heterogeneous backup unit is

$$R_{s(1,2)} = R_1 + (1 - R_1)^* R_2 \qquad (2\text{-}3)$$

and for three parallel components is

$$R_{s(1,2,3)} = R_{s(1,2)} + (1 - R_{s(1,2)})^* R_3 \qquad (2\text{-}4)$$

Thus a general form would be

$$R_{s(1,2,3,\ldots,\mathrm{n})} = R_{s(1,2,\ldots,n-1)} + (1 - R_{s(1,2,\ldots,n-1)}) R_n \qquad (2\text{-}5)$$

Suppose two tractors are in parallel to form some subsystem. Let's say that tractor 1 has a unit reliability of 0.90 and unit 2 is 0.78 (Fig. 2-3). Using Eq. (3), the reliability calculation would be:

$$R_{s(1,2)} = R_1 + (1 - R_1)R_2$$

Assuming Tractor 1 is selected first,

$$R_{s(1,2)} = 0.9 + (1 - 0.9)^{*}0.78 = 0.978$$

A Production System Example

The dynamics of production agriculture systems can become quite complex. Tractors may back up several subsystems, performing several functions, or be unable to serve as backups because of incompatibility of components or unmatched horsepower requirements. Reliabilities seldom are identical. The best approach is to calculate reliabilities for each subsystem separately and then to combine the subsystem values to attain the complete system reliability.

Suppose farmer A had two enterprises: dairy and peanuts. To some extent, the two separate agricultural systems must share equipment, such as tractors. Farmer A must recognize

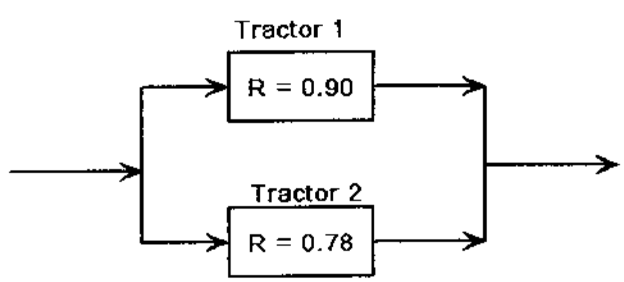


Figure 2-3 Heterogeneous parallel machines: $R = 0.90 + 0.10 * 0.78 = 0.978$.

the strengths and weaknesses of this arrangement. Let's analyze farmer A's peanut harvesting operation, as shown in the following table and Figure 2-4. Suppose it consists of a large tractor pulling a peanut combine. A wagon attached to the combine receives the peanuts. Another small tractor pulls the wagon away, empties the load and returns just in time to exchange wagons with the combine unit. The iterative process assumes that the unit of highest reliability is always used first. This is the usual management situation.

Farmer A's System

Subsystem	Machinery available	Reliabilities
1	1 100-hp tractor dedicated to pulling combine	0.83 each
	1 100-hp tractor backs up pulling unit, small tractor in subsystem 5, and tractor working at the dairy operation	
2	1 peanut combine and	0.85
	1 backup combine	0.72
3	1 wagon behind combine	0.90
4	1 wagon behind tractor	0.90
	1 extra wagon to back up either subsystem 3 or 4	0.90
5	1 40-hp tractor to pull wagon cannot back up 100-hp tractor	0.85

The calculations of each subsystem would be as follows:

Subsystem 1. From Eq. (2-3):

$$R_{ss1} = 0.83 + 0.17 * (0.83)^3$$
$$= 0.9272$$

Subsystem 2. From Eq. (2-3):

$$R_{ss(1,2)} = 0.85 + (1 - 0.85) * 0.72$$
$$= 0.9580$$

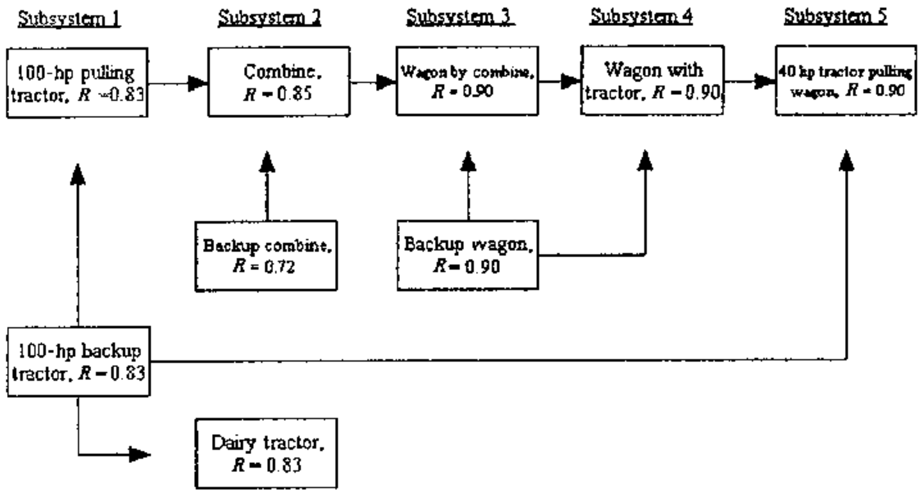


Figure 2-4 Peanut combine system with backups.

Subsystems 3 and 4. The added backup wagon is the same as having three wagons that must perform two functions. Thus, from Eq. (3):

$$R_{ss(3,4)} = 0.90 + 0.10(0.90)^2$$
$$= 0.9810$$

Subsystem 5. From Equation (3):

$$R_{ss(3,4)} = 0.83 + (1 - 0.83)*(0.83)^3$$
$$= 0.83 + 0.0972 = 0.9272$$

Total System. From Eq. (1):

$$R_{system} = 0.9272*0.958*0.9810*0.9272$$
$$= 0.8079$$

The iterative processes assume that the unit of highest reliability is always used first. In fact, one can see that doing otherwise might greatly diminish system reliability. The old philosophies of "I'll use the old ones first" and "I'll use the old ones 'until they wear out" simply do not pay.

Estimating Values of Individual Components

Just how does one attain the reliability values for machines, components, and functions? Absolutely the best way is to keep records on these units. Fortunately, computers and spreadsheet software make this task much easier today. Line foremen can record downtimes, as can mechanics or service managers. In the case of agricultural field machines this is certainly "doable." One of the world's largest field production sugarcane growers actually tracks each field machine and keeps a life record via computer database. A farmer could keep uptime and downtime records on a spreadsheet.

In the case of processing plants, maintenance records often exist, and data estimates can be made by "recouping" the past information on items such as blenders, mixers, conveyors, bagging machines, and chemical processes. Where no life records exist, a good manager can collect sample data using good statistical techniques. Data can sometimes be gathered from other plants or the engineering firms producing the devices.

The literature in processing journals does contain some reliability data. And when all else fails, an ASM could interview users of the machines and processes to backtrack in time to find failures and downtimes. The real bottom line is that attaining accurate unit reliability data requires forward planning. However, the effort to attain the data will yield great rewards in system performance.

Estimating Human Component Values

Many situational factors affect human performance. Operator unit reliabilities can range from zero to 0.99999 reliability. It becomes quite difficult to develop generalized relationships. The trade-off considerations that can be applied are consequently qualitative. Costs, hazards, state of the technology, and other factors often influence the human role in an agricultural system. It was also shown that the reliability in a space system with a maintenance person available could be higher than that of the same system with automated devices [1]. As monitor or "fail-safe" unit, humans can seldom be rivaled by equipment. The following illustrates the trade-offs that exist with use of humans.

Human long-term unit values seldom exceed 0.78. This is because there are so many time deductions one must make. Ignoring time lost for weekends and hours beyond 40 per week, the following lost time applies:

Sick time
Late time
Vacation time
Family leaves
Strike time
Break times
Other

Humans are also subject to errors from repetitive tasks. The value assigned to human subjects varies greatly, depending on how they are inserted into the system. With proper managerial planning and backups, the values can be very high.

Let's take a closer look at the true value of a human in an agricultural system. Suppose a woman operates a bagging machine in a line operation that produces bags of garden mulch for the Super Duper market outlets. In a year, if she worked an eight-hour day, five days a week, she would need to be available 2080 hours per year. But she is not likely to be able to deliver this. Consider the following time losses:

Activity	Hours lost
2 weeks of vacation	80
Holidays (11 days)	88
Family leave (5 days)	40
Break times (40 min/day)	143
Late/tardy (1 hr/wk)	50
Sick (7 days)	56
Total time lost	457 hours

$$\text{Total time lost (\%)} = \frac{457}{2080} \times 100 = 21.97\%$$

$$\text{Approximate reliability} = 78.03\%$$

The first reaction would be that this is unacceptable. But, this is just being human. It would be easy to develop a much worse scenario for an employee. So how does the plant manager cope with labor on a line that might involve 20 or more employees?

First, let's assume that the manager could back up this employee with another available employee. The manager might call in another qualified individual off-shift. Or maybe there is a pool of employees available. The calculation would be

$$R_{\text{bagger}} = 0.7803 + 0.7803(1 - 0.7803) = 0.9517$$

We can see that by having a backup available raises the reliability of the human component to 95.17%.

In some cases humans might be replaced by machines having higher reliability values. Or, in all fairness, maybe we should replace some machines with humans. It could be cheaper!

Managerial Implications

The use of parallel or redundant units becomes a very important factor in production management decisions, such as deciding what unit to replace and whether to buy new or used equipment. Reliability and machinery labor costs are clearly traded off to attain some acceptable level of performance.

It becomes clear that the use of redundant subsystems is often more economical than simply purchasing new units with higher reliability. Comparisons between ownership and operating cost of new purchases versus several older units and their maintenance and repair operating cost are necessary. Leasing and rental units must also be considered. Individuals or corporations “starting out” or with limited capital obviously have some alternatives that may be quite viable.

The human operator can be used to great advantage. If inserted properly into a system, reliability can be increased several-fold to save capital outlay.

Weighing the Cost of Attaining System Reliability

One can come to the supposition very quickly that most system’s must achieve a 0.95 total reliability or better to be considered “successful.” There are almost always alternatives. And each alternative has its costs. The decision could be driven by how to get an acceptable system reliability for the lowest cost. Let’s consider a struggling college graduate, Bob, desiring to farm. He owns an older combine of unit reliability of 0.88. He knows this is not good enough. So what are his alternatives? Suppose his dad is willing to allow Bob to use his new combine of 0.96 reliability as a backup, but only when he is not combining himself. The calculation would be

$$R_{\text{combining}} = 0.88 \times (1 - 0.88)0.96^2 = 0.9905$$

Now, if good old dad is generous and does not charge Bob, this is a no brainer. Use dad’s combine as a backup! (See how much smarter dad is now?) Each method of backup could have another opportunity cost. Here are some other alternatives:

Alternative	Depreciation cost
Buy a new combine	$ 45,000
Purchase a used backup	15,000
Lease a new combine	35,000
Rent a backup	?
Hire a custom operator to harvest and sell the old combine	?
Steal a new combine (maybe you would not want to do this)	?

In a processing situation some devices might be extremely expensive, such as a reactor in an ethanol processing plant. The backup alternative may be maintaining an extensive parts inventory or even an emergency contract with an engineering firm to perform immediate services.

Another alternative is to introduce the concept of scheduled repair versus maintenance. Suppose the huge sugarcane harvest system has hundreds of tractors. Based on past records, the managers may know what breaks down and when. They might actually shut down the operation of units with higher hours and rebuild the transmissions, hydraulics, and engines before they break down. This might be expensive and require a larger pool of tractors, but it might be cheaper than buying new units or stocking even more backup units. This concept is often used in situations where downtime is either extremely expensive or critical (no one wants their army tank to break down during battle)! Or the grain elevator operation does not want the bucket elevator to break down during a key harvest period. In any case, the ASM needs to be a true thinker! This type of evaluation and trade-off consideration should be ongoing. Arguably, reliability planning could be the most important agricultural systems decision—but the one most often neglected.

REFERENCES

1. McCormick, E. J. Human Factors in Engineering and Design, 4th ed; McGraw-Hill: New York, 1976.
2. Gordon, R. Optimum component redundancy for maximum system reliability. Operations Research 1957, 5, 229–243.
3. Lusser, R. The notorious unreliability of complex equipment. Astronautics 1958, 3(2), 26, 74–78.
4. Shoup, W.D. Predicting performance reliability of machinery systems. Agricultural Engineering, ASAE 1983, 64(12), 19–22.

3

Data Management and Spreadsheet Fundamentals

Robert M. Peart

INTRODUCTION

All applications of mathematical methods for agricultural systems in this book require use of the computer, so you need to be familiar with the modern personal computer. We use the terminology of Microsoft Windows®, but most of it also applies to other types of hardware and other operating systems, such as Unix®, Linux®, and the Apple® Operating System. This chapter reviews the software that will be used, beginning with the basics of file systems on the computer and applications versus data. Then the spreadsheet is covered for the reader not experienced with its use, because over half of the agricultural systems management methods in this text use the spreadsheet.

The widespread use of the Internet, the World Wide Web, and e-mail is making a big impact upon the way computer applications can aid the agricultural systems manager. One of the most significant parts of this truly worldwide system is the availability of current data that are of value to the manager. These include weather data, price information, and crop condition reports. Weather data are especially valuable when crop models and pest models are available to make simulation runs. With the grower's own soil and crop information, these models can help the manager make up-to-date decisions. Managers need to know how to use these applications and where the various files for data and for the computer programs are located for use either online or in a stand-alone mode after current data have been downloaded.

Between the writing of these words and your reading of them, versions of operating systems software will have changed, so our brief discussion of the computer will not get into specifics that may have changed (and which you probably already know). However, the concept of *files* that are kept within *folders* somewhere (on your hard disk, a removable disk, or a network server computer that has disk storage space for you) is crucial. Beginners need to remember, when working with files, to *save* them, even while they are being written, in a logical way so that they may be organized; and remember the three-character extension following the dot, which identifies the type of program that was used to produce the file. For example, the name of a word processor file produced by WordPerfect® will be followed by *.wpd*, while a spreadsheet file from Excel® will have the *.xls* extension. If you change this extension, the computer will not know that the file is for the original program used to produce it.

The general concept of *data* is important.*

---

* An aside to students: *Data* is one of those words you need to use to remind your friends back home that you have been to college. And one detail that most people do not know is that the *data* is a plural noun, not singular. Thus it is correct to say, "The data are correct."

Your computer probably has a spreadsheet program, such as Excel®. That program consists of many different files within your computer, but the general view of the program as a separate thing is that it is an *application*. When you examine your list of files with the "My Computer" or Windows Explorer" programs, the main operating files for Excel will be listed as "Applications." The file that is generated when you type numbers or words into Excel and save them is called a *data file*. Once you have started to develop a specific spreadsheet program and you save it, which you should do shortly after you start, the file that you have created is a data file. If you are using Excel and name the file *Problem1*, the data file is listed as *Problem1.xls*. Also, if you obtain weather data from an on-line weather service, that file is also considered data.

Downloading of data files or programs from the Internet is becoming more useful as time goes on, and it is getting faster. At this writing, the computer in my home is downloading (with a 56-Kb phone modem) a program at the rate of about 3000 bytes per second (3 Kb/sec), and it has taken over half an hour (tieing up my phone), to receive the 7.42 megabytes of the file that have been downloaded so far. With a cable modem or a DSL fast phone modem, this would take only a few minutes, perhaps 2 or 3. So with these faster access rates, we will be making much more and faster use of the internet. This is more costly, but it will make the World Wide Web even more amazing. More and more programs, trial copies, shareware, and full-fledged commercial programs are being delivered this way, rather than via mail on a compact disk (CD).

We will probably be running more programs that are not on our own computer with this faster system. In fact, we do that now, but it is slow. Currently there are a few online weather data providers who will accept farmer/grower information over the Internet, combine it with weather data from that grower's location, run the program, and return to the grower, online, a recommendation, such as "wait a week before spraying the fungicide." So in this case, the user has sent in some data, and the weather company has collected a weather data file from somewhere near the grower's field and provided a simulation program or knowledge-based program to obtain an answer (another file) for the grower's current concern.

A simpler example of running a program that is on a different computer somewhere on the Internet is ordering something from a company on the Internet. You go to their Web site and click a few buttons indicating you want to order something. Then you fill out a form, probably including your credit card number. The computer program on their end of the line accepts this information, probably checking that all the blanks have been filled in properly, and then replies that the order has been accepted.

In this book, we will be using several types of applications or programs—word processors, spreadsheets, graphics, presentation programs, and project management tools. However, the emphasis will be on the problem and the method of solution, not on the details of the computer application. For example, we will be presenting the concepts of crop simulation utilizing a spreadsheet such as Excel® or QuattroPro®. We will emphasize the idea that each row represents a time period—a week, for instance—and each column represents a process variable, such as soil moisture content or total leaf area. The formulas for calculating the new weekly values for each of these variables are presented, and the logic of the process (such as additions and deletions from the soil moisture) is presented.

With this book, you are provided a CD with many data files for various programs you will use, including color graphics files related to yield maps. You will also be able to update these files on the Web site for this text.

THE ELECTRONIC SPREADSHEET

The development of the electronic spreadsheet represented a powerful driving force in the rapidly increasing use of personal computers, even before the first IBM PC was introduced. Suddenly, small businesses and farmers had a tool they could use to do bookkeeping more easily. The *spreadsheet*, or *worksheet* (as the electronic version is called), is the basic document for capturing business data. It is composed of rows and columns upon which the data are entered. The paper version comes in standard forms with 7, 13, and 25 columns. The spreadsheet tabular format is a natural way to present many different types of business and scientific data. Just look at such diverse items as accounting journals, ledgers, time sheets, order forms, invoices, financial statements, tax tables, and even baseball and football standings for examples of the widespread use of the row/column format for data organization.

Both paper and electronic spreadsheets contain three types of information: *text* entries (as labels for identification), *numbers* (to represent numeric data), and *formulas*. On paper, the formulas are not written, but are implied. For instance, a column of numbers is added to yield in the total entered at the bottom of the column. In an electronic spreadsheet, the formula is written in the cell designated for the total, but it is not shown, and the number itself fills the cell. Usually the columns of numeric data are related. That is, one column of data is calculated from a previous one on the basis of the formula that has been entered into the cells in that column. The row/column layout makes calculation and posting the intermediate and final results very convenient.

Think of the spreadsheet as composed of *cells*, with each cell placed at the intersection of a column and a row. To make it easy to talk about an individual cell (see Table 3-1), we give it an *address* made up of the letter indicating the *column* and the number indicating the *row* of the cell. So the cell in the 3rd column from the left and the 4th row down is C4.

Just as on a paper spreadsheet, we can write numbers or text, sometimes called *labels*, in a cell. However, the real power of the electronic spreadsheet is its capability to have a formula in a cell. This formula can contain numbers, but it can also hold references to other cells. For example, we might write a

Table 3-1 Sample Spreadsheet, Cells A1 . . . F8, Inventory

Col. A	B	C	D	E	F
Row 2	Name of Item	No.	Value Each	Total Value	Comments
3	IBM Computer	2	$1,600.00	$3,200.00	Could be upgraded
4	HP Laser Printer	2	$400.00	$800.00	3 yr old
5					
6					
7					
8	Total			$4,000.00	

formula in cell D2 to take 12% of the sum of the numbers that have been entered into cells B2 and C2:

$$= 0.12*(B2 + C2)$$

This is a very powerful tool, as you will be demonstrating. With a little experience, you will be able to do a spreadsheet like this in about 10 minutes with QuattroPro or Excel. With this spreadsheet, you could fill in row 5 with information about other items in the inventory, and the spreadsheet would multiply the number you put in column C by the value of each item you put in column D, and it would enter that in column E, row 5. What follows is a brief outline about the spreadsheet, probably the most widely useful computer tool ever invented! We will try to be specific about what you can enter in the cells and especially about QuattroPro, although Excel is very similar.

Column–Row Matrix Notation

On a spreadsheet, you might have on screen about 20 rows, divided into some 9 columns, though this is variable. Each of these parts of a row is called a *cell*; your cursor moves from cell to cell, instead of moving 1 space at a time, as in a word processor. These cells are identified by their column–row, such as B3 for the second column from the left and the third row down. In Table 3-1, the words "IBM Computer" are in Cell B3.

Three Types of Cell Entries (see Table 3-1)

Numbers: Cell C3 contains the number 2.

Text, or labels: Cell F3 contains "Could be upgraded."

Formulas, or Functions: Cell E3 contains "+C3*D3," but it is hidden, and only the result, "$3,200.00," appears in the cell. With the cursor on cell E3, I typed in "+C3*D3." That appeared only at the top part of the screen, not in the cell. When I entered 2 in C3 and 1600 in D3, the spreadsheet entered $3,200.00 in cell E3. That is not so great, but you can easily copy that cell with the formula for as many rows as desired (the spreadsheet itself automatically changes C3 and D3 to C4 and D4 in the next row down when you copy the formula), and the results automatically appear whenever columns C and D are filled in with numbers. That is really powerful, when you consider the variety of complex formulas that may be used!

How Does the Computer Know?

The QuattroPro, Excel, and MS Works® spreadsheets operate by slightly different rules. But usually, when the first character entered in the cell is a number, the spreadsheet expects the cell to contain a number. If you want a number but want it treated as text (such as a product catalog number), enter an apostrophe (') or a space first.

An exception to this occurs when numbers are entered as the first character in a formula, such as 7 − (B3+C3). Spreadsheets accept dates written in the following formats: MM/DD/YY and MM/YY (among others), so if no math symbol (+, − , / or =) precedes an expression beginning with a number, then the spreadsheet usually treats it as a date or text. Therefore, the way to enter the given mathematical expression is with + or = first:

$$+7 - (B3 + C3) \qquad \text{or} \qquad = 7 - (B3 + C3)$$

When the first character entered is alphabetic (or a space), the spreadsheet knows it is text and will not try to compute anything from it. When the first character is a math symbol, such as +, −, or =, it knows you are entering a formula.

An important exception to all of the foregoing is the *Format* menu, which allows you to set a cell or a group of cells by treating the input to that cell as a date, as text with your choice of type font, coloring, and shading of the cells, or as currency with the dollar sign included.

What You Should Be Able to Do with the Spreadsheet

Many of the features you learned for Windows are also applicable in Excel, MS Works, and QuattroPro. Nevertheless, there are a number of new things you need to know, some of which have already been mentioned and others of which are covered by the spreadsheet "Coach" or tutor or online help. Here are the topics with which you should become familiar.

Feature	Coach topic
Entering data:	Entering and editing data
Labels	
Numbers	
Formulas	
Dates	
Specifying blocks with the mouse	Essentials
Copying:	Modifying notebooks
Cell to cell	
Cell to block	
Adjusting individual column width	Modifying notebooks
Formatting data	Modifying notebooks

Other Spreadsheets

Excel®, the Microsoft spreadsheet, is part of the Microsoft Office® so-called "suite" of commonly used office software, including word processing, spreadsheet presentations, e-mail, and Internet browser. Corel has its own suite, WordPerfect Office®, including QuattroPro as the spreadsheet and of course WordPerfect as the word processor. More of our work in this book will pertain to QuattroPro, but most of the same procedures also work with Excel. Office "suites" of software are available from Lotus® (IBM), as well.

At one time, Lotus, an early spreadsheet software company, successfully sued companies that had developed spreadsheets that looked like Lotus 1-2-3®. Borland, the original maker of QuattroPro, lost such a suit and had to remove the features they were infringing.

A Word About Ethics

The Lotus/Borland suit brings up the subject of ethics, and we get down to the nitty-gritty in the academic atmosphere when we discuss copying of software. If I copy Corel's QuattroPro® onto my hard drive from disks a friend loans me and then use it myself, I am stealing from Corel, just as if I walked into a software store and stole the disks. Yet around any university, there are plenty of people who see this as not so bad.

In business, your employer will expect and assume honesty and integrity from you on the job. Because you will be turning in expense accounts, reporting factory production, lab test results, sales, and reports of all kinds, your employer must trust that these are as accurate as you can make them. So my policy was to uphold the high ethical standards that I felt sure most students have had and to make it clear that copying software is unethical. OK, yes, I could actually borrow a copy of some software and its documentation from a friend and try it over the weekend to see if I wanted to buy it, just as I might borrow someone's textbook, use it over the weekend, and return it. Borland's official description of their software licensing was just like that of the copyright on a book. You could borrow a friend's book, but you should not borrow it, copy it, and use the copy. The operating system WindowsXP® has an electronic identification system that prevents the program from being installed in another computer.

Another ''fuzzier'' ethical problem is the technically possible free downloading of music files (MP3) that are copyrighted. A system was programmed and made freely available to computer users that wanted to set their machine up as a ''server'' for a Web site. With this program, they load any of their own music CDs on their hard drive and announce its free availability to others. These ideas border on the viewpoints of extreme ''hackers,'' who fight some enemy they imagine by creating viruses. Free copying of copyrighted material obviously cheats the artists and the recording companies, and it is illegal, but such a law is difficult to enforce. You or I might think that the artists and the recording companies are making ''too much'' money anyway, but this is another example of the need for ethics. Who decides these questions?

We believe that the consideration of ethics implies some basic standard, and for us this is the Bible, along with some common sense in its interpretation.

SPREADSHEETS: LAB 1, PROFIT

Enterprise Analysis

In this first lab with the spreadsheet, you will start with a partly finished spreadsheet file, PROFIT. It is on your disk, .WB3 or .XLS, and shown in Table 3-2. The .XLS file will also work on the Microsoft Works® unnamed spreadsheet as well as on Excel.

You will enter your full name, student number (as a label, not a number), and today's date (in date format) in the underlined cells. Make sure you adjust the appropriate column

Table 3-2 The Sample Spreadsheet PROFIT.XLS or .WB3

Name	
Student No.	
Date:	
Enterprise Analysis	
CROP	$ or Amount
No. of Acres:	
Seed Cost/acre:	
Fert. Cost/acre:	
Pesticide Cost/acre:	
Labor Cost/acre:	
Rent or Int. Cost/acre:	
Total Cost/acre:	
TOTAL COST:	
Expect.Yld, units/acre:	
Expect. Price, $/unit:	
Total Return/acre:	
TOTAL RETURN:	
NET RETURN:	

width so that all these entries fit! Then enter the following values:

There are 40 acres
Costs, in dollars per acre are:

Seed	22	(Don't type in the $ sign.)
Fertilizer	66	
Pesticides	77	
Labor	44	
Rent	160	

The expected yield is 3,333 units per acre. The expected price is $0.28 per unit.

When you first save the modified (filled-in) spreadsheet file to your disk, I recommend that you give it a new name, like L2SALLY.WB3. This way you will always have the original to return to, along with your updated file.

Once those data are entered, begin to utilize them by composing the formulas that will produce the correct information in each of the shaded cells. For example, one of the formulas is

$$@sum(B9..B13) \quad \text{or} \quad + B9 + B10 + B11 + B12 + B13$$

which is the same thing. Where should that formula be entered? These formulas should contain cell addresses, used as you would use variables in an equation. Remember, Net Return is Total Return minus Total Cost, so the cell with the space for Net Return should contain +B19−B15. Use * for multiplication, + and − for addition and subtraction, and / for division. The lab will be easier if you figure out the formulas beforehand, using the spreadsheet on your screen, because the one on the last page is not complete. Save the file every time you finish a cell.

When you are satisfied with your numbers, format the cell that calculates Net Return into currency format with two decimal places, and the cells containing numbers of acres and expected yield per acre into fixed format with one decimal place. Make sure the column is wide enough for all formatted entries.

Print Results

You will turn in two different printouts: the spreadsheet as it appears on the screen, and a list of the entries in each cell. The following directions work for QuattroPro, but you can easily figure out how to get the two printouts from any other spreadsheet. To print your QuattroPro spreadsheet, select the "File" menu and then "Print." Choose the "Print Preview" button from the "Spreadsheet Print" dialog box. Now increase the size of the spreadsheet as it will be printed, by selecting "Print Scaling" within the "Spreadsheet Page Setup" dialog box. Call up this dialog box with the "Setup" button on the preview screen. Increase scaling to 150%. Now call up the "Spreadsheet Print Options" dialog box by clicking on the "Options" button, next to the "X" on the preview screen. Select "Row/Column borders" and then "OK." Make sure the entire spreadsheet is included in what will be printed and that it is all contained on one page (check upper left corner of preview screen). If it is not, first make sure you are not printing too many columns or rows, because you need only three columns at most. If you need to change the block to be printed, exit the box by clicking on the red "X," and enter the correct block in the "Spreadsheet Print" dialog box. Now click on the "Print" button.

To print the list of cell contents, click on the "Options" button, select "Cell Formulas" and then click on "OK." Can you make this list print legibly on one page? Try adjusting the margins or the print scaling. When you are happy with the way it looks, choose the "Print" button. After printing, exit the print preview screen (red "X") and "Close" the "Spreadsheet Print" dialog box. Save the file to your disk, with your name, such as L2Sally.wb3 (if your name is Sally), and exit.

SPREADSHEETS: LAB 2, PUMP TEST, PUMP.WB3 OR PUMP.XLS

A small centrifugal irrigation pump is being tested over a range of pressures from 10 to 70 psi (pounds per square inch). To measure flow rate simply, we have timed the filling of a 55-gallon drum, in seconds. On the spreadsheet, we will convert this 55 gallons per seconds to gallons per minute by the formula given later. The efficiency calculation includes converting gal/min to cu ft/min and multiplying this by pressure in lb/sq ft (psi * 144 sq in/sq ft). This gives the ft-lb/min, or output power, for the top part of the efficiency equation. Below the line, we convert the input power in watts to ft-lb/min, and the whole equation is multiplied by 100 to convert it to percent.

Physics of Pump Efficiency Test

$$\text{POWER} = \text{energy per unit time (Ft} - \text{Lb/min)}$$

$$\text{Divide by } 33,000 \text{ to get horsepower (hp).}$$

$$\text{Other power units are [gal fuel/sec], [Btu/sec], and Kwhr/hr[KW]).}$$

ENERGY

mechanical = force through a distance, such as ft – lb

electrical energy = volts * amps * time = watt – hr

chemical energy or heat energy = Btu or calories

EFFICIENCY = OUTPUT/INPUT   always < 1.0, or 100%

The pump was tested working against various pressures by restricting the outflow to build up pressure. The higher the pressure, the lower the flow. Input power was measured with a wattmeter, showing electrical power input.

Output power was measured as a force (pounds in psi) moving through a distance (ft-lb) per unit time (ft-lb/min). This number was then converted to horsepower (hp) by dividing by 33,000 ft-lb/min/hp.

Efficiency, in percent, was 100 * output power/input power. Typically, the pump did not have its highest efficiency at either the low pressure or the high pressure, but in between, which the second graph will show.

The spreadsheet, which you can download, is named PUMP and is shown in Tables 3-3 and 3-4.

Conversion units	
7.481 gal/cu ft	746 watts/hp
33,000 ft-lb/min = 1 hp	psi(lb/sq in.) * 144 = lb/sq ft

Functions for columns F, G, H
- Column F: Time, sec = (end *t* - begin *t*)
- Column G: gal/min = (55 gal/time, sec) * 60 sec/min
- Column H: Eff, % = 100 * ((gal/min)/(7.481 gal/cu ft)) * (psi * 144)/((watts/746) * 33,000)

After starting QuattroPro, open the file PUMP.WB3. Begin by filling in your name and the date. Make sure the date is entered in date format. Now save the file with a new name.

Table 3-3 Pump Test Original File, Filename = Pump.xls (or Pump.wb3)

Run	Psi	Beg. time	End time	Watts	Time, sec	Gal/min	Eff., %
1	10	35.2	48.5		13.3		
2	20	16.2	28.9				
3	30	42.9	56.8				
4	40	7.3	22.7				
5	50	21.7	40				
6	60	35.8	59.2				
7	70	10.6	44				

Unlike the last lab, here the data are all in place; all you need to do is to enter the correct formulas. Also unlike Lab 1, some of these formulas may use numeric constants together with cell addresses. For example, the Eff., % formula is composed as follows and entered into cell H8:

+100 * (Cell address1/7.481) * (Cell address2 * 144)/
((Cell address3/746) * 33000)

Table 3-4 Complete Solution, Pump Test

A	B	C	D	E	F	G	H
Run	psi	Beg *t*	End *t*	watts	Time, sec	gal/min.	Eff., %
1	10.0	35.2	48.5	3450	13.3	248.12	31.29
2	20.0	16.2	28.9	3970	12.7	259.84	56.96
3	30.0	42.9	56.8	4470	13.9	237.41	69.33
4	40.0	7.3	22.7	4670	15.4	214.29	79.87
5	50.0	21.7	40.0	5040	18.3	180.33	77.84
6	60.0	35.8	59.2	5430	23.4	141.03	67.81
7	70.0	10.6	44.0	5570	33.4	98.80	54.03

Cell address1 is gal/min, G8; address2 is the psi cell, B8; and address3 is watts, E8.

Create each formula only once, in F8, G8, and H8, and then copy each into the rest of its own column, or copy all three at once by blocking all three and copying down. Format columns F, G, and H into a fixed numeric format, with one digit after the decimal point. Save the file, and we are finished with the spreadsheet itself. Save it!

Print out the spreadsheet as it appears on the screen, shown without titles in Table 3-4. Include the row and column borders, but *not* the grid lines. Also, do a one-page printout listing the cell formulas (contents) for cells B4 and E4 and block (F8..H14) *only*. If you need help on blocking of noncontiguous cells, select "Help" and then "Search" from the main menu. Type *blocks: non*, and choose the "Show Topics" button. Select the topic "Using Noncontinuous Blocks" and click the "Go To" button.

Producing a Chart from a Spreadsheet

QuattroPro and Excel allow for many kinds of graphs, which can be created in a variety of ways. The instructions here will be at best a brief introduction to QuattroPro, with a few suggestions for Excel. You are encouraged to experiment further on your own.

From numeric data on the spreadsheet, you will create a graph that shows something about the pump's efficiency and output volume. The graph will appear on the same screen with the spreadsheet, it will plot two series (two lines), "efficiency" and "gallons per minute," on the *Y*-axis (vertical, and the Value axis in Excel), with "pressure in psi" on the (horizontal) *X*-axis (the Category axis in Excel). Although after a few moments you will have a simple graph that is perfectly adequate for "looking at the data," you should still go through the procedures to label the *X*-axis on the bottom and the two *Y*-axes, with one title on one side (Flow Rate, gpm) and one on the other (Eff., %). Try to scale the two *Y*-axes so that both curves will be sized to use most of the vertical range. Put a title on or near the graph and include your name, the date, and your class. Make legends to identify which curve is which, and make a different line type, such as dashed, for one curve. In selecting the size of the fonts, consider that this chart should show up well in a classroom with a projection screen. This will create a graph, such as Figure 3-1 on the User CD, suitable for display in presentations or publications, and you should become expert at developing these.

Turn in the following. Make sure your name is on each page.

1. The printed spreadsheet file, including the row and column borders, and the graph
2. The printout listing the cell formulas

USING THE SPREADSHEET AS A DATABASE PROGRAM

Database programs are one of the big-three programs for PCs in use in business (word processor, spreadsheet, and database). They make it possible to have a blank form on the screen; a secretarial worker with little computer experience can fill in the blanks by entering data, such as names and addresses of customers, and workers with experience with the database program can then use the database program, for example, to send ads for riding mowers to all customers that have yards larger than 0.4 acres.

Spreadsheets can do some elementary database operations. QuattroPro can alphabetize a list or put the list in order according to any column that can represent some category of information about the members of the list.

The lingo of databases includes the *record* and the *fields* within that record. Think of a *record* as one line of information on the computer screen, although it could be much longer. Then think of each piece of information on that line as a *field*.

For example, here are two records, with the field names above each field:

	Field				
Record	Last name	First name	Class	Age	Phone number
1	Jones	Mary	ASM4455	19	355-1234
2	Smith	John	ASM5315	21	392-1234

This database has five fields in each record. Since last name and first name are in different fields, you could alphabetize a list according to last name as the primary category and then use the first name as the secondary category. Thus if the sorting was in *ascending* order, Amy Jones would be ahead of Mary Jones.

Lab Problem: Sorting a Database with a Spreadsheet (QuattroPro® used)

1. Load file DBASE.WB3 into QuattroPro.
2. Note that it has LastName in 1 column, FirstName & Middle Initial in another, SS No. in another as a text item (not a number), and curriculum in another column, with Male or Female indicated in another. Enter your name and date in the heading.
3. Sort the list alphabetically by last name, ascending, and print out the sorted spreadsheet.
4. Now sort the list according to SS number, smallest number first (ascending), and print the list again. But before printing, check to see if the SS numbers are all in order. *One will be out of order*, because it was not entered as text, but as a number. Change it back to text, with the apostrophe (') in the first space. Then resort, and they should be OK. Then print the file. This would also work if the SS numbers were entered as numbers.
5. Now sort the list with all females first, alphabetically ascending, males next, also alphabetically ascending. Print out and turn in all three printouts, making sure your name is at the top.

4

Fixed and Variable Costs of Machinery and Facilities

Richard C. Fluck* and Robert M. Peart

In considering the purchase of new equipment and facilities, costs should be estimated before the manager makes the decision to go ahead. The question is not only whether to purchase the new machine, but also what capacity should be purchased. The term *new machine* as used here does not necessarily mean a new, unused machine, but could include a newer used machine that is purchased to replace the old one. This chapter gives ways of estimating these costs.

Costs of agricultural machinery and facilities are grouped into two categories: *fixed costs* (also termed *overhead* or *ownership costs*) and *variable costs* (also termed *use* or *operating*

* Material contributed by Richard C. Fluck was taken from his course notes.

costs). These costs are very important in agriculture; for on-farm operations, the fixed costs are especially important. One of the major thrusts in this book is the study of the field crop problem of high fixed costs, when machinery is larger than necessary, and high yield losses, when machinery capacity is too low.

FIXED (OR OWNERSHIP) COSTS

Land

In any enterprises involving the use of land, land is a fixed cost, whether it is rented or has been purchased. It is immaterial whether the land is rented or has been purchased and totally paid for or has been mortgaged and payments are being made each year or month. If the property value is $100,000 and it has been totally paid for by the owner, it is still an annual fixed cost to the operation, because of the "opportunity cost" it represents. That is, if he stopped his operation and sold the land for $100,000, he would have the opportunity to rent the land to someone else or to invest the money in some other business or in stocks and bonds. So the annual fixed cost of the land is really the return that is being given up by not doing something else with it. However, land is not depreciated, so there is no other fixed cost for land.

Machinery

It is easy to remember the types of fixed costs for machinery with the acronym *DIRTI 5*. One item, repairs, does not match up perfectly with the definition given later in the chapter of repair as a variable cost rather than fixed. However, as noted there, it can be considered fixed in some cases; in addition, the R for repairs makes for an easy-to-remember acronym!

Depreciation: the difference in price between a new pickup and a 1-year-old one

Interest: the average interest per year you pay on the loan for your new pickup

Repairs: the average repair costs per year

Taxes: such as license and, in some states, annual personal property tax

Insurance: such as auto insurance, fire insurance on machines

DEPRECIATION

Depreciation is a reduction in value of a capitalized asset over time or with use due to:

Physical deterioration of the asset, such as wear and rust, etc.

Obsolescence. Technological advances either result in a better replacement or make the asset unwanted.

Changing requirements that the asset cannot meet, either as well as originally or not at all.

Depreciation is a cost of use if an asset's value is reduced with time or use, as most are. Some assets, however—for instance, a classic automobile—*appreciate* in value rather than *depreciating* as time passes.

There are several methods of calculating depreciation. However, it should be recognized that the cost of depreciation is included within capital recovery (returning or recovering total cost in increments over time plus interest on the remaining cost) or in a mortgage (paying increments of cost plus interest on remaining cost).

There are several reasons that depreciation needs to be determined:

To charge costs properly to enterprises.

For income tax purposes: the cost of most income-earning assets with a useful life of more than one year cannot be totally deducted in the year of purchase but must instead be spread over a set number of years. Land, however, is not depreciated.

To recover invested capital.

Depreciation is a rather invisible cost and concept. Interest costs can be shown as recorded dollars paid. Fuel can be measured by the gallon or liter, and you can see it. You can only view and evaluate depreciation when you try to trade in your 7-year-old combine, for example, on a new one. However, most of the time, depreciation is calculated and used as a cost to determine your or your company's net profit or loss for income tax purposes. So these methods are very useful. You must be sure and check with your accountant or tax adviser, because the methods acceptable for the IRS may change from what we show here.

Here are the symbols used in the following methods of computing depreciation:

$$P = \text{original cost of asset} \quad S = \text{salvage value of asset}$$
$$W = \text{writeoff life of asset (years)}$$
$$V_t = \text{Book value of asset at end of year } t$$
$$D_t = \text{depreciation in year } t$$
$$d = \text{depreciation rate, \% per year}$$

The expected life of a depreciable asset affects the annual amount of depreciation. Life is measured in time (years, hours, etc.), whether or not the asset is in operation, or in amount of use (hours of operation, tons of product handled, etc.). Typical lives (in years) of specific assets include:

Farm machinery	10–15 years
Buildings	20–40 years
Concrete structures	50 years

However, for accounting and income tax purposes (the most common uses for these rules), the life of specific assets are listed in the Internal Revenue Service rules, and they can change over time. These are listed under the MACRS heading in the following discussions of the various methods of calculating depreciation.

Two formulas generally applicable to each of the following depreciation methods are:

$$V_t = P - \sum_{t=1}^{t} D_t \qquad D_t = V_{t-1} - V_t$$

where

V = value of machine at age t years
P = original purchase cost of the machine
D = depreciation for year t

Straight Line Depreciation

Book value (cost minus accumulated depreciation) decreases linearly with time over the writeoff life of an asset, from cost to salvage value. Annual depreciation remains the same each year. This is called *straight line* because on a line graph of V, the value at any time, vs. the age in years, the plot will be a straight line sloping from the high original value, P, down to the salvage value, S, at the end of its useful life, W.

$$D = (P - S)/W = ((1 - S/P)/W) \times P = d \times P$$
$$V_t = P - D \times t = P - d \times P \times t = P(1 - d \times t)$$

Declining Balance Depreciation

Book value decreases nonlinearly and at a decreasing rate. Depreciation decreases each sucessive year. No salvage value can be assumed.

d_r = constant depreciation ratio or declining balance rates $0 < d_r < 1$

$$D_t = V_{t-1} d_r = V_{t-1} - V_t; \qquad D_1 = P \times d_r$$
$$V_{t-1} = P \times (1 - d_r)^{t-1} \qquad \text{or} \qquad V_t = P \times (1 - d_r)^t$$

A special case of the declining balance method is the double declining balance method. It allows the first year's depreciation to be double that of corresponding straight line depreciation:

$$dr = K/W$$

where $K = 2$ (same as 200% declining balance method under MACRS). For the conventional (nondouble) declining balance depreciation, $K < 2$ and can be 1.5 (150%) in the MACRS rules mentioned later. Published values for d_r include 0.145 for self-propelled combines and 0.29 for automobiles. Since book value approaches zero asymptotically, salvage value can never reach zero, unless another method (usually straight line) is used instead near the end of the life of an asset.

Sum-of-Years Digits Depreciation

This method was authorized and created by the 1954 U.S. tax law. Book value declines similarly to declining balance in the early years of asset life, but more so in later years as book life coincides with any predetermined salvage value, including zero.

$$D_t = \left((W - \mathrm{t} + 1)/\sum t\right) \times (P - S)$$

where for $t = 5$ yrs

$$\sum t = 1 + 2 + 3 + 4 + 5 = 15$$

$$V_t = P - \sum_{t=1}^{t} D_t$$

Accelerated Cost Recovery System (ACRS)

This was introduced in the United States by the 1981 tax act; it was generally used to depreciate property placed into service after 1980 and prior to 1987. For much property, ACRS provided for faster depreciation than any previously allowed method and therefore encouraged investment. Now, however, the modified ACRS system, MACRS, is used. The rules in the next section were taken from the U.S. Internal Revenue Service publication for application in 2002, for tax year 2001 (Publication 946) [1].

Modified Accelerated Cost Recovery System (MACRS)

The 1986 tax bill made further changes in determining depreciation for income tax purposes by requiring "modified" ACRS depreciation for property placed in use in 1987 and later. MACRS lengthened depreciation schedules by introducing more classes of depreciable property and shifting some property to different classes. It allows only 50% of the annual deduction in the first year, regardless of the date the property is placed in use, effectively forcing the depreciation interval to an additional year to completely depreciate the property.

Property is classified for MACRS as (agricultural categories):

3-year property: Personal property with a useful life of 4 years or less, including tractor units for over-the-road use and certain tools.

5-year property: Includes most office equipment and computers, automobiles, light and medium trucks, and trailers. Depreciation on automobiles for business purposes is now limited in amount per auto, which cuts down on the purchase of luxury automobiles for business purposes. Breeding cattle and dairy cattle are included in this class.

7-year property: Includes agricultural machinery and equipment and office furniture and fixtures.

10-year property: Includes single-purpose agricultural and horticultural structures, any tree or vine bearing fruits or nuts, and water transportation equipment.

15-year property: Includes certain improvements made directly to land or added to it (such as shrubbery, fences, roads, and bridges).

20-year property: Includes farm buildings (other than single-purpose agricultural and horticultural structures).

25-year property: Includes water utility property and any municipal sewer.

Nonresidential real property: Depreciated over 39 years, or 31.5 years if placed in service before May 13, 1993.

Residential real property: This class of mainly rental property, including mobile homes, is depreciated over 27.5 years.

For "farming business," use 150% declining balance (or straight line optionally) for all ages of property classes, with a switch to straight line when it exceeds declining balance so that the property can be depreciated to zero in the proper interval. Also, only 50% of this depreciation can be used in the first year. Nonresidential real property and residential rental property is depreciated straight line. Optional percentage tables are available and can be used to calculate MACRS depreciation.

Example Problem. Depreciation of a Freightliner tractor costing $45,000 and placed into service January 1, over 3 years, assuming no salvage.

Straight line:

$$P - S = \$45{,}000$$

$$D = (P - S)/W = \$45{,}000/3 = \$15{,}000/\text{yr}$$

(same for each year)

$$V_1 = P - D_t = \$45{,}000 - \$15{,}000/\text{yr} \times 1\ \text{yr} = \$30{,}000$$

$$V_2 = \$45{,}000 - \$15{,}000/\text{yr} \times 2\ \text{yr} = \$15{,}000$$

$$V_3 = \$45{,}000 - \$15{,}000/\text{yr} \times 3\ \text{yr} = 0$$

Declining balance with $K = 1.5$ (150%):

$$d_r = 1.5/3 = 0.5$$

$$D_1 = Pd_r = \$45000 \times 0.5 = \$22{,}500$$

$$V_1 = P(1 - d_r)t = \$45{,}000 \times (1 - 0.5) \times 1 = \$22{,}500$$

or

$$V_1 = P - D_1 = \$45{,}000 - \$22{,}500 = \$22{,}500$$
$$D_2 = V_1 d_r = \$22{,}500 \times 0.5 = \$11{,}250$$
$$V_2 = \$45{,}000 \times (1 - 0.5)^2 = \$11{,}250$$
$$D_3 = V_2 d_r = \$11{,}250 \times 0.5 = \$5{,}625$$
$$V_3 = \$45{,}000 \times (1 - 0.5)^3 = \$5{,}625$$

Sum-of-years digits with $W = 3$ yr, $P - S = \$45{,}000$:

$$D_1 = 3/6 \times \$45{,}000 = \$22{,}500$$
$$V_1 = \$45{,}000 - \$22{,}500 = \$22{,}500$$
$$D_2 = 2/6 \times \$45{,}000 = \$15{,}000$$
$$V_2 = \$45{,}000 - (\$22{,}500 + \$15{,}000) = \$7{,}500$$
$$D_3 = 1/6 \times \$45{,}000 = \$7{,}500$$
$$V_3 = \$45{,}000 - (\$22{,}500 + \$15{,}000 + \$7{,}500) = 0$$

ACRS:

$$D_1 = 0.25P = 0.25 \times \$45{,}000 = \$11{,}250$$
$$V_1 = P - D_1 = \$45{,}000 - \$11{,}250 = \$33{,}750$$
$$D_2 = 0.38P = 0.38 \times \$45{,}000 = \$17{,}100$$
$$V_2 = P - D_t = \$45{,}000 - \$11{,}250 - \$17{,}100 = \$16{,}650$$
$$D_3 = 0.37P = 0.37 \times \$45{,}000 = \$16{,}650$$
$$V_3 = \$45{,}000 - \$11{,}250 - \$17{,}100 - \$16{,}650 = 0$$

MACRS:

$$d_r = 2/3$$
$$D_1 = 1/2 \times \$45{,}000 \times 2/3 = \$15{,}000$$
$$\text{(half full – year depreciation for first year)}$$
$$V_1 = \$45{,}000 - \$15{,}000 = \$30{,}000$$
$$D_2 = \$30{,}000 \times 2/3 = \$20{,}000$$
$$V_2 = \$30{,}000 - \$20{,}000 = \$10{,}000$$
$$D_3 = \$10{,}000 \times 2/3 = \$6667.67$$

This last switches to straight line because D_3 is greater under straight line method, and it also gives a final value equal to zero at time W. So:

$$D_3 = 1/1 \times \$10{,}000 = \$10{,}000$$
$$\text{(straight line over the one remaining year)}$$
$$V_3 = \$10{,}000 - \$10{,}000 = 0$$

Table 4-1 gives a comparison of book values using the various methods, with an assumed 3-year life.

In general, the IRS gives the taxpayer some flexibility in choosing the method of calculating depreciation; but once a method is selected, the same method must be followed for the life of the equipment.

Interest

Interest is another major fixed cost. A purchased asset requires capital that must be either borrowed or provided by the buyer. To use borrowed capital, interest is paid. If the buyer provides the capital, it could instead be earning interest or generating profits elsewhere, and therefore an interest rate comparable to that obtained through alternative uses should be chosen. An owned asset could presumably be sold and the proceeds invested to earn interest.

For accounting purposes and if *straight line* depreciation is chosen, the average annual cost of interest for capital provided by the buyer may be calculated by

$$I = i \times (P + S)/2$$

Table 4-1 Remaining Value Each Year for the Example of the $45,000 Truck.

	Straight line	Declining balance	Sum-of-years digits	ACRS	MACRS
V_1	30,000	22,500	22,500	33,750	30,000
V_2	15,000	11,250	7,500	16,650	10,000
V_3	0	5,625	0	0	0

where i is interest rate, P is initial cost, and S is salvage value and which gives a constant annual interest cost I throughout the life of the asset, based on the average investment.

Taxes

Taxes are of several types, which are treated in different ways. Sales taxes can most easily be handled by including them as part of the original price. Income taxes, paid annually, will normally be associated with an enterprise rather than a single asset. Property taxes are paid annually, vary with the governing body, the assessed value, and the tax or millage rate, and are paid annually on specific assets. Property taxes may include special assessments, for example, for such governmental entities as a water management district. Property taxes should be computed at the applicable rate; but if this is unknown, they may otherwise be estimated at 1% per year of asset life of either the purchase price or the market value. Property taxes may in some locales, however, range up to and beyond 4% of market value.

Insurance

Insurance may be purchased by the owner, or the owner may instead be "self-insured" (assume the risk without purchased protection). Insurance may be purchased to cover losses due to fire, accidental destruction, theft, storm, etc. Cost of insurance may be assumed to be 0.25% of the asset's purchase price annually unless otherwise known.

Shelter or Housing

Shelter is a cost that applies mainly to machinery and some processing equipment. Shelter may easily repay its costs in extended life and reduced repair and maintenance costs of the equipment sheltered. Shelter costs may be estimated as 0.75% of P or less annually unless calculated or otherwise known.

Total annual fixed costs are sometimes estimated as a percent of P; for instance, for 10-year life, 10% salvage value, and an interest rate of 16%, "FC Percent" calculates to be $0.198P$; fixed costs are almost 20% of the original cost annually for this example.

VARIABLE COSTS

Variable costs "vary" according to the amount of use of the item. It is fairly obvious that a tractor will use more fuel plowing 100 acres than 50 acres, so *fuel* is a variable cost. Also, for any machine with an engine, *lubrication* is a variable cost because oil should be changed after a set number of hours of use. *Labor* is naturally a variable cost, since the longer the machine is used, the more the labor costs.

Labor costs are variable, in the sense that more hours equals more cost. However, for field operations, when we consider labor costs per acre, the calculation must take into account the capacity of the machine the laborer is using. For a driver paid $20 per hour, the labor costs for a tractor plowing at the rate of 2 acres per hour is $10 per acre. For a larger tractor and plow with a capacity of 4 acres per hour, the labor cost is $5 per acre. This shows one of the advantages of higher-capacity equipment. But, of course, the fixed costs of the larger machines are higher. In other chapters, we will be emphasizing the importance of the fixed costs of field machinery and also the importance of machine capacity, in acres per hour.

For livestock operations, the feed is a major variable cost, while the cost of buildings and equipment can be looked on as either variable or fixed. For example, a grower investing in buildings and equipment to raise broilers can look on the cost as variable, because it will cost almost twice as much for 20,000 broilers as for 10,000. However, if, in later years, she decides to raise only 10,000 broilers in a house large enough for 20,000, her fixed housing and equipment is really a fixed cost, because the costs for anything from 1 to 20,000 birds has already been set and is fixed.

Repairs and Maintenance

This category is one of the larger variable costs. It may be a function of both time and use and, to the extent dependent upon time only, may be considered a fixed cost. However, by convention, repairs and maintenance are generally considered variable costs. Repairs are often necessitated by component failures and therefore are unpredictable in the timing of their occurrence. Maintenance may be in part deferrable and therefore is fairly predictable.

Repair costs for agricultural machinery may be estimated by either of the following:

As a percentage of purchase price.

By using the formulas for accumulated repair and maintenance costs given in the *ASAE Standards* book [2]. These predict repair costs of older equipment to be more than repair costs for newer equipment. The formula given for accumulated repairs and maintenance of, for example, diesel tractors, is

$$C_{RM} = 0.01X^{2.0}P$$

where X is the number of thousands of hours of accumulated use and P is the initial cost of the tractor.

Total accumulated repair and maintenance costs over a number of years may exceed the purchase price of some equipment. Repair and maintenance costs for agricultural buildings are commonly 1% to 4% of the purchase price annually.

Fuel (for Machinery Powered by Internal Combustion Engines)

Estimates of fuel consumption may be made from experience, from the Nebraska Tractor Test Data, or from ASAE formulas.

a. Bashford and Shelton [3] gave fuel consumption per unit time and power output per unit fuel consumption for Nebraska. Average fuel consumption at 75% load for nine diesel tractors in the 100-hp range was 0.082 gal/hp hr.

b. A formula of the type (example for diesel)

$$F = 0.52X + 0.77 - 0.04(738X + 173)^{0.5}$$

where X is the ratio of equivalent PTO hp used to maximum available and the result is given in gal/hp-hr. With X = 0.75, diesel fuel consumption is calculated to be 0.082 gal/hp-hr, coincidentally agreeing with that in part (a).

c. A simpler, but likely less accurate, rule, that average diesel F = 0.0438X (max. PTO hp), with F given in gallons per hour. A 100-hp tractor is calculated to consume 4.38 gal/hr, or 0.044 gal/hp-hr, under "average" conditions.

Lubrication (for Machinery)

The *ASAE Standards* book's data suggest that 15% of fuel cost is oil cost. A more specific formula (for diesels) gives oil consumption, in gal/hr, as 0.00021P + 0.00573, where P is rated engine horsepower. By this formula, oil consumption of a 100-hp diesel would be 0.0267 gal/hr.

Utilities (Electric Power, Gas, Water, Sewerage)

One or more of these may be required for a particular structure, piece of processing equipment, etc.

Supplies

Cost of packaging materials, twine for balers, etc, may be estimated to include all product packaged plus a small allowance for wastage.

Labor

Labor costs should be calculated at local and timely rates and allow for nonproductive time. Fringe benefits (health insurance, workers' compensation, Social Security, unemployment compensation, etc.) may increase hourly wages by 10–40%.

SUMMARY

Fixed and variable costs for machinery and facilities are a large part of the costs in most agricultural systems, so they must be managed for optimal results. These calculations should be used while making a decision on the purchase of machinery and facilities. When determining what is optimal, the whole system must be included, so usually the minimum of the sum of fixed and variable costs for this equipment is not the optimal. This is because of the effects of machinery capacity, especially, on yields and yield losses, as we explain further in the following chapters.

REFERENCES

1. Anon. How to Depreciate Property, Publication 946, Dept. of the Treasury, Internal Revenue Service, 2002.
2. ASAE. Agricultural Machinery Management Data. St. Joseph, MI: ASAE, 1994.
3. Bashford, Leonard L.; Shelton, David P. Fuel Use for Field Operations, NebGuide G81-578-A; Agricultural Engineering Dept., Cooperative Extension Service, Lincoln: University of Nebraska, NB, 1981.

5

Machinery Selection and Management Program for Maize/Soybean

John C. Siemens* and Robert M. Peart

IMPORTANCE OF MACHINERY SELECTION TO CROP AGRICULTURE

Millions of acres of corn (maize) and soybeans are grown on U.S. farms, and most of these farms plant both corn and soybeans. The two crops are complementary in terms of the timing of operations—soybeans may be planted later without yield loss, and they are usually ready for harvest earlier than is corn. In addition, alternating the two crops on the same land

* Dr. John C. Siemens contributed a major portion of the material from his chapter entitled, "Field Machinery Selection Using and Optimization" in Robert M. Peart and R. Bruce Curry eds., Agricultural Systems Modeling and Simulation, Marcel Dekker, Inc., 1998, 543–565.

tends to reduce pests, such as nematodes. Machinery for the culture of these two crops is almost the same, the main difference being on the combine, where corn needs a "snapping head" adjusted for the row width to take in the rows of corn stalks, whereas soybeans require the cutter bar header, which is also used for small grains, such as wheat, as discussed by Black and Harsh [3], Rotz et al. [13], and Schwart [15].

Timing of operations is critical for both crops. Early planting of corn has been shown to increase yields. For example, in northern Indiana, a rule of thumb reported by Doster [6], states that corn yield of 1/2 bu/acre/day is lost for each day after May 10 that the crop is planted. On the other hand, if the crop is planted too early, there is a danger that frost will kill or stunt the crop. The need for early planting of corn is one reason to do tillage in the fall, after harvest, in areas where wintertime erosion of the soil is not serious. Then the planting can begin earlier in the spring, and tillage labor and equipment can be shifted away from the critical spring planting time. The yield loss due to late planting is a loss of potential yield, because the crop does not receive enough total solar radiation, and the yield is less than it could have been with an earlier start.

Harvesting is another operation where yield can be lost, but this is actual grain lost in the field because corn ears drop, stalks and stems break, and soybeans shatter from the pods before the cutting head can reach them. All of these are the result of late harvest. There are some losses if harvest is too soon, but these are normally not as important as losses due to late harvest.

These problems make selecting machine capacity an important decision [4]. Relatively high-capacity machines will help reduce yield losses due to late planting and/or late harvest. However, if the machinery is of larger capacity than necessary, much higher fixed costs result. Thus, proper selection of machine capacity is a problem of balancing high fixed costs against high yield losses.

Many researchers have studied this problem with models [8,10]. Bender et al. [2] worked with a linear program with an expert interpreter model to show more than just the optimum solution. Chen [5] developed a model for machinery selection, crop budgeting, and scheduling. A somewhat similar application by Schueller et al. [14] involved an expert system for troubleshooting grain combine performance. Also, Kline et al. [11] developed an intelligent decision support system for the farm level. McKinion and Lemmon [12] helped develop a very detailed model of cotton growth and development utilizing artificial intelligence concepts that has been widely used by cotton growers. Also, Hodges et al. [9] described the model well. Singh [18] and Wolak [19] developed early programs to simulate field operations and to select machinery.

Florida citrus harvest also has timing problems, but with different benefits and management strategies. As with many fruits, the market gives a financial incentive for bringing fruit to the market as early as possible. Very early Florida blueberries sell in Switzerland at five to ten times the price of mid-season blueberries much later in the year, in the author's experience, and transportation cost is a small part of that difference. Early fresh grapefruit command a higher price, but consumers recently have shown a preference for a sweeter grapefruit, which requires more time on the tree for developing a higher sugar content. Also, later harvesting of juice oranges produces higher solids (sugar) content and thus a higher yield of product per tree. On the other hand, later and later harvest results in losses because fruit develops past maturity, thereby drying and losing yield and flavor. One more harvest timing problem concerns labor availability for harvest, and this can dominate the decision. Finally, fruit-killing frosts will determine the decision, because only a few days are available to harvest the fruit for juice production before spoilage sets in.

These much more complex harvest-timing problems with citrus have not had the study that the corn/soybean problem has, so citrus growers and production managers use their experience and judgment and combine all these factors along with the particular type of citrus in making harvest decisions. They are presented here to remind students of agricultural systems management of the importance of horticultural and agronomic factors when analyzing the timing of operations.

S10, THE ILLINOIS MACHINERY SELECTION PROGRAM

The purpose of this chapter is to present the major factors involved in selecting an optimum machinery set and to use the farm machinery selection and management program previously presented by Siemens et al. [16] and Siemens [17] to demonstrate these factors. The program is written especially for U.S. Midwest farms. For most Midwest farms the major crops are corn and soybeans. However, the program is written so that it can be used for several other crops and locations, and the corn/soybean crop rotation is used outside the Midwest as well.

Methodology

Optimum machinery size is defined as that machinery set that results in the minimum total cost, as shown in Figure 5-1. In this chapter, *optimum* and *least cost* are used synonymously.

For corn-soybean farms and many other farms, machinery size can be varied by changing tractor sizes and matched implements and/or combine harvester sizes and matched attachments. This means that Figure 5-1 can be visualized as three-dimensional, the dimensions being: tractor size, combine size, and total cost. Total cost is the sum of the costs for machinery, labor, and timeliness. The least-cost machinery combination is determined by the low point on the three-dimensional surface.

Machinery Costs

If a specific set of machinery is used to perform a set number of field operations on a farm of a given size, the annual use of each machine and the fixed and variable costs can be estimated. Several sizes of farm machinery sets could be used on this farm. As the size of the machinery set increases, both productivity and initial price increase. The annual machinery costs, fixed and variable, would increase with increasing machinery

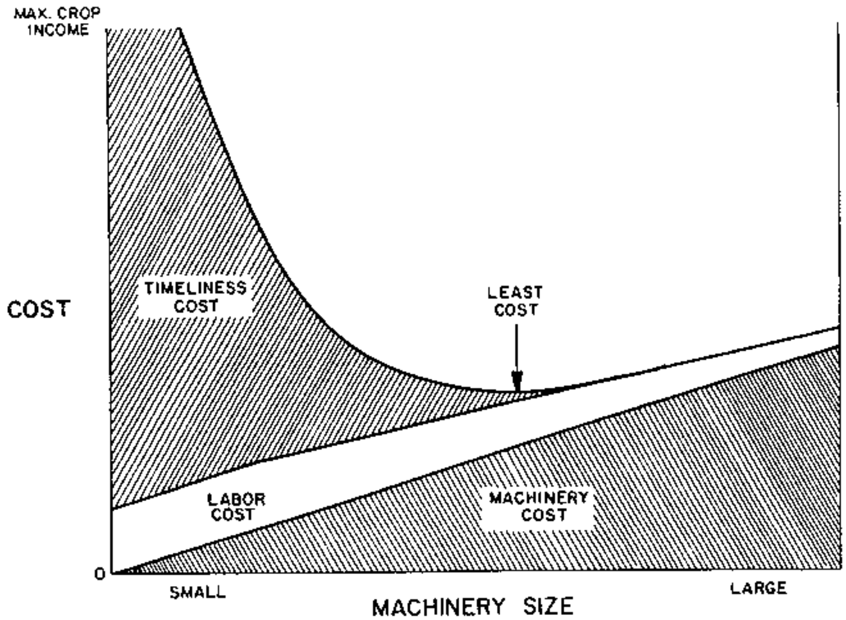


Figure 5-1 Components of total machinery costs as affected by capacity.

size, as estimated by the lower line in Figure 5-1. Labor costs decrease somewhat as machinery capacity increases, because of higher productivity. Variable costs, excluding labor, tend to remain constant, because fuel costs are about the same per acre for any size of machine.

Labor Costs

It is necessary to know the relation between productivity of machinery and labor cost. For the owner-operator of a farm producing field crops, the time used for operating machinery need not be considered in selecting the optimum machinery size, unless other enterprises compete for the time of the owner-operator and a value can be placed on that time. Other enterprises might include a hog or beef operation or a part-time job. Then the owner-operator's time is important and this cost should be considered.

If hired labor is available and used, the cost may be on an hourly or annual basis. On an hourly basis, total labor cost is directly proportional to machine operating time and inversely proportional to machine productivity. When labor is hired on an annual basis, total labor cost is independent of machine operating time and productivity. The question in either case is how to proportion labor costs between field operations and other farm tasks. If the only reason for hiring labor on a particular farm is to operate machinery, then the entire annual cost of hired labor should be assessed against the field operations.

Figure 5-1 assumes one man paid on an hourly basis only when operating field machinery. Labor cost decreases as machine capacity increases, because with higher-capacity machines, more acres are covered in one hour, so labor cost per acre is less.

Timeliness Costs

Timeliness is defined here as the ability of available labor, using a given set of machinery, to complete each field operation within an optimum time period. The measure of timeliness is the cost accrued because the operation was not completed in the optimum time period. Some operations, such as planting, may have a penalty assessed directly to them because of untimely completion. Other operations, such as primary tillage, may have only an indirect influence on timeliness cost because they may affect the completion of following operations.

It has been well established that a yield decrease occurs if corn is not planted before the middle of May in the U.S. Corn Belt. The value (or cost) of the yield decrease is the timeliness cost. The date at which this cost begins has also been reasonably well established in the literature of the various state agricultural experiment stations. There is little, if any, influence of factors other than the latitude of the location on this date. And there is general agreement that the rate of yield loss is approximately one bushel per acre per day.

No such penalty has been established for soybean planting. Indeed, there seems to be general disagreement as to whether one exists as long as time is available for the soybean to reach maturity. A realistic timeliness penalty for soybean planting and for planting of other crops is needed.

It is logical that harvesting also has a timeliness cost associated with it, and it is actual grain that is lost in the field because corn ears drop, stalks and stems break, and soybeans shatter from the pods before the cutting head can reach them. All of these increase with late harvest. There are some losses if harvest is too soon, but these are normally not as important as losses due to late harvest. Also, the timeliness cost for the harvest of both corn and soybean depends on the variety, the drying costs (later harvest usually means moisture content is lower), the weather (wind and ice, for example), and other factors. In this program, a timeliness cost for late harvesting is an option that is commonly used. More detailed discussion of these yield losses is covered in the next chapter.

A MACHINERY SELECTION PROGRAM

Stored Files

A primary goal in writing the program was to require as little input as possible from the program user and yet allow for changes. Therefore, several files of data contain default values that can be changed by the program user.

Equipment File

The equipment file is a stored file that contains a list of tractors with matched implements and combines with matched attachments available within the program. The program has space for nine tractor sizes, commonly varied in increments of 20 horsepower, from 60 to 220 hp and with four combine sizes of 125, 140, 180, and 240 hp. For each tractor and combine and appropriate attachments, the file contains the size and name, estimated productivity for each tractor/implement and combine/attachment combination, and a list price. The essential methodology used to match the size of the implements to tractor power and to calculate productivity is given in *Farm Machinery Management Data* from ASAE [1] or based on user experience. Table 5-1 lists an example of the file contents for only the 180-hp combine with attachments and the 140- and 160-hp tractors with matched implements. The file is similar for other combines and tractor sizes. The information in the file (Table 1) may be changed by the program user and stored.

A list price of 0 means the implement is not purchased by the farmer but is otherwise available. For example, fertilizer spreaders are often made available by fertilizer dealers, and the cost is included in the cost of the fertilizer. If a tractor does not have sufficient power to pull an implement, the productivity is set to 0.0 in the file. For example, for the 60-horsepower tractor the productivity for chisel plow is 0.0, which means the program will not allow the 60-horsepower tractor to be used for chisel plowing.

Planter and Row Cultivator File

There are two parts of this file. The first part includes matched pairs of planters and cultivators along with estimated productivity and the list price of each (Table 5-2). The second part of the file is an array used to match the size of the tractors, combine corn heads, and planters (Table 5-3). The array provides a choice of (1) the same number of rows on the planter as on the corn head, or (2) twice the number of rows on the planter as on the corn head. A constraint imposed is that the tractor, planter, and row cultivator sizes be compatible with regard to available or required power.

The cultivator may seem out of date, with today's emphasis on the use of expensive genetically modified seed designed to resist particular herbicides, which eliminate the need for a cultivator. However, the user of this program may wish to compare the old system, especially for soybean, where cultivating is done, usually when labor is easily available, and much less expensive seed is used, with the more expensive particular seed/herbicide combination.

Table 5-1 Portion of Stored File of Combines with Matched Corn Heads and Grain Platforms and Tractors with Matched Implements and Corresponding Productivity Values and Assumed List Prices

Machine	Productivity (acres/hr)	List price ($)	
180-hp combine		80,300	
8-row corn head	4.50	23,700	
22-ft grain platform	4.96	11,400	
140-hp tractor		55,500	
5 * 18 moldboard plow	3.48	8,700	
11-ft chisel plow	6.08	6,955	
22-ft disk	11.70	13,900	
22-ft field cultivator	11.46	7,600	
14-ft shredder	6.13	6,500	
21-ft rotary hoe	20.36	4,300	
9-knife applicator	10.22	0	(custom oper.)
40-ft fertilizer applicator	15.60	0	(custom oper.)
42-ft sprayer	18.32	3,500	
21-ft drill	14.61	19,300	
Subsoiler	3.33	6,900	
Paraplow	4.12	8,500	
Ro-till	4.12	10,500	
19-ft combination tool	10.31	14,300	
7-ft mower	3.60	4,300	
11-ft wheel rake	4.80	2,900	
9.25-ft mower-conditioner	4.04	10,000	
Baler (pto) wire	5.43	15,200	
160-hp tractor		63,000	
6 * 18 moldboard plow	3.94	9,100	
13-ft chisel plow	7.08	8,700	
25-ft disk	13.30	15,100	
25-ft field cultivator	13.34	8,800	
14-ft shredder	6.13	6,500	
21-ft rotary hoe	20.36	4,300	
11-knife applicator	12.27	0	(custom oper.)
40-ft fertilizer applicator	15.60	0	(custom oper.)
42-ft sprayer	18.32	3,500	
24-ft drill	16.26	21,200	
Subsoiler	3.75	6,900	
Paraplow	4.38	8,500	
Ro-till	4.38	10,500	
24-ft combination tool	13.16	17,200	
7-ft mower	3.60	4,300	
11-ft wheel rake	4.80	2,900	
9.25-ft mower-conditioner	4.04	10,000	
Baler (pto)[a] wire	5.43	15,200	

[a] pto = Powered through power take-off of tractor.

Table 5-2 Stored File of Planters and Row Cultivators with Productivity Values and Assumed Purchase Prices

Machine	Productivity (Acres/hr)	List price $
4-row planter	4.24	9,400
4-row cultivator	3.70	2,500
6-row planter	7.00	13,050
6-row cultivator	5.56	3,600
8-row planter	9.33	16,700
8-row cultivator	7.40	4,750
12-row planter	14.00	27,000
12-row cultivator	11.10	9,300
16-row planter	21.00	36,000
16-row cultivator	14.00	12,500
24-row planter	28.00	60,000
12-row cultivator	11.10	9,300

Table 5-3 Stored Array Used to Match Size of Tractors, Combine Corn Heads, and Planters

	Corn head (rows)							
	4	6	8	12	4	6	8	12
	Planter sizes (rows)[a]							
Tractor, hp	4	6	8	12	8	12	16	24
60	4	—	—	—	—	—	—	—
80	4	6	8	—	8	—	—	—
100	4	6	8	12	8	12	16	—
120	4	6	8	12	8	12	16	24
140	4	6	8	12	8	12	16	24
150	4	6	8	12	8	12	16	24
160	4	6	8	12	8	12	16	24
180	4	6	8	12	8	12	16	24
200	4	6	8	12	8	12	16	24
220	4	6	8	12	8	12	16	24

[a] Planters may have either the same number of rows as the combine corn head or twice the number of rows.

Machinery Cost Factors File

This file contains the constants for the equations used to estimate the fixed and variable machinery costs (Table 5-4). The constants and formulas were obtained from *Farm Machinery Management Data* from ASAE [1]. The formulas for estimating remaining farm value are:

Tractors: $RFV = LP \times 0.68 \times (0.920)^y$
Combines: $RFV = LP \times 0.64 \times (0.885)^y$

Table 5-4 Values of Repair Cost Constants RC1 and RC2 and Life

Machine	RC1	RC2	Life, hr
Tractor	0.007	2.00	12,000
Moldboard plow	0.290	1.80	2,000
Chiselplow	0.280	1.40	2,000
Disk stalks	0.180	1.70	2,000
Field cultivator	0.270	1.40	2,000
Stalk chopper	0.440	2.00	1,200
Plant corn	0.320	2.10	1,500
Row cultivator	0.170	2.20	2,000
Rotary hoe	0.230	1.40	2,000
Anhydrous applicator	0.630	1.30	1,200
Fertilizer applicator	0.630	1.30	1,200
Sprayer	0.410	1.30	1,500
Drill	0.320	2.10	1,500
Subsoiler	0.280	1.40	2,000
Paraplow	0.280	1.40	2,000
Forage chopper	0.150	1.60	2,500
Combination tool	0.270	1.40	2,000
Mower	0.460	1.70	2,000
Hay rake	0.170	1.40	2,500
Mower and conditioner	0.180	1.60	2,500
Baler	0.230	1.80	2,000
Self-propelled combine	0.040	2.10	3,000
Corn head	0.040	2.10	3,000
Grain platform	0.040	2.10	3,000

Source: Ref 1.

Balers, forage harvesters, self-propelled sprayers RFV: = $LP \times 0.56 \times (0.885)^y$
All other machines RFV = $LP \times 0.60 \times (0.885)^y$

where

$$\begin{aligned} \text{RFV} &= \text{remaining farm value at end of year } y, \\ \text{LP} &= \text{list price of machine}, \\ \text{Y} &= \text{age of machine, years} \end{aligned}$$

Depreciation is obtained by subtracting the remaining farm value from the purchase price.

Housing, interest, and insurance costs are estimated by multiplying the percentage entered by the program user for these costs times the remaining farm value at the beginning of the year.

Repair costs are estimated using the following formula:

$$\text{TAR} = \text{LP} \times \text{RC1} \times (h/1000)^{\text{RC2}}$$

where

$$\begin{aligned} \text{TAR} &= \text{total accumulated repair cost, \$} \\ \text{LP} &= \text{list price of machine, \$} \\ \text{h} &= \text{total machineuse, hr} \\ \text{RC1, RC2} &= \text{constants (Table 5-4)} \end{aligned}$$

The life of each machine is used as a maximum limit for the time of ownership.

Fuel and Lubrication Costs

Fuel consumption for tractors and combines is estimated using the equation for fuel efficiency in *Agricultural Machinery Management* Data of ASAE [1]:

$$\text{diesel fuel, gal/hp-hr} = 0.52\text{X} + 0.77 - 0.04(738\text{X} + 173)^{0.5}$$

where X is the ratio of the equivalent pto (power take-off) power required to the maximum available from the pto. X is set in the program at 0.85.

Fuel and lubrication costs are estimated from the fuel consumption value, the price of fuel, and the assumption that lubrication cost is 10% of the fuel cost.

Workday Probability File

In this file are the probabilities that a day is suitable for field work. Data are included for northern, central, and southern Illinois (Table 5-5). File space for other locations is provided. The program user must provide and store the workday prob-

Table 5-5 Stored Workday Probability Data for Illinois

Week	Northern	Central	Southern
1–13	0.00	0.00	0.00
14–15	0.12	0.14	0.07
16–17	0.36	0.26	0.17
18–19	0.44	0.36	0.30
20–21	0.39	0.28	0.30
22–23	0.59	0.46	0.43
24–25	0.46	0.46	0.50
26–27	0.61	0.51	0.57
27–28	0.61	0.51	0.57
29–31	0.64	0.60	0.62
32–35	0.64	0.70	0.62
36–37	0.66	0.70	0.68
38–39	0.47	0.51	0.59
40	0.47	0.56	0.54
41	0.48	0.56	0.54
42–43	0.63	0.71	0.58
44–45	0.46	0.51	0.54
46	0.56	0.58	0.40
47	0.56	0.50	0.40
48–49	0.42	0.26	0.11
50–52	0.00	0.00	0.00

Source: Ref. 15.

ability data for his or her location and when running the program must select the location to be used. The probabilities for northern, central, and southern Illinois are from Schwart [15] and represent the fraction of time during the year in which field work is feasible at least 5 of 6 years (83.3% of the time). The workday probability data may be changed by the user.

User Input Files

User input files contain data that are likely to vary between users or farm situations. After the data are entered, these files may be stored for a specific farm.

Economic Data File

In addition to the list price of each machine and the field capacity of each power unit/attachment combination, economic data common to each machine are needed to estimate the fixed and variable costs of each machine. These data are entered in the economic data file (Table 5-6). Data include the availability and

Table 5-6 Economic Data File with Default Values

Operators: Number: 2	Cost ($/hr):	7.50
Economic factors		
Purchase price, % of list		90.0
Housing, interest, and insurance		12.0
Percent inflation		3.5
Fuel Price ($/gal):		1.00

Crop prices, yields, and penalty dates

			Penalty dates	
Crop	Prices ($/bu)	Yields (bu/a)	Planting (mo/day)	Harvesting (mo/day)
Corn	2.50	150	5/15	11/15
Soybean	7.50	40	5/31	10/15
Wheat	3.00	60	10/30	7/20
Oats	7.50	40	5/31	10/15
Sorghum	4.50	100	5/31	10/15

cost of machinery operators; price of diesel fuel; a housing, interest, and insurance charge as a percent of remaining farm value; machinery purchase price as a percent of list price; and percent inflation. The maximum number of machinery operators the program will utilize is six, and their cost may be entered on an hourly basis. The program does not optimize the number of machinery operators.

Also, entered in the economic factors file are the crop prices, crop yields, and penalty dates for planting and harvesting (Table 5-6). These data are used to compute timeliness costs when the field operations are scheduled. These data, including the crops grown, may be changed by the program user. For each crop the yield is assumed to equal the yield entered for a specific crop if the planting and harvesting operations are completed on or before the penalty date entered. When a planting or harvesting operation occurs after the penalty date, a yield decrease is assumed and a timeliness penalty is calculated. The timeliness penalty is calculated by multiplying the crop yield, appropriate timeliness factor, acres delayed, and days of delay. The timeliness cost is equal to the timeliness penalty times the crop price. Here is example of the timeliness factors:

Timeliness penalties (% Yield Loss per Day of Delay)

Crop	Planting	Harvesting
Maize (corn)	1.0	0.5
Soybeans	1.0	1.0
Wheat	0.25	1.0
Oats	1.0	1.0
Sorghum	0.25	1.0

Desired Field Operations File

The most critical information input by the user for a specific farm is the list of desired field operations to be performed and the data related to these operations. The main objective of the program is to select the set of machinery required to complete the desired operations in a timely fashion and at least cost. A list of desired field operations for an example farm is shown in Table 5-7. Code numbers (column 1 of Table 5-7) are used to enter the field operations. The list of available code numbers for the 30 different field operations included in the program can be viewed on screen. Other data to be entered for each operation include the earliest start date, latest finish date, acres to be covered, available labor hours per day or the hours per day the operation can be performed, whichever is least, and a land area number. Entry of a latest finish date is optional and needed only if an operation must be completed by the date entered. The land area numbers are used to help ensure that the operations are scheduled correctly, they are explained in more detail below.

The first operation listed in Table 5-7 is "Combine soybean," with an earliest start date of 9/15. This is interpreted to mean that September 15 is the earliest date soybean is commonly ready for harvest. A latest finish date is not specified for soybean harvest. The next entry is the acres for the operation

Table 5-7 User Input of Field Operations for an Example Farm

Code no.	Field operation	Start date (mo/day)	Finish date (mo/day)	Area (acres)	Labor (hr/day)	Land area no.
2	Combine soybean	9/15	0/0	500	8.0	1
1	Combine corn	10/15	0/0	500	10.0	2
7	Chisel plow	10/15	0/0	500	10.0	2
8	Disk harrow	4/1	0/0	500	10.0	1
9	Field cultivate	4/25	0/0	500	10.0	1
21	Plant corn	4/25	0/0	500	10.0	1
8	Disk harrow	4/1	0/0	500	10.0	2
9	Field cultivate	5/1	0/0	500	10.0	2
22	Plant soybean	5/1	0/0	500	10.0	2
18	Row cultivate	6/1	0/0	500	10.0	1
18	Row cultivate	6/10	0/0	500	10.0	2

and then the hours per day the operation can be performed. The hours-per-day figure is assumed to be hours spent in the field operating machinery. No allowance is made for time used to adjust and service equipment or for traveling to the fields.

The second operation listed for the example farm is "Combine corn," with an earliest start date of October 15. The third operation listed is "Chisel plow," which is to be performed on the same land from which corn is harvested. Thus, the land area number is the same for both combine corn and chisel plow operations. Land area numbers are used in scheduling the field operations. For the example farm, the chisel plow operation will not get ahead of the combine soybean operation when the operations are scheduled.

The desired spring operations for corn are "Disk harrow," "Field cultivate," and "Plant corn." All of these operations are to be performed in sequence on the land that was in soybean the previous year; therefore, the land area number is 1 for each of these operations. For soybean, the spring operations are disk harrow, field cultivate, and plant soybean, and the land area number is 2 for these operations. Both crops are to be cultivated once.

A primary objective of the program is to determine the optimum set of machinery and the machinery-related costs for the list of desired field operations.

Matching of Implements to Tractors

For farms that can justify two or more tractors, and if the tractors, are different in size, a method is needed for determining which field operations the different-size tractors will perform. For large farms with several tractors, the number of alternatives is tremendous. Of course, a complete farm machinery selection program would include the solution for this problem. The method used by Freesmeyer [7] is a possibility. For the program described herein the user must assign the implements needed to perform the field operations to either large or small tractors, as shown for an example farm in upcoming Tables 5–9. The user must also specify whether the number of rows on the planter is to be the same as or twice the number of rows on the combine corn head.

The Search for an Optimal Machinery Set

Three options are available when running the program. The first option is an attempt to allow the user to run the program with a specified number and specified sizes of tractors and combines. The machinery set specified might be the current set of machinery on a farm or a set in which the user is interested. Most farmers have a set of machinery currently being used and may be interested in an estimate of the total cost, including potential timeliness penalties and the work schedule. Or they may want to evaluate the effects of changing only one or two machines, or they might like to know the effects of using the present machinery on expanding the farm. The first option of the program may be used for these purposes. The second and third options are programmed to determine the optimum set of machinery for the desired field operations. For the second option, the user specifies the number of tractors, combines, and laborers, and the program optimizes the sizes of the tractors and combines. The third option is an attempt to determine the optimum set of machinery, including number and sizes of tractors and combines and number of laborers. The search for the optimal machinery set will be explained using the second option.

Assume the program user has entered the list of field operations as shown in Table 5-7, specified the number of tractors and combines as shown in Table 5-8, and matched tractors to implements as shown in Table 5-9. Then the goal of option 2 is to find the least-cost machinery set. To find the least cost machinery set, the program first sets the size of the large tractors to 220 horsepower, the largest available in the program, sets the small tractors to one tractor size increment less than the largest tractor size, and sets the size of the combine at 260 horsepower, the largest in the program. With this set of

Table 5-8 Specifying Number and Size of Tractors and Combines

	Quantity	Size[a]		Quantity	Size[a]
Tractors (max = 6)			Combines (max = 3)	1	2 (215 hp)
Large	1	5 (160 hp)	Corn heads	1	
Small	1	1 (80 hp)	Grain platforms	1	
Available tractor sizes			*Available combine sizes*		
0 = 60 hp	5 = 160 hp		0 = 140 hp (4-row head)		
1 = 80 hp	6 = 180 hp		1 = 180 hp (6-row head)		
2 = 100 hp	7 = 200 hp		2 = 215 hp (8-row head)		
3 = 120 hp	8 = 220 hp		3 = 260 hp (12-row head)		
4 = 140 hp					

[a] Needed to run without optimization.

Table 5-9 Match of Implements to Tractors, with Values for Example Farm

Planter size? S (T or S)
(T): Twice the combine size
(S): Same as combine size

Large tractors (L): 1
Small tractors (S): 1
Total: 2

Implement	L	S	Implement	L	S
Moldboard plow	0	0	Spray pesticide	0	0
Chisel plow	1	0	Drill	0	0
Disk	1	0	Subsoiler	0	0
Field cultivate	1	0	Paraplow	0	0
Chop stalks	0	0	Chop forage	0	0
Plant	0	1	Combination tool	0	0
Row cultivate	0	1	Mow hay	0	0
Rotary hoe	0	0	Rake hay	0	0
Apply Anhydrous	0	0	Mow and condition	0	0
Apply fertilizer	0	0	Bale hay	0	0

machinery, the input data, and the stored data files, the field operations are scheduled and the costs for machinery, labor, and timeliness calculated. These costs are summed to get the total average annual machinery cost, $69.51 per acre in the lower right-hand corner of Table 5-10.

Then both the size of the small tractors and the combines are decreased, and again the work schedule and costs are computed, $66.46. The sizes of the small tractors and combines continue to be decreased, moving up in Table 5-10, until the total annual cost increases due to increased timeliness costs or until the reduced machinery sizes can no longer complete the tasks. Thus, the least cost machinery set has been found with the size of the large tractors fixed at 220 horsepower: 80-hp small tractor, 21hp combine, and a total cost of $60.23 per acre. Table 5-10 shows the costs in dollars per acre for the different machinery sets evaluated for an example farm, with the large tractor fixed at 220 horsepower. The x's on the screen indicate that a machinery set not able to complete the operations within a calendar year, a tractor is of insufficient size to pull an implement, or an operation could not be completed by the

Table 5-10 Initial Search for Optimal Machinery Set for Example Farm (One Large Tractor, 220 hp)

Small	Combines (hp)			
tractor (hp)	140	180	215	260
60		xxxx	xxxx	xxxx
80		$66.32	$60.23	xxxx
100		$68.79	$62.54	$64.88
120			$63.88	
140			$64.66	
160		$72.09	$65.50	
180			$66.46	
200				$69.51

xxxx = combinations not able to complete required operations.
Blank entries = combinations not tried during optimization.

latest finish date listed in the input data. The optimization procedure did not need to calculate the costs in the blank cells in Table 5-10.

Next, the size of the large tractors is reduced by one size increment, in this case to 200 horsepower, and the preceding procedure is repeated. The size of the large tractors is reduced until the least cost increases.

For the final trials, the least cost is determined with all tractors the same size. Thus, the total cost is determined for all possible size combinations of two tractor sizes and combine sizes that could result in the least cost. Thereby, the optimum, or least-cost, machinery set is determined.

Low-Cost Machinery Sets

In searching for the optimal machinery set for a farm, it is common for the program to determine the costs for over 40 combinations of tractor and combine sizes. For several of these combinations the total annual cost varies by only a small amount. For this and other reasons the user may be interested in a machinery set other than the set that results in the least cost. Therefore, when the optimal search is completed the program presents the eight lowest-cost machinery sets found during the search on the first screen shown when the optimization run is completed (Table 5-11). The first set presented is the least cost machinery set found during the search for the optimal machinery set. For each of the eight sets the presentation includes only the sizes of the large and small tractors and the size of the combines, costs for machinery, labor, and timeliness, and the total annual cost.

Output Information

The program user may obtain a presentation of the output information for any of the eight lowest-cost machinery sets found during the search by pressing the number of the set shown on the screen. For the example farm, the output information for the least-cost machinery set will be discussed.

Table 5-11 Screen List of Eight Lowest-Cost Machinery Sets, from S10

	Large tractors		Small tractors		Combines		Costs ($/acre)			
Rank	No.	Size	No.	Size	No.	Size	Machinery	Labor	Timeliness	Total
1	1	160	1	80	1	215	48.94	6.10	1.19	$56.23
2	1	180	1	80	1	215	50.56	5.93	0.00	$56.49
3	1	200	1	80	1	215	51.48	5.79	0.00	$57.27
4	1	160	1	100	1	215	51.20	6.10	1.19	$58.49
5	1	180	1	100	1	215	52.82	5.93	0.00	$58.75
6	1	140	1	80	1	215	48.18	6.37	4.64	$59.19
7	1	240	1	80	1	215	53.67	5.58	0.00	$59.26
8	1	200	1	100	1	215	53.73	5.79	0.00	$59.53

Type a number from 1 to 8 to see schedule, costs, etc.
Type 0 to return to Main Menu.
Type a number:

Machinery Set

The second output screen, after the list of eight solutions, is a list of the optimal machinery set (number 1 in the set of eight), including the assumed purchase price and the annual use of each machine (Table 5-12). Also, the annual number of hours each operator spends operating machinery is given.

Work Schedule

The computed work schedule is the most critical portion of the program output (Table 5-13). Considerable effort has been devoted to making the computed work schedule realistic in terms of utilizing operators and machinery.

The program schedules the field operations on a day-to-day basis, giving priority to the order in which the operations are listed in the input data. For the desired field operations listed in Table 5-7, the first operations scheduled are the harvesting operations. When only one machinery operator is available for harvesting, it is assumed that the operator spends 50% of the time hauling and processing the grain. Thus, the number of hours per day one operator actually spends operat-

Table 5-12 Optimum Machinery Set and Labor Use Determined for Example Farm

Machine	Purchase price ($)	Annual use (hours)	Acres
215-hp combine	106,020	173	
8-row corn head	25,200	91	500
22-ft grain platform	13,320	82	500
160-hp tractor	67,500	231	
11-ft chisel plow	8,190	76	500
25-ft disk harrow	15,930	89	1,000
29-ft field cultivator	11,970	66	1,000
80-hp tractor	35,100	236	
8-row planter	20,430	107	1,000
8-row cultivator	6,390	129	1,000

Number of machine operators = 2
Operator 1 would work 553 hr
Operator 2 would work 260 hr

Table 5-13 Work Schedule Using Optimum Machinery Set for Example Farm

Field operation	Start date	Finish date	Calendar days	Work days	Acres
Combine soybeans	9/15	10/8	24	10.3	500
Combine corn	10/15	10/31	17	9.1	500
Chisel plow	11/1	11/16	16	7.6	500
Disk harrow	4/1	4/24	24	4.5	500
Field cultivate	4/25	5/6	12	3.3	500
Plant corn	4/25	5/14	20	5.4	500
Disk harrow	4/24	5/22	29	4.5	500
Field cultivate	5/22	5/30	9	3.3	500
Plant soybeans	5/22	6/5[a]	15	5.4	500
Row cultivate	6/5	6/21	17	6.4	500
Row cultivate	6/21	7/5	15	6.4	500

[a] Indicates timeliness penalty applies.

ing the combine is reduced. When two operators are available, the combine operates the full number of hours per day listed in the input data, and the operation requires use of the two operators. It is realized that large variations exist in the time spent in unloading, hauling, and processing grain during harvest operations. Revisions of the computer program may be needed to account for these variations.

Each field operation starts on the date listed in the input data, unless an operator and machine to do the operation are not available. Other operations could be under way utilizing all operators or the machine required. The start date for such operations is the first date that both an operator and a machine are available. The acres completed on a given date equal the productivity (acres per hour) for the machinery being used, times the hours per day labor is available, times the probability that that date is suitable for field work.

If an operation is not completed by the latest finish date listed in the input data or if all operations are not completed within one calendar year, the machinery set is regarded as unacceptable.

For the example field operations listed in Table 5-7, the operations are scheduled beginning with the fall operations, and then the spring operations are scheduled. No timeliness penalties occur in conjunction with combine soybean, combine corn, or plant corn operations because these are completed before the respective penalty dates specified for these operations. Soybean planting is not completed until after the specified penalty date, (Table 5-6), and therefore a timeliness penalty is calculated.

Cost for Each Field Operation

As the field operations are scheduled, the annual hours of use are accumulated for each machine. The fixed and variable costs for each machine are calculated, as previously explained, using the annual use, input data, and data from the stored files. The fixed and variable costs are summed and the result used to calculate the cost per acre for each field operation (Table 5-14).

Table 5-14 Estimated Cost for Each Field Operation

Machine name	Years of use	Annual hours	Power and machine cost ($/acre)	Machine cost only ($/acre)
215-hp combine	9	173		
8-row corn head	10	91	25.07	6.61
22-ft grain platform	10	82	20.29	3.53
160-hp tractor	10	231		
11-ft chisel plow	10	76	9.40	2.44
25-ft disk harrow	10	89	6.40	2.30
29-ft field cultivator	10	66	4.75	1.70
80-hp tractor	10	236		
8-row planter	7	107	6.31	3.81
8-row cultivator	8	129	4.10	1.10

Detailed Costs for Each Machine

If desired, the detailed costs for each machine are provided for each year, up to a maximum of 10 years of ownership. For the example farm, the costs of the combine and corn head are presented in Tables 5-15 and 5-16. The program presents the costs of other machines in a similar manner.

Total Machinery-Related Costs for the Example Farm

Finally, the total machinery-related cost for the machinery set is given for the farm (Table 5-17). The machinery fixed cost includes estimated depreciation, housing, interest, and insurance. To the fixed cost is added the estimated fuel and repair costs, to get the total machinery cost. Labor cost is figured using the labor rates entered. Timeliness cost is calculated for the acres of any crop planted or harvested after the penalty dates specified. From the work schedule explained previously for the example farm, the plant soybeans operation was completed late. Thus, a timeliness cost is calculated for the operation. The costs for machinery, labor, and timeliness are summed to provide an estimate of the total annual machinery-related cost for the machinery set.

Table 5-15 Detailed Costs for 215-hp Combine

List price = $117,800, purchase price = $106,020, fuel price = $1/gal, fuel use = 10.88 gal/hr, machine use = 173 hr/yr

Year	Total use (hr)	Percent of life (%)	Accumulated Depreciation ($)	Accumulated HII[a] $	Accumulated Repairs ($)	Average cost ($/acre)
1	173	6	39,298	12,722	118	312
2	346	12	46,971	19,928	522	167
4	692	23	59,771	31,950	2,250	147
5	866	29	65,090	36,944	3,597	133
6	1,039	35	69,797	41,365	5,278	123
7	1,212	40	73,963	45,277	7,297	115
8	1,385	46	77,649	48,739	9,660	109
9	1,558	52	80,912	51,803	12,371	104

[a] HII = housing + interest + insurance

Table 5-16 Detailed Costs for 8-Row Corn Head

List price = $28,000, purchase price = $25,200, machine covers 500 acres/yr, fuel cost = $1.97/acre, productivity = 5.51 acres/hr, annual use = 90.7 hr/yr

Year	Total use (hr)	Percent of life (%)	Accumulated Depreciation ($)	Accumulated HII[a] $	Accumulated Repairs ($)	Average cost ($/acre)
1	91	3	9,341	3,024	7	24.75
2	181	6	11,165	4,737	32	15.90
3	272	9	12,779	6,253	75	12.75
4	363	12	14,207	7,594	138	12.00
5	454	15	15,471	8,781	220	9.80
6	544	18	16,590	9,832	323	8.90
7	635	21	17,580	10,762	447	8.20
8	726	24	18,457	11,585	591	7.65
9	817	27	19,232	12,313	757	7.20
10	907	30	19,918	12,958	945	6.75

Total costs ($25.64/ac) = cost for combine ($104/hr)(hr/5.51 ac) + corn head ($6.75/ac)
[a] HII = housing + Interest + insurance.

Table 5-17 Average Annual Machinery-Related Costs

Cost item	$/year	$/acre
Machinery fixed cost	40,867	40.87
Fuel cost	4,708	4.71
Repair cost	3,368	3.37
Total machinery cost	48,942	48.94
Labor cost	6,098	6.10
Timeliness cost	1,190	1.19
Total cost	56,230	56.23

USING S10 TO DEMONSTRATE EFFECTS OF FIXED COSTS AND TIMELINESS

The objective of the following projects is to show the principles of selecting machinery for a balance between fixed costs and timeliness costs, using the S10 program.

Running the S10 Machinery Selection Program

S10 is a DOS program, so to run it under Windows, from the Program List select Accessories and then Command Prompt. (For Windows older than XP, select MS-DOS Prompt.) Make sure you are in the directory that contains S10, probably the CD drive, and then type S10. It is a DOS program, but it has drop-down menus like Windows programs. However, it does not respond correctly to the mouse, so use the cursor keys and the Return key as you run the program.

Start with the menu on the left, SELECT (the down-arrow shows the list), and select Central Illinois. Then hit the Return key. Then you have to go down the list and select RETURN. All the menus are like this—you have to go down to highlight RETURN and then press the Return key.

Next, on the right is UPDATE. You can skip that for now and go to INPUT. The screen will look like Figure 5-2, or perhaps this figure is on your CD in color. Later, when changing

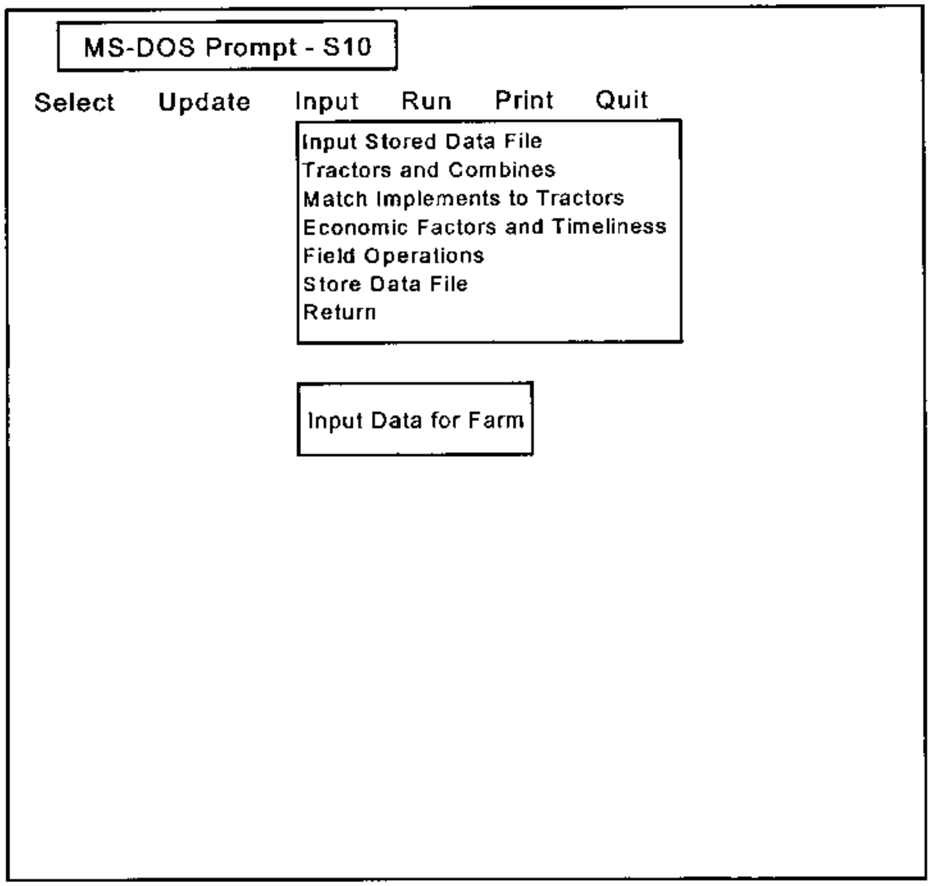


Figure 5-2 Schematic of screen of S10 with Input menu selected.

the inputs, you will use the UPDATE menu. Press Enter with "Input Stored Data File" selected; you will be asked to enter the name of the data file to enter. Type in EXAMPLE, as on the screen (input is case-sensitive). Later, when you are changing the inputs, you will name the modified file, and that will show up as an option on the next run. Now go down to RETURN, and press the Return key.

Move to the right to the Run menu, and select the top item under Run, Optimization. Figure 5-3 shows this screen, or it may be available in color on the CD with this book. Do not use the Print menu, and do not quit yet. Read the directions on the screen under the table that appears, shown in Table 5-11, the list of the eight least-cost combinations. To print any of the tables, one at a time, press the PrintScrn key, and then go to any Microsoft program, such as Word or MS Photo Editor®, use Edit, click on Office Clipboard, select the image, and it is ready to print.

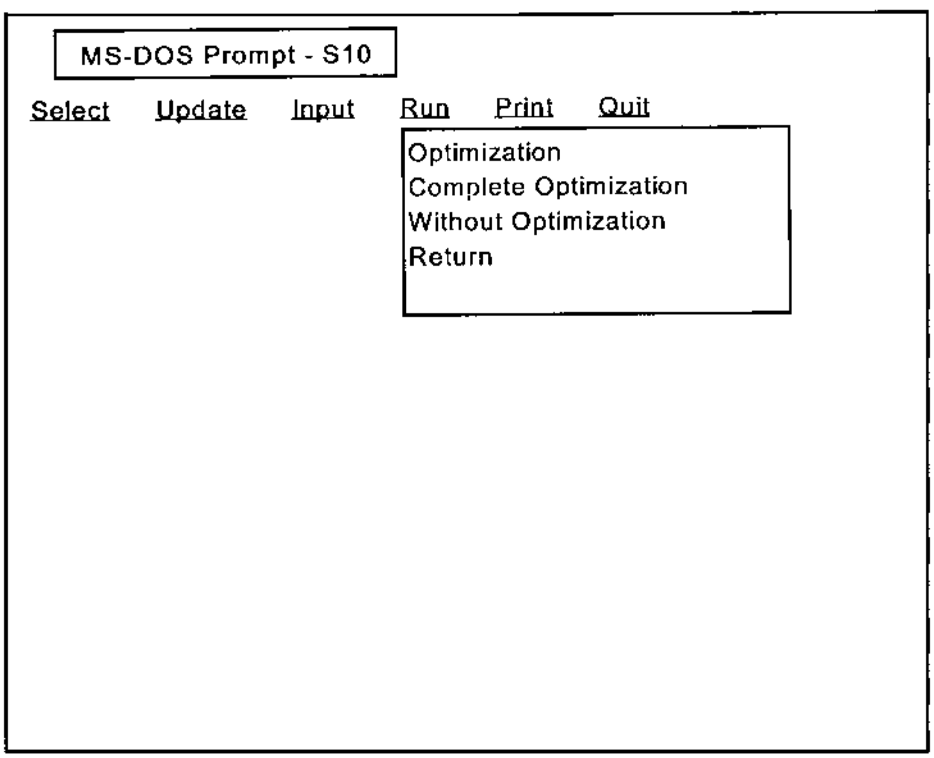


Figure 5-3 Schematic of S10 screen with Run menu selected.

1. The first task is to print (as described earlier) the various results for the standard run for Central Illinois with the default inputs. Tables 5-11–5-14, and 5-17 should match five of the six or seven screens that S10 produces.
2. Then we will change the housing, interest, and insurance rate to be charged to fixed costs from its default value of 12% to 10% to reflect a lower interest rate. Also, increase the daily hours of operation allotted for corn planting from the default value of 10 hr to 14 hr.
3. Check to see if these changes cause a difference in the recommended machinery sizes selected (probably not). Then note the difference in the planting time required (because of working more hours per day), both in actual workdays and in calendar days. Why is there a difference between workdays and calendar days?

Also note the difference in the fixed cost/acre due to the change in interest rates. Over the past years, interest rates have changed over a wide range, and they are still a major part of the cost of machinery, whether or not the equipment is purchased for cash or with borrowed money. Why? If the equipment was purchased with cash, that cash could have earned interest in some type of investment had it not been used to buy the equipment. Economists call this *opportunity cost*—you always have other opportunities for use of the cash, such as savings account and purchase fertilizer, that will bring returns.

S10 calculates a timeliness cost per acre. Since the revised hours per day for planting have been increased, this timeliness cost should decrease, right? Yes. For combination #1, 10 hr/day labor, the timeliness cost is $1.19 per acre. For 14 hr/day, it is zero.

The penalty for late corn planting in S10 is 1 bu/day after May 15 (confirm it shortly). There is also a late harvesting penalty.

Project 2: Test the Effect of the Late Planting Penalty Rate

Report on the change in timeliness cost for 10 hr/day vs. 14 hr/day for planting. Also, as a separate check, use the work schedule to note the planting period, and estimate how many acres were planted 1 day after May 10, 2 days after May 10, etc., to the end of planting. Then use the 1 bu/acre/day rule and calculate the number of lost bushels. Then, using $2.50/bu as a price, average the total lost-bushel cost over the 500 acres. Do this for both cases, and compare that difference to the difference in timeliness cost per day calculated by the program.

Project 3: Calculate Acres Planted Based on Probability of a Good Field Day

Using the original Central Illinois data, including 10 hr/day for planting corn, show how the date for completing planting of soybeans is calculated, using the weather probabilities, that is, the probability of a good field day. Remember that the 500 acres for soybeans must first be disk harrowed, then field cultivated. Field cultivation can start at the same time as soybean planting, because it is a faster operation, the planter following the cultivator (2 tractors and operators). Soybean planting starts on 5/22 and ends on 6/6. Calculate the actual number of acres planted each day, using the machine capacity and the weather probability. When the probability of a good day is 0.40, working 10 hr/day, then

$$\begin{aligned}\text{total acreage done} &= \text{prob.} \times \text{hr/day} \times \text{mach. cap., acres/hr}\\ &= 4 \times \text{mach. cap.}\end{aligned}$$

Print out the necessary tables to show the probabilities, machine capacity, and earliest starting dates. Why is soybean planting started on 5/22, when the earliest starting date is 5/1?

Write a report on this project, including the printouts of the tables, and answer the questions in the preceding paragraphs. Note any problems you had in operating the program and any improvements you would suggest.

Select "Input Stored Data File," type in or select EXAMPLE, and then go to RETURN. Go to Run & Select OPTIMIZATION, and it will go through some calculations trying out different combinations and then showing a table of the eight best combinations.

Pick the best, 1, and a series of tables comes up. You change to the next by hitting any key. Eventually, you get back to the table of 8. To print any of these tables, press the PrintScreen key. This puts the screen into memory. Transfer to your word processing program, set the cursor where you want it, and click on Edit and then on Paste, and you have the table as a graphic box on your word processor.

Remember this program is for Illinois corn/soybean operations. The main point, which is true over many agricultural areas and crops, is that yields are reduced for late planting and late harvest. Bigger equipment will reduce those losses but increase the equipment costs.

REFERENCES

1. ASAE. Agricultural Machinery Management Data. ASAE Standards 1994. ASAE: St. Joseph, MI, 1994.
2. Bender, D.A.; McCarl, B.A.; Schueller, J.K.; Kline, D.E.; Simon, S.H. Expert System Interpreter for a Farm Management Linear Program; Paper no. 85-5518. ASAE: St. Joseph, MI, 1985.
3. Black, J.R.; Harsh, S.B. Corn-Soybean-Wheat Farm Planning Guide. Telplan 26, Cooperative Extension Service, Michigan State University: East Lansing, MI, 1976.
4. Bowers, W. Machinery Management. John Deere Service Training, Dept. F., John Deere Rd., Moline, IL, 1987.
5. Chen, L.H. A Machinery Selection, Crop Budgeting, and Scheduling Model; Technical Bulletin 145. Miss. Agric. and Forestry Exp. Station, Mississippi State University: Mississippi Station, MS, 1987.

6. Doster, H. Top Crop Farmer Planning Model. Cooperative Extension Service, Purdue University: West Lafayette, IN, 1981.
7. Freesmeyer, S.R. A time-constrained optimal farm machinery selection program for microcomputers. M.S. thesis, University of Illinois: Urbana, IL., 1985.
8. Hughes, H.A.; Holtman, J.B. Machinery complement selection based on time constraints. Trans. ASAE. 1976, 19 (5), 812–814.
9. Hodges, H.F.; Whisler, F.D.; Bridges, S.M.; Reddy, K.R.; McKinion, J.M. Simulation in crop management: GOSSYM/COMAX. In: Agricultural Systems Modeling and Simulation; Peart, R.M., Curry, R.B., Eds; Marcel Dekker: New York, 1998.
10. Hunt, D.R. A Fortran program for selecting farm equipment. Agricultural Engineering 1967, 48 (6), 332–335.
11. Kline, D.E.; Bender, D.A.; McCarl, B.A. FINDS: Farm-Level Intelligent Decision Support System. Appl. Engin. Agric. 1989, 5 (2), 273–280.
12. McKinion, J.M.; Lemmon, H.E. Symbolic Computers and AI Tools for a Cotton Expert system. Paper No. 85-5520, ASAE: St. Joseph, MI, 1985.
13. Rotz, C.A.; Muthar, H.A.; Black, J.R. A multiple-crop machinery selection algorithm. Trans. ASAE 1983, 26 (6), 1644–1649.
14. Schueller, J.K.; Slusher, R.M.; Morgan, S.M. An expert system with speech synthesis for troubleshooting grain combine performance. Trans. ASAE 1986, 29, 342–344, 350.
15. Schwart, R.B. Farm Machinery Decisions, Worksheet No. 1, What Size Machinery for Your Farm? Circular 1065; Illinois Cooperative Extension Service, University of Illinois: Urbana, ILL, 1981.
16. Siemens, J.C.; Hamburg, K.; Tyrrell, T. A farm machinery selection and management program. J. Prod. Agric. 1990, 3, 212–219.
17. Siemens, John C. Field machinery selection using simulation and optimization. In: Agricultural Systems Modeling and Simu-

lation. Peart, R.M., Curry, R.B., Eds; Marcel Dekker: New York, 1998.

18. Singh, D. Field machinery system modeling and requirements for selected michigan cash crop production systems; Ph.D. dissertation, Michigan State University: East Lansing, MI., 1978.

19. Wolak, F.J. Development of a field machinery selection model; Ph.D. dissertation, Michigan State University: East Lansing, MI., 1981.

6

Simulation of Crop Growth and Field Operations: CropPlan

Robert M. Peart and Robert Smith*

SIMULATING FIELD OPERATIONS AND CROP GROWTH

The previous chapter, on machinery selection, ended with a statement that over many agricultural areas and crops, yields are reduced if planting and/or harvesting are late. We stated that machinery with higher capacity can reduce these losses but will increase the fixed cost of the equipment. Therefore, optimal selection of machinery requires a balancing of these

* Dr. Robert Smith was the original programmer for CropPlan and assisted with the chapter.

two types of losses, yield losses and financial loss due to higher fixed costs. The previous chapter introduced a program that makes such an optimal selection, given much detailed data about the cropping system and the available machinery sets. That program runs under DOS and also with the "Command Prompt" of the Windows XP operating system, and it was written in FORTRAN. It runs with assumptions of typical weather for central Illinois and has no other choices. The program described in this chapter, CropPlan, does a similar task, but it has choices about the type of weather data to be used. On the other hand, CropPlan does no optimization, but it does simulate the crop growth and yield as well as the weekly field operations based on weather-influenced *good field days* and the capacity of the equipment. The data on good field days came from reports of crop observers in Indiana on the weekly number of days when field conditions allowed machinery to be used, and these data were available for each of the four weather scenarios available in the spreadsheet files. It also has changeable economic inputs, so that results are expressed in dollars.

The program presented here is a simulation program, in spreadsheet form, that can help in making decisions about the capacity of equipment needed for an optimized balance between high fixed costs of equipment with overcapacity and high yield losses with undercapacity. CropPlan simulates the weekly field operations, from tillage through to harvest, and the crop development and yield; it also calculates fixed and variable costs of the whole enterprise. Being a spreadsheet template, the program can be examined easily, because the mathematical expressions are readable when the user highlights a particular cell to see the expression used to obtain the result in the cell.

The spreadsheet runs on Corel QuattroPro®; and the template mentioned earlier is the set of data and formulae that are in the file *CropPlan.wb3*, which is on the CD included in this text. Unfortunately, the program does not run correctly on Excel, apparently because of the difference in the "@MAX" command in QuattroPro and the "MAX" command in Excel.

This is a very large spreadsheet, but we do not intend to explain each of the many formulae. However, by using it in the exercises, you will get a working knowledge of how the program can evaluate machinery selection decisions, crop variety or cultivar decisions, and cost problems.

In grain production there are two parts of the timeliness cost, as mentioned in the last chapter. First, late planting can cause loss of potential yield; and second, late harvest can result in loss of actual yield. CropPlan uses some sophisticated rules to calculate losses, depending on the weather and the machinery capacities. These rules show something about the physiology of crop growth; they also show the importance of operational factors such as weather, machine capacity, and availability of labor.

GROWING DEGREE-DAYS

Corn that is planted late is harvested late, and there is increased probability of bad weather delays in the fall and increased harvesting losses. To be more specific about what influences the date when the crop will mature, corn (maize) varieties (or cultivars) are rated for the expected maturity time according to a *growing degree day* (GDD) value for a particular area. The GDD value is a value accumulated over time, accounting for time and temperature, starting at the planting date. For corn, the base temperature is 50°F. For a given day, each degree in the average daily temperature above 50°F adds 1 GDD to this accumulated value. The average is calculated as half of the sum of the maximum and minimum temperatures for the day. Thus, with a $T_{\max}$ of 80°F and a $T_{\min}$ of 60°F, the average temperature is 70°F, and the GDD value is (70 − 50), or 20, GDDs for that one day:

$$\text{GDDs per day} = (T_{\max} + T_{\min})/2 - 50$$

A typical GDD rating for a so-called "full-season" (late-maturing) variety in Peoria, IL, might be 2,800 GDD. A short-season (or "early") variety might be 2,400 GDDs. For the same planting date, obviously the accumulated 2,400 GDDs would be reached before 2,800, so the short-season variety would mature earlier than the full-season variety.

For temperatures measured in degrees C (Celcius), the value for each day is $T_{ave} - 20$, since 50°F = 20°C. The total GDD value for the season is scaled down by a factor of 5/9. Thus a total GDD value of 2,700 in °F would be 5/9 * 2700 = 1,500 GDDs (C).

CROP YIELDS AND LOSSES

Another important fact with corn (maize) is that, other factors being the same, the larger the GDD rating, the higher the yield. This makes sense, since the plant can be viewed as a photosynthetic system that produces carbohydrates and protein, with inputs of water and nutrients from the soil, carbon dioxide (and a little oxygen) from the air, and, very importantly, solar energy to power the whole process. The longer that the system produces, the more solar energy is received and the more "product" it will deliver in yield. Also, plants that have more leaf area during the long summer days near the summer solstice of June 21, receive more energy from the sun than plants that have less leaf area at that time.

The short-season varieties will shut down production when maturity is reached (at a lower level of GDD), while a full-season variety planted at the same time will continue in production and produce more. If a frost kills the plant before this GDD rating is reached, production stops and yield is less than would be expected by the same variety able to continue producing up to its GDD limit.

So the corn farmer has machinery selection problems and crop cultivar selection decisions. To get the highest corn yields, planting must begin early (before May 10), but not early enough to have frost on the new corn as it sprouts from the ground. So there is a window of time between the date of the last expected frost in the spring until the May 1 or May 10 date, when potential yields will decline because of the reduced potential for accumulating GDDs before the fall frost. The typical wet weather in many areas during this spring planting period is an additional problem, since fields may be too wet for machinery use. So farmers want relatively big, high-capacity equipment to get the corn planted within this planting window.

In cultivar (variety) selection, the full-season variety is preferable because of the higher yield potential. For a given planting date, the higher-yielding, full-season variety will mature later than a mid-season or early-season variety, thus delaying the start of harvesting. Ideally, the crop would all be harvested on the day when it reaches physiological maturity (end of adding carbohydrates to the grain). Each day after that maturity date, field losses from broken stalks, ears dropping from the stalk, etc., begin to mount. This is usually minor in the first week or so after maturity, but it gets progressively worse as the stalk dries and deteriorates. There is also a weather problem in the fall, when wet weather may occur and prevent the combines from harvesting.

Of course, during the time between maturity and harvest, the grain is drying; in the case of corn, this reduces the cost of artificial drying, which is normally needed on all the shelled corn harvested. This program, CropPlan, simulates grain drying in the field as a function of time after maturity, but the cost saving for less artificial drying is *not* taken into account.

There are three factors that can lead to delayed harvesting and accumulation of harvest losses:

Late planting.
Full-season variety delays maturity date (and increases yield).
Low-capacity harvesting equipment delays harvesting date.

In addition to the late-planting penalty already explained, there is a late-harvesting rule that is not a simple linear function, such as the "1/2 bu/acre" late-planting rule. After maturity or frost kill, the field losses and dry-down functions are piecewise linear in the spreadsheet formulae. The rates of loss and drying are changed as the fall season progresses, with the field losses increasing and drying rate decreasing. This is similar to the way it works in the field.

In summary, late-planting losses consist of yield potential that did not materialize, and late-harvesting loss is yield that was physically lost because the combine did not reach it or dropped it to the ground:

$$\text{timeliness cost} = \text{late-planting losses} + \text{late-harvest losses}$$

In soybean, the same types of losses apply, but the maturity date is not as closely tied to GDD value as it is in maize. Complicating the maturity calculations for soybean, different cultivars selected for northern vs. southern climate in the United States reach the time for harvest for two different reasons. In the southern areas, a killing frost, if there is one at all, may be very late in the calendar year. In these areas, soybean seed cultivars are from the *determinant* types, meaning that they are more dependent on day length and growing degree days to reach maturity, and they will mature without any frost or freeze. In the northern states, where frost dates are an important factor, *indeterminant* cultivars are used, and they will continue to grow and produce seed as long as they have not been killed by low temperatures.

Soybean is different from corn, because it starts producing beans at the bottom of the stalk long before the entire plant matures and drops its leaves. It continues to grow and produce seeds higher up the stalk as the season progresses. If soybean is planted very late in the season, some mature seeds may be harvested because of this characteristic, whereas corn may have no seed yield during the same period. Both these crops are amazingly productive. As a source of biomass energy, corn ranks very high, producing over 4 tons per acre of low-moisture grain that is easily handled and storable over long periods.

In the previous chapter, some examples of harvesting dilemmas with fresh fruit were given, where many other factors than just field losses and machinery fixed costs have an effect. Examples were given of earlier harvest dates resulting in higher prices for the produce. However, with some products, the earlier-harvested ones are likely to be less mature and perhaps less sweet and not as desirable to the customer. In some cases, early harvest may result in lower yield, because the crop is not yet mature. Other factors include the availability of harvesting labor for some produce, and the effects of the threat of frost and freezes on harvesting strategy. So the field grain examples used in CropPlan present simpler problems than is the case with many fruit and vegetable crops. There is room for profitable research in this area, we believe. CropPlan probably could be modified to work with other crops and situations.

All these factors make selecting machine capacity an important decision. Relatively high-capacity machines will help reduce yield losses due to late planting and/or late harvest. However, if the machinery is of larger capacity than necessary, much higher fixed costs result. Thus, proper selection of machine capacity is a problem of balancing high fixed costs against high yield losses.

CROPPLAN, A CROP GROWTH AND FIELD OPERATIONS SIMULATOR

The spreadsheet program CropPlan, by Smith [1], was developed to simulate the field operations and crop and yield development for a typical corn/soybean farming situation in the Midwest. It includes year-round operation, allowing tillage in the fall after harvest, if enough good weather is available, and finishing up the following spring, planting, applying fertilizer, etc., and harvesting, after the crop has developed to maturity according to the weather data and the crop cultivar that is selected. The concept of growing degree days is used for crop development. Also, temperature and moisture stress factors are used to adjust the expected yields according to the weather. The weather data include the actual percentage of days when field work can be done from Indiana weather and field operation reports for the particular historical year selected. Thus a rainy season combined with low-capacity machinery will result in late field operations and higher yield losses. On the other hand, extra-high-capacity machinery will result in timely operations and low yield losses but higher fixed costs for the large machinery. The program is described in Smith et al. [2]; these next few pages are based on that publication.

Two main uses for CropPlan are:

1. Comparative analysis during preseason planning, often called *strategic* or *long-range planning*. Examples include determining the effects of changing machinery capacities and costs; changes in the crop varieties, acreage, or mix; changing the number of hours per day to run the field equipment; changing crop and supply prices; and interest rates.
2. Sequential updating of the projected outcome during a particular season for short-range planning. Replacing the expected weather conditions with actual values and revising future values will update the expected cropping results and allow the user to modify the drying and marketing techniques and prepare for future operations on time.

Up to five crops, or fields, of corn and five crops of soybeans can be entered into the spreadsheet. Each of these five crops represents a given acreage that is planted in a few days to the same cultivar. Each "crop" need not represent just one specific field, but a specific number of acres that are treated the same, although the entire crop need not be planted in the same week.

The CropPlan spreadsheet lays out the entire yearly cropping season, using columns to represent time steps, normally one week each during the operational season. Rows are used to represent the many different variables in this program, including:

Number of acres planted with soybeans (during the week of this column)
Number of growing degree days accumulated that week
Number of stress days that week (stress = high temperature + dry soil)
Yield accumulated to that point in time
Moisture content of the grain at that point in time

The CropPlan spreadsheet has a number of other sections that contain data or calculations on costs, income, price per bushel, hours of labor, machinery fixed and variable costs, and, finally, net profit or loss for the year. CropPlan is very large, and it is not simple to navigate through on-screen. However, many of the main variables used are gathered together in an Input/Output section, in the upper right-hand corner, for analysis and for easily changing some of the major inputs.

CropPlan is designed to operate as a dynamic simulator of both the biological processes, such as crop growth, maturation, and drying, and operational processes, such as tillage, planting, and harvesting, with both processes influenced by weather conditions. The relationships between cell functions and the order of recalculation are used to direct the flow of control of calculations within the spreadsheet. This ensures that operations are performed in the correct order of priority; for instance, planting must follow tillage in each field, but one field may be planted before another one is tilled. Farming operations are interdependent, and the controlling, or rate-limiting, operations or processes will change as a season progresses.

Because the spreadsheet does its calculations from left to right and from the top down, control is passed from the field operations to the crops after planting and then back to the field operations when the crops are mature and ready for harvest. The cycle back to planting is completed by the carryover of land preparation from one season to the next. Machinery use is constrained by the number of units and their field capacities, as current inputs, and by the availability of good field-working days, contained in standard or user-defined lookup tables. Crop development is determined by variety, planting date, and weather data on the growing degree days, stress degree days, and water deficits during the season.

The sequence of spring field operations is hierarchically ordered during a particular week, with the land preparation operations being done before planting and the corn crops being planted before the soybean. The allowable field hours are constrained by:

The availability of remaining field hours for that period after the time used by higher-priority operations has been subtracted from the total available.
The remaining time, based on good field days available, after subtracting the sum of prior weekly hours done from the initial total for that operation.
The number of units that can be used for that operation and their field capacities.
The field hours may not be negative.

The crop planting is also constrained by the total number of planter units, including units that can be converted to plant corn or soybeans. Some of the specific spreadsheet functions used in the models are detailed in Shutske et al. [3].

The fall operation sequence has corn and soybean harvesting preceding the tillage and land preparation operations for the following year. Corn fields are harvested after soybean fields if both are ready for harvest at the same time. Corn crops may be harvested if they are mature and there are no soybeans ready for harvest during that week. Harvesting of the corn and soybean crops is constrained by:

The grain moisture being lower than the maximum value input by the user
The availability of field-combine hours to use

The availability of the second laborer and truck to aid with continuous combining
The sum of hours that have already been applied to that field

Fall land preparation is constrained by:

The crop harvest area finished up to that time
The availability of field-unit hours to conduct the operations
The availability of operators to drive the units

Crop development of the maize fields is determined by the accumulation of growing degree days, and the soybean development is determined from the expected maturity date for a particular variety and planting date. Expected grain yields are calculated from the initial user input of expected ideal yields after discounting for late planting and weather stress (low moisture) during the season. These adjusted grain yields are used as the potential yields for the crops at physiological maturity. After maturity or frost kill, the field losses and drydown functions are piecewise linear. The rates of loss and drying are changed as the fall season progresses, with the field losses increasing and drying rate decreasing.

In addition to the field operations and crop growth outputs, CropPlan contains summaries of the expected economic results for the current season being tested. User inputs include variable costs for each crop/field, common and crop-specific fixed costs, and the interest and depreciation rates that apply to different categories of equipment. An example of a corn crop variable cost is shown in Table 6-1. The preharvest items may be entered and changed by the user; harvesting and drying costs are determined from the final harvest yield, based on Peart and Barrett [4]. The variable costs are summarized for all the corn fields into an expected corn gross margin for two processing alternatives: (1) selling directly at harvest time for a lower price but with no fixed cost for storage and drying

Table 6-1 Upper Right-Hand Input/Output Screen for CropPlan, Typical Weather

Inputs	Value	Outputs	Value
Interest Rate, %	5.0	Net, Sell Wet =	$17,565
Labor, hr/day	10.0	Net, Dry-Store =	$10,034
Weather	TYPICAL	Corn, tot.ac =	375
Corn, $/bu, sell wet	$2.61	Corn, tot.bu =	41,932
Corn, $/bu, dry/store	$3.09	Corn, bu/ac =	111.8
Soybean, $/bu, sell	$6.81	Beans, tot.bu =	11,088
Soybean, $/bu, store	$7.51	Beans, tot.ac =	375
Mach. Purch. Price =	$271,200	Beans, bu/ac =	29.6

equipment; (2) drying and storing on the farm for a higher price expected the following spring.

The functions and models built into CropPlan are representative of the expected outcomes for maize and soybean in central Indiana. Different weather–crop–yield relationships should be applied in other cropping areas.

CROP GROWTH AND FIELD OPERATIONS SIMULATOR—APPLICATIONS

In the remainder of this chapter, we present exercises that can be used to show the interrelationships between machinery capacity, timeliness, and other factors that affect yields and profits in crop agriculture. Also, factors that have not been discussed in this chapter, such as interest rates, labor hours per day, and labor costs, can be evaluated easily using CropPlan.

Our purpose is not to detail the rules and equations used in the spreadsheet but to use it to show the effects of various management decisions in time-sensitive crop agriculture. The spreadsheet is not a perfect representation of a real crop system, but it can be used to learn more about how the real system reacts to management decisions. In fact, it is a different tool than experimenting on a real farm, because individual factors, such as different machinery capacities, can be compared in different runs of the program with no variation in other parts of the system. In the real system, comparing results from two different seasons—for instance, when we want to see how some new equipment affected results—has the problem of different weather in each year, and it is hard to separate the weather effect. These projects will help show how the simulation works, but they will also show the types of changes that can be made to the inputs and the effect of these changes on the results. The results are expressed as yields and also as financial returns, in the small table at the far upper right-hand corner of the spreadsheet. This table also allows some input changes to be made: interest rates and workday length. All costs of production, including fixed and variable costs and the cost of land use, are included in the spreadsheet and may be changed.

We will not try to explain all the functions built into this complex spreadsheet, but we will present some exercises in using the model to show how various management inputs can influence the yields and financial returns. The reason for studying this model is to learn how a model can be used in agricultural systems management, although this particular one is not generally available, except with this book. *Macros* are used in CropPlan to make it easier to change lengthier data sets, such as weather information, with just one command.

In addition to the macros for changing data sets easily, the far upper right-hand corner of the spreadsheet has been added since its first version, to put some of the important results in one place along with some important input numbers that are otherwise scattered throughout the large spreadsheet. We will be mentioning some specific numbers in pointing out trends and how the model works, but if your copy is not giving exactly the same answers, it probably is not set for the weather data we were using, which is called "typical."

Exploring CropPlan

First, a word about the general layout of this rather large spreadsheet. Almost every column represents a time period, usually one week, running from left to right, January to December. Most of the groups of rows represent activities, such as tillage, planting, and harvesting, going downward in the order of the activities. Individual rows represent different fields that are tilled, for example, in that week. In later columns, that same row shows how much of that field is planted or cultivated in the given week. So for a given crop, the processes and calculations can be visualized as starting at the top row for this field, with tillage occurring first, moving to the right for each week, and moving down when another field or activity is started.

In addition, many rows are weather data files, Good Field Days, Growing Degree Days, Stress Days (based on high temperature), and Water Deficit Days. These data are used in calculating yields and maturity days. Some lookup tables are in the spreadsheet to help with yield calculations based on planting date, crop cultivar, heat stress days, and water deficit days.

Start CropPlan. Go to cell A1 and go down to the messages on rows 174–190. Read the screens all the way across to column Z. The main values we will be working with, such as Average Yields, Interest Rate, and Labor Hrs/day, are set off separately on the far upper righthand corner of the sheet (see Table 6-1). Many of the cells are "locked" so that they are not subject to being accidentally changed. This is important for many of the complex functions and data values that are programmed into the cells. However, for our use, the cells on the upper far right, representing inputs to the program, may be changed by the user to make comparisons between runs. Then the commonly used outputs, Yields, Returns, etc., are also placed in this far right section to make them easier to find. Note the values on this upper right block of cells, Table 6-1 or on the screen, for the standard run, which is using the Typical Weather (this word *Typical* must be entered by hand) and should be on the screen when you open CropPlan.

Input Data

Macro commands allow selection of the weather data sets named, Typical, Drought, High Yield, Late Plant, and Your Values, the last one for the users who wish to put in their own values. These macros (in QuattroPro) are visible on the far right side of the spreadsheet under the Input/Output table. To switch the weather data to a new set, select the cell right under the title, Typical, Drought, High Yield, or Late Plant. It will be a command, such as: {SelectBlock A:C68..AQ68}, which is the first command of the High Yield macro. Then under the Tool menu, click Macros, and then Play, and the address of this macro will appear in the box. Click OK, and the data is almost instantly moved into the "Now" column. You may check this at rows in the area of C67 for Good Field Day data, T141, for Stress Degree Days, T149 for Water Deficit Days, and F157 for the Growing Degree Day data.

In rows 66–73 are listed the weekly Good Field Days (GFD) values for several years in Indiana. They represent a Typical year, a Late Planting year (1974), a High Yield year (1982), and a Drought year (1983). Row 70 is for the users to enter their own set of Good Field Days values. Row 72 gives the Good Field Days from a Typical year used in a linear program called B10, described by Doster [5]. The set, or row, of values to be used in the next run are placed by the macro into row 73, called the Now Value. If the macros don't work with your spreadsheet, simply copy the entire row of the year you have selected and paste it into row 73. There are three other rows of data to be moved into the Now row.

Starting in cell T140 is one of the two sets of weather data used in crop yield calculations. They give specific year values for Stress (Heat) and for MD, Moisture Deficit, each of which will reduce yields. If the macros don't work, select the same year as you used for the Good Field Days, and copy and paste each of those rows into the Now Value row for both Stress and Moisture Deficit. These values start in column T, July 5–11, because stress and moisture deficits do not usually occur before this date in Indiana.

The last set of yearly weather data to be entered starts in row 157, col. F, the GDD (Growing Degree Day) values for each year. This value is accumulated throughout the season, and CropPlan uses the planting date, as determined by the operation simulation, and then calculates when the crop has reached maturity. If the macros don't work on your spreadsheet program, just copy the Weather row that matches the year you have selected, and paste it into the Now Row.

The Typical year was chosen not as an average but to typify what might be called a normal year (if there is such a thing!). In fact, the use of weather data that have been averaged over several years is not a good practice in simulation. The averaging tends to take out the times of very low rainfall and very high temperature (or very low temperature). The average of the yields from the simulation of one dry year and one wet year are usually lower than the yield from one run using the average rainfall of the two years.

FIELD OPERATIONS

Now we look in detail at the programming of the calculations for the field operations. We will be looking at Tables 6-2–6-5, which are part of the CropPlan spreadsheet. We believe the weather data used are the same as those on the full spreadsheet on the CD that comes with this book. However, it is possible that a different data set was used on the CD, so in case of confusion follow the sections of CropPlan that are tabulated here. Machine capacities are listed in Table 6-5.

Observe cell D72 in Table 6-2. It shows only 0.5 Good Field Days (GFDa) during the period Mar. 1–21, and since 2 tractors and operators are available at 10 hr/da, in a half-day 10 total Trac Hr were available (D74). D78 shows that 5 Tractor Hr

Table 6-2 Section of Field Operations on CropPlan

Col. A operation:	Row	Column D	E	F	G	H
GFDa Avail.	72	0.5	1.0	1.0	1.0	2.0
Now Value	73	0.5	1.0	1.0	1.0	2.0
Tot Tr Hr Avail.	74	10.0	20.0	20.0	20.0	40.0
Spare HRS	75	0	0.0	0.0	0.0	0.0
Fert P+K	78	5.0	3.33	0.0	0.0	0.0
Acres, Fld 1 100	79	60.0	40.0	0.0	0.0	0.0
Plow MB	80	5.0	9.37	0.0	0.0	0.0
Acres, Fld 1 50	81	17.40	32.6	0.0	0.0	0.0
Plow CH	82	0.0	7.3	1.79	0.0	0.0
Acres, Fld 1 50	83	0.0	40.14	9.86	0.0	0.0
PrepDisc	84	0.0	0.0	10.00	10.00	20.0
Acres, 1–5 750	85	0.0	0.0	87.0	87.0	174.0
Fert NH3	86	0.0	0.0	8.21	10.0	20.0
Acres 375	87	0.0	0.0	41.04	50.0	100.0

Col. D = Mar. 1–21, E = Mar. 22–28, F = Mar. 29–Apr. 4, G = Apr. 5–11, H = Apr. 12–18.

were used to apply fertilizer during this week, and 60 acres were covered, D79. A79 shows that 100 acres are to be fertilized in this field. D80 shows that 5 more Trac Hr, using the other tractor, were used to Plow with the moldboard (MB) plow, and 17.40 acres were finished. The total of 10 Trac Hr could not be used for applying fertilizer, because that would require both tractors, and only one fertilizer applicator is available. Also note that the operations are done in the natural sequence of the spreadsheet calculations, which is top to bottom, so listing the operations in their correct sequence programs the desired priorities. This gives the pattern for all of the field operations. Notice that each row represents one field and that the total acreage for any operation adds up to the total acreage of that field, shown in the column to the left, column A in Table 6-2.

Table 6-3 shows the same process for the discing and herbicide application (D&H), the entire 375 acres for corn,

Table 6-3 Portion of CropPlan Showing Priorities of Operations

			Column				
Row	Operation	Field size	J	K	L	M	N
89			42.00	42.00	54.00	54.00	66.00
90	Tr Hr Rem		5.21	37.79	54.00	54.00	66.00
91	Trac Hr, each		2.60	18.90	27.0	27.0	33.0
92	Tr 1 D&H, hr		2.60	18.90	24.80	0.00	0.00
93	Tr 1 D&H, acres	375 ac	21.09	153.06	200.85	0.00	0.00
94	Tr 2 Plnt 1, hr		2.60	18.90	0.00	0.00	0.00
95	Tr 2 Plnt 1, ac	100 ac	16.93	83.07	0.00	0.00	0.00
96	Tr 2 Plnt 2, hr		0.00	6.12	9.27	0.00	0.00
97	Tr 2 Plnt 2, ac	100 ac	0.00	39.75	60.25	0.00	0.00
98	Tr 2 Plnt 3, hr		0.00	0.00	11.54	0.00	0.00
99	Tr 2 Plnt 3, ac	75 ac	0.00	0.00	75.00	0/00	0.00
100	Tr 2 Plnt 4, hr		0.00	0.00	6.19	1.50	0.00
101	Tr 2 Plnt 4, ac	50 ac	0.00	0.00	40.25	9.75	0.00
102	Tr 2 Plnt 5, hr			0.00	0.00	7.69	0.00
103	Tr 2 Plnt 5, ac	50 ac		0.00	0.00	50.00	0.00
104			9	10	11	12	13

and then planting fields 1 through 5 with the second tractor and worker. The Tractor Hours Remaining, row 90, comes from rows above, where the Good Field Days and machine capacity determine the total Tractor hours for that time period (column). In Table 6-3, column J, other operations above J90 have used all the Tractor Hours but 5.21. The program then splits these in two, 2.60 hours for each tractor, and they are used for Disc and apply Herbicide to 21.09 acres, with the second tractor planting 16.93 acres in Field 1.

In the next week, Col K, Table 6-3, the Tractor Hours Remaining totals 37.79, and again it is divided between the two tractors. One tractor is used for the Disc and Apply Herbicide operation, Row 93, and completes 153.06 acres. The second tractor is used for Planting in Field 1 and uses 12.78 hours to complete 83.07 acres, finishing the 100 acres. It then uses the remaining 6.12 hours to plant 39.75 acres in Field 2. Notice that the acres completed in each row total across columns to the

Table 6-4 Part of CropPlan, Showing Corn and Bean Harvesting

		Column			
Row No.		AF	AG	AH	AI
89	Harvest	9/27	10/4	10/11	10/18
90	Tr Hr Rem	70.00	70.00	70.00	70.00
91	CORN				
92	Disc + Herb	25.9	12.3	0.0	33.6
93	375	107.0	51.0	0.0	72.0
94	C-Plant 1	24.15	0.00	0.00	0.00
95	100.00	100.0	0.00	0.00	0.00
96	C-Plant 2	1.75	12.27	0.00	10.13
97	100.00	7.26	50.81	0.00	41.93
98	C-Plant 3	0.00	0.00	0.00	0.00
99	75.00	0.00	0.00	0.00	0.00
100	C-Plant 4	0.00	0.00	0.00	0.00
101	50.00	0.00	0.00	0.00	0.00
102	C-Plant 5	0.00	0.00	0.00	7.27
103	50.00	0.00	0.00	0.00	30.10
104	Harvest	31	32	33	34
105		**********	**********	**********	**********
106	Harvest	70.00	70.00	70.00	70.00
107	Tr Hr Rem	70.00	70.00	70.00	70.00
108	BEANS				
109	Disc + Herb	5.0	35.0	35.0	35.0
110	375	50	125	193	8
111	B-Plant 1	0.00	0.00	18.18	0.00
112	100.00	0.00	0.00	100.00	0.00
113	B-Plant 2	0.00	0.00	16.82	1.36
114	100.00	0.00	0.00	92.50	7.50
115	B-Plant 3	0.00	13.64	0.00	0.00
116	75.00	0.00	75.00	0.00	0.00
117	B-Plant 4	0.00	9.09	0.00	0.00
118	50.00	0.00	50.00	0.00	0.00
119	B-Plant 5	9.09	0.00	0.00	0.00
120	50.00	50.00	0.00	0.00	0.00

Table 6-5 Machinery Capacities for Field Operations in CropPlan

37 No 8–No 14	38 No 15–No 21	39 No 22–No 28	40 No 29–De 5	41 De 6–De 12	42 De 13–De 19	43 De 20–Ja 2		
Operation number	Field ops name	Capacity acres/hr	TIME hr/acre	No. of Units	Units per tractor	Field ops name	Area all acres	Carryover acres
1	Fert P+K	12.00	0.083	1	0.50	Fert P+K	750	100
2	Plow MB	3.20	0.313	1	0.50	Plow MB	375	50
3	Plow CH	4.80	0.208	1	0.50	Plow CH	375	50
4	Prep Disc	8.70	0.115	1	0.50	Prep Disc	750	750
5	Fert NH3	5.00	0.200	1	0.50	Fert NH3	375	375
6	Disc + Herb	7.80	0.128	1	0.50	Disc + Herb	750	Tractors
7	Plant C	4.70	0.213	1	0.50	Plant C	375	2
8	Plant B	4.70	0.213	1	0.50	Plant B	375	Hr Per Day
9	Optional	0.01	100.000		0.00	Optional		10.0
10	Cultivate	5.50	0.182	1	0.50	Cultivate	750	Drainage
11	Harvest C	3.00	0.333	1	0.50	Harvest C	375	1.00
12	Harvest B	3.00	0.333	1	0.50	Harvest B	375	Max Trac Hrs
13	Optional	0.01	100.000		0.00	Optional		20.00

total listed in column A. Also, the Tractors Hours Remaining for each column are used up as the hours are listed for each row or operation. For example, cell K91 shows 18.9 Tractor Hours Remaining for each tractor. The first tractor uses the 18.9 hours for the Disc + Herb operation. The second tractor uses its 18.90 hours by planting for 12.78 hours in Field 1, finishing that field and then planting for 6.12 hours in Field 2, totaling 18.90 hours in the two fields. All other field operations are programmed in this way, to move down in the weekly column, completing one field after another, and then continuing on down to other operations but moving to the right each week and completing fields and operations.

Changing to a harvesting operation, note Table 6-4. In AF90 we see that 24.15 hours of combine harvester time were available and 100 acres of corn were harvested, completing Field 1 and leaving 1.75 hours remaining. So 7.26 acres were harvested from Field 2 during the week beginning Sept. 27. Note that during the week of Oct. 11 (column AH), no corn was harvested. Why? Look down to rows below 108 and note that beans were being harvested during this week (Table 6-4).

YIELDS AND RETURNS

Now for corn growth and yield, go to Z22 on the computer screen. Here the three rows for each field give the accumulated Growing Degree Days (Z22), and below that the accumulated yield of the grain (Z23), and below that the grain moisture content (Z24). Note that the yield accumulates to a maximum, in this case, 134.17 bu/ac, in week 29, and then slowly decreases due to increasing field losses. Move across to column AQ and you have the Actual Yield for each field, according to when it was harvested, 132.17 bu/ac for Field 1, harvested in weeks 31 and 32, Row 95. This example shows very low field loss, as we would expect in this first field to be harvested. Undersized equipment and/or bad weather can delay the harvest and allow larger field losses to reduce these yields.

Now obtain the following results on this spreadsheet for the Typical weather, looking for Corn Yield in Field 1 at AQ23. Get the details of how many acres were harvested each week in each field, possibly by blocking off this area of the spreadsheet, printing it, and then circling the amount harvested for each week and each field, and include the average yield for each field from columns Y12 for corn and AE12 for beans. Also check the total profits from the Input/Output table for the "Sell Wet" option and the "Dry and Store" option. You could either write this on the table you have already printed or print out the Input/Output table.

After getting those values from the spreadsheet, which should agree with Table 6-1 (it is possible that the data on the CD may be for a different year), make another run by selecting the 1974 weather data (Late Plant macro). Remember that once you have made a change in the data, the results are immediately available in the Input/Output; there is no waiting for the run to be made, as in the old days of slower computers!

Then compute values for the different weather, which caused later maturing of the corn. Get the details of how many acres of corn were harvested each week in each field by going back to about row 94 and then searching the columns for the first corn to be harvested in Field 1. Also make note of or print out the Input/Output table to show differences in yields and profits between the Typical year and the Late Plant year.

With the Late Plant data, make one more comparison: Change the interest rates from 5% to 10%, and check the new Net Profits in the Input/Output table.

CropPlan Application 2: Crop Growth and Field Operations Simulator, Using the S10 Machinery Selection Program for Updating Machinery Costs and Capacities

The overall goals of this project are to:

a. Compare income results for different weather years.
b. Compare income results for different interest rates.

c. Compare results with more labor hours per day against higher-capacity equipment.
d. Compare income results from different sets of machinery.

To do this project, we will need to modify CropPlan somewhat. First, we will use machinery costs and capacities from S10, where more recent data are available than in the older CropPlan. Where data are not available on S10, use the original data in CropPlan. From the table at AF174, cut out the costs of the MB (moldboard) plow and the Forage Harvester, and get the Value (Cost) from S-10 for the Chisel (CH) Plow, Disc Harrow, Planter C+B, Tractors (2), Combine, C+B Heads (Corn and Bean Headers, summed), leaving the others the same. Equipment Capacities are at AL4 in CropPlan, so change them based on the capacities found in S10.

Second, we will follow through and see how the original CropPlan was modified to provide a formula for average fixed cost per year that allows us to change Interest rates separately and that includes Depreciation, Insurance, Repairs, Housing, and Taxes. We did this by using Straight Line Depreciation:

$$\text{Depr/yr} = (\text{Cost} - \text{Salvage})/\text{Life, yr.}$$

For Interest, Taxes, Repairs, Insurance, and Housing, we used a percentage of the Average Value, the average depreciated value of the machine over its whole life. Interest can be entered into CropPlan cell AP161, Interest Rate, Machinery Fixed Costs, and we will use 1.5% of the Average Value for Taxes, Repairs, Insurance, and Housing.

$$\text{Ave. value} = (\text{Cost} + \text{Salvage})/2$$

But CropPlan allows us to enter only the Cost (First Cost) of each machine, not the Salvage Value, so we will assume a percentage value of the Cost as the Salvage Value, depending on the Life you assume. For example, if you assume a Life of 10 years, a Salvage Value of 10% of the Cost would be reasonable. However, if you wanted to trade in the equipment more often, say, every 5 years, then Salvage Value might be 30% of the Cost.

We assumed a salvage value of 10% and a 10-year life. The formulas we developed for the average annual fixed cost went into cells AP164–166 in CropPlan. They calculate the average percentage to be multiplied by the Cost to get total annual fixed costs in the spreadsheet, *which are in cells AQ184–186*.

Using Life = 10 yr and Salvage = 10%,

$$\text{Depr/yr} = (\text{Cost} - 0.1 * \text{Cost})/10 = 0.09 * \text{Cost}$$

so for the Depreciation in AP164–166, we would use 0.09. Also,

$$\text{Average Value} = (\text{Cost} + 0.10 * \text{Cost})/2 = 0.55 * \text{Cost}$$

The Ave. Annual Interest, Taxes, Repairs, Housing, and Insurance are based on this Average Value. So in AP164–166, the 0.015 for Taxes, Repairs, and Insurance should be (0.015 * 0.55) because this number will be multiplied by the Cost (the First Cost) in CropPlan (AQ184–186). Last, the Interest rate from Cells AP160 and 161 should also be multiplied by 0.55 to adjust the Cost (AQ184–186) to an Average Value over the life of the equipment. So a typical cell function for AP164 should have these three terms to account for (1) Depreciation, (2) Interest, and (3) Repairs, Taxes, and Insurance:

$$+(0.09 + (0.55 * \text{AP160}) + (0.55 * 0.015))$$

These functions made an improvement in CropPlan, because they calculate more accurately the Average Annual Fixed Costs and still allow for changing the Interest Rates. Now look in cells AQ184–186 for the functions to calculate Fixed Costs (F.C.) for the three groups of equipment and machinery. Note that they follow the earlier form. Now when the interest rate is changed in the Input/Output table, it applies to all these equations and accounts correctly for the new interest rate.

Goal a. Replace the CropPlan machinery and equipment costs with S10 costs for equipment of about the same capacity. Use 5% Interest and the Typical Weather. This will be the Standard Run.

Make this run and record the Net Income for both the Sell Wet and Dry Store options. You could find a free spot on the spreadsheet to enter these results. Make three more runs with the Late Plant, Drought, and High Yield weather data, recording the same Net Income results.

Goal b. Now change the Interest Rate from 5% to 10%, and record those results for the Typical Weather.

Goals c. and d. Now we compare the original equipment set with the original hours per day with a lower-cost, lower-capacity set of equipment with the original hours per day and with a higher daily labor input to see if we can substitute labor for equipment. We will use the results of (a) with Interest at 5%, so reset those values. Then use S10 data and select another set of equipment with approximately 65% to 75% of the capacity of the standard set and run both Late Plant Weather and Typical Weather. List your equipment sets with Capacities and Costs. Then run all four Weather data sets with the lower-capacity equipment, first with the original hours per day and then with an increase in the labor available per day from 10 to 12, in the Input/Output table. That's eight runs in total.

CONCLUSIONS

Farmers the world over are plagued by weather problems: too much rain at one time, too little at another time, freezing temperatures when new crops or buds on fruit or berry plants are tender. Some of the delays caused by weather can be partially overcome if the capacity to complete field work is increased and if seed cultivars are selected carefully. The spreadsheet tool discussed and demonstrated in this chapter, CropPlan, can simulate field operations, crop development and yield, and crop maturity dates. With this software tool, agricultural systems managers and others can "test" the effects of changes in machinery capacity, crop cultivars (varieties), length of working days, number of workers, and planting dates. While this spreadsheet is not perfect, it is a very useful tool, not only for studying the effects of the variables mentioned but for making decisions based on its results.

REFERENCES

1. Smith, Robert D. Biomass storage, decision support systems and expert systems in crop production and processing; Ph.D. dissertation, Purdue University: West Lafayette, IN.
2. Smith, R.D., Peart, R.M., Barrett, J.R. Agricultural Production Management with Decision Support Systems, ASAE Paper No. 85-3076, St. Joseph, MI: ASAE, 1985.
3. Shutske, J.M., Peart, R.M., Smith, R.D., Lambert, J.R. Simulation with Spreadsheets, ASAE Technical Paper 85-5001, St. Joseph, MI: ASAE, 1985.
4. Peart, R.M.; Barrett, J.R. Energy use in maize harvest and drying. In: R.M. Peart R.C. Brook eds. Analysis of Agricultural Energy Systems. Elsevier: Amsterdam, 1992, 157–177.
5. Doster H. Top Crop Farmer Planning Model. Cooperative Extension Service, Purdue University: West Lafayette, IN, 1981.

7

Crop Simulation

Robert M. Peart

One of the areas of biological engineering that is being actively researched and developed for use in agriculture is crop simulation. In this work, crops such as wheat, soybean, and cotton are viewed as a system of processes that go on continuously, from germination of the seed in the soil to the full development of the grain (or forage) yield. Agricultural scientists and engineers have developed computer programs that calculate, on a day-by-day basis, crop growth and, eventually, yield, based on soil, weather, seed variety, and management, and these programs may be used to manage crops with regard to current environmental conditions [1]. Irrigation, timing of pesticide application, and fertilizer levels may be determined "on the go" throughout the season. These models have been developed through years of research in field plots, growth chambers, and computer labs [2].

Crop growth simulation will be an important tool in the technical agricultural systems management of the future. It is already used on hundreds of cotton farms [3] and by soybean producers [4].

CLIMATE CHANGE AND CROP MODELING

Accurate measurements of carbon dioxide levels in the atmosphere have been made for many years, and there is no question that they are steadily on the rise. Increased carbon dioxide increases the photosynthesis in plants, and some greenhouse crops are "fertilized" by adding carbon dioxide to the building. In experimental research at the University of Florida [5] and other research institutions, a 50% increase in carbon dioxide (forecast for the the year 2030, depending on efforts to reduce the rate of increase) would increase the yield of grasses such as maize (corn) by about 10% and of legumes such as soybean by about 30%, assuming other factors such as temperature, solar radiation, and rainfall did not change. Further interesting research has suggested that forecasts of the El Niño and La Niña weather shifts, along with climate changes due to increased carbon dioxide, may allow better management by using crop models. This is reported by Royce et al. [6]. We will work with this artificial model to study some effects of possible future climate change that are being predicted.

A significant finding of work on using crop models to assess the climate change effects on crops in the U.S. Southeast was the increasing value of irrigation. Peart et al. [7] found that in many locations, the reduced rainfall forecast for climate change reduced simulated yields more than the increase caused by higher carbon dioxide. This meant that irrigated soybean under climate change had an increased advantage over the nonirrigated crop.

THE ARTIFICIAL CROP MODEL ON A SPREADSHEET, CROPTOY

The spreadsheet crop model CropToy demonstrates some of the concepts of a dynamic, process-based, physiological crop growth model, but the relationships in this spreadsheet are very simple and are not accurately based on the actual processes, such as photosynthesis and evapotranspiration. In other words, this spreadsheet is developed to mimic crop simulation in a simple, understandable way.

The word *dynamic* means that the process is not static in time but is a continuous process that can change minute by minute. Actually, the plant senses and responds to such quick changes as a cloud covering the sun momentarily. *Process-based* means the simulation is written as a series of processes that go on in the soil–plant–atmosphere environment, some independently, some dependent on other factors, and some in parallel with time. These processes are based on the *physiology* of the crop, the effects that environmental variables have on physiological processes, such as the all-important and amazing process of photosynthesis, by which food is made from sunlight, carbon dioxide, water, and a few inorganic chemicals.

This spreadsheet demonstrates that the process of crop production by the plant is one that has a number of interactions between the parts of the plant, the processes, and the inputs. For example, leaf area index (LAI), a measure of the total leaf area of the plant, has an effect on evapotranspiration (ET), the total moisture evaporated from the soil and from the leaves of the crop, and this affects the soil moisture content. But soil moisture content affects the nutrients in the soil (excess water will leach out nutrients), which in turn affect growth and the LAI. Check this out by following through the equations in the upcoming section on Definition of Variables for F (evapotranspiration), G (soil moisture content), J (soil nutrients), M (photosynthesis), and N (leaf area index).

Another important concept of crop growth simulation is *integration*. The plant itself is an accurate integrator of all the various factors, in that it is continually accumulating nutrients and leaf area, so the results of an early week of drought will have an affect all the way through the growing season. On the computer, we do this integration approximately as *numerical integration*, which is adding the results of each time step—an hour, a day, or a week—to the total accumulated previously.

Crop growth simulation programs require much of the information about the crop in the field: seed variety, planting date, soil water-holding characteristics, soil nutrients, daily max-min temperatures, rainfall, solar radiation. With these data, and with each underlying crop physiological function, the simulation program grinds out calculations for each day; results such as leaf area and root density affect the next day's calculations. For example, as the leaves grow, they can absorb more solar energy, producing more photosynthate, which makes the leaves grow even more the next day. Rules are included to decide when the plant sends energy into seed growth instead of leaf growth; each favorable day adds to the eventual yield. Some models are even more detailed, calculating hourly changes in the physiological processes as the temperature and solar radiation change throughout the day. These programs are often called *process-based models*, because they simulate the physiological processes as they actually work in the plant. These processes have been discovered through years and years of research by plant physiologists and other scientists. The major processes are (1) photosynthesis, (2) transpiration, (3) evaporation, (4) phenology, (5) vegetative growth, (6) reproductive growth (seeds), and (7) maturation. These are briefly discussed later.

These models can be used in management, for strategic planning of the next year's crop, or for tactical day-to-day management of irrigation and fertilization. Managers have used models such as these to determine new machinery needs for the future, based on yields, maturity dates, and field losses.

Even with the most complex crop models, the actual crop–soil–atmosphere system is more complex. Effects thought to be caused by enzymes generally are not modeled, nor are the minute-by-minute changes that occur when a cloud covers the sun.

The spreadsheet model presented here, CropToy, is much less complex, less accurate, and less realistic than the real crop models. It is a "model of a model," designed strictly for teaching some of the major causes and effects in crop growth, the feedback processes, and a simplified concept of how a process-based crop model works. This spreadsheet model illustrates how a model can be used for crop management. It makes calculations weekly, instead of daily, to save space on the screen. It illustrates *interactions* between variables. For example, the soil nutrient level (Nutr) depends on leaf area (LAI) and soil moisture (Mcorr). But leaf area (LAI) in cell N30 depends on last week's soil nutrient level in cell J29. The units of the variables are shown in the descriptions that follow, but some of them are "relative" and undefined, since this is a hypothetical model.

In the spreadsheet cell references, each row is a new time step, one week, and each column is one of the variables, some inputs and some calculated outputs. We have used row 30 arbitrarily as the current week for which calculations are being made, so a cell designated row 29 is the value of a state variable in the previous week. Most of the processes are calculated as the sum of last week's value plus a function involving other calculated variables and/or weather and management inputs for this week.

DEFINITION OF VARIABLE

Column	Value or function
A: Wk, Week No., Week 1 = Planting Week Data input	
B: Tav, Ave. Temperature for the week, F Data input	

C: CGDD, Cumulative Growing Degree Days
= Last CGDD + (Tave − 50) * 7da/wk
= C30 = C29 + (B30 − 50) * 7

Cumulative GDD, gives a measure of the "physiological age" of many crops, especially corn (maize). This very important measure in plant physiology indicates when certain important changes, such as blooming and maturity, occur. These changes in plants that happen at fairly specific times during the life of the plant are called the *phenology* of the plant. Corn, for example, reaches maturity at a fixed number of growing degree days from the planting date. The GDD value for one day is the difference between 50°F and the average daily temperature. Insect growth stages may also be tied to GDD. Some plants and insects use a standard different from 50°F (10°C). Here, (Last CGDD) means the CGDD from last week, so the function for C30 is

$$C30 = C29 + (B30 - 50) * 7$$

D: Sol, Solar Radiation, Relative units — Data input

E: Rn, Rainfall, inches this week — Data input

F: ET, Evapotranspiration
= (Tave + Solar)/320 + 0.12 * LAI
= (B30 + D30)/320 + 0.12 * N30

Evapotranspiration is the movement of moisture from the soil surface by evaporation plus the movement of moisture from the crop leaves by transpiration. It is higher for higher temperature and solar radiation and will also be higher for more leaf surface area. The constants used in all these functions, 320 and 0.12 in this function, are purely arbitrary and were selected to give answers in a reasonable range.

G: MC, Soil Moisture content, inches
= Last MC − ET + Rain + Irrig, (MC <= 2.0)
= @IF((G29 − F30 + E30 + I30) > 2.0, 2.0, (G29 − F30 + E30 + I30))

The soil moisture content at any point in time is the sum of the moisture content at the last time period (G29) minus that lost by evapotranspiration this week (F30), that added by rainfall this week (E30), and that added by irrigation during the past time period (I30). The spreadsheet @IF function has the general form @IF ((a), (b), (c)); meaning IF (a) is TRUE, then (b) is the cell value, but IF (a) is NOT TRUE, (c) is the cell value.

H: Mcorr, Corrected Soil Moist. to prevent MC < 0 — @IF(G30 > 0, G30, 0)

Here we correct the soil moisture to make sure it does not go below zero, since these equations are rather crude, and negative moisture content could occur in the computation.

I: Irr, Irrig. applied this week, inches — Data input

J: Nutr., Soil Nutrients, relative units
= Data input for Week 1, and for following weeks:
= Last Nutr. − ((Last LAI * 2.8) + (Last Mcorr * 3.9)) + (Last +Ntr)
= J29 − ((N29 * 2.8) + (H29 * 3.9)) + K29

Soil nutrients can be calculated somewhat like soil moisture, by deleting from the past nutrient level the amount of uptake by the plants, which should be a function of the last week's leaf area index (the bigger the plant, the more nutrients it withdraws). Also, high soil moisture content last week would indicate that there may be more leaching of nutrients down through the soil layers and beyond the reach of the roots. Lastly, we must add in any nutrients (fertilizer) added to the soil during the time period (last week). The constants 2.8 and 3.9 in this equation were determined arbitrarily to give a somewhat reasonable response for this function.

K: +Ntr., Added nutrients (fertil.), relative units — Data input

L: Stg, Relative Crop Growth Stage — Data input

One of the more complex processes within a whole plant (especially annuals) is the switching of the plant nutrients from producing more leaves, stems, and roots to that of putting all the nutrients into seed production. In *determinant* plants, the process is rather abrupt; in corn (maize), for example, the state variable, cumulative growing degree days, is a rather accurate measure of when this switch from vegetative to seed production occurs. In determinant soybean, a combination of day length and cumulative growing degree days is the predictor. However, there are *indeterminant* soybeans, more common in the northern United States, where cool temperatures provide the mechanism to shut down the vegetative growth. The causes of the timing for this change are not well known for many other plants. In this simple spreadsheet, column L is a data entry column; if the number is 5 or greater, seed growth is carried on and LAI increase is stopped. For growth stages less than 5, we simply left the column L cells blank or zero. The functions in column N, LAI, are affected by this variable, Stg, with an @IF function, explained under that definition.

M: PSyn, Photosynthesis this week
= (Tave + Solar)/48 * LAI * Mcorr/2
= ((B30 + D30)/48 * N30 * H30/2)

Photosynthesis is a magnificent process, in my opinion. Humans and all other animals and other nonphotosynthesizing organisms on the earth, through respiration processes, use oxygen, O_2, and produce carbon dioxide, CO_2. Without photosynthesis, our oxygen supply would be decreasing. Green plants, with their chlorophyl, absorb solar radiation, nutrients, CO_2, and H_2O and produce carbohydrates, COHOH, and give O_2 back to the atmosphere, thus providing us with both food and oxygen, for which I am personally very grateful!

The current concerns about climate change are that CO_2 is increasing in the atmosphere due to burning of fossil fuels. Increased CO_2 generally increases the photosynthetic rate of plants, but the concern is that increased CO_2 will trap more heat and affect our climate.

Photosynthesis is directly proportional to solar radiation for most crops and within a certain range of solar radiation. The same is true for temperature. But at temperatures over about 86°F (30°C) photosynthesis levels off and then decreases. Leaf area affects photosynthesis until the LAI gets above a certain point, then it levels off too. Moisture is also important, because with lower moisture in the plant, photosynthesis is reduced. All four of these factors are shown as strictly linear in this function, so it is reasonably representative only for a limited range of inputs. In your second lab, you will have a chance to change one of these linear functions to a more accurate nonlinear function.

N: LAI, Leaf Area Index
= (Last LAI) + CGDD * (Last Nutr.)/62,400 (no growth when Stg ≤ 5)
= @IF(L30 < 5,(N29 + C30 * J29/62,400), N29)

Leaf growth is, of course, affected positively by the amount of nutrients available in the soil. Also, the cumulative GDD since planting will have an effect because the more mature plants, with more roots, stems, and leaves, can grow leaf area faster.

O: SdWt, Total Seed Weight (Yield)
= Last SdWt + ((PSyn * 48) + (Nutr − 40) * 1.2) (if 300 > Nutr > 50) or
= (Last SdWt + 1%) (if 300 < Nutr <= 50)
= @IF (J30 > 50 #and# J30 < 300, (O29 + (M30 * 48) + (J30 − 40) * 1.2), O29 * 1.01)

Total weight of the seeds is the yield we are after in grain crops. For so-called forage crops, harvested for hay or silage or as pasture, the LAI would be the desired yield. In this function, we have incorporated the idea of a *limiting factor*, the level of nutrients in the soil, Nutr. If this is less than 50 units, we simply increase the yield by a low 1%. Also, if the nutrient level, Nutr, is greater than 300, determined to be detrimental to the crop, the yield is increased by only 1%. This discourages the user from simulating fertilizer levels that are too high but that would otherwise show a very high simulated yield. Otherwise, if the nutrient level is between 50 and 300, the added yield for each week is directly proportional to the photosynthesis for this week and the nutrition in the soil, Nutr, above 40 units. Some indirect causes, such as temperature and solar radiation, rainfall, and LAI, show their effects through the process for photosynthesis and nutrition. The effect of growth stage, Stg, is simulated here by manually entering a blank or zero in the SdWt column, O, for rows where the Stg is less than 5.

DISCLAIMER

This model is only for teaching the principles of simulation of crop growth and does not represent a particular crop, nor does it necessarily follow plant physiological principles accurately.

APPLICATION EXERCISES WITH CROPTOY

Next we present some projects to demonstrate practical applications of a crop model, although we continue to emphasize that CropToy is not a real crop model. However, it is an easy tool to use in learning about dynamic crop models. The first project shows how the model reacts to the addition of fertilizer and to the addition of irrigation. The amount of yield will, of course, increase as more fertilizer is added, up to a limit, but we do not demonstrate that, although it is easy to do. In addition to the amount, the timing of added fertilizer is important to the crop, and that is part of the exercise, trying the addition of Nutrients, or fertilizer, for different weeks, with only one week at a time having the extra nutrients.

Before starting these tests with CropToy, save a second copy, the original, so you can go back to it after you have changed a number of the original input values, perhaps calling the original CropToy1.

If the soil moisture is low, irrigation will improve the yield. However, the soil moisture changes from week to week, so the effectiveness of irrigation will depend on the week it is added. That can easily be determined by noting the week when the soil moisture is lowest and adding irrigation then. Or do you add the irrigation the week before the soil moisture is lowest? Check this out by experimentation and also by noting that:

a. SeedWt (Yield) is a function of Photosynthesis and Nutrients.
b. Photosynthesis is a function of Mccorr (moisture content). And it is a positive linear function: The greater the Moisture Content, the higher the Photosynthesis and, thus the higher the yield.
c. Both these functions depend on the moisture content and photosynthesis for that same week, not the week before.

Project 2 is a contemporary one dealing with global warming and its possible effect on crop yields, and Project 3 introduces non-linearity.

Project 1: Managing Timing of Fertilization and Irrigation

Your first goal is to get the highest possible yield in week 20, column O. You have three cases, and you will use trial and error to arrive at the best times. First note the original final yield, and then add 50 units (or pounds) of nutrients in a particular week, noting the new final yield. Then set the nutrient back to zero and add it in a different week, continuing until you find the best week. Second, leaving the fertilizer as in your best week, and find the best week to add 1 unit (say, 1 inch) of irrigation. Third, still with fertilizer added, find the best two weeks to add 1 inch of water each time.

1. Note the definitions of column headings, given previously.

2. Move the cursor to various columns to see how the formulas agree with the definitions.
3. Note interactions between variables, as illustrated in Figure 7-1.

Project 2: Climate Change and Effects on Crop Growth

1. Use the spreadsheet file CropToy to plot the effect of temperatures for one week (Week 18) from 50°F through 90°F, in steps of 5°, on Evapotranspiration (column F), setting the Solar constant at 62 units and the LAI at 5.02. (LAI of 5.02 means the leaf area of the crop is 5.02 times the soil surface area that the crop occupies.) Note the ET value for Week 18 for each Temperature (50, 55, 60, . . . , 90); then put these

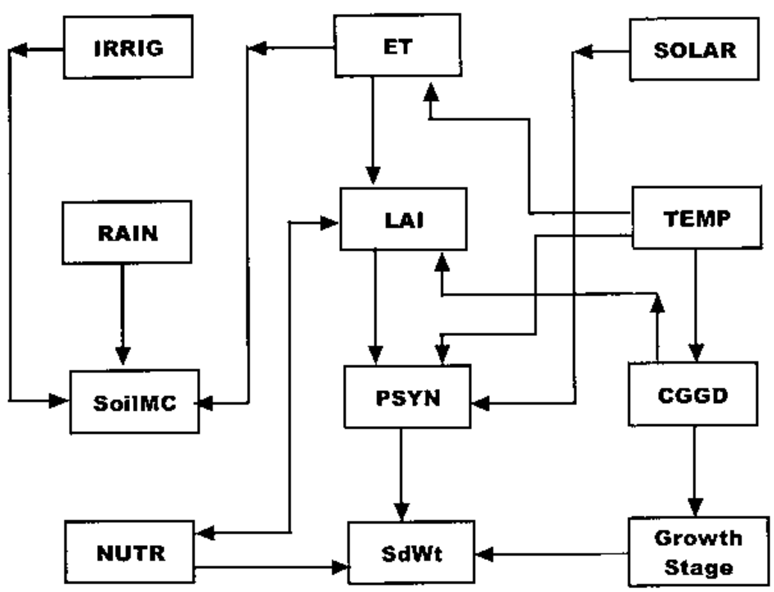


Figure 7-1 Information and material flow diagram for CropToy, artificial simulation model.

values along with the temperature values into a simple spreadsheet so you can plot ET vs. Temperature. Give the plot a Title, label both *X*- and *Y*-axes, and make it a line graph.

2. Similarly, plot the effect of Solar Radiation for one week (Week 18) from 20 to 70 units, in steps of 10 units, on Photosynthetic Rate (column M), setting T_{ave} constant at 79°F, M_{corr} at 1.4 inches, and LAI at 5.02 units. As with temperature, enter the different values of Solar Radiation into Week 18, and note the Photosynthesis value. Then start another spreadsheet using the values of Solar Radiation vs. Photosynthesis. Turn in the line graph of Photosynthesis vs. Solar Radiation. This may give a clue about one possible effect of global warming, changes in the amount of solar radiation, although this effect has not been seen as a major factor in global warming.

   Are these straight-line relationships, according to the spreadsheet? Should they be straight-line relationships according to crop physiology?
3. To get an indication of a possible climate change effect, note the final yield on the spreadsheet with the original inputs that are given. Then go down the T_{ave} column and increase each temperature by 3°F, a predicted climate change effect. What is the effect on the yield? Based on the formulae in the spreadsheet, why does this temperature increase reduce yields?
4. Keeping the increased temperature input, next go down the Rain column (E) and add 0.2 inches to each value. Note the new yield and the combined effect of increased temperature and rainfall. (In our research in climate change, the rainfall with climate change is not affected uniformly; One month's rain may be above the normal climate average, and the next month's rain with climate change may be lower, so the effects are not as simple as the spreadsheet shows.)
5. One factor that is not included in this simple model is the effect of carbon dioxide, which is probably the most

important greenhouse gas and which is definitely increasing over time. Accurate measurements of carbon dioxide level in the atmosphere have been made for many years, and there is no question that it is steadily on the rise. This model does not include the carbon dioxide effects, but we can try some possibilities by using some approximations of research results, as given next.

Increased carbon dioxide does increase the photosynthesis in plants, and some greenhouse crops are "fertilized" by adding carbon dioxide to the building. We mentioned earlier that a 50% increase in carbon dioxide (forecast for the the year 2030, depending on efforts to reduce the rate of increase) would increase the yield of grasses such as maize (corn) by about 10% and of legumes such as soybean by about 30%, assuming other factors such as temperature, solar radiation, and rainfall did not change.

We could experiment by increasing the yield of CropToy by 30%, pretending that this crop is soybean, and reducing the rainfall by 15%, which is in the range of climate modeling results for an increase of 50% in the carbon dioxide level. Add a column on the right side of CropToy, call it Yld + 30%, and insert the formula + O11 * 1.30 in the new column P. Note that the O after the + is the letter O, not the number 0. The formula says, "Multiply the yield in column O in this row by 1.30." Start this in the row of your version of CropToy where SdWt starts to be above zero, shown as row 12 in Table 7-1. Compare the yield without climate change to the yield in column P, which includes the 30% increase for more carbon dioxide and the 15% reduction in rainfall.

Project 3: Linear vs. Nonlinear Biological Functions

In this relatively simple spreadsheet model, all the functions are linear, whereas the real functions are mostly nonlinear.

Table 7-1 CropToy Spreadsheet Model with Input Data Values and Yield (SdWt)

Wk	Tav	CGDD	Solar	Rain	ET	MC	Mcorr	Irr	Nutr	+Ntr	Stg	PSyn	LAI	SdWt
1	65	105	51	0.5	0.4	2.0	2.0	0.0	300	0	1	0.24	0.10	0
2	67	224	52	0.7	0.4	2.0	2.0	0.0	292	0	2	0.63	0.25	0
3	68	350	53	0.6	0.4	2.0	2.0	0.0	283	0	2	1.23	0.49	0
4	68	476	53	1.4	0.5	2.0	2.0	0.0	274	0	2	2.01	0.80	0
5	69	609	54	0.0	0.5	1.5	1.5	0.0	264	0	3	2.22	1.18	0
6	72	763	56	1.3	0.6	2.0	2.0	0.0	255	0	3	4.38	1.64	0
7	74	931	58	0.3	0.7	1.6	1.6	0.0	243	0	3	4.87	2.18	0
8	77	1,120	60	0.6	0.8	1.5	1.5	0.0	230	0	3	5.86	2.81	0
9	76	1,302	59	2.4	0.8	2.0	2.0	0.0	217	0	3	9.85	3.49	0
10	78	1,498	61	1.6	0.9	2.0	2.0	0.0	199	0	4	12.25	4.24	0
11	81	1,715	63	1.4	1.1	2.0	2.0	0.0	180	0	4	15.07	5.02	0
12	83	1,946	65	0.4	1.1	1.3	1.3	0.0	158	0	5	10.33	5.02	637
13	79	2,149	62	0.2	1.0	0.5	0.5	0.0	138	0	5	3.63	5.02	929
14	82	2,373	64	2.1	1.1	1.5	1.5	0.0	122	0	5	11.71	5.02	1,590
15	80	2,583	62	0.7	1.0	1.2	1.2	0.0	102	0	5	8.82	5.02	2,088
16	82	2,807	64	2.8	1.1	2.0	2.0	0.0	84	0	5	15.27	5.02	2,874
17	81	3,024	63	0.4	1.1	1.3	1.3	0.0	62	0	5	10.15	5.02	3,387
18	79	3,227	62	1.1	1.0	1.4	1.4	0.0	43	0	5	10.36	5.02	3,421
19	78	3,423	61	0.7	1.0	1.1	1.1	0.0	23	0	6	7.76	5.02	3,455
20	77	3,612	60	2.1	1.0	2.0	2.0	0.0	5	0	6	14.33	5.02	3,489

Your task in this lab is to make Photosynthesis a nonlinear function of (T_{ave} + Solar), rising linearly at first, and then slowing its rate of increase as the temperature and solar radiation increase. This type of function is more realistic. Try to make PSyn match the following values with fixed values of LAI = 5.0 and Mcorr = 2.0, and the following values of Tave and Solar. Use the small table on the right-hand side of the spreadsheet CropToy.

Function in the Model, Linear: PSyn = (Tave + Solar)/ 48 * LAI * Mcorr/2
Form of the Nonlinear Model: Let T + Solar = TS

$$\text{PSyn} = (\text{TS})/48 * \text{LAI} * \text{Mcorr} * 0.7 - 3.5 - (a * \text{TS})\text{\^{}}2 - (b * \text{TS})\text{\^{}}3 - (\text{c} * \text{TS})\text{\^{}}4$$

or

$$\text{PSyn} = (\text{TS})/48(* \text{LAI} * \text{Mcorr} * 0.7) - 3.5 - (a * \text{TS})^2 - (b * \text{TS})^3 - (c * \text{TS})^4$$

(Try a, b, and c in the range of 0.002 – 0.01, with $a < b < c$.)

The objective is to produce values for PSyn that are close to the values in the Table 7-2, which are the desired (goal) values, by adjusting the values for a, b, and c.

Table 7-2 Data for the Nonlinear Function Project

T_{ave}	Solar	T + Solar	Desired nonlinear photosynthesis
70	60	130	13.50
70	70	140	14.58
80	70	150	15.30
80	80	160	15.80
90	80	170	16.10
90	90	180	16.30

Hard copy to be turned in for Lab 3: graph and results. The spreadsheet is set up with a graph of TS vs.

1. The desired value of PSyn from Table 7-2.
2. Your new nonlinear function in the form shown earlier, but with better values for a, b, and c. Print out this

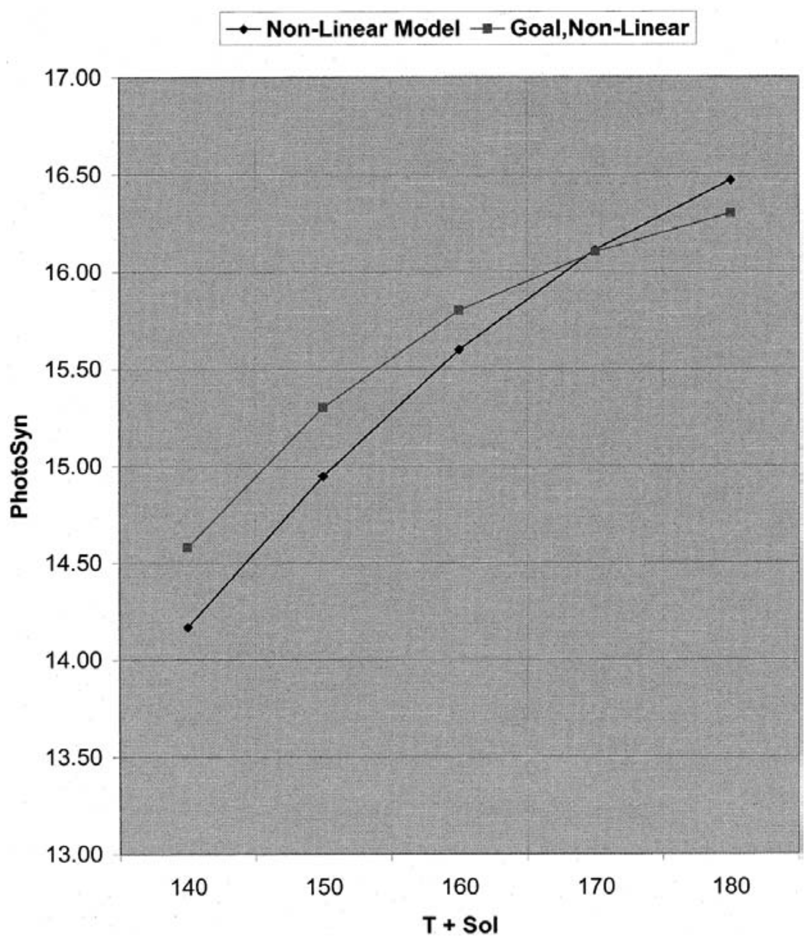


Figure 7-2 Plot of the desired nonlinear function (diamonds) and the nonlinear function developed (squares).

graph when you have values for a, b, and c that approximate the nonlinear goal values. Also, list the values for a, b, and c. It should look like Figure 7-2, except the values of a, b and c are not the best in this figure.

CONCLUSIONS

The simple spreadsheet presented in this chapter is meant to give the basic fundamentals of crop simulation in a simple, easily usable form. The concept of interactions between various parts of the soil/plant/atmosphere system is important, and these effects show up in the flow diagram.

The concept of a dynamic, ever-changing system is shown by the use of rows in the spreadsheet, each representing a different week. Even though changes occur much more rapidly than once a week in the real world, the model shows that each time step depends partly on the previous one and partly on the inputs in the current time step. This dynamic effect can be shown easily with this tool, for example, by changing the time of application of water or fertilizer. The effect can be quite different depending on the timing of the application.

This study also shows how a crop model can be used in management for planning ahead (strategic planning) as well as for making changes during the growing season (tactical planning). The agricultural systems manager may make decisions before the start of the season, such as selecting crop types and planting dates or purchasing different equipment. Other management decisions may be made during the season, such as the timing and amount of irrigation and the timing of pesticide applications. We believe the agricultural systems manager will be using crop models increasingly in the 21st century.

REFERENCES

1. Boote, Kenneth J.; Jones, James W.; Hoogenboom, Gerrit. Simulation of crop growth: CROPGRO model. In Agricultural Systems

Modeling and Simulation; Peart, R.M., Curry, R. Bruce, Eds.; Marcel Dekker: New York, 1998.

2. Jones, James W.; Luyten, Joep C. Simulation of biological processes. In Peart, R.M., Curry, R. Bruce, Eds.; Agricultural Systems Modeling and Simulation; New York: Marcel Dekker, 1998.
3. Hodges, Harry F.; Whisler, Frank D.; Bridges, Susan M.; Reddy, Raja K.; McKinion, James M. Simulation in crop management: GOSSYM/COMAX. In Peart R.M., Curry, R. Bruce, Eds.; Agricultural Systems Modeling and Simulation; New York: Marcel Dekker, 1998.
4. Welch, S.M.; Jones, J.W.; Brennan, M.W.; Reeder, G.; Jacobson, B.M. PCYield: model-based decision support for soybean production. Agricultural Systems 2002, 74 (1), 79–98.
5. Curry, R.B.; Peart, R.M.; Jones, J.W.; Boote, K.J.; Allen, L.H. Jr. Response of crop yield to predicted changes in climate and atmospheric CO_2 using simulation. Trans. ASAE 1990, 33 (4), 1383–1390.
6. Royce, F.S.; Jones, J.W.; Hansen, J.W. Model-based optimization of crop management for climate forecast applications. Trans. ASAE 44(5), 1319–1327.
7. Peart, R.M.; Rosenzweig, C.; Curry, R.B.; Jones, J.W.; Boote, K.J.; Allen L.H. Energy and irrigation in Southeastern U.S. agriculture under climate change. J. Biogeography 1995, 22, 635–642.

8

Optimizing the Use of Resources: Linear Programming

Robert M. Peart and Fred Royce*

Linear programming is a powerful tool used extensively in many agricultural, feed, and food operations. A classic type of problem it solves is to select the amount of ingredients to put in a mixture to meet certain criteria, or constraints, such as "Protein content must be at least 15%," and "Select the lowest-cost combination of these ingredients." Often there is an almost infinite number of combinations of types and amounts of ingredients that will meet the criteria, but the manufacturer obviously wants to minimize the cost of the mixture.

Linear programming problems use the terms *activities* and *resources*, which we will also be using in connection with

* Fred Royce contributed to the text and made suggestion for the examples.

project scheduling problems in Chapter 10. In general terms, the resources are used to complete the activities. For instance, in the feed-mixing problem, the activity could be fulfilling the required amount or percentage of a certain nutrient, such as protein, needed in the feed mixture. A resource would be one of the feed ingredients that may be used to provide protein in the mixture. Typically, in a real feed-mixing problem, a dozen or more ingredients are available, such as wheat, brewer's grains, bran, and cottonseed meal, that might be a part of the mixture. The activities, or requirements, are the minimum or maximum percentage of nutrients guaranteed by the manufacturer to be contained in the mixture. A minimum level of protein is usually specified, for example, and the mixture may contain protein from many different ingredients that are contained in the final mixture.

Much more information and further examples are given by Hillier and Lieberman [2] and by Sowell and Ward [3]. Several requirements must be met for a problem to be solvable by linear programming.

REQUIREMENTS OF THE LINEAR PROGRAMMING MODEL

1. The constraints must be *linear*. This means they must be in a form such as

   $$0.40 * X + 0.08 * Y <= 15$$

   where

   X = pounds of soybean meal per 100 pounds of feed

   Y = pounds of corn per 100 pounds of feed

   This is a linear equation because the coefficients (0.40, 0.08) are constants and the variables (X and Y) are not raised to a power. The equation can be plotted as a straight line, so it is a linear equation.

2. The equation defining the total cost (or return) is also *linear*. For example, the cost of the feed would be some constant cost per pound for each ingredient, multiplied by the number of pounds of each ingredient. The only practical problem here is that a small amount of a particular ingredient might cost more per pound than a large amount. Usually a feed mill buys quantities large enough that the cost of each ingredient is essentially the same per pound; but in other cases, this linearity requirement could cause a problem with the accuracy of a solution.
3. Another important requirement is that the variables, such as X and Y earlier, be continuous, not integer. That is, the solution for the number of pounds of ingredient may be any number such as 0, 22.34 or 2000.5. This is no problem for pounds of feed, but it is a problem if we want to solve for the number of 120-hp tractors in some other situation and we want an answer of either 0 or 1 or 2. Ordinary linear programming might recommend 0.67 tractors of this size! Much research has been done on how to get around this problem with linear programming, but it is actually a mathematical problem (which we will not study).

USING QUATTROPRO® TO SOLVE LINEAR PROGRAMS: HOG/CATTLE OPTIMIZATION

Learning how to solve practical problems with linear programming is easier if we use and solve small but realistic examples. This first one is very simple. You might think the answer could be found by hand calculations or by intuition, and it probably could. After you have set up the numbers in the spreadsheet, you may want to try finding the solution without the linear programming algorithm.

The program we will use, QuattroPro, uses a variety of different algorithms, or programmed rules, to solve the problem. In general, it tries many different feasible combinations of amounts of ingredients, as long as each new try is closer to the "optimal," or best, solution than the last one. Thus, when no lower-cost combination can be found, the optimal solution has been found. The optimal solution desired may be either a minimum or a maximum, for example, a minimum cost or a maximum profit. Microsoft Excel®, the other major spreadsheet, will also solve linear programming problems through its Tools menu and selecting Solver, but we do not include a description of this procedure.

This lab assignment involves doing a very simple linear programming example using QuattroPro Optimizer. Optimizer, as the name suggests, finds minimum, maximum, or exact solutions to problems involving sets of linear (or nonlinear) equations and inequalities. Although Optimizer can handle problems involving rather complex, nonlinear equations and constraints, the concepts are the same as those required for a simple linear programming problem, such as the following.

A man has 300 acres of land on which he wants to go into animal production instead of raising crops. He has the following facts for the management systems for hogs and cattle he has decided to use.

a. Hogs require half a year and 0.6 acres of land per head, and cattle require one year and 1.0 acre per head. Since two hogs can be produced on the 0.6 acres in one year, the annual land requirement for hogs is 0.3 acres per year. A total of 300 acres is available. It is important to recognize these time differences for a problem such as this and to understand how to view the problem. In this case, the problem may be viewed as a one-year time span, with two batches of hogs and one batch of cattle raised during the period under consideration.
b. Hogs require about 0.4 hours of labor per week per head; cattle require about 0.1 hours of labor per week

per head. Since two hogs per year can be raised with this 0.4 hours, the requirement for labor is 0.2 hours per week per head on an annual basis.

c. There are 60 hours of labor available per week to satisfy these labor requirements.
d. Cattle require no housing, but hogs require 20 sq ft each, and a 2000-sq ft building is available. Thus, a maximum of 100 hogs can be handled at a time, or 200 hogs per year. Since two groups of hogs can be produced per year, the housing requirement is 10 sq ft per hog on an annual basis.
e. To simplify the problem, the costs for land, labor, and housing are not considered, because they are available but have no alternative use. These could easily be included in the problem, but it would make this first example problem larger, so we simplify it this way.
f. Hogs return $10 net profit per head and cattle $15 per head, for the year, taking into account feed costs but not land, labor, labor, or housing, for simplicity, as already explained.

The question is what the best combination of hogs and/or cattle is that he can he raise to maximize his profit within the limits of these resources. He also wants to know what his profit would be. In addition, he wants to know whether he should try to obtain more than 60 hours of labor per week, even though that would cost more money. In other words, how much could he afford to pay for extra labor? And similarly, he would like to know how much he could afford to pay to rent extra land or add more housing in order to make more profit. All these questions may be answered with linear programming. This information, in addition to just the amount of each ingredient to be used in the mixture, can be very valuable. For instance, a ''near-optimal'' solution could be more favorable if there is a small cost difference and the alternative solution makes for a simpler manufacturing process. The optimal solution data also show the increased cost of certain ''near-optimal'' solutions.

Any linear program has *constraints*; these are described in linear expressions, or formulas. These are made up of constants and variables that each define an unknown in the problem. In an ordinary algebraic equation or set of equations, there must be as many equations as unknowns to find the one solution for each of the variables. Linear programming is similar, but it will usually have more equations than unknowns, so many different solutions will satisfy the set of constraint equations. The difference is that with linear programming, there is an additional expression to define the objective. This is also an equation with constants multiplied by unknowns and added together, but instead of being equal to some other constant, the sum is to be maximized or minimized. This requirement guarantees that there will be only one unique set of solutions for the variables.

In this problem the following facts define the set of linear constraints:

1. There are only 300 acres of land, and each hog takes 0.3 acres (2 hogs per year on 0.6 acres) and each cow takes 1.0 acres. This is linear because each animal requires the same acreage per head, no matter how many. If you graphed hogs vs. acres required, it would be a straight line, i.e., linear.
2. Similarly, there is a constraint on unsalaried labor, 60 hr per week, and the hours per animal are constant, meaning there is a linear relationship between labor and number of animals. Hogs use 0.4 hr/week each, and cattle require 0.1 hr/week each. Since two batches of hogs can be raised per year, the labor requirement for hogs is 0.2 hr/week throughout the year, and a maximum of 300 hogs could be raised per year using all the labor for hogs.
3. There is a housing constraint of 2000 sq ft, and each hog requires 20 sq ft. However, since hogs require only 6 months, 2 hogs can use the 20 sq ft during the year, so the housing requirement is 10 sq ft/hog each week

> throughout the year, and the maximum number of hogs *per year* is 200. It is important to recognize these time differences. In this case, the problem may be viewed as a one-year time span, with two batches of hogs and one batch of cattle raised during the period under consideration.

The second "linear" requirement about an LP problem is that the *objective function* (describing profit or costs) also be linear, as it is in this case, because each hog returns a net profit of $10 each and each head of cattle $15, regardless of the total number of animals. In QuattroPro, Optimizer refers to the objective function as the formula you want to maximize (or minimize). This formula is entered into a spreadsheet cell, which is called the *solution cell*. In this problem, the objective function is to be maximized. These profits are returns for one year based on returns, minus the cost of feed only, since the land, labor, and housing costs are considered to be available at no extra cost.

Here is how Optimizer wants to have the LP problem formulated, so follow these instructions to enter the numbers and names. In keeping with linear programming conventions, you will be naming the rows as constraints and the columns as activities, as follows.

Bring up QuattroPro; the blank spreadsheet represents a matrix, as shown in Table 8-1. Include row names (constraints: LAND, LABOR, HOUSING) and column names (activities: HOGS and CATTLE). In addition to constraints, a row should be added for the objective function, PROFIT, which we put above the constraints. Then two additional columns are used to the right of HOGS and CATTLE. The first of these two columns is there to allow space for inequality symbols; the second, farthest to the right, is labeled RHS (right-hand side). Your empty matrix should look like Table 8-1.

Now that the rows and columns are labeled, what is entered into the body of the matrix? In the cells where activities (HOGS, etc.) meet constraints (LAND, etc.), enter the amount

Table 8-1 Labels for Resources, PROFIT through HOUSING, and Activities, HOGS and CATTLE

A	B	C	D	E	F
1					
2		HOGS	CATTLE		RHS
3	PROFIT				
4	LAND				
5	LABOR				
6	HOUSING				

of the constraint required per unit of activity (e.g., land per hog). Although the profit is not really a constraint, the amount of profit per unit of activity is entered in the same way (remember, always enter only amounts, no units).

The RHS (right-hand side) column contains the constraint amounts, for example, the total land available. In this case, there are three constraint numbers. The unnamed column next to RHS allows for the placement of inequality or equality symbols that correspond to each constraint. The symbol used depends on whether the constraint represent the maximum or the minimum amount that can be used. If the constraint is the maximum available, the amount used by the activities must be "less than or equal to" that constraint number, so you type in "<=". Now fill in the numbers as shown in Table 8-2, and remember their meaning (0.3 means number of acres of LAND per unit of HOGS).

Think about the information you need to solve this problem. You want three pieces of information, or solutions: optimal number of hogs, optimal number of cattle, and the profit per year. A cell for each of these figures must be selected, and here we will deviate somewhat from usual linear programming conventions. Below the matrix, label three cells, as shown in rows 8, 9, and 10, starting in column A; the then empty cells in

Table 8-2 Complete LP Matrix with Coefficients, Inequalities, and Right-Hand-Side Values (see *HogLP.wb3* or *HogLP.xls* on CD)

A	B	C	D	E	F
1					
2		HOGS	CATTLE		RHS
3	PROFIT	10.00	15.00		
4	LAND	0.3	1.0	<=	300
5	LABOR	0.2	0.1	<=	60
6	HOUSING	10.0	0	<=	2000
7					
8	Number of hogs =	Variable cell			
9	Number of cattle =	Variable cell			
10	Total profit =	Solution cell			

column C (C8, C9, and C10) will be used for the final solution numbers, see Table 8-2.

Objective Function

The two cells labeled for the numbers of hogs and cattle are what Optimizer refers to as *variable cells*, C8 and C9. (You should be familiar with naming each cell by its column/row designation.) The Total Profit cell is called the *solution cell*, C9. In the solution cell, you must enter the mathematical expression (formula) that is to be maximized or minimized. In linear programming terminology, this is known as the *objective function*, which is the equation describing what our objective is, in this case to make as much profit as possible .

We can calculate the total profit for any particular numbers of hogs, X1, and cattle, X2, in this way:

$$10 * X1 + 15 * X2 = \text{total profit (to be maximized)}$$

These coefficients, 10 for hogs and 15 for cattle, are best entered as cell addresses and multiplied by other cell addresses that contain the numbers of hogs and cattle. Where are these found? Remember the *variable cells*. Although your specific addresses may vary, the form of the entry into the solution cell, C10, will be as shown next; it is the same as the earlier equation, but it uses cell addresses:

$$+ C3 * C8 + D3 * C9$$

Constraint Equations

Now only one detail remains to finish the spreadsheet entries. Expressions must be entered for each constraint that describe the amount of that constraint used by each activity. For example, the concept for the amount of land used is:

$$\begin{aligned} \text{LAND:}\quad & (0.3 \text{ acres per hog} * \text{no. of hogs}) \\ & + (1 \text{ acre per cow} * \text{no. of cows}) \\ & = C4 * C8 + D4 * C9 \end{aligned}$$

whereas that of housing is just

$$\begin{aligned} & \text{HOUSING (remember, no housing is required for cattle):} \\ & \quad 10 \text{ sq ft per hog} * \text{no. of hogs} = + C6 * C8 \end{aligned}$$

These concepts must be converted into mathematical expressions, or formulas, as we are showing here, one for each constraint, and entered into one cell on the spreadsheet. Exactly where they are entered doesn't matter, since Optimizer will ask you for the cell address later. For the sake of simplicity, the cell in column A immediately to the left of each constraint name is a good place. The form of the cell entry for LABOR will be

$$\text{LABOR (entered into cell A5):} \;\; + C5 * C8 + D5 * C9$$

Similar entries must be made for LAND, cell A4, and HOUSING, cell A6. Make entries very carefully, and review each expression when finished. Incorrect cell addresses at this point are a common error.

Concept of the Mathematical Model

What we have here in a simple form is a *model* of the problem. The three constraint equations (actually inequalities, since <= is used, not =) tell us the rules of the problem. Also part of the model is the objective function, which tells us what we wish to optimize and how much each hog and each head of cattle contribute to that objective.

Before going ahead with the solution, it is interesting to "try out" the model just as it is on the spreadsheet. Do this by entering 20 in cell C8 for number of hogs and 10 in Cell C9 for number of cattle. Note that immediately the profit is shown to be $350, 16 acres of land are used, 5 hours of labor, and 200 sq ft of housing. These are correct according to the rules we entered in the formulas. Our model of the hog/cattle problem works! You could experiment with various numbers for hogs and cattle; in this simple problem, you could eventually come up with the optimum solution. But the spreadsheet Optimizer is faster!

Optimizer Dialog Box

Now that your spreadsheet entries are completed and the model works, it is time to call up the Optimizer dialog box. This dialog box must be used because the program does not actually read the numbers and the inequality symbols we have put there; it reads the equations we have entered into the cells. Now we have to tell it where these expressions are, where the RHS values are, and what the inequality symbol is between the expression and the RHS. These instructions apply only to QuattroPro.

From the menu at the top of the screen, choose "Tools," then "Numeric Tools" and then "Optimizer." First, provide the address of the solution cell, C10, and make sure the setting is on "Max." Then enter the addresses of the two variable cells (in our example: C8..C9) by clicking the arrow on the right-hand end of the space, blocking C8 and C9 together on the spreadsheet, and then clicking the open box on the right-hand end of the blue bar that appears in the upper right part of the screen.

To enter the constraint formulas and constants, select "add" from the dialog box, enter the cell address of a constraint formula (we just entered those into A4, A5, and A6), select the proper inequality symbol, and then enter an address for the constraint constant (RHS). An example from our illustration would be

A6 <= F6

which, after returning to the Optimizer dialog box, would appear as

A:A6..A6 <= A:F6..F6

Select "Add Another Constraint" to enter another constraint formula and constant. When all three are entered, select "OK," which returns you to the main Optimizer dialog box. Now comes the moment of truth! Select "Solve," and then "Close." Hopefully, you have an answer. If an error message of some sort appears, check each constraint and solution cell expression for correct form and addresses. Also, did you remember to enter the constant values in the RHS column?

Noninteger Solutions

You will notice that the optimal numbers of hogs and cattle include fractional numbers, a practical impossibility. As mentioned earlier, this would be a problem if the situation involved numbers of machines, such as tractors or combines. You could have a problem where you wanted the program to select the size of the tractor, so you might be looking for one 180-hp tractor or two 120-hp tractors. The answer might well come out to be 1.76 tractors of 180 hp. As mentioned earlier, this is a classic difficult problem for linear programming, and some complex methods of solution have been found. However, for our hog/cattle problem, we can just round off the numbers to whole numbers and have a practical optimal solution.

Optimizer Reports

Further information on the problem can be obtained from the Optimizer Report. To obtain a report, return to the Optimizer dialog box, and select "Options" and then "Reporting." Enter the address where you'd like the upper left-hand corner of the "Answer Report Block" to begin (A12, for example); then select another empty cell for the upper left-hand corner of the Detailed Report. Then click "OK," and then "OK" once again in the "Optimizer Options" dialog box. Finally, again choose "Solve" and then "Close" from the Optimizer dialog box. You will see two detailed tables of results.

We will examine only one aspect of the Optimizer Detailed Report: the constraint dual values. These values indicate the amount by which the solution would change if the corresponding constraint were changed by one unit. In our case, find the dual value corresponding to the labor constraint. Recall which cell contains the labor constraint formula, and find a row within the answer report that corresponds to that cell. In a column for "Restraining ?" the answer is "Yes." This dual value shows how much more profit could be made if one more hour of labor were available. Looking at the dual value, would it make sense for the manager to pay a worker $15 to perform an extra hour of labor per week for the entire year? Probably yes, but the worker is not going to want to get paid a total of $15 to work an extra hour per week for a whole year!

Results

You will turn in two different printouts: the spreadsheet, including answer report, and a list of the entries in each cell. To print your spreadsheet, select the "File" menu and then "Print." Select "Print Preview" from the "Spreadsheet Print" dialog box. Make sure the report results are included in what will be printed. If they are not, exit the box by clicking on the red X, and enter the correct block to be printed in the "Spreadsheet Print" dialog box. When you are sure you have the entire matrix and report included, call up the "Spreadsheet Print

Options" dialog box by clicking on the Options button, next to the red X on the preview screen. Select "Row/Column borders" and then "OK." Now click on the Print button. To print the list of cell contents, click on the Options button, select "Cell Formulas," click on "OK," and click on the Print button. When printing is complete, exit the print preview screen (red X), and "Close" the "Spreadsheet Print" dialog box. Save the file to your disk, and exit the program. Put your name on each page. In the Optimizer Answer Report, circle four items: the number of hogs and the number of cattle to be produced, the total profit, and the dual value that indicates whether an additional hour of labor per week at $15 dollars per hour per week for the whole year is a good deal. On the page itself, write what that dual value indicates, in 25 words or less.

USING QUATTROPRO® TO SOLVE LINEAR PROGRAMS: OPTIMAL FEED MIX

Activities

In this simplication of a real-world problem, you are to set up and solve the problem of determining the amount of each type of feed ingredient to use to make a ton (2000 pounds) of mixed feed with certain specifications. If you don't believe this is a simplification, just look at the feed ingredients and the feed specifications on a bag of pet food in the grocery store (Table 8-5 and Figure 8-1)! Here are the specifications or activities:

The amount of digestible protein in the feed must be greater than or equal to 16%, or 320 lb/ton (2000 lb)
Total digestible nutrients must be greater than or equal to 90%, or 1800 lb/ton
Fat content must be less than or equal to 8%, or 160 lb/ton
Fiber content must be less than or equal to 4%, or 80 lb/ton

The first two of these criteria, protein and total digestible nutrients (TDN), are desirable, and the feed purchaser will be looking for these minimum percentages for the type of livestock and the stage of development of the animal (very young, growing, fattening, etc.). Depending on the use of the feed, the fat may need to be kept below a certain maximum percentage (8% in this problem), or the user may want it to be kept above a certain minimum. In this problem, the fat and the fiber should be kept below a given maximum, 8% for fat and 4% for fiber. Fiber in most mixed feed is a low-cost ingredient and does not do much for the animal, except for ruminants (cattle, sheep, or goats). Therefore, for hog and poultry rations, the feeder usually wants fiber percentage kept low.

Resources

Many different types of feed ingredients are available to the feed manufacturer, and each of them has various amounts of the constituents, protein, TDN, fat, and fiber. Each of these ingredients has a price, and that price may vary from week to week. Since the objective here is to minimize the cost of a ton of feed while still meeting the criteria or constraints, the solution could vary as the prices change. Manufacturers using linear programming will usually run the program every week or two when prices are changing.

The data on the various ingredients are given in Table 8-3. These specifications may not be accurate, but they are in the ball park and fine for an example problem.

Table 8-3 Specification of Ingredients and Their Nutritional Constituents and Prices

Ingredient (Abbrev.)	Protein, %	TDN, %	Fat, %	Fiber, %	Price/lb
Corn	8	97	4	3	$0.05
Corn miller's feed (CMF)	10	85	0	8	$0.04
Cottonseed meal (CotMeal)	43	93	0.5.	4	$0.12
Soybean oil meal (Sbom)	48	95	0.5	3	$0.13
Wheat millings (Wmill)	12	90	5	6	$0.07
Wet miller's grain (Wet)	14	85	0.5.	7	$0.10

Constraints

The specifications or limits on the protein, fat, etc. are called *constraint*s in linear programming, because they constrain what the solution can be. The constraints are entered as shown in Table 8-4. The number in each cell is the constant that is to be multiplied by the column variable. For example, the number 0.08 in cell C4 is to be multiplied by the variable for the number of pounds of corn. It means that corn contains 8% protein, so each pound of corn used contributes 0.08 pounds of protein to the mixture. The names for the constraints, such as Protein in Column B, have been entered for you, as well as the column headings to describe the ingredients in Row 3, starting with Corn in Column C. Also, some of the numbers from Table 8-3 have been entered. Finish entering these numbers into the spreadsheet in rows 4 through 7. Use Table 8-4 for help.

Another important constraint must be entered (in row 8) to make sure the program produces 2000 pounds of feed. Otherwise, it will produce 0 lb of feed at a minimal cost of $0!

$$\textit{Total feed}: \text{Corn} + \text{CMF} + \text{CotMeal} + \text{Sbom} + \text{Wmill} + \text{Wet} >= 2000$$

This is done in row 8 by entering the value 1 in each of the six columns for Corn, CMF, CotMeal, Sbom, Wmill, and Wet. It simply adds the weights of all ingredients to make sure the total is at least 2000 pounds.

The sign > = is used instead of = only, because this makes the problem less restrictive, yet linear programming will not produce more than 2000 lb, since any more would cost more.

The next six rows of the table, or matrix, make sure that Optimizer does not try to use negative values for the ingredients in order to mathematically reduce the cost. Since this is a problem of minimizing, the linear programming procedures try to reduce the cost, even to a negative value. Mathematically, with the constraints we have so far, negative values for the ingredients would give a large negative value for the objective function, thereby satisfying the objective of lowering costs. In real life, of course, costs do not usually go negative, so

Table 8-4 Complete Matrix for the Feed Mixing Problem, *FeedLP.wb3*

					Column					
	A	B	C	D	E	F	G	H	I	J
Row			Corn	CMF	CotMeal	Sbom	Wmill	Wet	Sign	RHS
4		Protein	0.08	0.10	0.43	0.48	0.12	0.14	> =	320
5		TDN	0.97	0.85	0.93	0.95	0.90	0.85	>=	1800
6		Fat	0.04	0	0.005	0.005	0.05	0.005	<=	160
7		Fiber	0.03	0.08	0.04	0.03	0.06	0.07	<=	80
8		Tot. Feed	1	1	1	1	1	1	>=	2000
9		Prices:	.05	.04	.12	.13	.07	.10		
10		nnCorn	1						>=	0
11		nnCMF		1					>=	0
12		nnCotMeal			1				>=	0
13		nnSbom				1			>=	0
14		nnWmill					1		>=	0
15		nnWet						1	>=	0
16										
17	Corn	Variable								
18	CMF	Cells								
19	CotMeal	B17								
20	Sbom	Through								
21	Wmill	B22								
22	Wet									
23	TotCost=	Solution Cell								
24										

we need the following expressions to prevent having a negative value for pounds of any ingredient in the mixture. By putting a 1 in the column under each ingredient, each in its own row, and setting it as >= 0, you are specifying that we cannot have negative values for any feed ingredient. For example, for Corn, 1 * X 1 >= 0 is in row 10, and the label is nnCorn, meaning nonnegative.

When you have the spreadsheet filled in to this point, print a copy of it; it will help you in filling in the other cells needed to do linear programming with Optimize. Print it with column and row headings.

Constraint Cells and Solution Cells

Column J, RHS, meaning right-hand side, is for the total amount of the constraints, such as Protein, which is 320 lb, as listed. In the Sign column, I, we have entered the sign of each constraint, >= in the case of Protein. This row means the following constraint on Protein: 0.08 (8%) multiplied by the pounds of corn plus 0.10 times the pounds of CMF, etc. must be greater than or equal to 320 pounds. We show it in equation form first and then in the second line using cell addresses.

$$\text{Protein} = 0.08 * \text{Corn} + .10 * \text{CMF} + .43 * \text{CotMeal} \\ + .48 * \text{Sbom} + .12 * \text{Wmill} + .14 * \text{Wet} >= 320$$

This expression, using cell addresses, must be entered into cell A4 to the left of Protein. Check the cell before typing, because some of these expressions have been entered for you. Be sure to start the expression with the + or the = sign, to show the program that this is an expression to be calculated.

$$+ \text{C4} * \text{A17} + \text{D4} * \text{A18} + \text{E4} * \text{A19} + \text{F4} * \text{A20} \\ + \text{G4} * \text{A21} + \text{H4} * \text{A22}$$

The other constraints, TDN, Fat, and Fiber, are entered in the same way. Be sure to use cell addresses instead of the abbreviations. These cells, A4 through A15, are called the constraint cells.

As you did in the hog/cattle problem, you must now fill in labels in column A below the main matrix for ingredients Corn through Wet (we have already filled these in). Also, see Table 8-4 and spreadsheet file *FeedLP.wb3* on the CD with this book. This takes six rows, cells A17 through A22; column B, to the right of these labels, holds the cells that will contain the amount of each of these ingredients in the final solution. These cells are called the *Variable Cells* by Optimizer, as shown in Table 8-4.

Next, in A23, is the label Total Cost. The cell in column B to the right of this will be the cell for the cost equation, or objective function; it is called the *Solution Cell*.

Objective Function

In a problem like this, there are many different mixes that will meet the constraints, but the objective of linear programming is to either maximize or minimize some objective function. In this case, we wish to minimize the cost of the feed mix. So we calculate that by multiplying the pounds of each feed used in the 2000 pounds by the price per pound from the table. It looks like this and goes in the cell to the right of the Total Cost label, cell B23, called the *Solution Cell* by Optimizer (use cell labels, as shown in the second line). Check the spreadsheet, because this expression may already be entered.

$$= .05 * \text{Corn} + .04 * \text{CMF} + .12 * \text{CotMeal}$$
$$+ .13 * \text{Sbom} + .07 * \text{Wmill} + .10 * \text{Wet}$$

$$= \text{C9} * \text{B17} + \text{D9} * \text{B18} + \text{E9} * \text{B19} + \text{F9} * \text{B20}$$
$$+ \text{G9} * \text{B21} + \text{H9} * \text{B22}$$

At this point, you should have gone through the same procedures as with the Hog-Cattle problem.

a. Type in the constraint equations using cell numbers (C4, etc.) in column A to the left of each row name, starting with Protein.

b. Type in column A the names of the variables: Corn, CMF, CotMeal, Sbom, Wmill, and Wet; below that type "Total Cost =".
c. Type in the objective function in the Solution Cell in column C to the right of the "Total Cost =" cell.

Check the Model

As with the hog/cattle example, now is a good time to check the model by entering numbers into the variable cells in column B, rows 17 through 22. For example, entering the number 100 in cell B17 means you are trying 100 pounds of corn as a solution. Notice that numbers now appear in cells A4–A8 that show how much of the requirements are being met by the 100 pounds of corn. For example, cell A8, for total pounds of feed, will show 100. If these numbers do not look reasonable, check the expressions you have entered, to correct them. Make sure you know how the numbers are calculated in the constraint cells in column A.

Solve Using the Optimizer

Now go to Tools, Numeric, Optimizer; enter the constraints, Close, and Solve. Further information on the problem can be obtained from the Optimizer Report. To obtain a report, return to the Optimizer dialog box, and select "Options" and then "Reporting." Enter the address where you'd like the upper left-hand corner of the "Answer Report Block" to begin (below your matrix), select "OK," and then "OK" again on the "Optimizer Options" dialog box. Finally choose "Solve" and then "Close" from the "Optimizer" dialog box.

We will examine only one aspect of the Optimizer Answer Report: the constraint dual values, in the right-hand column of the Detail Report. These values indicate the amount by which the solution would change if the corresponding constraint were changed by one unit. In our case, find the dual value corresponding to the constraint that requires 320 pound of protein per ton of feed. The report notes in one of the columns a Yes or

No answer. This is the answer to the question "Is this constraint binding?" If the constraint is binding, then the solution has used all of that resource that is constrained by the problem. In the case of the 320 pounds of protein, it means that the cost of the 2000 pounds of feed could have been less by this amount, if we had not required this much protein in the mixture.

Look at the dual value for this row. This value, in dollars, is the amount that could be saved per ton if 1 less pound of protein were required (319 lb = 15.95% protein). What is that value?

Further down the column of dual values is a negative 28 cents (0.28). Since this constraint, 80.0<=80.0, is a <= constraint, the 28 cents is the change (a reduction) in the total cost of feed if the 80.0 constraint could be *raised* by 1 pound of fiber.

RESULTS

As in the hog cattle problem, you will have two different reports: the spreadsheet, including the answer report, and a list of the entries in each cell. To get the spreadsheet all on one page, in portrait setting, first format the various columns of numbers with an appropriate number of decimal points, no more than three. Then block the entire spreadsheet and set the font to 10 pt. to save space. Adjust the column widths to be no larger than necessary, and when you go to Print Preview, it should all come out on one page, including the Report area. When you are sure you have the entire matrix and report included, call up the "Spreadsheet Print Options" dialog box by clicking on the yellow icon 2nd left from the black X on the preview screen. Select "Row/Column borders" and then "OK." Now click on the Print button.

To print the list of cell contents, first select the block with just the spreadsheet, not the Report area, to cut the size of this printout. In Print Preview, click on the yellow icon (Set Print Options) again, select "Cell Formulas," click on "OK," and click on the Print button. When through printing, exit the Print Preview screen (blackX), and "Close" the "Spreadsheet Print" dialog box. Save the file to your disk, and exit QuattroPro. In the Optimizer Answer Report, circle six items: the number of pounds of each ingredient, Corn through Wet, to be used, the total profit, and the dual value that indicates whether more profit could be made if a constraint could be changed.

Table 8-5 Requirements (Constraints) for a Typical Cat Food

Guaranteed Analysis			
Crude protein	Min. 31.0%	Zinc	Min.75.0 mg/kg
Crude fat	Min. 10.0%	Iodine	Min. 0.35 mg/kg
Crude fiber	Max. 4.5%	Selenium	Min. 0.1 mg/kg
Moisture	Max. 10.0%	Vitamin A	Min. 9,000 IU/kg
Linoleic acid	Min. 0.5%	Vitamin D-3	Min. 750 IU/kg
Arachidonic acid	Min. 0.02%	Vitamin E	Min. 750 IU/kg
Calcium	Min. 1.2%	Thiamine	Min. 5.0 mg/kg
Phosphorus	Min. 1.0%	Riboflavin	Min. 4.0 mg/kg
Potassium	Min. 0.6%	Pantothenic acid	Min. 5.0 mg/kg
Sodium	Min. 0.2%	Niacin	Min. 60.0 mg/kg
Chloride	Min. 0.3%	Pyridoxine	Min. 4.0 mg/kg
Magnesium	Min. 0.08%	Folic acid	Min. 0.8 mg/kg
Iron	Min. 80.0 mg/kg	Biotin	Min. 0.07 mg/kg
Copper	Min. 15.0 mg/kg	Vitamin B-12	Min. 0.02 mg/kg
Manganese	Min. 7.5 mg/kg	Choline Tourine	Min. 2400 mg/kg Min. 0.1%

Source: Ref.1.

INGREDIENTS: GROUND YELLOW CORN, POULTRY BY-PRODUCT MEAL, CORN GLUTEN MEAL, GROUND WHEAT, BEEF TALLOW PRESERVED WITH MIXED TOCOPHEROLS (SOURCE OF VITAMIN E), OCEAN FISH MEAL, SOYBEAN MEAL, BREWER'S DRIED YEAST, ANIMAL DIGEST, PHOSPHORIC ACID, SALT, CALCIUM CARBONATE, TETRA SODIUM PYROPHOSPHATE, POTASSIUM CHLORIDE, CHOLINE CHLORIDE, TOURINE, ZINC SULFATE, FERROUS SULFATE, L-ALANINE, RIBOFLAVIN SUPPLEMENT (VITAMIN B-2), VITAMIN E SUPPLEMENT, ADDED COLOR (RED 40), BIOTIN, VITAMIN B-12 SUPPLEMENT, THIAMINE-MONONITRATE (VITAMIN B-1), CITRIC ACID, VITAMIN D-3 SUPPLEMENT, MENADIONE SODIUM BISULFITE COMPLEX (SOURCE OF VITAMIN K ACTIVITY), CALCIUM IODATE, SODIUM SELENITE.

Figure 8-1 List of ingredients for the cat food of Table 8-5.

To show that complex feed-mixing problems are solved this way, note Table 8-5 and Figure 8-1, a list of feed requirements (constraints) and the list of ingredients, respectively, used in a popular cat food from a local grocery store.

USING QUATTROPRO TO SOLVE LINEAR PROGRAMS: A POULTRY PRODUCTS MARKETING PROBLEM

This problem is the result of a field trip by a class of agricultural systems management students with the second author of this text. The visit was to a poultry processing plant, where live chickens are processed into packages of whole chickens or various parts of the chicken. Naturally, the various parts have a different price. The company wanted to decide how many of the various products they should make in order to satisfy their customers and optimize (in this case, maximize) their return. There are several restrictions about the number of the different products they can sell, so it seemed to be an ideal problem for linear programming.

Defining and Modeling the Problem

In this simplification of a real-world problem, you are to set up and solve the problem of determining how to market 5000 processed chickens per day from a poultry processing plant. (By the way, the company did apply the solution, with good results.) Table 8-6 shows the various packaged products from the broiler chickens and details, including fictitious wholesale prices. Breasts are not defined here as what might be called a "full" breast, two halves, as seen in the grocery store, but as one breast on each side of the carcass, two breasts per bird.

One problem this example illustrates is the need to be able to figure out all of the constraints or rules that the processor must include to make the equations represent the system accurately. This is really *mathematical modeling*, that is, representing how the system works by expressing it in equations.

One constraint is that the company has promised its biggest customer to sell it at least 1000 whole birds per day. This means that the number of wholes must be greater than or equal to 1000. So cell C9 in Table 8-7 contains a 1, and cell I9, in the Sign column, has >= entered. The RHS for cell J9 is 1000.

Table 8-6 Specifications for Activities (Products) in the Poultry Marketing Problem

Column	Part	No. per bird	Weight, lb	Price/lb	Price/Part
C	Whole birds	1	2.0	$0.60	$1.20
D	Half birds	2	1.0	$0.65	$0.65
E	Breasts	2	.30	$1.16	$0.35
F	Legs	2	.40	$0.60	$0.24
G	Wings	2	.20	$0.40	$0.08
H	Backs	1	.20	$0.25	$0.05

Table 8-7 Incomplete Spreadsheet for Chicken Marketing Problem (See *ChickenLP.wb3 or .xls*)

A	B	C	D	E	F	G	H	I	J
3		Wholes	Halves	Breasts	Legs	Wings	Backs		RHS
4	Variable:	X1	X2	X3	X4	X5	X6		
5	BrLimit	2	1	1				<=	10000
6	LegLimit	2	1		1				10000
7	WingLimit	2	1			1			10000
8	BackLimit	1	0.5				1		5000
9	MinWhole	1						>=	1000
10	MaxBr			1				<=	2000
11	MaxHalf								
12	MaxLeg								
13	nnHalf								
14	nnBr								
15	nnLeg								
16	nnWing								
17	nnBack								
18	Prices:	1.20	0.65						

Another problem is that the plant is limited on the packaging capacity for some parts; for example, the breasts must be limited to no more than 2000 per day, so in row 10, labeled MaxBr, we have a 1 in the Breasts column, the sign <= in cell I10, and 2000 in cell J10. Also, halves are limited to 3000, so in row 11, MaxHalf, in column D, Halves, 1 is entered, in column I the sign is <=, and cell J11 is 3000. Legs are limited to 2500, so cell C12 in the MaxLeg row has the number 1, column I has <=, and cell J12 is 2500.

The other constraints have to be derived to keep the linear programming solution from selling more chicken parts than there are in 5000 whole birds, yet allowing it to sell all of the parts in whatever combination is most profitable. This can be a little tricky, so this problem experience is unique and, hopefully, valuable, because this is not the usual "typical" example linear programming problem, such as the feed-mixing problem. If we are not careful, it is possible to overly restrict the problem so that some of the possible combinations of products are not allowed. Yet the constraints need to prevent the linear programming procedure from finding some odd combination of products that will allow an optimal mathematical solution but one that is not practical in the real-world system.

Here are the rules:

One whole bird = 1 whole bird, OR
One whole bird = 2 half birds, OR
One whole bird = 2 breasts + 2 legs + 2 wings + 1 back, at most

There are many other combinations of products that might be optimal, and these must not be excluded by the constraints. For example, 2 whole birds could be packaged as

1 whole bird
1 half bird
1 breast
1 leg
1 wing
1-1/2 backs

The constraints here should make it possible that some products are not produced, but usually the optimization rules will make sure that all of the actual chicken parts are sold. The Halves, for example, might not be produced, but all the chickens could be sold in other forms. However, if any of the "double parts": breast, wing, or leg, are produced, the others will also come into the optimal solution in equal amounts, because the process will not let them be "wasted," when they have a price that will increase the total return, so long as the constraints are not violated.

Setting Up the Matrix

Start your matrix (see Table 8-7, and on the CD the file *ChickenLP.wb3*) by putting in column headings, starting in column C, labeled Wholes, Halves, Breasts, Legs, Wings, and Backs. (This and other parts of this spreadsheet have been filled in on the included file.) Then leave one column for the <= and >= signs, and label the next column RHS, as you did with the hog cattle problem. Then in column B, name the rows BrLimit, LegLimit, WingLimit, BackLimit, MinWhole, MaxBr, MaxHalf, MaxLeg, nnHalf, nnBr, nnLeg, nnWing, and nnBack. These are shown in Table 8-7 and on the CD file *ChickenLP.wb3*.

In the row labeled BrLimit, put a constraint that says that twice the number of whole birds sold plus the number of halves plus the breasts must not exceed 10,000 breasts (two per bird). These three products are the only ones in this expression, because each product contains breasts. This makes sure that the number of breasts in the three products that contain breasts cannot exceed 10,000. In these expressions, we will use the variable names Wholes, Halves, and Breasts to mean the number of each part named. Remember there are two halves, breasts, legs, and wings per whole bird. The expression, or constraint equation, that says we have only 10,000 breasts available is

$$2 * \text{Wholes} + 1 * \text{Halves} + 1 * \text{Breasts} <= 10,000$$

On the spreadsheet, enter just the coefficients 2, 1, and 1 under the column for that product, the <= sign in the column I, and the number 10000 (without the comma) in column J.

For the row labeled LegLimit, the constraint says the number of Legs in the Whole, Half, and Leg products must be less than or equal to 10,000:

$$2 * \text{Wholes} + 1 * \text{Halves} \qquad + 1 * \text{Legs} \qquad <= 10,000$$

The position of 1 * Legs is shifted to the right to show that it will be in the column to the right of Breasts. Since this constraint does not contain Breasts, it means that the number of Breasts does not have any effect on this limit for Legs. Similarly, the next two constraints limit the total number of Wings and the number of Backs:

$$\text{WingLimit}: \quad 2 * \text{Wholes} + 1 * \text{Halves} \qquad + 1 * \text{Wings} \\ <= 10,000$$

$$\text{BackLimit}: \quad 1 * \text{Wholes} + 0.5 * \text{Halves} \qquad + 1 * \text{Backs} \\ <= 5,000$$

There is only 1 back per bird, so the coefficient for the number of Halves is 0.5, because the Half chicken product uses one half of a Back. The number in the RHS column is 5000, since there are only 5000 backs. It is important to remember the definition of each variable and to make sure the units are consistent in each of the constraint expressions. The number 5000 in the RHS of this expression means there are a total of 5000 actual backs that can be used in these products. These constraints will allow sale of any combination of parts without requiring birds with more than two legs each!

Next, following down in the rows of Table 8-7, we have discussed adding in constraints that define the rules about the minimum number of Whole birds and the limits on the ability to produce Breasts, Halves, and Legs. Here we repeat those constraints.

In the row labeled MinWhole, put the constraint on selling at least 1000 whole birds per day, because of the deal with one customer, and notice that the >= must be used instead of<=, as was done before.

MinWhole:	1 * Wholes	>=1000
MaxBr:	1 * Breasts	<=2000
MaxHalf:	1 * Halves	<=3000
MaxLeg:	1 * Legs	<=2500

Due to the peculiar nature of this problem, both<= and >= constraints, and the fact that QuattroPro Optimizer© does not automatically forbid negative solutions, as true linear programming algorithms do, we have to add five more rows to make sure the numbers of Halves, Breasts, Legs, Wings, and Backs are not negative. Wholes, the number of whole birds, is already limited by the constraint MinWhole. So add rows nnHalf, nnBr, nnLeg, nnWing, and nnBack (nn=non-negative). Put in these five rows the coefficients (the number 1) for:

$$1 * \text{Halves} >= 0, \quad 1 * \text{Breasts} >= 0, \quad 1 * \text{Legs} >= 0,$$

$$1 * \text{Wings} >= 0 \quad \text{and} \quad 1 * \text{Backs} >= 0$$

Now enter the price coefficients in row 18, and make sure you enter the price *per piece*, not the price per pound.

When you have the spreadsheet filled in to this point, print a copy of it, it will help you in filling in the other cells needed to do linear programming with Optimize. It should look like Table 8-7, which has the coefficients filled in for rows 5-10.

Go through the same procedures as with the hog cattle problem. Some of these headings are already entered in the file *ChickenLP.wb3* on the CD with this book.

a. Type in column A below the row name Prices the names of the variables: No. of Wholes, No. of Halves, . . . , No. of Backs, and below that "Total Profit =."
b. Type in the constraint equations using cell numbers (C5, etc.) in the A column to the left of each row name, starting with A5 in row "BrLimit."

Table 8-8 Optimizer Report for Poultry Packaging Problem

		Wholes	Halves	Breasts	Legs	Wings	Backs	Sign	RHS
	Variable:	X1	X2	X3	X4	X5	X6		
10000	BrLimit 2	1	1	1				<=	10000
10000	LegLimit	2	1		1			<=	10000
10000	WingLimit	2	1			1		<=	10000
5000	BackLimit	1	0.5				1	<=	5000
2500	MinWhole	1						>=	1000
2000	MaxBr			1				<=	2000
3000	MaxHalf		1					<=	3000
2000	MaxLeg				1			<=	2500
3000	nnHalf		1					>=	0
2000	nnBr			1				>=	0
2000	nnLeg				1			>=	0
2000	nnWing					1		>=	0
1000	nnBack						1	>=	0
	Profit	1.2	0.65	0.35	0.24	0.08	0.05		
Whole	2500	<=Variable Cells							
Half	3000	B20–B25							
Breast	2000								
Leg	2000								
Wing	2000								
Back	1000	<=Variable Cells							
TotalProfit:	$6,340.00								

Answer Report									
Solution Cell	Starting	Final							
A:B27	6340	6340							
Variable Cells	Starting	Final							
A:B20..B20	2500	2500							
A:B21..B21	3000	3000							
A:B22..B22	2000	2000							
A:B23..B23	2000	2000							
A:B24..B24	2000	2000							
A:B25..B25	1000	1000							
Detail Report	Value		Constraint		Binding?	Slack	Dual Value		
A:A5..A5	Variable Cells		<=10000		Yes	0	0.255	Solution Cell	
A:A6..A6	A:B20..B20		A:B21..B21		A:B22..B22		A:B23..B23	A:B24..B24	A:B25..B25
A:B27									
A:A7..A7	10000	<=10000	Yes	0	0.08	1000	6340		
A:A8..A8	5000	<=5000	Yes	0	0.05	1000	6340		
A:A10..A10	2000	<=2000	Yes	0	0.095				
A:A11..A11	3000	<=3000	Yes	0	0.05				
A:A12..A12	2000	<=2500	No	500	0				
A:A9..A9	2500	>=1000	No	1500	0				
A:A13..A13	3000	>=0	No	3000	0				
A:A14..A14	2000	>=0	No	2000	0				
A:A15..A15	2000	>=0	No	2000	0				
A:A16..A16	2000	>=0	No	2000	0				

c. Type in the objective function in column B to the right of the "Profit =" cell.

Checking the Model

At this point, the "model" of the problem is set up, and it is a good check and interesting to enter some trial values in the cells to the right of the labels for each product in the bottom of the spreadsheet. For instance, by entering 1 for the number of wholes, the total return should show $1.20, and constraint cells in column A should all show 1 whole being counted in all the limits from BrLimit down through MinWhole. If not, recheck your constraint equations as entered into the cells.

Optimizer Report

Now go to Tools, Numeric, and Optimizer; enter the constraints, close, and solve. Further information on the problem can be obtained from the Optimizer Report. To obtain a report, return to the Optimizer dialog box, and select "Options" and then "Reporting." Enter the address where you'd like the upper left-had corner of the "Answer Report Block" to begin (below or to the right of your matrix), select "OK," and then "OK" once again on the "Optimizer Options" dialog box. Finally choose "Solve" and then "Close" from the "Optimizer" dialog box (Table 8-8).

We will examine only one aspect of the Optimizer Answer Report: the constraint dual values. These values indicate the amount by which the solution would change if the corresponding constraint were changed by one unit. In our case, find the dual value corresponding to the constraint that requires that at least 1000 whole birds be sold. Recall which cell contains this constraint formula, and find a row within the Answer Report that corresponds to that cell. Would it make sense to try to get out of the agreement to sell 1000 whole birds at this price?

Results

As in the hog cattle problem, you will turn in two different printouts: the spreadsheet, including answer report, and a list of the entries in each cell. To print your spreadsheet, select from "File" menu and then "Print." Select "Print Preview" from the "Spreadsheet Print" dialog box. Make sure the report results are included in what will be printed. If they are not, exit the box by clicking on the red X, and enter the correct block to be printed in the "Spreadsheet Print" dialog box. When you are sure you have the entire matrix and report included, call up the "Spreadsheet Print Options" dialog box by clicking on the Options button, next to the red X on the preview screen. Select "Row/Column borders" and then "OK." Now click on the Print button.

To print the list of cell contents, first select the block with just the spreadsheet, not the Report area, to cut the size of this printout. Click on the Options button, select "Cell Formulas," click on "OK," and click on the Print button. When through printing, exit the Print Preview screen (red X), and close the "Spreadsheet Print" dialog box. Save the file to your disk, and exit QuattroPro. Put your name on each page; in the Optimizer Answer Report, circle six items: the number of Wholes, Halves, . . . , Backs to be marketed, the total profit, and the dual value that indicates whether more profit could be made if less than 1000 whole birds could be sold. On the printout, write what that dual value indicates, in 25 words or less.

Conclusions

We have demonstrated how to model linear problems to find a unique solution that meets a condition, minimizing or maximizing, a linear objective function. Constraint equations have been formed to define the "rules" of the problem, and the spreadsheet Optimizer allows trial values to be entered in the variable cells, giving solutions to the constraint equations. This has been done without using the objective function, thereby demonstrating the modeling of the problem. For example, in the feed-mixing problem, if 100 is entered for Corn, 100 appears in the constraint cell for Total Feed.

A very common application is in the feed-mixing industry, using models larger than our example but based on the same principles. Many agricultural research applications have been made with linear programming determining, for example, what mix of crops will be most profitable on a given land base, often with limitations (constraints) on the amount of labor, the capacity of machines, and the amount of capital available. Many of these applications are available in the agricultural economics literature.

Linear programming is sort of an unseen wonder as a management tool. It is not widely publicized, but it is used weekly by many large companies. Probably not many agricultural systems managers will need to be able to set up and run a large agricultural application for linear programming, but many will benefit from knowing what types of problems the technique can solve.

REFERENCES

1. Anonymous. Guaranteed Analysis and Ingredients from Friskies® Ocean Fish Flavor, Nestle Purina Petcare Co., St. Louis, MO 63164, 2003.
2. Hillier, F.S.; Lieberman, G.J. Operations Research: Principles and Practice. Wiley: New York, 1974.
3. Sowell, Robert S.; Ward, R.C. Modeling processes and operations with linear programming. Agricultural Systems Modeling and Simulation. Peart, R.M., Curry, R. Bruce, Eds.; Marcel Dekker: New York, 1998; 113–156.

9

Queueing Theory and Waiting Line Applications

Robert M. Peart

INTRODUCTION

In many agricultural systems, waiting lines occur, and they can be a problem. Trucks waiting to unload fresh fruit or vegetables at a processing plant, grain trucks unloading at an elevator, and customers waiting in line for service of some sort are examples. The costs of waiting lines may be a definite, measurable item, such as payment for trucks and drivers while they are being nonproductive in a waiting line, or they may be more difficult to measure, such as when customers decide to go to another place of business because lines are too long.

For many such real-world systems, some high-level math has been applied that makes for some very simple and usable equations. We will deal with only the simplest cases involving one waiting line with one service station (unloading dock, cashier, etc.), but more complicated cases with more than one service station and priorities can also be handled.

This type of analysis has been named *queueing theory*, based on the British use of the word *queue* for what we would call a waiting line and on their spelling of the word. The British began the application of many of the mathematics used in this book under the overall term *operations research*, described by Giffin [1]. The well-known beginning of this work was in World War II, when they were trying to find the most efficient way to use airplanes to find submarines on the surface.

DISCRETE AND CONTINUOUS PROBABILITIES

We will be using some simple probability ideas and terminology here. The most basic is the idea of a *probability distribution*. Most books on probability start with coin tossing and the probability of the *occurrence* of a head or a tail, or the *event* that the head of the coin was up. This is a *discrete* probability, because there are only two possible events, heads and tails. Likewise, in queueing theory we are interested in events such as 34 trucks arriving at an unloading site in one hour, not 34.35 trucks, since this is impossible. The arrival of 33 trucks, the arrival of 34 trucks, and the arrival of 35 trucks in one hour are each separate events, that is, discrete events, and the integers 33, 34 and 35 are used, not fractions.

A separate way to measure the arrivals of these trucks is to measure the time from the arrival of one truck to the arrival of the next one — the time between arrivals. This number must be a *continuous* number, not discrete, because two trucks might arrive, say, 14.6 seconds apart, and the third truck could arrive 13 minutes and 44.35 seconds later! The theory of numbers tells us that there is an infinite number of numbers between 44.35 seconds and 44.36, so the numbers are continuous, even though we cannot measure down to the nearest 0.00000001 microsecond.

For a given waiting line system, then, we have a probability of a discrete number of arrivals in one time period, and for 12 arrivals we use the notation *P*(12 arrivals/hr). Here is the difference between a discrete probability and a continuous probability: Thinking about the time between arrivals (a continuous number), we can have only a probability that this time is in a certain range, say, between 3.50 and 5.00 minutes. The probability that this time is exactly 3.50000000 minutes is essentially zero. This is significant only for the derivation of the important and useful equations for the *average* number of customers in the line and the *average* waiting time for each one.

You have heard of the *normal distribution*, the bell-shaped curve showing the probability of having results in a certain range, with values near the average being more likely. Queueing theory is based on the assumption that the *number* of arrivals *per time unit* follows the *Poisson distribution*, a discrete distribution that gives the probability of a certain number of arrivals in a fixed time period. This is a *discrete probability distribution* because there can be a probability of, say, 3 arrivals in one particular hour, but not 3.35 arrivals. This means that for any one time period, only a discrete (or integer) number of arrivals can occur, for example, 3 or 4 or 25, but never a fractional (or continuous) number.

The *average* number of arrivals over many time periods is a continuous variable, such as 3.35, but the *actual* number for any one time period is discrete. Thus the probability of 3 arrivals per hour, *P*(3), may be 0.28, or 28%, and *P*(4) may be 0.32, or 32%, but *P*(3.35) = 0.0.

Imagine that you are doing research on this and are stationed at a grain elevator where trucks are arriving to be unloaded. You are counting the number of trucks arriving every hour. You may have 20 in the first hour, 24 in the second hour, 18 in the third hour, etc. You may collect data like these for several days and many hours. You can then average the number of arrivals per hour over the entire time you took data, and it may be a number such as 21.35, a continuous number. The original data in arrivals per hour were discrete, all whole numbers, obviously, since you cannot have a fraction of a truck arrival. Also, you can average the time between these arrivals, and it will be 60 minutes per 21.35 arrivals, averaging 2.81 minutes between arrivals, another continuous number. These numbers describe what the mathematicians call the *probability distribution* of the data. It has been found that arrival data of this sort usually fit what is called the *poisson distribution* for the number of arrivals per time unit.

Table 9-1, from a probability text, shows in the second column, for a Poisson distribution with an average arrival rate of 2 per time period, the probabilities of having zero arrivals, 1 arrival, 2 arrivals, or 3 arrivals in the time period. The third column is called the cumulative distribution because it gives the probability of having 0 or1 arrivals (0.406) and 0 or 1 or 2 arrivals (0.677), etc. Of course, the top row shows the same probability because the cumulative probablility for 0 is the same as the probability for 0. It is interesting that $P(2)$ is the same as $P(3)$.

P(3 arrivals in 1 hr), of course, depends on the *average* number of arrivals per hour over a long time period. If this average number of arrivals is 30.25/hr, then $P(3)$ will be very low and $P(30)$ will be much higher.

Table 9-1 Arrivals/Time, X vs. P(X arrivals in one time period), discrete, and P(X or less arrivals in one time period), for X_{ave} = 2.00

X	$P(X_1 = X)$ (for $X_{ave} = 2$)	$P(X_1 <= X)$ (cumulative)
0	0.135	0.135
1	0.271	0.406
2	0.271	0.677
3	0.180	0.857

Derivation of the Steady-State Waiting Line Equations

Mathematicians have shown that if the distribution of the number of arrivals per time unit (discrete) is a Poisson distribution, as many waiting lines are, then the time between arrivals will follow the *exponential probability density* function. Here is how they do that, based on Ref. 1:

1. The Poisson distribution is the probability of n arrivals during a time interval of t time units:

   $$P_n(t) = ((\lambda * t) ** n) * (e ** (-\lambda * t))/n!$$

   or

   $$P_n(t) = (\lambda t)^n e^{-\lambda t}/n! \qquad (9\text{-}1)$$

   where

   $\lambda =$ average number of arrivals per time unit

   $n! = 1*2*3*\cdots*n$

   $0! = 1$ by definition
2. The probability of one or more arrivals in a time interval t, a cumulative probability, is indicated by the letter F rather than P:

   $$F(1 \text{ or more arrivals in } t) = F(0 \text{ or more arrivals in } t) - F(0 \text{ arrivals in } t)$$

   Since $F(0 \text{ or more arrivals in } t) = 1.0$ (there is no other alternative, that is, no negative arrivals),

   $$F(1 \text{ or more arrivals in } t) = 1.0 - F(0 \text{ arrivals in } t)$$

For $n = 0$ in Eq. (9-1):

$$F(0 \text{ arrivals in } t) = e^{-\lambda t}$$

Thus:

$$F(1 \text{ or more arrivals in } t) = 1 - e^{-\lambda t} \qquad (9\text{-}2)$$

Equation (9-2) is a cumulative distribution for the probability of 1 or more arrivals in a certain time, t. The derivative of any cumulative distribution such as this, [Eq. (9-2)], gives the density function,

$$f(t) = \lambda e^{-\lambda t} \qquad (9\text{-}3)$$

which is the density function of the *exponential* distribution. Thus, the Poisson distribution for the number of arrivals per hour implies an exponential distribution of the time between these arrivals.

This is much more than an interesting mathematical relationship; it allowed the development of the following steady-state equations. They are called *steady state* because they are the average values to which a system settles down after operating for a long period of time. For instance, in the first few hours of operation, a system might have a higher-than-average number of customers and the waiting line may become rather long. The opposite might also occur. However, over a longer period of operation, such as 1000 hours, the average number in the line (calculated over the 1000 hours) will settle down to a value close to that given by these equations. The actual number can still vary up and down over time, but the running average will settle in to a steady state.

STEADY-STATE EQUATIONS

Let

$$A = \text{arrival rate, number/time unit (lambda,} \lambda)$$

$$S = \text{service rate, number/time unit(mu,} \mu)$$

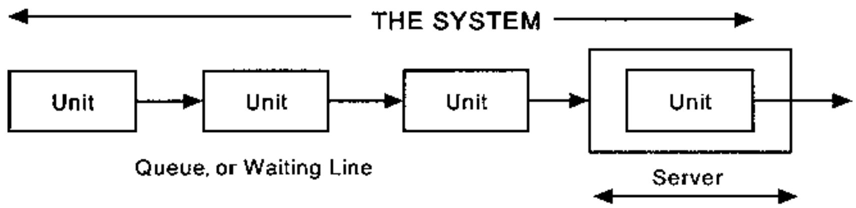


Figure 9-1 Representation of a queueing, or Waiting line, system with 4 units in the system, 3 units in the queue, or line, and 1 unit in the server.

Then

$$\text{Ave. number in system} = A/(S-A) \quad (9\text{-}4)$$

$$\text{Ave. number in queue} = (A/S) * A/(S-A) \quad (9\text{-}5)$$

$$\text{Ave. time in system} = 1/(S-A) \quad (9\text{-}6)$$

$$\text{Ave. time in service} = 1/S \quad (9\text{-}7)$$

$$\text{Ave. time in queue} = 1/(S-A) - 1/S \quad (9\text{-}8)$$

Notice the distinction in these equations between

the *system*, which includes the queue and the server,
the *server*, which may have one or zero units included, and
the *queue*, which has one less than the system, except when the server is also empty.

See Figure 9-1 for graphic representation of these terms in the queueing system.

FOOD PROCESSING PLANT APPLICATION OF THE QUEUEING EQUATIONS

A food processing plant hires its own trucks and drivers to haul product from the growers' fields to the plant to be unloaded. During the season for sweet corn (4 months) the length of the waiting line for unloading seems to be a problem. The plant operates 24 hours a day during the 120-day season, the average rate of truck arrivals at the plant is 20 trucks per hour, and the average service rate is 24 trucks per hour. In other words, the plant has the capacity to unload 24 trucks per hour, but because sometimes no trucks are available for unloading, waiting lines will develop, even though the average rate of arrivals is only 20 trucks per hour.

Setting Up the Problem

The plant operations manager is putting together figures to justify increasing the capacity of the unloading facility. He wants to try various unloading capacities to see the effect. The hourly cost of a truck and driver is $20. Use the earlier equations to set up a spreadsheet as shown in Table 9-2. This format is set up on your disk as file QUE, but you need to enter the correct formulas. Column A is for Arrivals/hr, A in the earlier equations; it is 20 for all rows (all trials). Column B is for Services/hr, S in the equations, and the first row is the present situation. Each of the rows below that is a trial of a remodeled system for higher service rates, from 26 to 40 trucks per hour, each with a different Investment Cost as shown in Column I. The equations for columns C through G are the steady-state equations, but they use the matrix cell designation rather than S and A. For example, the first cell in column C, Ave. # in System assuming row 7, is

$$= A7/(\mathrm{B7} - \mathrm{A7})$$

Be sure to enter the = sign or the + sign so that the spreadsheet knows this is a function. Do each equation in the first row. Then copy them all down to all the other rows, dragging the mouse over the first row to highlight it, clicking on Copy under the Edit menu, dragging the mouse to highlight all the rows C8..G15, and then pressing Enter.

To calculate the Gross Savings, column H, you do not need to know how many total trucks are in use in the system. Think

Table 9-2 Spreadsheet Template for Queueing Problem

	NAME:								
A	B	C	D	E	F	G	H	I	J
A = Arrivals per hr	S = Serv. per hr	Ave. # in System	Ave. # in Queue	Ave. Time in System	Ave. Time in Queue	Ave. Time in Service	Gross Savings	Investment Cost	Net Savings
20	24						0	$0.00	0
20	26							$100,000.00	
20	28							$120,000.00	
20	30							$140,000.00	
20	32							$160,000.00	
20	34							$180,000.00	
20	36							$200,000.00	
20	38							$220,000.00	
20	40							$240,000.00	
							# of days to break even =		

of the total truck-hours and man-hours accumulated (wasted) in the line over the entire season.

The *gross* Savings from the new system will depend on the difference in the average number of trucks in the queue between the old system (C7) and the new system (C8, C9, .., etc.), and this must be multiplied by the cost per hour for 1 truck ($20) and by the number of hours in the total season (120 days * 24 hr/day).

The *net* Savings (column J) will be (Gross Savings−Total Investment Cost). Add column K (not shown here) labeled "Days to BrkEven," defined as the number of days until Gross Savings (column H/120 * no. of days) equals Total Investment Cost, column I. The formula is: column I/(column H/120):

$$\text{column H}/120 = \text{Net Savings/day}$$

Plot a graph to show the effect of increasing the capacity of the system. Set the *X*-axis, or Category axis (as Excel calls it) as the Service Rate, Units/Hr, *column B*. Show the Net 1-year Savings on the Primary Axis, Y1 from column J. and Investment Cost, *column C*, on the Secondary Axis, Y2. Remember the Properties Box for Y2 if using QuattroPro.

Analysis of Results

Which change in service rate cut waiting line costs more—(a) raising the service rate from 26 to 28, or (b) raising it from 28 to 30? You will notice that the increase in service rate, from 26 to 28, had a much larger gain in the first year and that the gains peaked then and finally dropped into the negative area. This is an example of *diminishing returns* that economists see in many systems, the most common example being the amount of increase in yield brought on by ever-increasing fertilizer rates.

Does the negative Net Savings (Gross Savings−Investnvestment Cost) mean that the decision is not economically feasible for these cases? No, because our comparison for only one year of service is somewhat unfair—the improvement will be much greater next year, when the investment in new equipment has been totally paid for. For example, for a new service rate of 30 units per hour, the investment of $140,000 is paid off in the first year, with an additional savings of over $20,000, so in the second year, with the investment paid, the new operation should save about $160,000! As for the negative net savings, even the increase to 40 units per hour with an investment of $240,000 had a loss of about $30,000 in the first year but would pay off the $30,000 next year and then gain about $21,000 in savings that second year.

Remember that the *break-even point* for each case in this problem is the point in time when the investment equals the total savings (breaks even), or the investment has been paid for by the savings.

What is the theoretical length of the waiting line when the service rate exactly matches the arrival rate? This is a very interesting question; the quick answer, without a knowledge of queueing theory, would be that everything would work perfectly, and the service rate would keep the waiting line small or perhaps zero. However, our steady-state equations tell us that the average length of the waiting line will be some number divided by zero, or a very long line. A little thought shows that at some time in the start-up period, there will be no one in the line and none in service. Thus the service facility develops an actual average service rate less than its rating because it is empty for part of the time. After that, it can never catch up with the arrival rate.

Print the spreadsheet file with your results filled in; your table should be similar to the one shown in Table 9-2, except with all columns filled. Print the graph as described earlier.

REFERENCE

1. Giffin, W.C. Introduction to Operations Engineering. Homewood, IL: Richard D. Irwin, 1971; 467 p.

10

Project Scheduling

Robert M. Peart

INTRODUCTION

As a systems or operations manager, you will at some time be in charge of the completion of some project that requires cooperation and coordination among several people in charge of several different parts of the project. One example is the construction or assembly of a new food processing line within a food processing plant. Plans must be drawn, equipment must be ordered, new water and electric lines must be installed, concrete foundations for the equipment must be poured, preliminary trials of the system must be run, etc. Many of these *activities* (or *tasks*) must be done in a priority, or dependency, order; for example, the equipment cannot be installed until the utility lines are in place. However, some activities may be done at any time after some point in the project, and no other activity will depend on having these activities finished. Other combinations are possible, such as start task B at any time while task A is being done, or start task B and task A at the same time.

During the project, changes will be made, some activities will be delayed, and some may be finished early; the project manager needs a method to see easily how these changes affect the project completion date and other dates for scheduled activities. Costs are an important part of any such project, and these can change as work progresses if extra time is required or certain tasks are finished early. Many different people will be involved, inside and outside your own organization. Contractors, subcontractors for electrical, plumbing, framing, etc, inspectors, sales representatives, and many others need to be up to date on your project's progress. Various forms of reports of progress need to be made to keep everyone up to date, and a method of quickly and easily getting these reports out to the right people by e-mail is needed. A computerized method of planning and keeping track of projects can be very helpful to the manager and to everyone involved in the project.

TERMINOLOGY OF PROJECT SCHEDULING AND MS PROJECT®

Software packages are available that help keep track of such important and dynamic (changing) information. Microsoft Project 2002® is such a package. Its cost is low for the value it can offer any company involved in project management. (There is a "Standard" and a "Professional" version of MS Project 2002, but the "Standard" version contains everything we will be covering and more). Farm operations also can benefit from using scheduling software, although the effects of weather will mean that lots of updating will be required.

In fact, the use of MS Project with a field crop operation, including some of the concepts of CropPlan from Chapter 6, would be a very interesting research project. A similar software project has been under development for several years in Florida under a project named Decision Information Systems for Citrus (DISC).

In the following paragraphs, important terms are in italics. It is helpful to remember these words, because they are the words used on screen by the software. For instance, if you are looking for something about a "job," you will not find it in MS Project—you must use the term *task*. Also, we have used the word *activities* in this book, but this term is not used in MS Project either.

The project example introduces methods of entering the data about each *task*, the *duration* (how long it requires), what *resources* are needed, including people and equipment, and how it fits into the priorities. This priority is shown by naming in the task data any predecessor activities, or *dependencies*, where one task, the *predecessor*, must be finished before the *dependent* task may be started. *Resources* are entered into a list, and costs are assigned to each of these on an hourly, daily, weekly, or monthly basis. One tip: In listing the tasks and resources, such as a "concrete truck," and later selecting that resource, avoid typing in "concrete truck" again, because misspelling can easily occur, confusing the program. MS Project has handy ways of selecting these resources by pointing to the name, in a dropdown menu or with up/down arrows on the screen, so don't type it a second time.

Here we list several more important terms about project scheduling in general; they are all mentioned in MS Project, with the exception of the PERT chart, which is called the *Network Diagram*, under the *Reports* box. Then we go into a fairly simple example application to bring out the features of this project-scheduling software and to show how to use it.

Gantt Chart

A Gantt chart has horizontal bars on a time scale showing the time period when each task will be carried out, with the length of the bar showing the beginning time and ending time for the task. Also the dependencies are shown by an arrow from the end time of task A to the beginning point of task B, if task B is dependent on task A. In the older terminology, task A is the predecessor of task B.

A Gantt chart view is one of the views available in Project. It includes a column listing the tasks, generally in the order of their execution, with a timeline extending to the right; the bar for that task is shown on the timeline. Special note: Project provides a very long timeline, stretching out more than a year into the future, as it should for a big project. When you open the file for the example project, you may not find the Gantt chart, simply because the timeline is not set to your date. So you may need to scan forward several months to find the bars of the Gantt chart.

Critical Path

Microsoft Project shows you the *critical path*, the list of tasks that must follow each other and that will dictate the completion date. It is important to know this critical path, because any delay in tasks in this path will delay the whole project. On the other hand, if any task in the critical path can be done more quickly, the whole project will be finished sooner. This method also helps recognize tasks that are not in the critical path and therefore can be done with more flexibility in timing. Along the path, you can decide to add more resources (such as laborers or electricians or tractors and operators) in order to speed the process.

Critical Path Method (CPM)

The initials CPM are generally used in project scheduling, referring to the method used to determine exactly which tasks are in the critical path. In projects larger and more detailed than the example here, determining the critical path is not straightforward, and computer programs have been developed to do that. This methodology has been incorporated into Project to show the critical path as a colored line in several of the views available.

Program Evaluation and Review Technique (PERT)

The Program Evaluation and Review Technique is a method, similar to CPM, for evaluating projects where tasks must be carried out on a certain schedule with dependencies between tasks to complete a total operation. A PERT chart, called a *network diagram*, is one of the screens available in MS Project. It shows the network of tasks and how they relate to each other on a time basis, that is which tasks must precede others and which can be carried out independently. From the View menu,

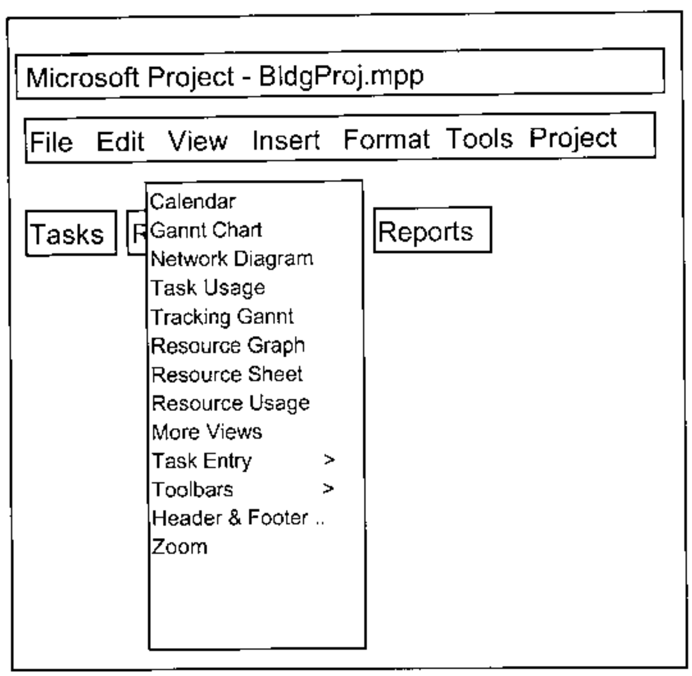


Figure 10-1 Schematic of MS Project screen: View menu.

Figure 10-1, select "Network Diagram" to see this view. It shows a red line for the critical path and gives complete information about every task within the box for that task.

PROJECT EXAMPLE: CONSTRUCTION OF A FARMERS' MARKET BUILDING

The project has been started for you, in the file *BldgASM.MPP*. The extension *.MPP* identifies a Microsoft Project file. This example is a construction project for a small farmers' market, where some stages (called Tasks in Project) must follow others (digging a trench for footings must precede pouring the concrete footings), but others may be independent (selling space in the completed building can be done any time before the building is finished).

The best way to learn MS Project is to fill in the forms and note how changes can be made to improve the planning. There is usually more than one way to accomplish changes in the program, so you can experiment on your own if you wish. Project data are listed here in two tables, and this information will need to be entered into tables on the screen, but not necessarily in the exact order shown in these tables.

Our example is a construction job, from clearing the land to painting the building; that also includes obtaining a building permit as well as sales of rental space in the completed building and planning of an open house. Most of the tasks are dependent upon another one as to the priority of the completion.

Start MS Project, click on Help, then on Getting Started, and open and study the Tutorial. Notice how you work through the steps to list Tasks, set time relationships between Tasks, list Resources, assign Resources to Tasks, Track, and Report; see the schematic of the MS Project main screen in Figure 10-2. There are many features of MS Project that we will not cover. Many of the newer capabilities have to do with sharing information between different locations and people involved with the project by e-mail and the Web. We are just going to set up

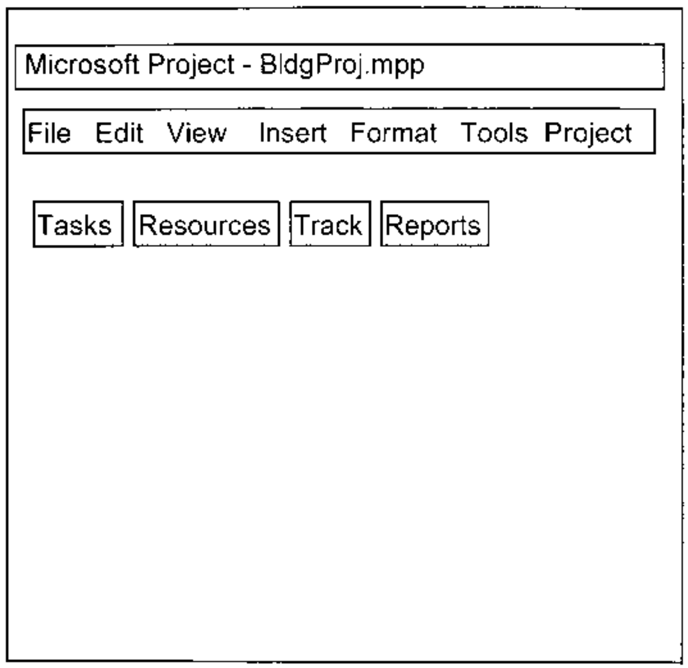


Figure 10-2 Schematic MS Project window. Note Tasks, Resources, Track, Reports.

the plans for the project to learn how the program helps visualize the project and how changes can be made in the plans to shorten the duration of the entire project.

The instructions here are written for MS Project 2002. Beginning with the 2002 version, many directions are given in the left-hand pane that appears when you click Tasks, Resources, Track, or Report. These will more or less "walk the user through the process." The second source of directions is reached from the Help menu and then Getting Started and then Tutorial. We will have you mix these two sources, because it seems necessary, especially to get the correct number of resources, as shown in Table 10-1, for each task.

Table 10-1 Tasks and Resources in Building Project

ID	Task name	Duration	Resources	Predecessor
1	Obtain permits	4/days	1 Manager, 20%	None
2	Grade and clear	4/days	2 Laborers 2 Tractors 2 Tractor drivers	1
3	Dig footers	2/days	2 Laborers 1 Tractor 1 Tractor Driver	2
4	Pour footers	2/days	2 Laborers 1 Concrete finisher 1 Concrete truck	3
5	Build fence	2/days	2 Laborers	1
6	Remove forms	2/days	2 Laborers	4
7	Framing	2/days	2 Carpenters 1 Laborer 1 Foreman	6
8	Roofing and Siding	5/days	2 Carpenters 3 Roofers	7
9	Plumbing	6/days	2 Plumbers	7
10	Electrical	7/days	2 Electricians	7
11	Heating and air conditioning	12/days	2 HVAC installers	7
12	Apply wallboard	10/days	2 Carpenters	8, 9, 10
13	Painting	10/days	2 Painters	11
14	Sell space	10/days	1 Manager, 80%	1
15	Plan open house	5/days	1 Manager, 50%	13

Entering Task Data

Start the program, and open the file *BldgASM.MPP* from your CD. Some of the data for this project have already been filled in for this example. To fill in the rest of the data, click on the Task box. Then on the left of the screen you have a list in blue color of specific operations to be done to fill in the information. Here is the "blue list":

Define the project
Define general working times

List the tasks in the project
Schedule tasks
Link to or attach more task information
Add columns of custom information
Set deadlines and constrain tasks
Add documents to the project
Publish project information to the Web

Click the first one, "Define the project," and follow the instructions. First you can set the starting date for the whole project. Go through the "Save and go to next step" instructions until you get back to the blue list again. "Define the general working times," by going through the next few steps, where the program is set for the usual 8–5 working times, an hour for lunch, and M–F. Then choose the third item, "List the tasks in the project," and fill in only the Name and Duration, in days (d), hours (h), or weeks (w). The rest of the form will be filled in automatically as you enter Resources and the Number of Resources later on the Resource form.

Priorities, Dependencies, and Predecessors

When the form is filled out, you can change the entire schedule by clicking on the starting date of the first task, and change it with the up and down arrows. This shifts all the starting and finish dates to match up with the new starting date. MS Project sets its date as the current day from your computer; you can move the Start date as you wish. Notice that the table for listing the tasks is like a spreadsheet, in that you can make the columns more or less wide, and you can move the right-hand edge back and forth to read more of the information.

Upon completing the Task list and Duration data, select the fourth item in the blue list, "Schedule tasks." Here we will identify which tasks are predecessors and which tasks are dependent on them. The most common condition is called "finish to start," meaning that the first task you select must finish before the second task you select may start. To show this, after selecting the predecessor task and then the dependent one, click on the blue box to the left for "finish to start," under the heading "Link dependent tasks." You must select the predecessor first and then the dependent task. When you have done this, look at the Gantt chart to the right. Notice that a line with an arrow has been drawn from this predecessor to the dependent task, and the bars are positioned to show this. As you add tasks in priority order in the list, Project assumes they are in the usual "finish to start" order and places the bars that way.

Another choice is "start to start," meaning both tasks must start together. You select that in the same way. The third choice is "finish to finish," meaning the dependent task may not finish until the predecessor does. A fourth choice is to break a link you have already entered by mistake. Check the Gantt chart at this point and notice how the arrows from one task bar to the next indicate these dependencies. When you have completed making all these choices, check the Gantt chart as well as the column labeled "Pred." to see that the predecessors for each task are as desired in Table 10-1. You may have to stretch the table of tasks to the right to see the "Pred." column. At the bottom of the blue list for tasks is a blue prompt to lead you on to resources.

Resource Data

Enter the resources by the method based on the Tutorial. Click on View, on the top row, and select Resource Sheet. Then click View again, select Table:Entry and then Entry, and the Resource Sheet is available with Name, Type (Work), Max. Units, Std. Rate, and Overtime Rate. We will not be using the Material Label or Group columns. In the Type column, type "work" for each Resource. We could enter "material" if we were keeping track of material in addition to the work. Maximum Units refers to the maximum number of each of these resources that could be available at any one time. It is entered here just as a check, so you don't overcommit any resource. For instance, if only one tractor is available, Project will not let you schedule the tractor for two different tasks at the same time. Now from Table 10-2, enter Name, Type (enter "work"), Max. Units, Std. and Overtime Rates (multiply standard rate by 1.50). The $ sign will be filled in for you, so you don't have to type it. Use per hour, day, week or month as: /h, /d, /w, /mo. For the overtime pay, multiply the regular pay by 1.5. Machine costs are usually listed on a per-hour or per-day basis, assuming that your company can rent the necessary equipment.

At this point, we have not been able to enter the number of each resource, specified in Table 10-1, to go with each task in order to complete the task according to the duration we set. We have set the maximum number of each resource that is available at one time, but not the number listed in Table 10-1. Later, we will be working with changing the number of the various resources in order to shorten the overall time to complete the project. To do both of these things, you will need to get to the important, but hidden, Task Form, under the blue list of the Resources menu, Assign People to Tasks. We will do this next.

Table 10-2 Resources Needed for the Building Project

ID	Resource name	Type	Maximum units	Standard rate	Overtime rate
1	Managers	Work	1	$200/day	$300/day
2	Laborers	Work	8	$12/hr	$18/hr
3	Tractors	Work	1	$100/day	$150/day
4	Tractor drivers	Work	1	$15/hr	$22.50/hr
5	Concrete finishers	Work	2	$20/hr	$30.00/hr
6	Concrete truck/drivers	Work	2	$200/day	$300/day
7	Carpenters	Work	6	$120/day	$180/day
8	Roofers	Work	6	$120/day	$180/day
9	Plumbers	Work	4	$20/hr	$30/hr
10	Electricians	Work	4	$22/hr	$33/hr
11	Wallboard appliers	Work	4	$130/day	$195/day
12	Painters	Work	5	$12/hr	$18/hr
13	Foreman	Work	2	$150/day	$225/day

Another way to enter the resource data, which we have just done from the View menu, is to click on the Resource box; another blue list appears. The choices are:

Specify people and equipment for the project
Define working times for resources
Assign people and equipment to tasks

and three others we will not use: Link, Add, and Publish.

First, "Specify people and equipment for the project." You could enter the resources, but they are already there if you did it from the View menu earlier, except there is no "Max Units" column. Now we will get to the Task Form, where you can make sure each task has the number of resources listed in Table 10-1.

Assigning Resources to Tasks

Next, from the same blue list, click "Define working times for resources," and go through a few screens, which are preset for an 8-to-5 day with a 1-hour lunch, Mon. through Fri. You could put holidays in if you wish.

Then click on the first task and then the blue "Assign people and equipment to task." Follow through on these directions to get the right resources with each task, using Table 10-1, but do not worry yet about how many laborers, for example, are needed for each task. Click on each of the resources needed for this task. For showing more than one resource, hold down the Ctrl key while selecting the resources needed.

A special note is in order here about assigning resources. Whenever you want to use more than one of the resources, such as laborers or trucks or drivers, special care is required. This is true when less than 100% of the resource time is needed for the task. For example, we have the manager scheduled for only 50% of his time during the task of obtaining the building permit. For these reasons, it is important to access the Task Form screen, under Editing Resources, that allows you to specify the number of these resources.

After entering a resource, such as the manager for Task 1, obtaining building permit, scan down the left-hand column and see the summary of the task and the resources assigned to it, including a percentage of time each resource is working. This may be over 100% or under 100%, as in the case for Task 1. Now scroll down to the very bottom of the left-hand instruction column. This is where we can access what I call the "secret table," the Task Form that comes up under the Gantt chart. When you click on the blue "Edit Task or Assignment Information," the Task Form appears. This has three useful cells that can be calculated by Project (and/or you can fill in your own values): Units, Work, and Duration.

The first task, obtaining permits, requires 10 days, with the manager working 50%, or half-days, on this task. We mean that this task probably cannot be rushed, with various offices being contacted and some waiting time between visits. We still have not entered this information (except for the duration) into Project, but we can now do so on the Task Form, by getting 05 Units, 40 h of Work, and 10 d as the Duration. These three cells interact with each other, so when you enter 40 h for the Work, it may assume 100% time for the manager and change the duration to 5 days. Keep trying until you get what you want. Good Luck! Actually, the Task Form is not a total secret, because it may be found by clicking View, which has a menu of the main views but also includes a choice "More View," as shown in Figure 10-3. This reveals a longer menu of views that may be scrolled down to "Task Details Form."

Take the Building Fence task as another example. If you originally filled in a duration of 3 days and then assigned "Laborer" to that task, the Task Form shows 24 hours required and assumes just one laborer is needed. However, we meant that 2 laborers would require 3 days to build the fence; you can make that change in the Task Form. Our 2 laborers for 3 days of 8 hours each means 48 hours of work, so you should enter that in the Work column of the Task Form. As you click on that cell, you can see tiny arrows to let you select the number, or you can type it in. I recommend using the arrows. After entering 48 in

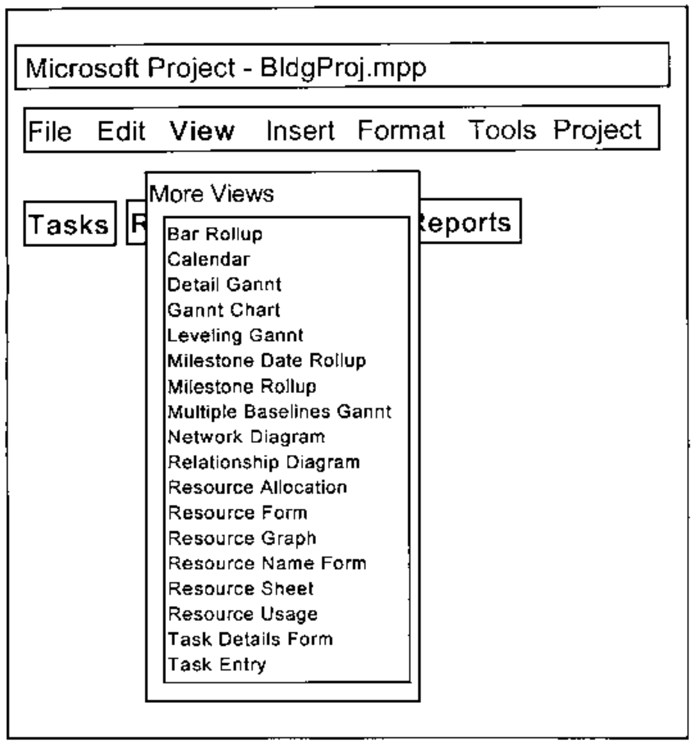


Figure 10-3 Schematic of MS Project window: More Views.

the Work column, click OK in the upper right-hand corner of the Task Form, and watch the Units column show 2 for the number of laborers, the duration should stay at 3 days.

To summarize what may seem rather complex, remember that the three cells on the Task Form—Units, Work, and Duration—can be changed by the user to get the proper information into the program. In the second part of this example, we will use the Task Form again to increase the number of resources on some tasks in order to cut the duration and the time needed for completion.

Now go ahead and finish entering the resources for each task. Go to the Task Form to make sure the correct amount of work is entered, according to the number of each resource and the duration given in Table 10-1. Be sure not to use the Maximum Units in Table 10-2, for the actual number of the resources listed in Table 10-1, which is what we want in the Task Form. Now that data entry is finished, the reports may be studied, and then optimization for shortening the duration will be explored.

Reports and Consulting Services

Once all the resources are assigned to the tasks in the correct number, you can explore the various reports that Project has available for review and printout. The Gantt chart, the Network Diagram, and some of the cost reports are the main ones, but note also the Calendar view, which makes a more convenient way to visualize the process. The cost and other general reports are found under "Report," Getting Views and Reports. Put the dot on "Print a project report" and then select the blue Display Reports. Five types of cost reports are available, and they may be edited to provide a customized report with your name and project name as a heading. Even though you have checked Print, you can see the output on screen before you print it.

Many other report forms are available. From the "Views and Reports" menu just mentioned, there are slightly different reports available on the Display menu and the Print menu. Also, any screen that you want to print can be blocked with the usual spreadsheet technique. Then click the usual Windows File and Print Preview items to see these tables or diagrams on screen for printing.

These reports are very important for every user but especially for the professional who will use these reports as a main part of the "deliverables" to the client. A good variety of useful specialized reports, such as these from MS Project, is very important to both the consultant and the client, because it gives the client several ways to study the results, and it gives the consultant a very nice tool for "adding value" to the work. We encourage liberal use of the reports.

Optimization by Changing Resource Assignments

Next you will do some informal optimization to see how you can finish the project earlier by adding available resources and reducing the duration time of some of the tasks. The tasks to be speeded up are the ones in the critical path, otherwise the total project time will not be reduced. The main idea is that an activity that takes 10 days using 2 laborers would have a 5-day duration if 4 laborers were used.

Of course all resources needed for the task being shortened must be changed, including any equipment needs. If you change only part of the resources, such as laborers, but not carpenters, Project will calculate the duration of the task according to the resource in shortest supply. However, you can't specify part of a tractor unless you are renting it and could complete the task without having the tractor there the whole time. If you schedule more than the maximum number of units available, Project will show this in the Resource Graph and the Resource Usage Reports with red bars and numbers. It is also shown by red print in the Resource Sheet. This maximum number of units can be thought of as the maximum number of resources (people or machines) that are reasonably available at any one time.

The principle is that each task requires a fixed number of resource-time units. For example, 2 laborers for 10 days means 20 laborer-days, which could be met with 1 laborer for 20 days or 10 laborers for 2 days, as shown by the following equation:

$$\text{number of Resource}_1 * \text{time}_1$$
$$= \text{number of Resource}_2 * \text{time}_2$$

where

$$\text{number of resource} = \text{a whole number (integer) value}$$

Of course in the real world the systems manager must know whether 1 laborer can get the work done without a second one, and also if 20 Laborers for 1 day would be too crowded so that the job could not be finished in 1 day.

Fractional machine requirements could come up, for example, if a task required one concrete truck and 3 workers for 5 days (15 worker-days and 5 truck-days). If the maximum units for workers is only 5 and we want to shorten this task, we could use 5 workers for 3 days, but the calculation for trucks would be

$$5 \text{ truck–days}/3 \text{ days} = 1.67 \text{ concrete trucks}$$

Assuming that the concrete trucks are required full time for the 3 days, you must use 2 trucks for 3 days. Of course, it might be possible that 1 mixer could keep up with the 5 workers, but we cannot assume that.

Try this by changing at least two of the tasks in the critical path to reduce the overall duration of the project. Make sure you increase all resources for the task in proportion to the reduced duration (rounding up fractional units as needed). If you specify more of one resource than is required to finish the work in the correct duration time, Project will not warn you. It will charge you for the extra time that you have specified.

Try exceeding the maximum units for one of the resources that are listed. Project should warn you, but it does not, until you go to Reports, and choose Resource Graph or Resource Usage reports to find the excess utilization showing up as red above the maximum number of units specified.

At this point, you should be able to do the "keyboard work" of entering data into MS Project and visualizing the results in diagrams, graphs, and tables. Many important features are available in the program for both strategic (longer-term) planning as well as tactical shorter-term, operational, or "this week" planning. For example, in this problem, how much time was saved by increasing resources to shorten the duration of the project? How might this relate to contracting jobs where contracts are based on penalties for missed deadlines or on bonuses for finishing ahead of the deadline? Did the total cost of the project change? If it did change, why?

We have not talked about tracking, entering milestones, use of overtime work, and other features of MS Project. These are areas you will want to investigate if you become involved in a larger project. Tracking the project, that is, making changes due to weather changes or equipment failure problems, is a very important feature of many agricultural systems. Chapter 2 in this book, on reliability, has much to say about the equipment failure problem. Tracking of crop field operations, for example, using MS Project could be very useful. Delays due to current weather conditions could be entered to dynamically recalculate the new expected date for planting. This could be very useful in connection with CropPlan, which we used in Chapter 6, for projecting expected dates for harvesting crops. We encourage you in efforts to more fully adapt software tools for practical agricultural systems problems such as these.

REFERENCE

1. Microsoft® Project, version 2002, Microsoft Corporation, Bellevue, WA (www.microsoft.com).

11

Artificial Intelligence and Decision Support Systems

Robert M. Peart

INTRODUCTION

In the 1990s, many managerial leaders believed that one of the major sources of productivity, creation of jobs, and the generation of new wealth would be in the general area of ''turning information into knowledge,'' and they were right. Information is available in amazing breadth and depth. Stock market quotes, weather data at thousands of locations, commodity prices and futures and option prices on these commodities, including grain, orange juice, cotton, live cattle, and hogs, make up a part of the mass of new data that are generated each day and hour in the United States. And now data such as these are becoming available from around the world as we become part of a global economy. In addition, less volatile data, such as pesticide recommendations, crop variety selections, machinery specifications, soil types, and fertilizer recommendations, are available, and some of these are different depending upon location. So a bewildering amount of information is available.

Making use of this information in a way that will improve productivity, reduce the losses of nutrients, cut costs, improve profits, and meet regulatory requirements is a challenge for agriculture today. We hope this material will make a start in explaining a relatively new technique for turning information into knowledge using the concepts of artificial intelligence. These concepts have led to the development of what were called *expert systems* and now are more accurately covered under the more inclusive term *decision support systems*, according to Barrett and Jones [1].

The concept of expert systems, artificial intelligence, "fuzzy logic," and knowledge-based decision support systems (information systems) was accepted rapidly in business and industry. Production control systems in factories have included these concepts so that operating problems, such as bad welds, can be either prevented or fixed much more quickly than under simpler control systems.

A quick example of such a system in agriculture is a relatively simple program that includes the recommendations of the citrus disease expert and asks questions of the user so the user can decide when a fungicide application is needed. The particular fungus causes small, very young citrus fruit to drop off the tree shortly after the bloom stage; it is called *postbloom fruit drop*. Blooms become discolered, indicating that they are affected by the fungus. The recommendation is to count the number of bad blooms per tree, note the calendar time within the season, remember if there was a similar problem in the same location last year, and note the weather. The weather data come into the program through the World Wide Web. The user enters the other data and gets a recommendation that may be to wait and continue observations, to apply fungicide now, or not apply fungicide because the conditions are such that the fungus threat is gone for the season.

Developing a decision support system is quite different from writing a conventional program in FORTRAN, C++, or any other procedural language. However, it is easy to get started with the concepts of what is called a "rule-based" program, and knowledge of a procedural language is not needed. We will introduce these concepts with ordinary English-language statements and then show how these can be turned into Web (WWW) pages.

If you are not already familiar with the field of artificial intelligence, it would be helpful to know some of the special vocabulary that rapidly developed. The field did expand rapidly, and many of these terms overlap in meaning. We will try to clarify these meanings, because there can be important distinctions between, for example, an expert system and a knowledge-based decision support system. Whereas *expert system* is probably the most used term for work in this area, it does not accurately cover much of the more recent work, especially in agriculture, where integration of databases and simulations makes these systems so powerful.

In the mid-1980s, this whole subject area was developing rapidly, and technical articles about these terms were popular. Special programming languages were developed for artificial intelligence applications, and new computers were designed just for these applications and languages. Since then, this publicity has faded, but the concepts are important and have been incorporated into many special operating programs using conventional computers and have saved a lot of money in industry.

ARTIFICIAL INTELLIGENCE

This field is very broad. Here we define and describe some of the types of research and development that have been and are being done. Even broader than the following terms, the concept of artificial intelligence was exciting to the general public and even inspired imaginative fiction about future computers that would approach, or even surpass, the intelligence of human beings. For many years, the informal test of this idea has been development of computer programs to play chess against a human. People have worked on this for years, and computers have had a phenomenal growth in speed of processing and size of memory available. The latest heard about the chess game was that a computer and one of the top chess champions of the world came to a draw! Probably one of the advantages the computer has in such a task is its huge memory for storing a very large number of strategies and its ability to search them rapidly and compare them with past games and current tactics of the opponent.

If the reader will allow a little philosophy here, I will introduce two strong concepts that the artificial intelligence scientific community has come to realize. An early one was sort of a marketing slogan for the concept of utilizing artificial intelligence to solve problems.

Knowledge Is Power

This is certainly true in many aspects of business and life in general. We spoke earlier about the need to handle vast amounts of information and convert it into knowledge that is useful for the agricultural systems manager and his or her client. This has been recognized for a very long time. From the Old Testament of the Bible, Proverbs 24: v. 5: "A wise man is mightier than a strong man and a man of knowledge than he who has strength." The second principle was recognized after the failure of earlier ideas that a supercomputer with vast reasoning powers and utilizing artificial intelligence could "reason" by itself and then go on to learn new knowledge that, perhaps, mankind had not learned! Researchers later realized that for the development of useful applications with artificial intelligence, the system needed, in addition to the ability to reason, a set of rules about the problem and that these rules must include "knowledge" that humans, usually experts, could provide. This second principle was also known to the writer of Proverbs 18, v. 15: "An intelligent mind acquires knowledge, and the ear of the wise seeks knowledge." (Both quotes from the Revised Standard Version). So although we are aiming in this chapter to define and encourage the development of decision support systems, it is interesting to view the whole area and a little of the history of the relatively new field of artificial intelligence.

Robotics

Robotics has been considered a part of the overall field of artificial intelligence by many authors. A robot is not just an automatic welding machine on a car body production line, but a machine that can be programmed to do a variety of tasks and that can interact with its environment. A robot may need to make a decision about whether an object that it must select is a nut or a bolt, a green tomato or a ripe, red tomato. Thus robots need to "see," recognize objects, and make decisions, so they need intelligence—"artificial" intelligence.

Natural Language

For easier and greater application of the computer in our working world, we need better and more natural ways for humans to communicate with the computer. The computer needs to be shown more about how we communicate so that we can spend less time learning how the computer communicates. We want to be able to ask the computer, "What did the Dow Jones do today?" or "What are the soybean futures for next July?" or "What are the probabilities for a freeze tonight?" This kind of language is (naturally!) called natural language, and the computer needs a natural language program to make this possible.

This is a difficult field, but progress is being made. The programs that can process natural language sentences must determine which words are the noun, the verb, and the object, for example. One of the big problems is that humans can pose a question in many different ways. In addition, voice recognition by the computer is a part of this, because we often do not want to or are unable to type our input, but should speak to the computer. The development of programs that understand human natural language is a vital part of the whole artificial intelligence investigation, because this requires intelligence. We are going no further into this area.

Fuzzy Logic

To simulate human intelligence, artificial intelligence must be able to handle more than just numbers, yet the heart of any computer is just a very fast processor of data in binary form, zeros and ones. Our programming languages, such as FORTRAN, C++, and Java, have allowed us to program computers with English words and mathematical symbols, yet most programs are very precise and objective in their results. They usually produce a table of numbers, and they can rank these results numerically, even with huge numbers of possibilities.

But humans often must make decisions in which the input data and the resulting output are not in neat mathematical or completely logical form. For example, a computer using a linear programming algorithm can select the one best combination of several ingredients that will result in the lowest-cost feed mixture that meets the specifications in terms of protein, fat, fiber, and total digestible nutrients from among an almost infinite number of possible combinations. However, until artificial intelligence, the computer could not solve less precise problems, such as determining the most profitable combination of crops to plant for the coming year, with prices and costs being uncertain. And managers often want a recommendation in terms somewhat like a weather forecast, such as, "If you do not spray, chances are about 1 in 5 that the disease will cause more damage than the spraying cost."

These less well-defined problems are solvable by human experts, but they are difficult for the computer because many of the "facts" are not known with certainty, and they are represented by humans with terms such as *more, less, low, very* *severe*, and other nonnumeric words or symbols. In artificial intelligence, this concept was termed *symbolic computing*, because symbols were handled. When "facts" are not known with precision, the problem seems fuzzy, and thus the term *fuzzy logic* was coined, in fact, it was trademarked by a camera company to describe its automatic camera focus control system.

Expert Systems

An expert system simulates a human expert in a narrow subject matter domain. For example, to develop an expert system program to give soybean growers advice about insect problems like a consulting entomologist might give, the program needs to do the following:

1. Ask the grower some general questions to find out what the problem is.
2. Find out the farm's location, variety of soybeans, stage of growth, identification, or description of the bugs.
3. Finally, give the best estimate the system can on the type of insect, whether or not treatment is needed at this time, and when and what type of insecticide is recommended if treatment is needed.

Programs such as these probably will not replace the consultant, but they will be used by the consultant to give better advice and probably to produce good printed reports for the client. Many agricultural expert systems are diagnostic in nature, such as the example just given. In addition, expert systems may be (and a few have been) developed for making technical management decisions, such as purchase of new equipment, deciding on a crop rotation, making a marketing plan for grain, or culling livestock from a breeding herd.

Knowledge-Based Decision Support Systems

The term *knowledge-based decision support systems* (or *decision support systems*) includes expert systems but covers a broader range of program types. Often, it would be advantageous for an expert system to have available the latest data from the commodity futures market or cash markets or to be able to run a simulation program with current weather data to get crop yield estimates in order to give the user the best up-to-date expert advice. When an expert system uses a database, a spreadsheet, or some other external program, such as a simulation program, the whole integrated system is referred to as a decision support system. An expert system is also a knowledge-based decision system or *decision support system*, because it contains the knowledge of the expert and it helps, or supports, the user in making a decision.

The word *support* emphasizes the important idea that the computer is not controlling the decision. It is not the decision maker. It helps (supports) the human decision maker by keeping track of many factors, whereas the decision maker is also likely taking into account other factors, especially more subjective ones. A citrus production manager in Florida makes a very sound point about the use of computers in management: "Use the computer for what it can do best, calculating and remembering lots of data, and use the human for what the person can do best, integrating the output of the decision support system and other factors, including the human's experience, and come to a decision based on all these things."

More recently, a broader common term has come to include decision support systems: *information systems*; the field has become known as *information technology* (IT).

Decision Support System Applications

Potential applications are innumerable, but many of them will fit under one of the following types.

Diagnostics—Experts can tell what is wrong with a car when it doesn't run right, why a lawn doesn't look so good, or whether the cotton farmer should spray for insects now or later. Expert systems on a personal computer will be very valuable for problems such as these. An auto manufacturer developed such an expert system for mechanics.

Marketing—Stock and commodity futures traders have programs to guide their buying and selling, and farmers and grain buyers can use the rules of an expert in determining when to buy and sell to reduce risk and maximize returns. One such program has been developed by Thieme et al. [2]. The field of commodity marketing lends itself well to a decision support system, because experts commonly use specific rules and decision trees, which are relatively easy to program for the computer.

Systems operations management—Decision support systems are being developed to help engineers design the layout and type of machine tools in a factory to get a good balance and efficiency of use for a variety of jobs that will be run through the factory. Growers of food crops need decision support systems to determine the optimal time to plant and harvest crops and to control pests. Khuri et al. [3,4] and Lal et al. [5,6] have developed experimental systems for citrus management and field operations simulation.

Automatic control—Many control systems have been improved greatly by adding rules such as "Set the air conditioning controller to a higher temperature if today is a holiday with no one in the building." Controlling peak electrical demand by turning off water heaters during peak periods is another excellent application.

Strategic planning—Planning on a longer-term basis, such as annually, can be aided with well-designed decision support systems. Also, models to make projections about the future would be helpful to answer some of the expert questions that must be asked in strategic planning. A decision support system can integrate these functions and can then answer questions such as "Were July electrical costs higher this year because of the weather, because of controlling high-peak use, or because of different rates?"

Static and Dynamic Decision Support Systems

Especially for agricultural systems, the idea of dynamic vs. static decision support systems is important for the development and operation of these systems. *Static* systems are those that are used, usually, at a single point in time; and each use is a new one, keeping no information from the last time it was used or "run." A diagnostic system telling the user with a poor-looking crop what the problem is—disease, some nutrient lacking, drought, etc.—is a typical static system. An early example of such a system was used to identify soybean insect problems and recommend treatment, Beck [7].

However, many agricultural problems may be used throughout a growing season. Once the user enters data about the crop to assess the threat of an early-season disease, for example, the user may want to do it a week later to check on the same disease or on a question such as irrigation needs. These subsequent uses can take advantage of the earlier data entered to give decision support based on the history of the crop up to that point. These programs are called *dynamic* decision support systems, and they must keep earlier data from one use to the next.

DEVELOPMENT OF DECISION SUPPORT SYSTEMS FOR AGRICULTURAL SYSTEMS MANAGEMENT

Currently, one of the best ways to understand how a decision support system can be developed involves the concept of a series of Web (WWW) pages. Most people are now familiar with a typical Web application, where you look up the site and then click on various available options to lead you to the information you want. A decision support system works the same way, with various options available on each screen to go to the next screen in search of the knowledge you need. This concept makes the idea of a decision support system easier to understand than many of the older methods that referred to the knowledge base, backward-chaining, forward-chaining, objects, source code, and other programming jargon.

We will not go very far into the software programming aspects of this development. But it is important to understand the general idea of how such software works and specifically how you, as an agricultural systems manager, can help a programmer make the program relate well with the potential user. Also, this concept of development of a decision support system will be valuable to you as you advise your client or employer in the use of such systems that are available to them and/or for your use for them. Many available systems would provide you, as a consultant or system manager, reports that may be printed for the owner on a periodic basis, enhancing the value of your service.

Importance of the User

Decision support systems are typically developed by at least three people: the domain expert, the knowledge engineer, and the computer programmer. And it is very important that they know and consult with a fourth person, the user, very well.

The *domain expert* is the specialist or consultant whose expertise will be simulated.

The *knowledge engineer* has the overall concept of the expert system structure and oversees writing of the program. An important job of the knowledge engineer is to accurately elicit from the domain expert the rules, generalizations, exceptions to the general rules, the things he needs to know about the problem before he can give advice, etc. This knowledge engineer could very likely be an agricultural systems manager, because this person, having agricultural training, will understand and be able to communicate very well with the domain expert, who will usually be a specialist in a particular problem area. The ag systems manager, having the overall systems concepts of an agricultural operation and the particular jargon and specialized terms will be very helpful in communicating with the programmer on how the user will want to interact with the program.

The *programmer* will most likely be an expert in Web design, because most of the newer programs will operate online through a Web page. Design of a Web page (World Wide Web) is a difficult task, currently poorly done in some cases because it incorporates the need for excellent programming skills, an artistic ability with shapes and colors, and an understanding of how an unskilled computer user can more easily use the system and recover from errors. One of the advantages of the Web page approach is that it has the built-in capability to "back up" when the user has gone in the wrong direction.

The *user* is, of course, the whole reason for development of the program. The agricultural systems manager must have a very clear idea of the range of individuals who will be users of the system. Their knowledge of the problem, the jargon, and the units of measure and their experience level with computers in general are all important and must be considered in designing the decision support system.

Planning Development of a User-Friendly Decision Support System

Sometimes, it has been incorrectly assumed that the farmer or grower himself or herself will be the primary user of the system. In many cases, the consultant for the grower is the more likely person. For example, in citrus production, production managers are used to direct when various sprays are needed, when and how much fertilizer is applied, when picking crews are scheduled, and various other necessary processes. All over the country, the *crop consultant* is becoming a major part of agriculture; there is even a professional society for crop consultants.

In designing a decision support system, the agricultural systems manager must think somewhat like a medical doctor trying to diagnose a patients problems, but without talking directly to them or seeing them. The doctor can ask questions but has to give the patient just two or more possible answers, and the patient cannot say anything more.

Barrett and Castore [8] have said, "The program developers' dilemma is to develop a program that makes sense to the end users, whomever they may be."

The good knowledge engineer never forgets the users. Users are coming to the expert system for help, and this computerized help is probably new to them. The users are intelligent managers and probably know the problem area better than the computer experts do. The users would prefer to talk one-on-one to the domain expert, but they cannot; the expert system will help many users have simulated discussions with the domain expert. The overall goal of the knowledge engineer is to make this simulated discussion nearly as easy and enjoyable and helpful as a live, personal discussion between user and expert. One of the simple but important rules is to make every effort to use the particular terminology and jargon that is familiar and meaningful to the user. For example, in Florida a field full of fruit trees (citrus) is called a *grove*, whereas in Michigan a field full of fruit trees (perhaps cherries) is called an *orchard*. The wrong term in the wrong place gives the user less confidence in the system.

A very recent excellent publication admits that some decision support systems in agriculture have not been widely accepted [9]. The editors include nine technical articles about experiences with decision support systems in agriculture, including enterprises such as cotton, wheat, soybean, and grazing. These experiences come from Australia and the United States, so the interest is widespread, and research in this field is major. The interesting title of the publication is *Probing the Enigma of the Decision Support System for Farmers: Learning from Experience and from Theory*.

Our emphasis is on expert systems based on rules. If we want to simulate an expert who can diagnose crop disorders, for example, we usually think of the rules the expert employs in order to eliminate the possibilities that are less likely and focus in on the most likely diagnosis and then also the cure.

In its simplest form, the main parts of the expert system are (1) the rules and (2) the recommendations, answers, or goals. Each rule will result in a recommendation.

Decision Tree

The decision tree is an excellent tool for designing the decision support system and showing the programmer how you want the system to work. Typically, the decision tree may be laid out starting at the beginning on the left, with the possible decisions to be made in each box shown by an arrow leading to the next decision point. Each box also indicates a computer screen. Each screen can contain information and instructions to help the user make the next decision.

Each rule is described by one complete path through the tree leading to one particular recommendation or answer. The following decision tree and decision table, or matrix, present methods of putting on paper the logic you want to show in the decision support system, regardless of the programming method. A good programmer can take these diagrams and make the system appear on the screen as desired using his or her favorite programming language. We will be recommending that the program be set up as a World Wide Web page, WWW, so the user will mainly be using the "point and click" method to answer questions and work through the rules to the final recommendation.

Auto Air Conditioning Example

A simple automobile air conditioning problem is developed here as a model of the process of developing an expert system, or a decision support system. This problem is visualized as a one-time use, or a static expert system—no follow-up on the same problem later, and no database or simulation to be included. Just like a doctor making a diagnosis, we have to ask some questions about the symptoms in order to find out how to treat the problem.

We visualize the problem of trouble with the air conditioning in our car. We assume that the fan is OK and that air is circulating but that it is not cool or not cool enough. This keeps the problem simple. First we think about the symptoms of the problem and how we are going to ask the user about them. We could do this in several ways, but in this example we ask first about the belt that drives the air conditioning compressor under the hood, next to the car engine. This answer about whether or not the compressor itself is turning will help us separate the possible problems.

Now think about the user, maybe not very knowledgeable about air conditioning mechanics, looking under the hood to see if the compressor is turning. It is easy to see if the belt is running, but this does not mean the compressor is turning, because there is a clutch that engages or disengages the belt to the compressor. So some instructions are needed about how to tell if the pulley wheel itself is turning the compressor. As an aside, you can see that on the computer you could have a picture of a typical compressor with an arrow indicating the drive wheel to be checked. Also, what we are trying to emphasize here is that you, as a systems manager, need to "see the whole picture" as you help develop an expert system. Part of that is being conscious of different types of users for whom the system is being designed.

On the decision tree, this first question about the compressor turning leads us to the first decision point on the decision tree; see Figure 11-1. You can see from the complete decision tree that if the compressor is turning, we are next going to ask about the temperature of the air from the air conditioner; and if it is not turning, we will ask about the condition of the belt driving the compressor. Assume now that the user responds that the compressor is turning.

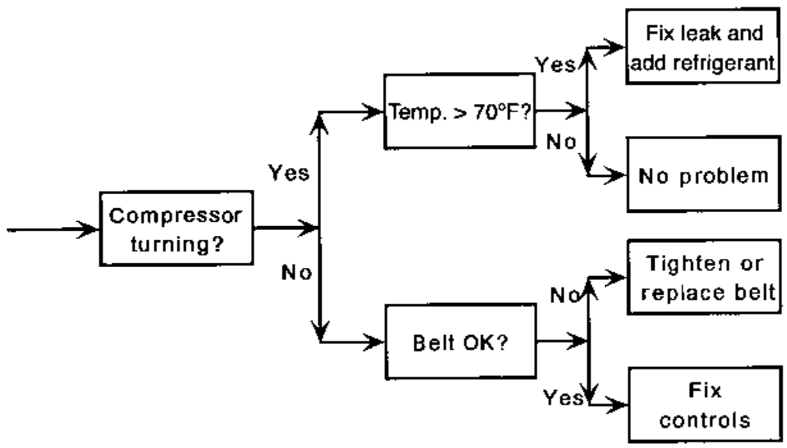


Figure 11-1 Decision tree for air conditioner expert system.

Then we ask the user about the temperature of the air coming out of the unit (we could also ask the user to get a thermometer and measure it). But at this point, a rather fundamental question needs to be raised. Many programmers writing an example like this would just ask the user: What is the temperature of the air coming out of the unit? However, in the case of a unit doing no cooling at all, the user can be sure, without a thermometer, that the temperature is above, say, 70°F. Also, the user should be reminded to let the unit run for a couple of minutes, to give it a chance to cool off the system, before checking the temperature of the exhaust air. Then, after giving the user advice about these situations, we could ask if the temperature is obviously too high or if the unit is partially cooling. We could ask for a temperature reading to see if it is above or below 70°F. Try to put yourself in the user's place as you design these questions. We ask the temperature question to find out if the unit has totally failed, if it might still be partially working, or if it really is working OK but the user thinks it should be doing better.

Our point here is that all of these possibilities should be covered for the user at this decision point. We will just go ahead and ask the question about whether the temperature is above or below 70°F. In a real system, however, these explanations could be presented at this decision point screen, and then more than two questions could be asked (making the decision tree larger). In addition, a "dead-end" branch of the decision tree could be designed for the user that wants to dig further into the workings of the air conditioning system. This type of addition is fairly easy to do with the Web model of the expert system.

Back to our example: With the compressor turning, we recommend repairing the system if the temperature is above 70°F; if the temperature is below this point, we say the unit is actually running OK.

Next, if the compressor is not turning, we will ask the user to check the belt to see if it is tight enough and not showing lots of wear. If it seems OK, then we recommend having the controls checked, because the clutch connecting the belt to the compressor must not be working. If the belt is loose or worn, we recommend tightening or replacement.

The decision tree is an excellent tool for planning the expert or decision support system, and it also is an excellent way to communicate with the programmer who will implement the system as a Web program. Normally, this Web program would be part of a larger Web site that relates to the particular decision support system. For example, an agricultural fertilizer company could use such a program to help a grower or crop consultant decide what amounts and timing to use for various fertilizers. At the fertilizer company's Web site, they could have information and perhaps prices of their products and other marketing features. The availability of a decision support system on this site could be a good marketing tool, inducing customers to use this free program to select the type and amount of fertilizer they need. In the other form, the Web program could be put on a separate disk that a user could buy and run offline without any connection to the Internet.

Decision Table or Matrix

A second way of representing the flow of questions and information in a decision support system is to set up a table (or matrix), with each cell in the table representing a particular solution to the problem and the rows and columns representing "states of the system" or answers to the questions, such as "The temperature is below 70°F." Our air conditioning decision support system has three questions, with two possible answers to each. To set up the problem in a decision matrix, let us set up the first question, about the compressor turning, as two columns of the matrix, one for turning and the other for not turning. See Table 11-1. Then we will set up the questions about the temperature and the belt, in rows. We need four rows to show this so that every possible combination of the answers is possible. This is a very important aid in planning the program, because it ensures that we have not forgotten some possible combination.

There are eight cells in our matrix, each one for a unique state of the system and one recommendation or answer from our expert system. Yet looking at the decision tree of Figure 11-1, we see only four different answers! Nothing is really wrong, but the matrix method guarantees that every possible combination of answers to the question is represented by one of the cells. Our decision tree happened to avoid some of the

Table 11-1 Decision Matrix for Air Conditioning Decision Support

Compressor turning		Compressor *not* turning	
Temperature > 70°F	(3) Repair and add refrigerant	(1) Fix controls	Belt OK
Temperature < 70°F	(5) Unlikely state	(6) Unlikely state	Belt *not* OK
Temperature > 70°F	(7) Unlikely state? No, should be (2) Fix belt	(2) Fix belt	Belt *not* OK
Temperature < 70°F	(4) No problem	(8) Unlikely state	Belt OK

missing combinations, because we were "expert" enough to know that some of the combinations were not likely to happen. In the decision tree, we first asked about the compressor turning, and that seemed to divide the problem into just two more questions, each with two answers, or a total of four answers: (1) Fix controls, (2) Fix belt, (3) Repair and add refrigerant, and (4) No problem.

The decision matrix, Table 11-7, however, shows there are eight *theoretical* answers, since there is a total of eight different combinations of the three two-answer questions. Let us find the least likely (in real life) combinations of these conditions. The correct answers are filled in on the table. The first row of cells with unrealistic combinations of conditions is the row labeled "Temperature <70°F and Belt not OK." These two cells represent the two conditions of the compressor turning and not turning, and these combinations do not seem likely when the temperature is less than 70°F, indicating that the system is working OK. These two cells are numbered (5) and (6) as unlikely states. The cell numbered (7) has a question mark, because this could happen: Temperature high, Compressor turning, and Belt not OK. The belt may be just slipping, and the compressor is turning, but too slowly to cool the air enough. The answer for this condition should be the same as answer (2), Fix belt. We go into all this to show that the decision matrix, very similar to a logic table, is a good way to make sure you are considering all the possibilities.

The disadvantage of the decision matrix is that for larger problems, with many more combinations, the matrix becomes large and unwieldy. We have shown only examples with two decisions at each decision point, but of course more decisions than two can be choices at any decision point.

Programming Web Pages for Delivery of a Decision Support System

The advantage of using Web pages for this method of programming is that the Web page already gives the user the capability to click the Back button to step back in the process. The user then has the choice of the *links* or the Back button on each screen. These links are part of the decision points in the system. They are just like the blue-colored phrase you see in a normal Web page; the arrow turns to a hand when you point to it, and clicking on that spot takes you to the next screen.

The decision support system program, whether a Web page or not, may be programmed in other languages, or may involve special programs for making development of Web pages quicker and more efficient. Our reason for emphasizing this method is that it is easy for us to show the decision process we want and then to show the rather simple HTML files that are written to produce the Web pages. HTML stands for "Hypertext Markup Language." The files can be written with only a text processor, such as MS Notebook®, which is a part of all Microsoft operating systems. Then the filename is simply changed from *.TXT to *.HTM. When the *.HTM files are activated under either MS Internet Explorer® or another Web browser, the screens appear with the decision questions in blue. Regular programs for developing Web pages make it easy to show buttons on the screen, for example, to direct the user where to click.

Citrus Freeze Decision Support System Example

This simple decision support system was developed to demonstrate the process of using linked Web pages as the programming method for delivering a system to users. Such a system could be set up on a Web site so that the user could use it online, or it could be delivered on a disk for individual offline operation by the user. The advantage of the online system is that the system can gather current data from other Web sites, especially weather data. Then these data can go into the decision support system to be used in models to give the latest advice on questions such as "Should I spray for mites at this time?" This sort of dynamic decision support can be very helpful for the grower.

However, users are sometimes not confident about entering private data from their operation to an online program, where the concern may be just how private the data may be. In cases such as this, programs on a separate disk staying in the users' hands may be more acceptable. Dynamic data, such as weather data, can be accessed and selected separately on the Web by the user; the user can then go off the network to enter data onto his or her own private disk to use in the decision support system.

The designed sample decision system is shown in Figure 11-2. It was designed to stress not the choices about the technical problem so much as the flexibility of the Web system. Notice in Figure 11-2 that all of the arrows go in both directions, because the "Back" feature of the Web screen makes this possible. This flexibility allows the user to study several aspects of the problem, browsing forward and perhaps back, to find the particular knowledge needed to make the decision. Expert input was not used in this example, so the screens just refer to the type of expertise that would be put into a real Web decision support system such as this.

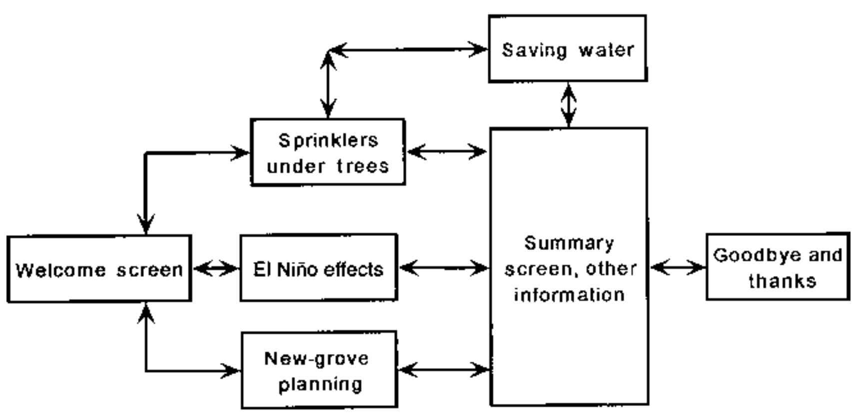


Figure 11-2 Decision tree for freeze protection decision support system.

Some users will want to go straight through all the decision points to get to the final answer of what type of system to choose and what operating decisions should be made when a freeze is forecast. Others will want to find information about designing a whole new grove but may also want to back up and choose to study the information about the E1 Niño southern oscillation, because recent research is available. This flexibility of the Web system is an advantage in making the computer operation of the program user-friendly. Most users are already Web surfers, so no lengthy directions for use of the system are needed.

HTML Files for Each Web Page

The *.htm files that make up the example system are described by the decision tree. Note that to move from one screen to the next, the user is switching from one of these *.htm files to another.

The file listings for the screens used for this simple example are given in Figures 11-3 to 11-9; they are listed as *.htm files. They can be edited with the text editor MS Windows Notebook® and saved as either *.txt or *.htm files. These files are included on the CD with this text, so you can try them out. Simply look up these files on the CD, grouped under the folder named "FreezeDemo," and click on the Welcome file, *welcome.htm*. It will be read by your MS Internet Explorer® browser, and then you can search forward and backward through each of the screens. The graphic file *25yrENSOwF.gif* must be in the same directory as the *.htm files so that it can be called onto the screen when needed.

It is interesting to use Notebook to modify one or more of these files and then quickly see how it turns out under Internet Explorer. You may have to change the extension from *.htm to *.txt to get Notebook to accept it, but then when finished, just put the .htm extension on when saving it, instead of the .txt.

The general objective for this example decision support system is to show how a decision support system can do more

```
Filename: welcome.htm

<html>

<head>

<title="Agr. Systems Management"></title></head>

<body>

<H3> Simple Demo of Decision Support System - Citrus Freeze Adviser</H3>

<P>For the usual irrigation system of sprinklers under trees,</P>

<P>Click on -- <A HREF="sprinklers.htm">Sprinklers under trees</A></P>

<P>For discussion of the effect of El Niño on Florida citrus freezes,</P>

<P>Click Here <A HREF="elnino.htm">El Niño & La Niña</A></P>

<P>For information on planning a new grove in Florida</P>

<P>Click Here <A HREF="newgrove.htm">New Grove in Florida</A></P>

</body>

</html>
```

Figure 11-3 HTML file: *welcome.htm*.

than simply lead the user through a series of diagnostic questions as was done with the auto air conditioning problem. Of course, both systems are so small that they may not seem realistic, but we feel they are better from an educational standpoint than more complex systems.

The Citrus Freeze program shows how the developer can present relevant information, such as the El Niño effect on freezes in Florida, that may help the user in making his or her decision. But this material is presented without making it directly a part of the decision process. In fact, this example is

Filename: sprinklers.htm

```
<html>
<head>
<title="Agr. Systems Management"></title></head>
<body>
<H1>Citrus Freeze Demo DSS, Ag Systems Management</H1>
<p>In one sentence, for this case, the general rule is:</p>
<p>  Turn on your sprinkler system when the temp drops to about XX deg.,</p>
<p>And leave it on until the danger of further freezing is past (usually when the air
 temperature goes above YY deg.F.)</p>
<H3>Cutting Water Costs</H3>
<P> <blockquote><blockquote> However, water costs may be cut by turning
sprinklers off before the air temperature goes this high.</P>
<p>Turning them off sooner, according to temperature and dew point, can save money safely.</p>
<P> Click here for more information <A HREF="watercosts.htm">Water Costs</A></P>
<p> To skip ahead to start to close out your session:</p>
<A HREF="summary.htm">Summary of Session</A></P>
</body>
</html>
```

Figure 11-4 HTML file: *sprinklers.htm*.

```
Filename: elnino.htm

<html>

<head>

<title="Agr. Systems Management"></title></head>

<body>

<H3>Welcome to the Citrus Freeze Demo DSS </H3>

<P> <blockquote><blockquote> Recent analysis of effect of El Niño,

La Niña, and a neutral year (one with Pacific sea temperatures within

about half a degree (C) of average) have shown that over the last

25 years, serious freezes of citrus in Florida have occurred only

during a neutral year, that is, one with neither the El Niño or the La Niña

effects. Freezes have not occurred in every El Niño or La Niña year,

but none have occurred in the neutral years, as shown by this graph.</P>

<P> You may want to consider this in planning for freeze protection.</P>

<P>   <IMG SRC="25yrENSOwF.GIF">  </P>

<P> To end this session, Click Here<A HREF="summary.htm">
Summary</A></P>

<P> To go back to the last screen, Click on Back, above.</P>

</body>

</html>
```

Figure 11-5 HTML file: *elnino.htm*.

```
Filename: newgrove.htm
<html>
<head>
<title="Agr. Systems Management"></title></head>
<body>
<H3>Citrus Freeze Demo DSS, Agr. Systems Management</H3>
<P>For planning a new grove, consider more southern locations,
air drainage, hardy varieties, and use an irrigation system with microjets
under each tree for use as freeze protection as well as irrigation.
See further information at ___(good place to put another Web source for
planning tips on planting a new grove).</P>
<P>To go to the Summary, click here: <A HREF="summary.htm"> Thanks
for visiting our DSS.</A>!</P>
</body>
</html>
```

Figure 11-6 HTML file: *newgrove.htm*.

so short that it does not even give a recommendation to the user. This is pointing to what could be a trend in decision support systems. In more complex systems, such as real-life agricultural systems, users may not need or want a system that leads them to a "hard-and-fast" single recommendation. Rather, perhaps the decision support system should be looked upon as an educational program that leads the user through the significant areas of consideration and makes it easy to obtain the relevant and current information needed, such as prices and weather data. Then the system may give some

```
Filename: watercosts.htm
<html>
<head>
<title="Agr. Systems Management"></title></head>
<body>
<H3>Welcome to Citrus Freeze Demo Decision Support System - WATER COSTS </H3>
<P><blockquote><blockquote>Here's how to save water at the end of sprinkling
for freeze protection. If you turn off the sprinklers too soon, frost damage may occur,
but if you leave them on too long, lots of water and pumping energy is wasted.</P>
<P>This is where the ag systems manager puts more specific information about
 turning off the water based on temperature and dew point.</P>
<P> Click on Back, upper left corner, to go back to last screen,
or Click here to finish the Citrus Freeze Adviser:
<A HREF="goodbye.htm">Goodbye</A></P>
</body>
</html>
```

Figure 11-7 HTML file: *watercosts.htm.*

weighted guidance to the user to support him or her in making the decision.

Growers' experience of freezes in citrus in Florida are important in trying to develop a system to give support in the process of deciding what to do. A series of disastrous freezes occurred in the 1980s that greatly reduced the citrus-growing area north of Orlando. So today a great deal of the citrus area is located in southern areas and is not so susceptible to a damaging freeze. Also, about the only practical protection method is sprinkling from the irrigation system. This groundwater is

Filename: summary.htm

```
<html>
<head>
<title="Agr. Systems Management"></title></head>
<body>
<H3> Thanks for visiting our demo Freeze Site, Ag Systems Management </H3>
<P><blockquote>This is where we would put in more information about the
organization sponsoring this Web site. You can talk about (or show) current
Research & Development, tell how to learn more about the group, etc.
For a sales organization, this is your chance to keep your name and business in the
 user's mind, and of course give all your addresses, phone numbers and e-mail
addresses. In fact, you can easily list an e-mail address in blue, so that by clicking
on it, the user will have his e-mail program start and enter your e-mail address. <brk>
<P>To go back to the previous screen, Click Back, upper left corner. Thanks!
Robert M. Peart and David Shoup, authors of Agricultural Systems Management,
published by Marcel Dekker, Inc., New York, NY </P>
<P>Click here to finish: <A HREF="goodbye.htm">Goodbye!</A></P>
</body>
</html>
```

Figure 11-8 HTML file: *summary.htm*.

relatively much warmer than freezing, so it warms the trees and also provides a convective force moving air from the ground up through the tree branches, warming them. Environmental pollution and need for lots of labor on the spur of the moment have practically ruled out the old method of burning fuel oil in simple furnaces spread throughout the grove. There

Filename: goodbye.htm

```
<html>
<head>
<title="Agr. Systems Management"></title></head>
<body>
<H3> End of Demo Freeze DSS, Agr. Systems Management,
Peart & Shoup, Marcel Dekker, Inc.</H3>
<P> This really is Goodbye! To rerun, click Back in the upper left-hand
corner several times to get back to the beginning.</P>
<P>To quit the program, click the X in the upper right-hand corner to
turn off the browser. Thanks, Robert M. Peart and David Shoup</P>
</body>
</html>
```

Figure 11-9 HTML file: *goodbye.htm*.

are many factors that can be enumerated on the screen and make for interesting reading, but some users may not want to go into that much depth. The Web page design can allow such "offshoots" from the main line of reasoning so that they can easily be bypassed by the user if desired.

New developments, such as the discovery of the apparent influence of the ENSO (El Niño Southern Oscillation), can be included readily into such a Web-based decision support system. That branch happens to be shown right in the middle of the decision tree, but it can also be bypassed.

The third alternative from the Welcome screen is the one about planning for a new grove. Here many choices are available that are not available in the management of a current grove. Geographical location of the grove, slope of the land, and variety of root stock and bud stock are among the important decisions that can be made when planning a new grove. So it makes sense to have a separate option for new groves. You can visualize quite a number of decision points that would be involved in a real decision support system for planning new groves.

The decision point on saving water is an important one, and looking at the decision tree, Figure 11-1, it could have been put between the Sprinklers screen and the Summary screen. By looking at the HTML files, you can see how the choices could be rearranged to accomplish this. At the filename *sprinkler.htm*, the only choice given the user would be to go ahead and look at the Water cost screen and after that the Summary screen. This is mentioned as another example of the flexibility of using Web page design to develop a decision support system.

DECISION SUPPORT SYSTEMS, CROP MODELS, AND PRECISION AGRICULTURE

The last chapter of this text is on precision management, an important new technology that is being used to show crop yield differences in fields. Once these yield differences are noted, the next question is ‘‘What is the problem, and how can we fix it?’’ Some solutions are fairly easy to identify, such as the low-yielding area being poorly drained or a different soil type. But many differences are not as easy to diagnose.

A crop model, as shown in simple form in Chapter 7, can calculate, on a time basis, the development of the yield in a field, depending on rainfall, temperature, fertility, and other factors. Could a crop model, given the weather, fertility, soil, and other agronomic inputs, help in determining the cause(s) of these measured yield differences in farmers’ fields? In working toward that goal, researchers will be using the principles of decision support systems to help the grower or crop consultant identify the problem and prescribe a solution.

REFERENCES

1. Barrett, John R.; Jones, D.D. *Knowledge Engineering in Agriculture*; ASAE Monograph No. 8, American Society of Agricultural Engineers: St. Joseph, MI, 1989; 214 pp.
2. Thieme, R.H.; Uhrig, J.W.; Whittaker, A.D.; Peart, R.M.; Barrett, J.R. Grain marketing analysis with an expert system. ASAE Paper No. 85-5519, ASAE: St. Joseph, MI, 1985.
3. Khuri, R.S.; Shoup, W.D.; Peart, R.M.; Kilmer, R.L. Expert system for interpreting citrus harvest simulation. *Applied Engineering in Agriculture* 1988, *4*(3), 275–280.
4. Khuri, Ramzi S.; Beck, H.; Shoup, W.D.; Peart, R.M. A knowledge-based citrus data and decision system. ASAE Paper No. 90-7531, ASAE: St. Joseph, MI.
5. Lal, H.; Peart, R.M.; Jones, J.W.; Shoup, W.D. An object-oriented field operations simulator in Prolog. Trans. of the ASAE 1990, *34*(3), 1031–1039.
6. Lal, H.; Jones, J.W.; Peart, R.M.; Shoup, W.D. FARMSYS—a whole-farm machinery management decision support system. Agricultural Systems 1992, *38*(3), 257–273.
7. Beck, Howard W.; Jones, Pierce; Jones, J.W. SOYBUG: An expert system for soybean insect pest management. Agricultural Systems 1989, *30*(3), 269–286.
8. Barrett, John R.; Castore, C.H. Decision making and decision support. In *Knowledge Engineering in Agriculture*; Barrett, J.R., Jones, D.D., Eds. ASAE Monograph No. 8, ASAE: St. Joseph, MI, 1989; Chap. 2.
9. McCown, R. L.; Hochman, Z; Carberry, P.S.; Eds. Probing the enigma of the decision support system for farmers: learning from experience and from theory. Agricultural Systems 2002, *74*(1), 1–220.

12

Precision Technologies for Precision Management

W. David Shoup, Wonsuk "Daniel" Lee, and Tony Harrison

If we were to take a historical review of agriculture in America, it would be easy to cite certain significant technologies that catapulted production to new levels. Some of these technologies would include the advent of petroleum-fueled tractors, fertilizers, hybrid seeds, chemical pesticides and herbicides, alternative tillage practices, and biotechnologies. Without a doubt the total future impact of adopting precision technologies will be far-reaching and of great economic significance. Certainly the ability to increase crop yields and reduce input costs exists. But adopting precision technology in agriculture offers us far more than just making money. These technologies can improve water quality, reduce environmental impact, reduce risk of crop loss, reduce need for field chemical inputs, optimize wildlife populations, and greatly improve farming and natural resource planning.

There are two unique impacts regarding precision technologies. First, the use of these new and exciting technologies gives the agricultural systems manager (ASM) greater managerial control of processes. These technologies are heavily data driven and very close to "real-time" decision making. Numerous alternatives can be explored quickly, efficiently, and accurately. And thanks to mathematical models such as simulation, the ASM can project outcomes of various alternatives and management proposals. Computer hardware and software technologies supporting these precision tools are getting faster and more economical as each month passes. Second, the precision technology tools are so broad and powerful that ASMs can now explore environmental and natural resource outcomes as well as economic outcomes of agricultural systems decisions. Thus, the marriage of agricultural sciences and natural resource management is now very real. The use of powerful precision tools helps relieve the tensions of economic trade-off versus environmental impact of our natural resource base. Precision technologies allow us to integrate many "layers" of data and analyze decision alternatives. These technologies tend to be very "visual" in nature.

The color figures for this chapter are included as a PowerPoint®; file on the CD that accompanies the book. You are encouraged to study the figures as you progress through the chapter.

WHAT IS PRECISION AGRICULTURE, OR PRECISION MANAGEMENT?

Precision management is the use of high-technology equipment and software for assessing field conditions and micromanaging the elements or resources of small land areas or large land areas to obtain *optimum* benefits. The word *optimum* is paramount in this statement. It is the recognition that the ASM can rarely go for maximum output in any management criterion without greatly sacrificing some other goal management wants to attain. Thus, management must carefully analyze potential impacts and utilize tools to *obtain optimum-benefit packages*. In field production agriculture the ASM manages each crop production input (fertilizer, lime, pesticide, herbicide, seed, etc.) on a site-specific basis to reduce wastes, increase profits, and maintain the quality of the environment. However, precision management in agricultural systems is not limited to field production agriculture. Precision technologies are also used every day in food and fiber processing as well.

The goals of precision management are actually quite clear. And although the goals of the farmer, the government, the natural resource manager, and the process manager differ somewhat, the high-technology tools are available to each.

Agriculturists have several goals. The first and foremost goal of most farmers is searching for higher yields and/or higher profits. The "bottom line" necessarily drives farmers. Income provides for family needs, enhances the community, and keeps the farming operation viable. Being able to compete in selling products internationally is critical. Reducing the risk of farming is also a goal. Satellite weather information would certainly be used wisely to protect crops. Emergency cold-protection methods might well save a blueberry crop if the information is fast, timely, and accurate. And a satellite image showing growth and movement of a disease within a crop might allow a farmer to selectively spray areas to save a valuable crop yet reduce the amount of pesticide so as to protect the environment. Reducing inputs normally results in lower input costs and lower impacts on air, land, and water. Reduction of impact on the environment is an overriding goal imposed by today's society. Closely tied to these goals is the goal of reducing legal liability. Through the use of selected precision technologies, a "trail" of input use can be provided. A good example might be the electronic flight log of an aerial crop duster. Data regarding the flight application are recorded and can be played back on the computer screen. An ASM can tell application rates, when it was applied, how much was applied, flight factors, weather factors, and various drift conditions. The flights can even be replayed via graphics on the computer screen. On several occasions these flight logs have provided courts with critical information regarding pesticide drift litigation. But just as importantly, the ASM has a permanent log of information regarding the crop and the field-critical information for future field management decisions.

The natural resource manager has several goals. Society expects farmers to be natural resource managers and good stewards of the environment. Foresters, professional conservationists, environmental groups, and governmental agencies have additional responsibilities for carrying out the mission of attaining society's goals of good stewardship. A central goal is to maintain and enhance species of animals and plants. A computer-driven geographical information system (GIS) can maintain key data regarding geographical position, species identity, habitats, food supplies, and many other relevant factors maintaining species. Special electronic devices may even be employed to identify and track movements of individual animals or herds. Another goal is to minimize the environmental impact on natural species of plants, animals, and the landscape that supports them. Remote sensing devices can carefully gather key data to monitor air, water, and support supplies. And careful data analysis utilizing GIS can monitor and assist in wildlife planning.

The lands and natural resources provide a support base for animals and plants. These same lands provide humans with environmental education and recreation. Nowhere is this more apparent than in the semiarid lands of the American west. The land provides for agriculture, natural species stabilization, homes for humans, and recreation for many. Use of precision technologies enables the stewards to manage the land to serve the needs of many. Precision technologies such as GIS, global positioning systems (GPS), photogrammetry from airplanes, satellite imaging, and radio telemetry allow tracking, mapping, and resource planning. These precision technologies support the work of farmers, ranchers, the U.S. Forest Service, the U.S. Department of Agriculture (USDA), the Bureau of Land Management (BLM), the Bureau of Indian Affairs (BIA), and the Department of the Interior. Use of precision technologies ensures that our lands will be available for future generations as well as today's recreation seekers. Finally, using precision technologies fulfills the goals of natural resource managers to work toward enabling the aforementioned agencies in project and financial planning.

Managers of agricultural processing also utilize technologies from the precision umbrella (Figure 12-1, in text). Like farmers, these ASMs must seek reduced costs and higher profitabilities. They essentially have the same goals of both the agricultural and natural resource groups and utilize the full breadth of the precision technologies.

In summary, the goals of agriculturists and processors are:

Higher yields and/or more profit
International competitiveness
Reduced risk
Reduced inputs and/or cost
Reduced legal liability
Reduced environmental impact

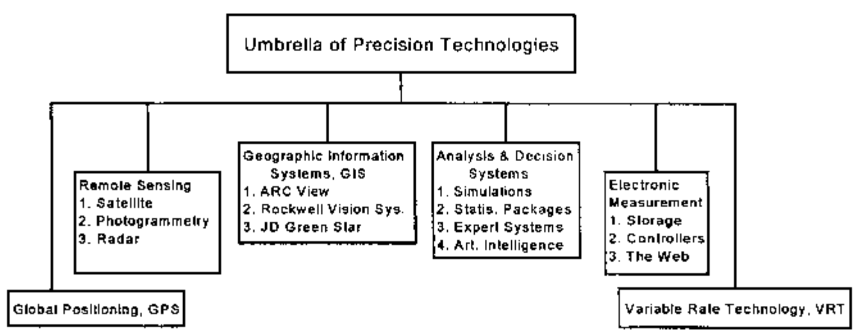


Figure 12-1 The umbrella of precision technologies.

The goals of natural resource managers are:

To maintain and enhance species
To minimize environmental impacts
To preserve recreational enjoyment for future generations
To achieve well-planned projects

Through laws, regulations, planning agencies, and enforcement, society is pushing toward a total food system that must subscribe to all of the listed goals. The complex management needed must be supported by precision technologies. Precision technologies provide data gathering, storage, geospatial referencing, and analysis that all three groups will use. The information can be available to all. Often agricultural systems managers stand in all camps. This drives many groups to plan together and to coordinate management efforts.

SOME OTHER USERS OF PRECISION TECHNOLOGIES

The number of precision technology users has escalated at a phenomenal rate. At the time of this writing, the military was emerging as one of the central users of precision technology. Use of global positioning systems (GPS) has clearly changed the face of war and minimized civilian casualties. Other major users include:

Wall Street brokers
Airlines
State agencies
Federal agencies
County/city agencies
Real estate planners
Construction contractors

A GPS unit is becoming standard equipment for fishermen, boaters, hunters, and campers. Automobile manufacturers and car rental agencies are rapidly adopting GPS and GIS technologies.

THE UMBRELLA OF PRECISION TECHNOLOGIES

There are many tools of precision today that support the ASM's information, analysis and decision making. The "umbrella" of technologies, Figure 12-1 in the text, is powerful, growing more accurate and affordable each day. Fortunately, these technologies are also becoming more user friendly with each passing day. The precision technologies span six basic areas:

Global positioning systems (GPS)
Remote sensing
Geographic information systems (GIS)
Analysis/decision software
Variable-Rate Technologies (VRT)
Electronics and instrumentation (yield monitors, soil sensors, etc.)

TYPES OF PRECISION MANAGEMENT

Precision management in agricultural systems must be accomplished in several ways. First, *site-specific management* (SSM) is a key to success. In farming operations we want to increase yields and outputs yet reduce costs. In order to optimize this system, the ASM must vary the inputs, such as fertilizer, seed, herbicides, pesticides, organic matter, water, and seed. While using the history and composition of the field site, precise amounts of inputs may be delivered without adding too little or too much in terms of payoffs per costs. Today's debate is focused on how small the "cell" should be that the manager manages. Although the new technologies could manage cell sizes down to a few millimeters, that scope likely is not practical or cost efficient. In most cases the scope is very useful in sizes considerably larger. Cell sizes in production agriculture today are more likely to be in the range of the 1–5 acres.

However, there are now operations managing within a few inches. It is possible, utilizing geographic information systems, to develop ‘‘layers’’ of information over a cell-sized piece of land. Each layer is placed over the land map, with data georeferenced to the specific location. Accuracy of location may vary, but the goal is within a few centimeters.

Some operations in production agriculture are very *time specific*. Pest scouting would be a good example. Utilizing a GPS unit and a small personal digital assistant, a field scout can do insect counts on specific plant locations over several hours. Using pest simulation models he or she could determine when populations would warrant spray and where to spray. It would not be necessary to spray the whole field at a high rate. By mapping pest populations with a GIS, the field person could return and spray specific areas. Or the person could use a sprayer equipped with GPS and variable-rate technology to cover the field and apply spray only where needed and in the correct amount. Pesticide costs are reduced, yields are improved, and the environment is protected by using lower amounts of chemicals. Other good examples of time-specific production agriculture would be irrigation and cultivation of crops.

Another type of precision management is dedicated to the *coordination of land use*. A county planning commission might be dedicated to efficient, productive land use. The commission might use every one of the six precision technologies available. Wildlife management, wetlands management, land reform or restoration, utilities placement, and property easements are just a few ‘‘coordination’’ tasks for which precision technologies can be applied to management.

There are also many so-called ‘‘*dedicated,*’’ *or specialized*, *missions* of precision management in agriculture. Weather data or climatic data layers of GIS are good examples. Specialty data layers have been developed for earthquake forecasts by the U.S. Geological Survey (USGS), digital soil surveys of the United States by the NRCS, and compliance models by EPA for dust, chemicals, and noise. Any and all of these sources may be taken into account in planning by the ASM. As information and layers of information become more detailed and available, both agriculture and natural resource managers will use the data for policy and decision making.

Farmers and ranchers have been prompted to enter the field of precision management via a number of entry points. Most have entered through monitoring yields of crops across their farms. Developing georeferenced yield maps of various fields have led many to the next phase. Yield mapping is often followed by either soil sampling or crop scouting. Variable-rate technologies are then applied in an attempt to increase yields and reduce costs.

Natural resource managers have entered precision management with a slightly different point of view. Their view has been on a larger land scale, with stronger emphasis on land uses, water management, air and water quality, fire control, land preservation, and maintaining species viability.

FUNDAMENTALS OF GLOBAL POSITIONING SYSTEMS (GPS)

The heart of managing resources is knowing exactly where and when data are obtained. When we know where and when data are obtained, data become information. And thus, the ASM begins to develop an information system he or she can rely upon to make good decisions. Positioning is critical. A positioning system is a method for identifying and recording the location of an object, event, or person. An accurate and reliable position is essential in planting, cultivation, harvesting, spraying, fire identification, hiking, and group location.

For centuries navigation relied on dead reckoning. Dead reckoning methods always assume constant velocities (speed and direction). On the sea, modest changes in current, tide, or wind can greatly alter outcomes of dead reckoning positioning. On land, changes in terrain, weather, etc. can also introduce error. In agricultural systems management we have relied on this positioning method for calculating acreage, field efficiencies, machine throughputs and field capacity. Errors compound quickly in these calculations.

In an effort to gain greater reliability, precision, and accuracy, two newer methods are now employed: land-based triangulation and satellite ranging. *Land-based triangulation* systems consist of three or more towers in a given area of coverage. The towers broadcast a signal in all directions. The user or machine in the field carries a receiver device. The receiver acquires the signals from each of the towers, determines the distance to each, and determines its location by the crossing of the signal intersections. This type of system is often dubbed "NGPS" (not GPS). Accuracy can be as good as ±6 inches at up to 25 mph at a range of up to 30 miles. A drawback to achieving accuracy in this system is that there is no vertical ranging or estimation. This prevents truly intensive management requiring 3D positioning.

The triangulation system is not inexpensive. The system, though very accurate in coordinate positioning, can be very costly. The cost of towers, receivers, and operation add to the cost per unit delivered. The area of coverage is very limited as well.

There are two global satellite positioning systems in existence today. The U.S. supported navigation system is operated by the U.S. Department of Defense. The system consists of 24 active NAVSTAR satellites. Twenty-one are in active use, with four spare satellites to provide backup reliability. This system became fully operation in 1995 and operates in orbit at 20,200 km above the earth's surface. There are six orbital paths, with four satellites in each path. Each satellite makes a single revolution of the earth every 12 hours. This guarantees that at least four satellites are in view of a GPS receiver anytime and anywhere. It is possible to obtain up to eight in view above the horizon in some locations and times. Access to this system is free of charge. This NAVSTAR (Navigation by Satellite Timing and Ranging) group is often referred to as the space segment of the system. These satellites broadcast radio signals in the range of 1200–1500 MHz and are equipped with four atomic clocks each in order to attain reliability. Another existing satellite system, supported by Russia, is known as GLONASS. See Figures 12-2 and 12-3 on the CD.

The control segment of the GPS consists of five monitoring stations around the world that receive and transmit information to the satellite vehicles. These stations ensure the accuracy of satellite positions and the atomic clocks. They compute the exact orbits and update the satellite navigational signals. A master control station is located in Colorado Springs, Colorado.

Users utilize a GPS receiver to track satellites. The receivers use the satellite signal to calculate position, velocity, and time. The GPS receiver calculates the satellite signal travel time by comparing signals from the satellite with those generated by the receiver itself. The receiver calculates the distance from the GPS receiver to each of any of the satellites that are in view. The signal speed is very fast (300,000 km/sec). The receiver identifies each satellite and PRN code and knows each satellite position from an electronic almanac. The receiver uses triangulation to calculate its position in latitude, longitude, and altitude. A prerequisite for calculation is that at least four satellite reference points be available. This is needed in order to determine a three-dimensional position. Receivers can be handheld or located on or in vehicles. Figures 12-4 and 12-5 on the CD show receiver and input device types. Figure 12-6 on the CD shows a complete DGPS receiver and output system.

The GPS satellites transmit two separate L-band radio signals (L-1 and L-2). The C/A (course acquisition) code on L-1 contains the standard positioning signal for civilian users. The P code on L1 and L2 gives the precise code for GPS signals used by the U.S. Military. This code is encrypted and normally reset every seven days to prevent unauthorized use.

The standard signal of GPS is subject to physical forces that introduce errors into the system. There are essentially six sources of errors. Atmospheric effects have impacts. The particles contained in our ionosphere actually slow radio signals. Slight changes in elevation angle, time of day, season, or solar activity can affect the signals. And water vapor in our troposphere can increase delays. Satellite orbits are slightly affected by natural phenomena such as gravitational forces from the moon and sun. The Department of Defense monitors and corrects for these on a regular basis. Satellite clocks are expensive yet may vary by a single millisecond. Multipath errors can originate from signals "bouncing" from large objects such as buildings or even the edge of a forest. Signals can arrive at the receiver by two or more paths. GPS receiver units can be small sources of error due to mathematical precision or rounding errors or internal noise of the unit. Finally, until May 2, 2000, the Department of Defense (DoD) degraded GPS signals to introduce errors for location protection. As of this writing, the DoD was no longer altering signals for this purpose.

DIFFERENTIAL CORRECTION

The purpose of adding differential correction is to improve the accuracy of GPS. Differential correction involves adding an additional stationary signal so we can increase precision. There are several sources of differential signals:

- U.S. Coast Guard
- Local FM signals
- Satellite-based differential corrections
- Field stationary base stations
- Wide-area augmentation systems (WAAS)

In cooperation with the Army Corps of Engineers and the National Geodetic Survey, the Coast Guard provides signal sources for correction. The GPS base stations are located along coastal and inland waterways. Most of the United States has single coverage via the signals, and much of the country has double coverage. Figures 12-7 through 12-9 on the CD show the American coverage areas. Access to these beacons is free and provides positional errors of less than three meters.

Local FM stations can provide contracts via a subscription service. There are charges for this service. Reception distance is typically limited to 60 miles.

Satellite-based differential correction is transmitted from geostationary satellites. Geostationary satellites remain over the same point on the earth at all times. GPS base stations on the ground calculate correction data and uplink these data to the geostationary satellite. The correction data are then downlinked for use in correction of the receivers. To have access to these signals, the user must purchase a DGPS receiver and pay for the linking service. This service is very reliable since ground entities do not interfere with the signal and the coverage area is very wide. Once again, the user must pay a fee. Figures 12-10 through 12-16 on the CD provide information regarding the OmniSTARTM service at the time of this writing.

Field base stations are another alternative. The stations can be purchased or leased, and they have very limited coverage area. They do provide very accurate signal location, and some are accurate enough to support vehicle guidance. Laser land planting operations often use field base stations and can assist in providing land contours to within hundredths of an inch.

GPS, GEODESY, AND CARTOGRAPHY

A basic knowledge of maps and cartography is essential to a better understanding of precision management. Not all map coordinate systems are the same. They differ depending on the "view" of the earth, the type of projection viewpoint, and its spatial display. *Geodesy* is the geologic science of the size and shape of the earth. And though the size and shape of the earth may be debatable, most can agree that the earth is not really round. It is, rather, considered to be an oblate ellipsoid. A *geodetic datum* is an origin and orientation of the coordinate systems used to map the earth. These datums and coordinate systems were used to describe geographic positions. Many different datums have been used over the centuries and even in recent years. The challenge is that referencing geodetic coordinates to the wrong datum can result in positional errors of hundreds of meters, rendering any GPS or GIS futile. Several datums have been used in the past century, including:

NAD27 (North American datum of 1927)
NAD83 (1983)
WGS84 (World geodetic system 1984)
Geoid99

Today, most GPS receivers use WGS84 datum and NAD83 or offer the user several datums to select from.

Precision applications utilize one of four different global coordinate systems. Everyone has some familiarity with the latitude/longitude system. In this system the earth is divided from $-90°$ to $90°$ from south to north. Longitudes run from $-180°$ to $180°$ from east to west. GIS maps do not overlay without some transformation. The most commonly used system for GIS mapping is the universal transverse Mercator (UTM). The UTM divides the world into 60 zones, each $6°$ wide in longitude. Latitude is from S $80°$ to N $84°$. The polar regions are excluded. The first zone starts at the international date line (Lon $180°$) proceeding eastward. UTM has been used on USGS maps since the 1950s. The blue tick marks on these maps are the UTM markers. UTM projection produces very little distortion. The UTM system is the basis for the military system and many state plane systems. Three elements compose a location: the zone, a northing, and an easting. Most GPS receivers now can utilize UTM.

The military grid system, started in 1947, is based on UTM. A lettering system is used to reduce the number of digits to isolate a zone. The following rules apply:

Within zones, $8°$ strips of latitude lettered from C to X
Letters A, B, Y, and Z reserved for universal polar sterographic designations

State plane systems evolve from either NAD27 or NAD83, and their conversion can be accomplished with available software often contained within a GPS receiver or GIS.

United States Geological Survey maps serve as the basis for most precision work within America. The maps can be obtained in 7½-minute intervals, with both lat/long markings and UTM markings. These maps contain scales, contours, outstanding features, and events of note. When working within farm fields, it may not be necessary to use these maps. However, broader-based projects will certainly require use of these databases or maps. It is possible to obtain many maps in digital format or from the Internet. When utilizing a GPS and a topographic USGS map, you may want to purchase a small plastic overlay device called a GPS TOPO to assist with translations.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Georeferenced data are geographic data that contain a precisely identified location on the earth's surface. A geographic information system is a computer database that contains georeferenced data but is capable of acquiring, assembling, storing, manipulating, and displaying the georeferenced data. A somewhat cleaner definition of a GIS would be: a set of computer- and electronic-aided tools for analyzing spatial data and devloping georeferenced files and records of specified attributes.

Computer software allows the ASM to develop and superimpose layers of data over the land area being managed. The layers are essentially "themes." A *theme* is a single spatial distribution of an attribute of interest. Let's say a farmer is analyzing a particular field. One data layer may be a "yield map," or yields expressed as bu/a. The map would reflect variable yields across the field. Figure 12-17 on the CD illustrates a typical yield map layer. Across the single field could be the following additional thematic data layers:

Soil pH
Elevation contours

N levels
P levels
K levels
Ca levels
Drainage tile locations
Crop moisture levels
Weed maps

Literally scores of thematic maps could be developed. Again, let's consider a natural resource management use. Suppose a state park manager uses a GIS to assist overall natural resource management. The following thematic layers could be developed:

Park boundaries
Location of buildings
Location of electrical services, water, sewer, and easements
Campsites
Wildlife population counts
Surface waterways, wells, and impoundments
Roads and trails

Again, many themes could be developed. There are also numerous software products that support GIS. Some of the most popular are ESRI ArcView and SSToolbox. Several of the agricultural machinery corporations support versions to incorporate data from their combnes and harvest equipment. Several companies support excellent software for spray and fertilizer applications. Some of the most widely known and used GIS software packages today are:

Arc/Info
ArcView
Atlas*GIS
GRASS
IDRISI
Maptitude

MGE
Vision MapInfo
System
AGLEADER

Figures 12-18 and 12-19 on the CD illustrate the thematic data layer and yield map layer concept.

A natural question is: Where do we get data to create layers? First, data can be obtained from GPS receivers. These receivers might be simple handheld units. In the simplest case a person might actually write the data locations and observations on a paper notepad. At the next level, most GPS units have the ability to record data locations and observation via keypad entry. These data can be downloaded to computers later. In the case of field harvesting, the harvest unit can have a receiver that downloads the GPS location data attached to data from a yield monitor on the machine. The yield values, associated with the coordinate locations, are stored on a disk or similar storage device for transfer to a computer for analysis. In another case, a fixed-wing aircraft may similarly store spray information associated with both coordinate positions and the time clock. The data can be downloaded and actually played back in graphic form on the computer monitor screen.

Data can also be attained by utilizing a digital scanner to scan data attributes and their geographic locations from maps or images. See Figure 12-20 on the CD. USGS maps can be "digitized" as well as maps supplied by the Farm Services Agency, USDA, U.S. Forest Service, U.S. Geological Survey, etc. Some sources of maps and data are:

Department of Defense
DARPA
USDA/ARS
BLM
Bureau of Mines
U.S. Forest Service
USGS

NOAA
Bureau of the Census

In some cases the data may be free, but in most cases there are charges for maps or file transfers.

Data can be attained from images as well. Satellite photos, photogrammetry from aircraft, or sensor data from thermal images can supply data. Many times those data may originate from digital sources.

Obtaining data sources is only the first step. Data must be "*registered*." In other words, one must line up data with other existing data layers geographically. Data from source to source will not have exact data locations to overlay. This means that interpolation and "smoothing" of data must be performed. Accuracy of maps and images is absolutely essential.

Data Formats

Data arrive in two different formats: raster and vector. In *raster* format, the space is divided into cells. These cells, or squares, are addressed by row and column. Raster data often contain thousands of cells. There might be variation of values among cells, but a single cell has only a single value. A group of cells with the same value identify a type of feature. Suppose we scan a map of a lake area. Water would be one type of value and land would be another. See Figure 21 on the CD.

In vector format, a coordinate-based approach is used. The basic unit, instead of cell, is a point. Points may transfigure to lines or polygons (areas). Objects on the map become shapes. The identified shapes can be stored as a single set of (x,y) coordinates. See Figures 12-22 through 12-24 on the CD.

Attributes of Data

Sometimes it is of interest to know some of the characteristics or attributes of data or specific details. This aspect is called *topology*, that is, the study of the details of the connections between spatial objects or areas that bound the objects, such as lines, polygons, or various shapes. This type of study often leads one to postulate regarding yields of fields, spread of diseases, etc. We often assume continuity of data. Contour maps of field elevations are a good example of continuity. It is assumed that data flows from point to point in a known linear fashion.

Geographic data have eight basic features:

1. Size
2. Distribution
3. Pattern
4. Shape
5. Neighborhood
6. Scale
7. Contiguity
8. Orientation

Figures 12-25 through 12-32 on the CD depict the relationship these features have in interpretation of maps.

A LOOK AT HOW A FARMER ENTERS AND UTILIZES PRECISION TOOLS: CASE STUDY 1

Farm managers can enter the world of precision agriculture in a number of ways, as mentioned earlier in this chapter. A farmer can choose a tool or certain tools or attempt to utilize all precision technologies available. Most managers find that a selected group of tools makes affordable sense. Trying to utilize all the technologies under the umbrella can be overwhelming and quite expensive, both in time and in dollars. In this case study we will explore a potential scenario regarding a farmer's entry into precision management.

Farmer Bill Young has heard about potential benefits other farmers could be accruing from precision farming on both the radio and television. The subject has come up from time to time as Bill has worked with his local fertilizer and chemical representative regarding applying varying rates of fertilizer over his fields instead of his old practice of uniform application. He has also seen bits and pieces of information in the weekly and monthly farm periodicals he receives and has heard that the local cooperative extension office will be offerig some introductory sessions at his county extension office. Bill's final cue comes when he stops by his local farm equipment dealership to purchase some parts for his old combine. The salesperson approaches Bill regarding trading in the old combine for a new one. As the discussion continues, the salesperson asks Bill if he would like to include a yield-monitoring system on this new $200,000 purchase. Bill decides he should learn more about the new technologies prior to a purchase. Can he afford this new technology? Or is it the case that he cannot afford to be without it? How do these new technologies work? How do they translate into more profits?

Bill's entrance into the world of precision management begins with a view of a yield map of a field as presented by the salesperson. She explains that the yield map (See Figure 33 on the CD) shows variations in yields of the crop across the field. This map, along with some "ground truthing" and study, could lead Bill toward micromanaging areas as small as a few square feet in an attempt to either increase yields or reduce input costs. The salesperson demonstrates how profit multiplies either by saving a few dollars per acre in application costs or by increasing yields per acre.

Bill is intrigued and wants to know how the map is developed. The salesperson gives Bill a brief overview of GPS and how it works. She explains that each yield point on the map was developed by the combine's on-board software assigning a GPS location to each yield weight calculated at that location. She follows this with a brief discussion about GIS software and how the data from the datalogger on the combine are downloaded into the GIS software program on a computer. She explains that he has the option of purchasing either simple yield map software that displays a color yield map or advanced software that can "import" many "layers or themes" of data from many sources. The salesperson demonstrates on her computer that the GIS allows one to "query" data displayed on the map. She focuses in on small sections of the field at a time, looking at areas of higher and lower yields.

When Bill asks the salesperson how the combine gets these data, she promptly gives Bill a color booklet showing and describing the locations of GPS components and special sensors that measure the grain flow as the combine moves through the field.

The combine's DGPS receiver (Figure 34 on the CD), used in global positioning, looks like a small grapefruit located on top of the combine cab. Inside the cab is a small computer monitor screen containing menu-driven commands. The display screen (Figure 35 on the CD) allows the operator to view operational and field data on the go. In the cab is also a "light bar" and audible tones that guide the driver where to drive. A small on-board computer logs crop and positioning data onto a PCMCIA data storage card. The card can be downloaded to a computer or a storage disk for transfer to a computer in the farm office. The salesperson points out that these devices can be transferred to another combine, harvest machine, or sprayer or to any field machine equipped for precision management.

Inside the workings of the combine are three key sensing devices. First, there is a mass flow sensor, a curved impact plate located at the top of the clean grain elevator that measures true mass flow (See Figure 36 on the CD). As the grain impacts the plate, the sensor measures the force and transmits the data to the on-board computer. At the same time a speed sensor in the clean grain elevator measures the speed. This also is transmitted to the on-board computer. A moisture sensor mounted on the side of the clean grain elevator (See Figure 37–38 on the CD) continuously measures and sends crop moisture data to allow the systems to establish correct dry weights. The on-board computer's software is designed to make operational data adjustments and calculations.

Bill has seen enough at this point to be convinced that he should begin by developing yield maps of his farm. He purchases the precision technologies for harvest when he purchases his new combine. However, Bill realizes that he must now seek more information regarding these fields so he can draw some inferences regarding yield variability.

ASSESSING YIELD MAPS AND ATTAINING MORE LAYERS OF DATA: CASE STUDY 2

Farmer Young studies his GIS yield maps and wonders what causes the variability of yields across his fields. Some variations are fairly obvious. He can actually walk the fields and see some of the reasons (ground-truthing). Bill can see the locations of his grass waterways and easily see those locations reflected on the yield maps as zero yields. He can also associate fence locations, bordering trees, standing water, and numerous other physical inhibitors to yields. Some of these attributes or events he can elect to alter to improve his future yields. Bill also may vow not to place any seed or fertilizer in those locations next year because the input placement would be wasted investment. In some more subtle ways Bill begins to suspect that some areas of lower yields could be due to poor drainage, excessive drainage, poorer soil types, etc. Bill just isn't sure what some of those causes might be, but he vows to explore further.

Bill pays a visit to his local cooperative (coop), where he buys his fertilizers, seed, and chemicals. They have a young woman there who is trained as a certified crop consultant and has been winning the praises of some farmers for saving them a lot of money. Ms Julianne encourages Bill to consider evaluating his soil and fertility management programs. She compliments Bill on his yield-mapping endeavors. Viewing the maps she suggests that soil sampling could reveal some reasons for his field variations. And she might be able to prescribe different fertilization formulations for selected field locations. Ms Julianne also volunteers that the coop has special variable-rate application (VRA) equipment to deliver the formulations across the fields. She shows him the equipment (Figures 39–40 on the CD). Bill notes that the GPS equipment is very similar to his.

The next events certainly take Bill a little by surprise: Ms Julianne enters base coordinates from Bill's yield map into her computer. She accesses the USDA state NRCS (Natural Resource Conservation Service) digital soil maps and superimposes them over Bill's field map. In just a few minutes Bill has a new data "layer" of information regarding this field. Ms Julianne has now given Bill a complete layer of information containing the soil types and their locations within this field. Bill and Ms Julianne begin to see if they can associate the soil type locations with the yields. Ms Julianne cautions that there are dozens of other soil factors that could be contributors to yield differences. She recommends that Bill develop some base fertility maps of his fields. Bill's fields have soils varying from low potential benefit to high yield potential, but she simply does not have an inventory of the available nutrient supplies across the field. He could be overfertilizing some areas and underfertilizing other areas. She also notes that some of his soil types are very susceptible to deficiencies in key micronutrients. She also does not know the variation in soil pH. Ms Julianne enters the computer record of Mr. Young and can review the fertilizer that has been applied by the coop to his field over the past four years. Ms Julianne notes that she knows little regarding the soil structure, texture, or past tillage practices. She suggests that she can begin to assess and construct some new data layers of information. She needs these data layers in order to formulate her fertility "prescriptions." Both she and Bill agree that an intensive soil-sampling process will commence immediately. At this point Bill learns that he can pay for these "variable-rate" services by either paying the coop hourly fees for Ms Julianne's consulting or paying "up charges" for precision farming services and variable-rate applications on a per-acre basis as inputs are applied. Bill has a good relationship with his coop and elects to pay an additional per-acre fee for precision service and variable-rate application. Bill reasons that the high investment for VRT equipment prohibits his ownership. He calculates the variable cost ‘‘upcharge’’ per acre to be less than the fixed costs he would outlay.

Ms Julianne suggests that the coop develop data layers for the following nutrient maps:

N (nitrogen)
P (phosphorous)
K (potassium)
Ca (calcium)
Mg (magnesium)
S (sulfur)
Micronutrients (B, Ci, Cu, Fe, Mo)
Soil pH

A discussion ensues regarding how the soil samples will be collected from the field site. Bill finds out that there are basically three plausible choices. Two of them involve grid sampling. In *grid sampling* the field is mapped into rectangular or square sections of several acres or less. This would be layed out on the GIS map of the field. Samples are gathered from each section, georeferenced for location, and sent to a laboratory for analysis. Thus, nutrient needs are determined on a smaller scale rather than averaging needs for a whole field. If the *grid center method* is used, measurements would be taken at the center of the grid cell (Figure 41 on the CD). The DGPS receiver would be used to pinpoint the center of each grid cell. If the *grid cell method* is used, the field would be divided into more and smaller cells. A number of random samples would be drawn from each cell and averaged. The alternative to grid sampling would be *soil type sampling*. In this method soil survey maps would be used to select site locations based on the soil types. Bill and Ms Julianne decide on utilizing the grid center method on cell sizes of 1 acre. She explains that farmers commonly utilize 2.5-acre cell sizes, partially to reduce sampling costs. Bill’s costs will be $6 per acre for sampling and developing the thematic map layers. In the future, samples will be collected close to the same date each year in the early spring. Bill and Ms

Julianne view the digital soil survey map and layout 1-acre grids on the screen. They lay out sampling sites, avoiding:

Field boundaries
Gravel roads where limestone might sway pH reading

The position coordinates of the cell centers are identified. Ms Julianne explains that these coordinates will be entered into the DGPS field unit for data collection prior to her arrival with the field unit.

A few days later Ms Julianne arrives with pickup and trailer. On the trailer is a GPS-equipped ATV (all-terrain vehicle). See Figure 42 on the CD. Bill and Julianne drive the ATV to each predetermined georeferenced coordinate and take samples with a hand probe. The samples are placed in bags. She collects and identifies the samples. The samples are sent to a soil analysis laboratory. About two weeks later the results are returned to Ms Julianne. She enters the data and develops the 12 map layers agreed to. She also refines a soil-type map layer from the NRCS state digital surveys. Further analysis ensues and specific fertility formulations for each cell are devised. Examples of soil theme layers are included on the disk in Figures 43–45 on the CD. Note also that at the time of this writing, nutrient sensors were being developed as well as on-the-go electrical conductivity field-sensing devices. Development of these tools can greatly decrease sampling costs. Currently, extensive sampling is done about every two years.

A CLOSER LOOK AT VARIABLE-RATE TECHNOLOGIES AND APPLICATIONS

Equipment used to deliver variable-rate applications is often called *variable-rate technology* (VRT). There are two basic methods for VRT: map based and sensor based. *Map-based* VRT adjusts the rate of a product based on the need as cited by an electronic GIS map. Electronics aid in determining machine position and finding the desired rate. Statistical algorithms adjust flow rate based on the speed of travel. Use of DGPS is essential as well as data developed from a GIS plan. Sensor-based variable-rate application utilizes data from real-time sensors and does not require application-rate maps. Soil and plant sensors have been developed for some nutrient levels, light reflectance to identify weeds and crops, soil moisture, and soil organic matter content. There are even a few sound-based sensors that can "hear" and identify various chewing insects. Clearly, the frontier of precision technologies lies in sensor devices.

Regardless of the type of sensor or map-based technology, certain key components are necessary in all VRT systems. Each system requires sensors that aid in positioning, pressure flow, and ground speed determination. Each system also requires a computer controller with software and actuators to produce the response movements necessary to vary rates.

Pressure sensors produce an electronic signal proportional to fluid pressure in sprayers. They essentially measure the deflection of a diaphragm and regulate a spray pattern. See Figure 46 on the CD. Flow sensors measure the quantity of a fluid moving through a hose or pipe. By measuring the volumetric or mass flow rate, total flow can be calculated by multiplying the flow rate by the duration.

Speed can be measured by shaft speed sensors, radar/ultrasonic sensors, or the GPS itself. It is common now to use the speed calculations of DGPS.

The variable-rate controllers can now be purchased off the shelf. These controllers change the application rate of products being applied on the go. Most controllers contain algorithms that are "burned" into the E-proms. Some actually contain a microprocessor, storage devices, communication ports, and displays. Figures 47 and 48 on the CD depict some VRA controllers now available.

The actuators are devices that regulate the amount of material applied to fields by the controllers. Often these are hydraulic. They respond to electrical, pneumatic, or hydraulic signals from the controllers. Servo valves, solenoid valves, and hydraulic cylinders are common examples. Figures 49 and 50 on the CD depict examples.

Variable-rate systems are often used today to distribute seeds, dry chemicals such as lime, granular fertilizer, or pesticides, and liquid fertilizers, herbicides, or pesticides. Variable seeding of planters is relatively simple. Variable-rate seeding is accomplished by coupling or uncoupling the drive wheel and metering system from the ground drive wheel. Figure 51 on the CD depicts such a system. Seeding depth is accomplished by using a soil-moisture sensor.

Most dry applicators utilize spinner spreaders, as shown in Figure 52 on the CD. The application rate is adjusted by changing either the speed of the conveyor belt or the opening of the flow door. Some of the newer machines use pneumatics to draw from several bins. In this case, deflector plates control the flow rate. See Figure 53 on the CD. An Internet search will yield many new devices and manufacturers.

REMOTE SENSING

Remote sensing (RS) is the process of viewing objects and analyzing characteristics about them from a distance. In the case of agriculture and natural resources management, the object could be farmland, crops, weeds, pests, diseases, or even animals. Distance might be as small as a few inches, such as viewing pests through binoculars or a microscope. The distance could be as large as viewing an image from a satellite in space. An especially intriguing concept is that remote sensing allows one to see things that the human eye can't detect. One may "see" things via remote sensing *sooner* than the eye can detect. In either case, an ASM might gain significant advantage either operationally or economically if either is accomplished. Thus, the real impetus for expanding into the remote-sensing arena is financial potential. The greatest progress might actually be in managing around the weather. Thanks to satellite images and simulation forecast models, we can see things we could not before. And we know trends very much in advance with greater accuracy. Protecting crops from cold, drought, flood, or disaster is vital. One good management move to avoid weather impact can pay for years of investment with one event. Aerial photography and satellite imaging now serve as two key remote-sensing instruments for agricultural systems management.

Generally, remote sensing involves measuring electromagnetic wave energy that is emitted or reflected from an object. The waves differ in length depending on the characteristics of the object. The differences in the emitted or reflected wavelengths allow one to differentiate one object from another or certain characteristics from others. The electromagnetic energy spectrum is continuous, but we often subdivide it into some familiar types, ranging from very long waves (low frequency) to very short waves (x-rays or ultraviolet). See Figure 54 on the CD detailing the electromagnetic spectrum. Only a small band of this spectrum (ultraviolet and infrared) is usually of consequence in agricultural and natural resource applications. One can note that the visible spectrum available to the human eye is only a small portion of the RS spectrum. Thus, utilizing the larger spectrum allows RS to "see" and differentiate items that the human eye cannot. And in some cases impacts can be seen before being detected by the human eye.

EARLY DETECTION BY SATELLITE IMAGING: CASE STUDY 3

Bill Young is growing a high-value crop of broccoli. He irrigates the broccoli and field scouts the crop by walking the rows and doing pest counts. The worth of the crop is in the millions of dollars. Bill's costs per acre are also extremely high. He wants the security of knowing that a pest or disease does not intrude rapidly on his crop. Bill subscribes for images from the SPOT (Systeme Pour l'Observation de la Terre) Image Corporation and another source of images from the LANDSAT satellite source.

There are four basic measures of performance related to remote sensing systems. First, there is spatial resolution. *Spatial resolution* refers to the size of the smallest object that can be distinguished in an image. *Spectral resolution* refers to the ability of a sensing system to distinguish between electromagnetic radiation of different wavelengths. This is important because Bill hopes to be able to distinguish diseased plants from healthy plants. *Spectral response* refers to the ability of the sensing system to respond and collect measurements, in other words, the sensitivity of the sensor. And finally there is the *frequency of coverage*, or how often the system can be available to collect data. Satellite repeat cycles vary from 16 to 26 days. This cycle may or may not be acceptable, depending on the need. Satellite systems have one or both multispectral or panchromatic (grayscale) sensors.

Several images are taken of Bill's fields. Spectral bands are identified for the normal reflectance of healthy broccoli at different growing stages. An April image suggests that the field is now reflecting different spectra throughout the field. Bill decides to "groundtruth." As Bill walks through his fields, he cannot see the differences. However, using a GPS unit to identify the affected areas, he takes some leaf samples. Back at his small laboratory he finds the onset of the disease downey mildew. Bill realizes that in a matter of hours the whole crop may be infected. Bill decides to spray a fungicide on the affected areas indicated from the image. However, the image is several days old. He uses a simulation model to forecast on his GIS picture the approximate locations of the disease. He sprays with a VRT sprayer. Bill saves on the cost of spray and saves the crop. By reducing the amount of fungicide applied, he also reduces environmental impact. But Bill also realizes the drawback of using the satellite images. Frequency of coverage might not be timely enough in the case of a disease or pest such as downey mildew. He may wish to consider gathering data by aircraft-based photogrammetry. This might be more expensive, but some crops could justify the cost.

A CLOSER LOOK AT OBTAINING IMAGES

Electro-optical sensors containing photodiodes are used to produce digital images that can easily be transmitted. But the images created must be *geometrically corrected*, or *rectified*. By establishing the exact georeferenced location of key ground control points, the image can be aligned to correct for satellite scan skew, yaw variation, variation in satellite altitude, earth rotation, and satellite velocity. Images must also be *radiometrically corrected*. This distortion is a result of atmospheric variations such as fog or haze, variations in illumination, and viewing angles.

Resolution varies and depends on what the user is willing to pay. Recently, 2.5-meter-resolution scenes have become available. An archived scene of 60 m $\times$ 60 m typically will cost about $6,500, whereas a current multispectral scene of the same resolution of 20 m is $1,900. Services such as geocoding, orthocorrection, and colorizing add considerably to the cost. Three-dimensional and/or vegetative discrimination views are obtainable. Figure 55 on the CD is an illustration of a 3D image generated via satellite.

Today there are several mathematical methods for developing digital images. Most methods rely on spectral change identification methods.

- Raw image differencing
- Change vector analysis
- Inner product analysis
- Spectral signature similarity
- Image ratioing
- Vegetative index differencing (VID)
- Normalized image differencing (NID)
- Radiometically normalized image differencing (RNID)
- Albedo differencing

Principal component analysis (PCA)
Principal component comparison (PCC)
Normalized difference vegetative index (NDVI)

The NDVI method is currently the most widely used for agricultural and natural resource purposes.

Remote sensing products must provide farmers help in decision making, must be accurate and properly processed, and must provide economic benefit. Remote sensing can provide crop status (i.e., nutrient, water, weeds, stress, disease), yield estimation, land use, or animal location and population. The advent of hyperspectral sensors (generating and identifying hundreds of wavelengths) now enable the identification of many smaller crop and field "irregularities." More accurate crop diagnosis is just around the corner.

While many farmers and ASMs may decide that private use of remote sensing is prohibitive, there still may be some interaction with remotely sensed data. The USDA Agricultural Statistics Service and the Foreign Agricultural Service utilize and attain many multispectral satellite images and data related to crop production. It is also truly amazing that much of these data can be obtained for free or at a very low cost. The innovative ASM can find many images for free on various Internet Web sites. Aerial photos can be obtained from the Farm Services Agency. Data can often be transferred to an ASM via the Internet within 24 hours. It is very clear that the ASM would find remotely sensed data a very good source database for simulation and planning models.

SUMMARY

Precision technologies hold great promise for the ASM. Establishing the cost/benefit of their use is still a major issue and is variable due to differing managerial conditions. Essentially each chapter of this text discusses managerial tools that can interact with any of the six major categories of precision technologies. As technologies progress, costs typically decrease. Each day the feasibility of utilization of precision technologies increases.

REFERENCES

1. Shoup, W.D.; Butler, J.N. *The Precision-Farming Guide for Agriculturists—Student Guide*; John Deere Publishing: Moline, IL, 1998.

2. Shoup, W.D. AGET 682 Course Note. *The University of Tennessee System*; Gil Parker Chair of Excellence for Agriculture and Natural Resources: Martin, TN, 1999.

3. Shoup, W.D.; Pelran, E. Teaching a precision technologies course via distance technologies. *Refereed Proceeding of the First International Conference on Geospatial Information in Agriculture and Forestry*; Lake Buena Vista, FL, 1998; Vol. II.

4. Morgan, M.; Ess, D. *The Precision-Farming Guide for Agriculturists-Student Guide*; John Deere Publishing: Moline, IL, 1997.

5. Clarke K.C. *Getting Started with Geographic Information Systems*; Prentice Hall: Upper Saddle River, NJ, 1997.

6. Lee, W. *AOM 5435 Advanced Precision Agriculture Class Notes*; The University of Florida Agricultural and Biological Engineering Department: Gainesville, FL, 2003.

7. Lunetta, R.S.; Elvidge C.D. *Remote Sensing Change Detection*; Ann Arbor Press: Chelsea, MI, 1998.

8. Howarth, J.P.; Wickware G.M. Procedure for change detection using Landsat digital data. International Journal of Remote Sensing, 1981; *2*, 277–291.

Index