Systematic versus Intuitive Problem Solving on the Shop Floor: Does it Matter?

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Abstract

This paper examines the role of systematic problem solving compared to more intuitive approaches in complex organizational settings. Using a longitudinal study of problems encountered during the start-up of Saturn Corporation's new manufacturing facility, we address four questions. 1) Does a systematic approach contribute to superior problem solving outcomes in a manufacturing setting? 2) Does a systematic problem solving take longer than more *intuitive* approaches? 3) When is a systematic approach most useful? 4) In what ways does problem solving in real-world organizational settings depart from a systematic model?

Our results suggest that a systematic problem solving approach not only leads to better quality, more robust solutions under a wide variety of situations, but also requires no more time than do more intuitive approaches. We discuss implications of these findings for managers (such as the need to encourage data-gathering at various stages during a problem solving effort) and for theorists (notably, the need to reconcile these findings with research that reveals the highly idiosyncratic, interactive, and localized nature of problem solving in real organizations).

Introduction

There is considerable evidence that technological and other changes in organizations bring problems; to survive and prosper, organizations must be competent in identifying and resolving these problems (Rosenberg, 1982; Leonard-Barton, 1988; Tyre and Hauptman, 1992; von Hippel and Tyre, 1995). However, while many studies have investigated the importance of problem solving activities, we know very little about the actual problem solving processes involved. Even less is known about the effectiveness of different kinds of problem solving approaches.

Despite this lack of data, many authors are promoting the use of systematic problem solving approaches as a way of improving manufacturing output, quality, and competitiveness (Womack, Jones and Roos, 1990; Enczur, 1985, Bhote, 1991). In particular, today's popular Total Quality Management (TQM) literature advocates structured methodologies to guide team-based problem solving (Ishikawa, 1985; Robinson, 1991).

At the same time, researchers argue that, in a variety of realistic operating environments, the approaches actually used to deal with technical and operating problems are distinctly non-systematic. Empirical work suggests that intuitive, idiosyncratic, and *ad hoc* processes are at the heart of competent performance in the face of both routine and novel problems (e.g., Brown and Duguid, 1991; Scarselletta, 1993; Pentland, 1993.)

One implication of these two streams of research is that people in organizations, who tend to use intuitive problem solving approaches, are acting in ways that are inefficient or even dysfunctional. However, this is difficult to argue because there have been few studies assessing the usefulness of such approaches. This leaves us with the question: Do systematic approaches really improve problem solving outcomes in actual operating environments?

In this study, we examine a sample of production problems encountered in a new automobile manufacturing operation. For each of 23 problems, we examine both the structure of the problem solving approach used and the problem solving outcomes achieved. We find striking evidence that a more systematic approach does in fact lead to superior results. Moreover, we find evidence that, considering the nature of the issues involved, a more systematic approach does not take a longer time than a more intuitive mode of problem solving. We discuss both managerial and theoretical implications of these results, and we begin to outline ways in which systematic problem solving may actually support, and not contravene, more intuitive and idiosyncratic ways of thinking.

The Problem with Intuition and the Need for Systematic Problem Solving Approaches

According to psychologists, most people are poor intuitive problem solvers. They tend to adopt a definition of a problem without having collected descriptive data on the situation. They formulate hypotheses based upon incomplete data, and fail to seek out possible alternative explanations. Even when information is available, it is often ignored if it does not support existing preferences and assumptions (Dawes, 1982). Testing of hypotheses is often incomplete, since people are reluctant to seek disconfirmation (rather than confirmation) of their ideas (Bruner, Goodnow, and Austin, 1956). In the same way, people tend to select solutions without sufficient consideration of alternatives, and to consider the problem solved without appropriate testing of the solution's efficacy.

Theorists argue that despite these shortcomings, people can become better problem solvers by following some basic structuring heuristics. Polya (1945), for example, suggested a set of simple heuristics for solving mathematics problems. These "can be understood as suggestions to facilitate more extensive search for useful possibilities and evidence" (Baron, 1988:64). Polya's heuristics outline a systematic approach to considering problems, such as:

1. Try to understand the problem: gather available data and try to identify unknowns.
2. Devise a plan: try to examine the problem from multiple angles in order to restate the problem in a solvable mode.
3. Carry out the solution plan.
4. Check the solution.

In a series of experiments, Schoenfeld (1985) found that training in such heuristics improved subjects' problem solving performance; he suggests that heuristics helped subjects to plan their solutions rather than simply rushing into them. A review by Dawes (1982) of psychological studies comparing explicit decision processes with intuitive ones finds overwhelming evidence that decisions or solutions made in an explicit manner are superior to those based on intuitive judgments, even by experts in a given field. In general, the message from existing studies is that systematic approaches support effective problem solving. Lab studies suggest that when people adopt such approaches, they are less likely to ignore relevant information, and less apt to fail to consider its implications.

Yet these principles have seldom been demonstrated in the real world. This is important because field-based research studies show that findings from the psychology lab do not always translate directly into actual working environments (Lave, 1980; Levin and Kareev, 1980; Scribner, 1984). Unlike laboratory experiments, everyday problems are often ill-defined; frequently, they become clear only as people work on them. Useful or necessary information is often unavailable. On the other hand, a great deal of information is often embedded in a given work context and its everyday practices; local actors absorb these cues through normal routines, perhaps without the need to undertake explicit "data gathering" or "hypothesis testing" (Scribner, 1984). Moreover, in most everyday situations, problem solvers act in a rich social context; they draw on others' expertise, respond to others' demands, and frame problems in terms of local norms. Higher-order goals are generally well-understood and can serve to guide decisions, even if specific problems remain somewhat vague (Lave, 1980). Time pressures can also be severe. One of the earliest findings in management science is that senior managers very seldom have the time required to use orderly, rational analysis in their approach to solving problems. Instead, managers necessarily rely on intuitive responses to difficult situations (Barnard, 1938).

All of these issues are especially relevant for understanding problem solving in manufacturing situations. Such problems tend to be highly complex (Jaikumar and Bohn, 1986) and information or clues are frequently equivocal (Weick, 1990). Skills and knowledge are often tacit (Murname and Nelson, 1984), with information or capabilities embedded in the local operating system itself (Tyre and von Hippel, forthcoming).

Furthermore, "problems" in a manufacturing environment are not abstract curiosities; they represent sub-optimal output or waste. Particularly in startup situations, the problem-solving pace can be quite hectic, with personnel "fighting fires" almost continuously in order to keep production running. Key goals for manufacturing personnel generally involve production volume and quality, not attending to problems *per se*. Thus manufacturing engineers and operators must respond to a complex set of mixed goals. Their task is complicated by the need to respond to multiple time pressures related to both problem solving and production goals.

Reflecting these realities, some researchers conclude that formal problem solving approaches simply do not work in an actual organizational environment, even when tasks are highly technical. Orr (1990) and Brown and Duguid (1991) studied technical personnel responsible for resolving photocopier breakdowns. They found that successful problem solvers exercised improvisational skills that enabled them to circumvent formal procedures. Brown and Duguid argue that competence among such technical personnel is not (just) a set of explicit, formal skills, but "the embodied ability to behave as community members."

The need for improvised, idiosyncratic, and informal approaches to non-routine problems has also been documented among medical technicians (Scarselletta, 1993) and software "help-line" support staff (Pentland, 1993). Even in the realm of mathematics, research suggests that when people confront math problems in actual work environments, they tend to rely successfully on informal, improvised techniques far more than on the well-structured approaches learned in the classroom (Lave, 1980; Scribner, 1984.)

These findings raise important questions about the efficacy, and even the feasibility, of systematic approaches to solving problems on the shop floor. Thus, our study was designed to answer four questions. 1) Do systematic approaches to problem solving contribute to superior solutions in a manufacturing setting? 2) What is the cost of a systematic approach in terms of the time required to solve problems? 3) What circumstances call for a systematic approach? 4) In what ways does problem solving in an actual production setting diverge from a model of systematic problem solving?

Defining "Systematic" Approaches to Problem Solving

As noted in previous research, there does not exist a generally-accepted measure of what constitutes systematic problem solving (Langley, 1989). Some of the measures used in the literature, such as the amount of quantitative analysis carried out or the amount of time spent in coming to a solution (Dawes, 1982; Langley, 1989) do not directly measure whether the approach itself was systematic, but only look for elements that are commonly associated with such methods. Thus, we base our measure of systematic problem solving on various theorists' observation that the essence of systematic problem solving is following a set of logically connected steps that lead the problem solver from problem identification through devising and testing a preferred solution. An example of such a step-wise structure is Polya's (1945) four-step problem solving heuristic, described above; many others have been proposed, either as prescriptive or descriptive devices, by, among others, Johnson, 1955; Simon, 1977; Kaufman, 1988; and Van Gundy, 1988. While these vary in length and detail, they all incorporate a general progression from problem definition to alternatives testing, solution development, implementation, and checking.

Drawing on these and on problem solving heuristics developed for use in manufacturing environments (Kawakita, 1991; Shiba, Graham and Walden, 1993), we developed an eight-step model of systematic problem solving. This model is more detailed than three- or five-stage models discussed in the literature (e.g. Johnson, 1955; Simon, 1977; Kaufman, 1988), while also being specifically relevant to the problems faced in manufacturing environments.

As noted by Shiba et al. (1993), an important aspect of this model is that the problem solving steps alternate between analysis or planning activities, and data gathering (or other action) steps. Specifically, steps 2, 4, and 7 involve data gathering and observation, whereas steps 1, 3, and 5 involve analysis. Finally, steps 6 and 8 involve action.

1. Problem Description: Recognize a set of symptoms as "a problem" and describe the symptoms.
2. Problem Documentation: Gather quantitative and/or qualitative data on the nature of the problem in order to characterize it more fully.
3. Hypothesis Generation: Consider one or more alternative explanations before settling on an agreed "cause" of the problem.
4. Hypothesis Testing: Develop experiments and collect data to test (alternative) hypotheses.
5. Solution Planning: Once a diagnosis is made, collect, analyze, and select among possible solution ideas.
6. Solution Implementation: Translate the solution plan into hardware, software, and/or procedures as required. May involve adoption of existing approaches or development of new technology.
7. Solution Verification: Collect data to test whether the solution implemented actually solves the problem.
8. Incorporation: Formally incorporate the solution into the process so that the problem will not recur at other times and places.

According to the prescriptive problem solving literature, the benefits of following a step-wise approach include that it encourages broader information search, it results in more careful solution planning and consideration of alternatives (instead of simply embracing the first solution considered), and it leads to more complete consideration of the possible implications of actions taken (or not taken) (Polya, 1945; Fredrickson and Mitchell, 1984; Schoenfeld, 1985; Baron, 1988).

Study Methodology

1. The Research Site

The research site chosen was General Motors' Saturn Corporation, a "greenfield" automobile manufacturing facility located in Spring Hill, Tennessee. The Saturn facility was built between 1986 and 1990. At the time of our study, it was in its "startup" phase and had been producing cars for less than one year. The manufacturing process incorporated many innovative technologies, such as the "lost foam" method of casting engine components. Thus, Saturn's operations offered a large and varied set of problems for study. A unique employee relations approach at Saturn also facilitated the study of problem solving processes and their effects. All Saturn employees (including those new to the auto industry, as well as those who had previously worked for GM at other plants) received six weeks of introductory training and follow-on training sessions, focusing on empowerment and teamwork. Special emphasis was placed on breaking down barriers (potential and actual) among people with competing interests (Keller, 1994). Saturn's organizational structure was also team-based, with operating personnel organized into self-directed work units of between six and 15 people, and management functions performed through a system of overlapping teams. From the beginning, Saturn strove to support team based problem solving by providing relevant information directly to working level teams-- such as an on-line accounting system with terminals on the factory floor, so that teams could calculate the financial impact of any problem or proposed change. At the time of the study, there were over one hundred problem solving teams active at any one time at this site.

Given this background, Saturn appeared to be an excellent choice as a research site because many of the familiar barriers to effective problem solving (such as conflict among actors with competing interests, failure of communication across functional lines, or lack of access to necessary cost or other data) were minimized. Thus, we would expect the impact of different problem solving approaches to be relatively easy to detect. At the same time, the site offered a wide variety of problem solving approaches for study, partly because no official problem solving methodology had yet emerged at Saturn. As a highly vertically integrated manufacturing site, Saturn also offered several distinct manufacturing settings to study. By comparing results across these settings, we were able to test whether our results are unique to a specific kind of technical environment or a given production process.

2. Problems Studied

All of the problems examined were technical operating problems encountered in the manufacturing system, and all were currently being addressed by at least one person at the time of the study. For ease of investigation, problems that were being dealt with jointly by two or more work units were excluded. Also excluded from the final sample were problems that were unfinished at the end of the research period, abandoned problems, or problems that mysteriously "solved themselves" without intervention. There was no indication that the use of systematic problem solving techniques varied across completed and uncompleted problems. Examples of the kind of problem included in the sample are shown in Table 1.

A total of 23 problems were identified and tracked from discovery through resolution during the nine-month research period. The sample represents a reasonable cross-section of the type of problems that were occurring in the plant. The problems studied affected 14 different production areas and involved 24 different vehicle parts.

3. Data Collection

Data collection was undertaken by one of the researchers over a period of nine months. Problems were followed longitudinally, with information collected once every two weeks for each ongoing problem. The primary mode of data collection was the structured interview, with additional data collected from plant records, a questionnaire, and expert panel evaluations.

Due to the extremely heavy time investment required by plant personnel to participate in this study, primary information came from one informant per problem. The primary respondent was most often the manufacturing engineer who had direct responsibility for resolving that issue; in each case it was someone with knowledge about all problem-solving activities taking place. The potential problems associated with using a single respondent were mitigated by the fact that the researcher was on site full time during most of the research period, and therefore could supplement and corroborate formal interviews with informal observation and conversations with other members of the problem-solving teams. In addition, the researcher had full access to all relevant problem documentation. Where discrepancies surfaced, they were discussed with the primary informant in greater depth.

Three structured interview instruments were used to gather data on each problem. The initial interview elicited basic information about the problem (e.g. technical description; problem history to date, perceived complexity and novelty of the problem). Follow-up interviews were conducted approximately every two weeks; these explored the actions taken since the last interview, the information gathered, and the progress achieved toward solving the problem. A final evaluation interview was used to summarize the solution and confirm problem closure. Also completed at this time were a five-item questionnaire regarding perceived problem outcomes, and a three-item questionnaire on the respondent's prior work experience.

Additional information was collected from problem solving documentation and was used to corroborate interview responses. For example, if the respondent mentioned that a designed experiment had been conducted, a copy of the related analysis was requested.

Information about problem solving outcomes was collected from a five-person panel of in-house experts (those most knowledgeable about problem solving and quality issues, as well as the technical issues involved in such manufacturing problems). The procedures used to rate each problem are described below.

4. Variable Measures

For each problem-solving case, we measured nine variables: two problem descriptors, four process metrics, and three performance results, as follows:

Problem Descriptors
- complexity
- novelty

Process Metrics
- number of steps
- number of hypotheses generated
- number of hypotheses tested
- number of solutions considered

Characteristics of Problem Solvers
- manufacturing experience

Performance Results
- solution quality
- expert time rating
- solution time

Problem Descriptors

Variables used to control for technical differences among problems were based on information collected in interviews and questionnaires. Complexity is a four-item aggregate scale (alpha=.68) including, for example, "How many possible causes are there?" and "How complex is this problem?". Novelty is a three-item aggregate scale (alpha=.76) based on items such as, "How new is this type of problem to you?".

Process Metrics

We assessed the degree of systematic problem solving in each case by counting the number of steps (out of the eight possible steps described above) that were actually undertaken. This method allows for iteration and repeats, as is frequently observed (Mintzberg et al., 1976; Mukherjee and Jaikumar, 1992). (Results did not differ significantly when adherence to the step-wise procedure was assessed in other ways, such as counting only steps executed in nominal sequence, without backtracking.)

Coding the interview data to determine which steps were used or skipped was done by one of the authors in collaboration with a colleague also knowledgeable about problem solving approaches. A coding guide is shown below (Table 2). A collaborative rather than sequential approach to coding was used in order to enable constructive debate on definitions and interpretations.

The coders also worked together to count the number of hypotheses generated, number of hypotheses tested, and the number of solutions considered as additional metrics to describe the process.

Characteristics of Problem Solvers

Manufacturing experience of the key problem solver was based on the number of years he/she worked in a manufacturing environment, as noted by informants on the final questionnaire.

Performance Results

Solution quality was assessed by the five-member panel of experts. Panel members were convened for a total of three meetings, during which each person provided ratings on the effectiveness of the solution in each case. Information on the problem and its solution was provided by the researcher; panel members asked clarifying questions, and rated each problem outcome according to the rating scheme shown in Table 3. Ratings were collected and averaged across the panelists to produce a single rating of solution quality for each case. (Interrater reliability, as measured by Cronbach's alpha, was .81.)

Panelists also provided an expert time rating, which captured their professional judgment of the length of time that the problem should have taken to reach completion. Specifically, panel members were asked to estimate, "How long should it have taken the problem solvers to come up with this particular solution to the problem?" The expert time rating assigned each problem represents consensus agreement among the five expert raters.

Actual solution time was computed directly from the project documentation. This measure is defined as the time elapsed from problem awareness until solution verification. Problem solving time efficiency is then calculated by taking the ratio of actual solution time to the expert time rating.

Results

In order to assess the utility of a systematic approach to problem solving in the manufacturing environment, we explored each of our four research questions by means of correlation and regression analysis. A correlation matrix of all measured variables is provided in the Appendix. In all cases we report Pearson correlation coefficients; due to the small sample size, we also examined the data using nonparametric correlation analysis (Spearman correlation). No significant differences were revealed. Physical examination and statistical tests revealed the data to be approximately normally distributed.

1. Does a Systematic Approach to Problem Solving Improve Solution Quality?

The data strongly suggest that systematic problem solving improves solution quality. There is a strong relationship between the use of a systematic approach (i.e., the number of steps completed) and the solution quality ($r=.70$). As shown in Table 4, variations in problem solving approaches account for a large portion of the observed variance in solution quality, especially when one controls for the novelty of the problem.

One reason for the power of a systematic problem solving approach could be that it is associated with development and testing of a larger number of hypotheses regarding the problem's root cause. As shown in Table 5, both the number of hypotheses generated and the number tested are positively related to the systematic nature of the approach used, as well as to solution quality. However, multiple regression reveals that the number of hypotheses generated (or tested) has no independent effect on solution quality when the number of problem solving steps completed is also taken into account. Similarly, the number of solutions considered is positively related to the degree of systematic problem solving, but also did not have an independent effect on solution outcomes. Thus, there appears to be some independent, additional advantage to a systematic approach (such as more thorough examination of the problem itself) beyond its tendency to be associated with broader consideration of alternatives.

2. Does a Systematic Approach to Problem Solving Take More Time?

A surprising finding is that a more systematic problem solving approach does not take more time, at least not when one accounts for the nature of the problem and the quality of the solution. In terms of the absolute time elapsed between discovery of the problem and identification of a solution, systematic problem solvers took somewhat longer than more intuitive ones (see Table 6). In particular, more elaborate hypothesis generation is indeed time consuming. However, when we compare the approach used to the *time efficiency ratio* (the relationship between the actual solution time and the time that expert judges said it *should* have taken to reach the solution), systematic problem solvers actually performed a bit better than others (see Table 6).

3. When is a Systematic Problem Solving Approach Appropriate?

Despite a common sense view that systematic problem solving is most important when problems are especially complex, or when problem solvers are relatively inexperienced, we found that the benefits of systematic problem solving applied broadly across many situations. Problem solvers did tend to adopt a more systematic approach when dealing with complex or novel problems (the correlation between number of steps and complexity of the problem is .39; between number of steps and problem novelty r=.60). However we found no evidence that the impact of a systematic approach is greater under these conditions. Specifically, when we tested the interaction effects of using a systematic approach for problems of higher complexity or novelty, there was no significant effect (see Table 7, below).

Moreover, the importance of systematic problem solving appears to hold not only for new or novice problem solvers, but also for experienced manufacturing personnel. As shown in Table 8 (model 1), more experienced problem solvers tended to produce poorer solutions than did newer colleagues. This appears to be partly accounted for by a tendency to use less systematic approaches to problems (number of steps and manufacturing experience are inversely related, r=–.36). In model 2 of Table 8 we examine the effect of manufacturing experience on solution quality, this time holding constant for the number of steps completed. Results suggest that had experienced personnel used systematic approaches to the same degree as did newer employees, the detrimental effect of experience would have decreased significantly.

Taken together, these two results suggest that a systematic problem solving approach is important not only when problems look especially difficult, but also when problems seem familiar. In the latter situations, systematic approaches may guard against sloppy or habitual responses to problems that may appear simple, but may in fact contain unexpected new elements.

4. To What Extent do Real Life Problem Solving Efforts Follow a "Systematic" Model?

In our sample, no problem followed all eight steps included in our model of systematic problem solving (the range of steps used was four to seven, with a mean of 5.6). The steps involving data-gathering (problem documentation, hypothesis testing, and solution verification) were the ones most frequently skipped. Indeed, the most common departure from our step-wise model of systematic problem solving was to skip both problem documentation and hypothesis testing, moving straight from problem recognition to hypothesis generation to solution planning, all without the benefit of explicit efforts to gather data about the problem. This pattern was observed in five cases, or 22% of the sample. In all, 86% of the sample skipped at least one data-gathering step before they formulated a solution (15 problem solvers, or 65% of the sample failed to gather data to document and characterize the problem, and 10 problem solvers (43%) failed to gather data to test their hypotheses). Another commonly skipped step was solution planning; in six cases (26%), solutions were implemented with no explicit effort to consider and analyze the options available.

Discussion and Conclusion

In this paper, we have attempted to test whether systematic problem solving approaches lead to better solutions, not in the psychology lab, but in real-world manufacturing settings. Our data strongly suggest that, for the sample of problems studied, systematic problem solving did result in higher-quality solutions than did more intuitive approaches. This was true for routine problems as well as for novel ones. It was also true for experienced employees as well as for novices who had little experience to draw on. Furthermore, we find that while systematic problem solving took slightly longer than intuitive approaches on an absolute basis, the time penalty disappeared when we took into account the nature of the problem and the quality of the solution achieved.

An important question that these results raise is, *how* did adherence to a more systematic problem solving approach result in superior outcomes in our sample? Several reasons emerge from the literature. One possibility is that a systematic approach dominates because it encourages problem solvers to develop multiple alternatives, rather than simply accepting the first causal explanation or the first solution idea that occurs to them (Baron, 1988). We attempted to test this idea by examining whether the number of hypotheses generated or the number of solutions considered had an independent effect on solution quality. We found that they did not.

Another possible explanation for the power of systematic problem solving is that it encourages problem solvers to test (gather data on) multiple explanatory hypotheses (Baron, 1988). We found that the number of hypotheses tested did not predict solution outcomes, once we accounted for the number of steps taken. Because hypothesis testing not only generates data but also forces explicit consideration of decision criteria, this finding further suggests that systematic problem solving did not have its effect by rendering decision criteria explicit and discussible (Wills, 1982).

Another possible explanation for the effectiveness of systematic problem solving approaches is that they encourage broader information search, including consideration of disconfirming evidence. More thorough collection of data can have beneficial effects in several ways. First, analysis and deliberations (e.g., to generate causal hypotheses, or to generate solution possibilities) based on data are likely to be more productive than those based on assumptions or guesses. Another possibility is that data-gathering activities, and/or the data themselves, serve to "tickle the memory" of problem solvers who may have seen or solved similar problems in the past (Newell, 1983). Also, recall that all of the cases we studied were worked on by groups of people; having data to refer to can facilitate deliberations among problem solvers by providing the means to test ideas when arguments arose, or simply by providing a focus for discussions. Finally, data gathering activities could be important by providing a time buffer between analytical stages (problem awareness, causal hypothesis generation, and solution planning) that are logically distinct but that are often run together.

The idea that systematic problem solving works, in part, by encouraging more complete information search would be consistent with our finding that systematic problem solving was beneficial not just for novices, but also for experienced manufacturing employees. Several studies have shown that experience in a given job can actually lead to worse performance in solving job-related problems (Allen and Marquis, 1963; Hecht and Proffitt, 1995). An important reason for this is that people tend to collect and process the least amount of information needed to carry out their work, and this level of information tends to decrease as experience increases (March and Simon, 1958; Abernathy, 1993). This would suggest that experienced manufacturing employees had a special disadvantage in solving production problems, because they tended not to attend to potentially-relevant information in the manufacturing environment, especially if they were not following a systematic problem solving approach.

However, results do not support the idea that the benefits of systematic problem solving can be attributed simply to more complete data gathering. As noted, there were five cases in our sample where problem solvers skipped directly from problem recognition to hypothesis generation to solution planning, all without systematic data collection to support their efforts. Surprisingly, the mean solution quality in those cases was 6.2, or slightly above the full sample mean of 5.6. Moreover, when we examine the five lowest-rated problems (in terms of solution quality), we find that data steps and analytical steps were skipped almost equally. Likewise, while the five top-rated problems were resolved using more systematic approaches, in all but one of them at least one data-gathering step was skipped.

Thus, it appears that the essence of systematic problem solving is not that it prevents skipping *specific* critical step(s) in the process (such as hypothesis generation, or data collection), but that it ensures attention to all (or most) of the steps we have outlined. In particular, in our model of systematic problem solving, analytical or planning steps alternate with data collection and testing; such alternation between two different modes of problem solving may be the key feature of systematic problem solving. For example, it may be that data-gathering *per se* is not as important as moving between data-gathering and analysis of that data; similarly, generating multiple alternative hypotheses may be important, but it can only lead to better problem solving outcomes when it is coupled with careful observation of the problem and testing of the alternatives generated.

It is important to note that these results reflect problem solving experience in one U.S. company -- specifically, a new automobile manufacturing company. Since specific characteristics of this setting could influence our findings, it is difficult to know the generalizability of these results. However, several considerations mitigate this concern. First, our data come from two distinct operations within the larger manufacturing complex; these operations represent very different technical and organizational contexts, yet results were consistent across the two operations. Also, it is useful to note that employees at the company studied received no special training in systematic problem solving techniques that would make them unusually able to apply such approaches.

Thus, although our findings have yet to be replicated in different settings, they still have potentially important implications for both managers and for management theory. Managerially, our results are interesting because there is currently tremendous interest and significant investment in introducing systematic problem solving approaches as part of "total quality" or other programs. Yet there has been little evidence to support claims that systematic approaches work better than other modes of problem solving for dealing with technical problems in organizations. A clear implication of our research is that attention to systematic problem solving is likely to be a worthwhile investment for production managers to make. However, it is notable that our research did not examine specific, formal problem solving methodologies (such as the "KJ" technique (Kawakita, 1991)), and therefore we cannot comment on the utility of these systems. Rather, our research points to the need for training of a more general sort, to remind problem solvers of the need for a methodical progression from empirical data to analysis and back to empirical testing as they struggle to find an appropriate and robust solution.

Moreover, our results reveal some specific steps that could be taken by managers to promote more systematic problem solving in manufacturing environments. We noted above that the most commonly missed steps involved data gathering during early problem solving phases (i.e., failure to document the problem and failure to test hypotheses regarding a problem's cause). Thus it appears that one important way to improve shop-floor problem solving might be to emphasize the importance of early data gathering, both for characterizing the problem and for examining possible causes of the problem. In addition, we noted that problem solvers frequently neglected to stop work to analyze and compare alternative solutions, but rather plunged directly into implementing an uncertain solution. Thus, further emphasis on the importance of careful and thorough solution planning is also likely to be useful in production settings. We also found that training efforts should not focus solely on inexperienced personnel. Experienced manufacturing employees appear to benefit from using systematic approaches as much as novices do, yet they may be even less likely to apply them without special incentives.

Theoretically, this paper addresses a significant gap in the research. We know that problem solving is important for introducing and refining new process technology (e.g., Leonard-

Barton, 1988; Tyre and Hauptman, 1992). Yet there are conflicting views about what represents effective problem solving. While psychologists' studies show that effective problem solving is systematic and well-structured (Dawes, 1982; Schoenfeld, 1985), ethnographic and other clinical data from actual organizations suggest that competent everyday problem solving (and especially problem solving in production settings) is not a purely mechanical, formal process. It also requires intuition, local knowledge, and a "feel for" the idiosyncratic practices of the specific setting (e.g. Brown and Duguid, 1991; Pentland, 1993; Scarselletta, 1993). It is often an unfolding or fuzzy process because real problems are not always easily tractable. Multiple, often conflicting goals and interests require great flexibility and sensitivity to the problem's context.

Are these findings compatible with our results? We suggest that they can be. As conceptualized here, a systematic approach does not mean rigid compliance with a specific set of rules and procedures. Rather it means giving explicit attention to the many data-gathering requirements presented by a problem, and to the need for careful analysis of the data collected. Newell (1983) suggests that, in mathematics, problem solving heuristics are mainly "memory ticklers". Similarly, we could say that a step-wise set of heuristics for shop floor problem resolution may serve, in part, to tickle the tacit and even intuitive capabilities of shop floor personnel. For example, documenting a problem can be an opportunity for manufacturing personnel to use their local or idiosyncratic skills in noticing anomalies, as well as to exercise disciplined skills for quantitative data gathering. Hypothesis exploration also serves to elucidate the intricacies of the production environment and helps to develop important new expertise in the problem domain. Similarly, solution planning not only can but often must be an interactive, social process in which different actors brainstorm, debate, and bargain with one another, as well as engaging in analytic assessment of the solution options available.

In short, it may well be that systematic and intuitive problem solving approaches are not necessarily opposites, but rather can be important complements. Further research, and especially further empirical work in actual production settings, will be necessary to clarify this relationship and to better reveal the benefits of each approach.

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Table 1: Examples of Problems Studied

Problem Type	Example
Product Design	Brittle/broken threads on metal part due to overly thin section
Process Design	Wet parts (resulting from an early process step) cause surface defects downstream
Design for Assembly	Possible to confuse two similar parts that belong to different assemblies
Product-Process Match	Burrs on metal parts interfere with downstream assembly operation
Material/Product/Process Match	Part distorts during processing
Materials Processing Understanding	Wet process erodes sealer used between two mating parts, resulting in leaks after curing
Material Selection	Component degrades when exposed to temperature extreme within the range of use
Dimensional Tolerance	Tooling wear leads to out-of-spec dimensions on a metal part

Table 2: Coding of Problem Solving Descriptions

Step	Definitional Criteria	Source
Problem Awareness	• Evidence of the means by which the problem has come to the attention of the problem solver(s) • Clear statement of what the problem is	• Initial Interview
Problem Documentation	• Evidence that some investigation has been conducted to understand and characterize the problem	• Initial Interview • Follow-Up Interview
Hypothesis Generation	• Evidence that one or more alternatives were considered in finding the root cause	• Initial Interview • Follow-Up Interview
Hypothesis Testing	• Evidence of data collection to support or refute the alternative(s); confirming or disconfirming evidence	• Follow-Up Interview
Solution Planning	• Evidence that a strategy was used to implement the solution; analysis of available solutions	• Follow-Up Interview
Solution Implementation	• Evidence that the solution has been put in place in the actual production system	• Follow-Up Interview • Final Evaluation
Solution Verification	• Evidence that data was collected to substantiate that the developed solution really solved the problem	• Follow-Up Interview • Final Evaluation
Incorporation	• Evidence that the learning from the problem-solving effort is being standardized into the plant, so that the problem will not recur	• Follow-Up Interview

Table 3: Rating Scheme for Solution Quality

Quality Rating	Guiding Definition	Interpretations/ Applications
1	Solution is poor, temporary, does not appropriately address problem. Problem will recur.	• "A 'luck-of-the-draw' solution." • "Didn't go far enough with the Five Whys."
2	Solution is relatively poor. Problem likely to recur.	• "Never found the root cause. Don't know if it's the process, the material, or an interaction. • Suspect recurrences."
3	Solution is very questionable; Problem may recur.	• "I'm not sure they know the real root cause."
4	Solution is questionable.	• "Likely to recur if they don't do something to keep checking on the solution."
5	Solution is not entirely robust; There is some feeling that the problem may recur under the worst-case situation.	• "Don't have a [process] control plan."
6	Solution might be robust, but not sure.	• "The knowledge for the critical [process] sequence still isn't part of the operator's job."
7	Solution is reasonably strong; Probable that the problem will not recur.	• "Changed the process and incorporated some checks. There's a pretty good chance that the problem won't recur."
8	Solution is good, strong.	• "Reasonably good solution until [product engineers] can design out the problem."
9	Solution is excellent and addresses the root cause of the problem; Problem will not likely recur.	• "Not a 10 because there is some slight mystery — an opportunity for recurrence."
10	Can't think of a better solution. Very excellent.	• "They can turn the problem on and off — and they know why."

Table 4: Relationship between Systematic Approach and Solution Quality

Dependent variable = solution quality

n=23

Model 1: R^2=.472; f= 12.06 (d.f. 21)

constant	+ number of steps
1.42	.98
(1.02)*	(.22)***

Model 2: R^2=.528; f=13.3 (d.f. 20)

constant	+ number of steps	+ problem novelty
1.05	1.26	–.18
(.99)	(.22)***	(.09)*

*p<.10; **p<.05; ***p<.005. Standard errors are shown in parentheses.

Table 5: Relationships among Systematic Problem Solving, Number of Hypotheses, and Solution Quality

n=23

(Pearson correlations)	Number of Steps	Number of Hypotheses Generated	Number of Hypotheses Tested	Number of Solutions Considered
Solution Quality	.70	.49	.54	.22
Number of Steps	—	.37	.47	.31

Regressions; Dependent variable = solution quality

Model 1: R^2=.509; f= 12.04 (d.f. 20)

constant	+ number of steps	+ number of hypotheses generated
1.31	.85	.16
(.99)	(.22)***	(.10) [not significant]

Model 2: R^2=.510; f=12.5 (d.f. 20)

constant	+ number of steps	+ number of hypotheses tested
1.62	.80	.26
(1.00)	(.23)***	(.16) [not significant]

*p<.10; **p<.05; ***p<.005 Standard errors are shown in parentheses.

Table 6: Relationship between Systematic Problem Solving and Time to Reach a Solution

n=23

(Pearson correlations)	Number of Steps	Number of Hypotheses Generated	Number of Hypotheses Tested
Solution Time	.26	.50	.29
Time Efficiency Ratio	–.21	–.11	–.25

Table 7: Differential Effectiveness of a Systematic Approach for Difficult Problems

Dependent variable: solution quality n=23

Model 1: R^2=.504; f= 8.44 (d.f. 19)

constant	+ number of steps	+ complexity	+ (complexity*# of steps)
–4.65	2.03	.60	–.10
(4.76)	(1.02)*	(.42)	(.09)

Model 2: R^2=.523; f=9.05 (d.f. 19)

constant	+ number of steps	+ novelty	+ (novelty*number of steps)
2.95	.86	–.56	.08
(2.32)	(.52)	(.43)	(.09)

*p<.10; **p<.05; ***p<.005 Standard errors are shown in parentheses.

Table 8: Relationship between Manufacturing Experience and Problem Solving Outcomes

Dependent variable: solution quality n=23

Model 1: R^2=.178; f= 5.78 (d.f. 21)

constant	+ experience
6.92	–.06
(.47)***	(.02)**

Model 2: R^2=.503; f= 12.1 (d.f. 20)

constant	+ experience	+ number of steps
2.47	–.03	.86
(1.21)**	(.02)*	(.22)***

*p<.10; **p<.05; ***p<.005 Standard errors are shown in parentheses.

Appendix

Correlation Matrix of Measured Variables

(Pearson Correlation Coefficients)

N = 23

	# of Steps	Hypotheses Generated	Hyp's Tested	Solutions Consid.	Solution Quality	Solution Time	Time Ratio	Novel
Hypotheses Generated	.37	--	--	--	--	--	--	--
Hypotheses Tested	.47	.81	--	--	--	--	--	--
Solutions Considered	.31	.24	.13	--	--	--	--	--
Solution Quality	.70	.49	.54	.22	--	--	--	--
Solution Time	26	.50	.29	.47	.27	--	--	--
Time Efficiency	-.21	-.11	-.25	-.04	-.43	.15	--	--
Novelty	.60	.16	.21	-.04	.20	.02	-.35	--
Complexity	.39	.49	.43	-.05	.47	.17	.13	.19
Experience	-.36	-.45	-.46	-.40	-.46	.21	-.06	-.06