

A Scheduling Model of Coal Supply Chain Based on Supply Chain Management (SCM)

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Abstract In this paper, we develop a scheduling model based on SCM to deal with the contradiction between scale production and customized demand on coal industry. When analyzing the coal logistics from coal mine to end-customers, we draw an operating flow chart, from which we can find out the relationship among the departments in coal supply chain. According to the flow chart we can describe the input/output (I/O) constraints by algebraic expression. The objective function minimizes the operating costs of every department in coal supply chain, and an optimal solution can be obtained through the use of Mixed-integer linear programming (MILP). In that way we can get a specific task timetable to guild their work and the activities.

Keywords: SCM, optimization model, scheduling, MILP, I/O

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1. Introduction

The coal industries in China are facing the pressure of intense competition from all aspects and the coal supply chain operations become more complex increasingly. Each end-customer needs one or more special kind of commercial coal to satisfy his requirements efficiently. Therefore, it's necessary for a coal washery to produce enough different types of coal to meet them. So, in the micro-planning level, a lot of efforts need to focus on how to schedule and to manage coal supply chain.

The coal supply chain of China is experiencing the integration of internal and external functions for a long-term cooperation. And perhaps it just belongs to the fourth stage of the supply chain management which can be divided into four stages as the statements of Stevens (1989) [10]. The goal of SCM is to coordinate the procurement, production, supply and related auxiliary activities, it has been shown the schedule model to manage the supply chain has to consider two essential issue (Twill, Naim, Wikner, 1992) [11]: 1st, when a department can start its work? 2nd, how long the department can complete the task? As a result, the scheduling model we present in this paper has to guide the functional departments in a reasonable way to work together to complete the orders of the end-customers. It was found that analyzing the customer order decoupling points (CODP) can solve the optimization problem of the mass customized quantity (Biswas, Narahari, 2004) [3].

Moreover, the scheduling work is a tool of managing supply chain to optimize production, distribution, and storage resources to respond properly to the external

conditions (Christopher, 1993) [5]. An effective scheduling model can guide the departments completing the orders from the upstream of supply chain over a short to medium term. Namely in the coal supply chain, raw coal stone is moved from mine to washery, then finished commercial coal is moved from the washery to the end consumers.

Similarly, as Singh, *et al.*, (2012) [9] stated, supply chain is a process to implement the plan effectively in a specific environment. As known to us, a customer purchasing special coal based on his technological standard. When a coal washery collect dozens of orders from different customers in a special period, the challenges to the integration of scheduling problems in different departments are reconciling their implementation frequencies and the magnitude of orders' cost.

In general, as Amaro, Barbosa-Póvoa (2008) [1] outlined, a scheduling model consists of two integrated models run sequentially as a MILP after they studied the scheduling of industrial supply chains with reverse flows. As a result, the scheduling model is optimized by exploiting the I/O details in each department of supply chain with the concrete operational conditions. Under the similar situation, the coal washery is connected through a coal supply chain of transportation resources where a large number of coal materials flows are considered in an I/O system. The input is a set of coal mines, and the output is another set of customers who send the purchasing information to the coal washery at the same time (Zaklan, *et al.*, 2012) [14].

After the analysis above, in this paper, we develop a scheduling model based on SCM to deal with the contradiction between scale production and customized demand. Based the objective function which minimizes the operating costs of every department in a coal supply

chain, an optimal solution can be obtained through the use of MILP. In that way we can get a specific task timetable to guild their work and the activities.

2. Problem Scenario

2.1. The Operating Scenario of a Coal Washery

The activities in a coal supply chain, and hence the model, are driven by commercial interests to satisfy a specific coal demand pattern. The origin of coal supply chain is the demand information from the customers' orders, while the termination is the completion of orders (Leviäkangas, 2011 [6]; Wang, Cheng, 2009 [12]). But, unfortunately, the coal business in China is confused and disordered to some extent(Xu, Li, 2011) [13]. A coal supply chain can be represented as a flow map in fig.1 where the departments of coal washery act as nodes and links related with coal logistics and sub-process among the facilities. There are several external nodes involved the set of customers, e.g. the third party logistics for coal

transport, the coal companies those selling semi-finished coal, and the coal mines. Each departments of a coal washery has to coordinate with internal system and external facilities. So, a coal supply chain is described as a network rather than a linear process (Zaklan, *et al.*, 2012) [14].

2.2. The Analysis of Coal Supply Chain

The coal scheduling model is developed to permit to reduce costs and ensure the durability of the enterprise. Above all, we have to figure out the research object and use a feasible method to deal with the contract among departments. The nodes in Figure 1 are essential elements in coal supply chain, which work together to finish the orders one after another. The coal logistic is a circle system throughout the operating processes. And we can get two main materials flows from Figure 1. As shown in Figure 2, flow A is a whole coal supply chain from raw coal mines to customers. And it's the key object by which we could create the scheduling model. Correspondingly, flow B is a supplementary flow that exist to ensure all the orders can be finished in time when the washery cannot process enough commercial coal to fulfill the customers.

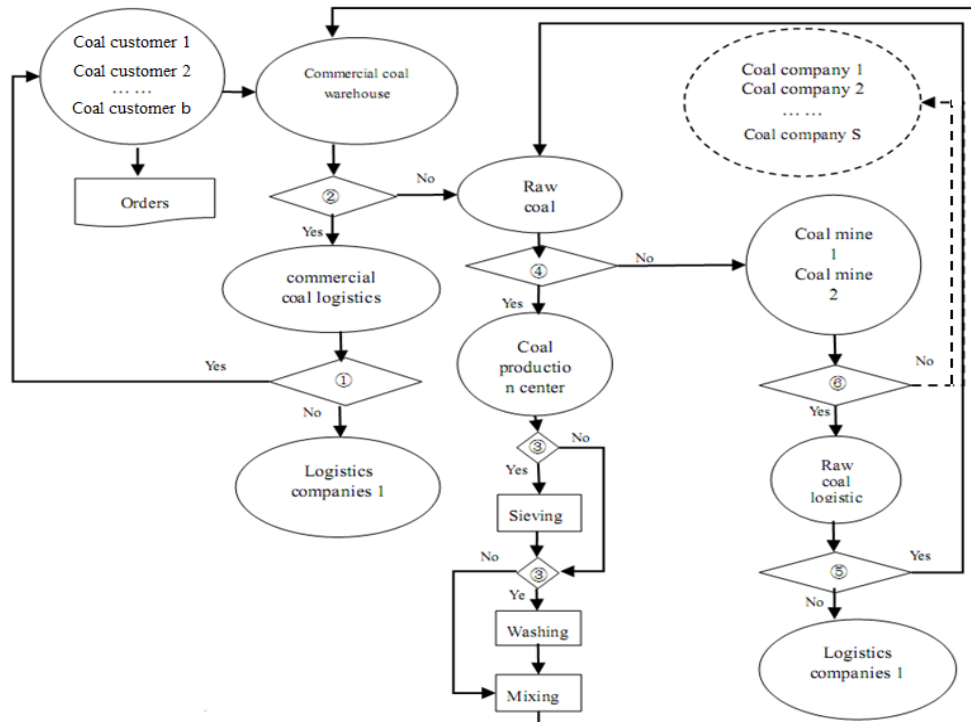


Figure 1. The Operating Map of the Washery

- ①: Whether the commercial coal logistics is enough or not; ②: Whether the commercial coal is enough or not; ③: Whether to take this processor not; ④: Whether raw coal is enough or not; ⑤: Whether the raw coal logistics is enough or not; ⑥: Whether the raw coal is enough or not.

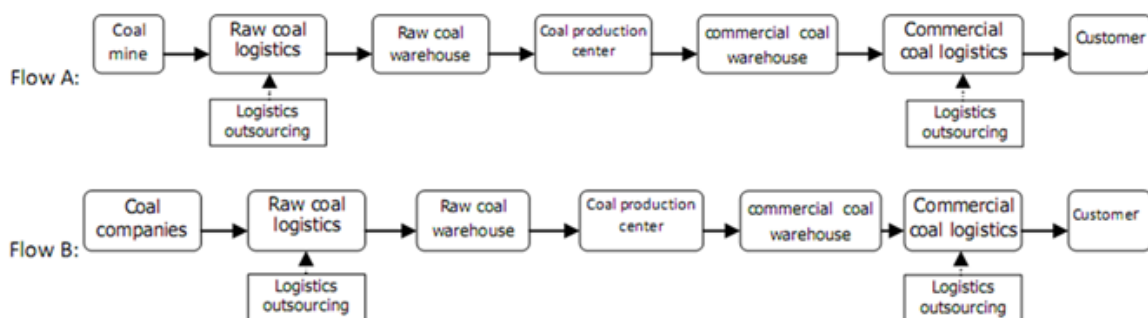


Figure 2. Coal materials flow

3. The Scheduling Model for Washery

3.1. The Premise and Tool Architecture

As mentioned above, the scheduling model refers to manufacturing processes, the operating period and the I/O controlling of departments. These are closely linked and interdependent aspects which need to be analyzed before entering the model. On the analysis of flow B in Figure 2 we can manage the certain information that combine time dimension, requirement of orders and quantity of task.

The coal companies usually make plan and statistic in each month, and the process of finishing one order takes at least 8 days (Xu, Li, 2011) [13]. Some of the orders are foreseeable and easy to prepare, but, most of orders need the fast reaction and take measures in a short time. If the washery looks forward to managing its coal supply chain effectively to finish dozens of order in the limited period, the scheduling model should has a dynamic response to deal with the coming orders in one scheduling cycle.

We suppose to consider $T = \{1, 2, 3, \dots, t, \dots, T\}$ as the set of scheduling cycles, and $t \in T$; $T' = \{1, 2, 3, \dots, 10\}$ as the set of work days, each scheduling cycle has 10 work days, $n = 10$ and $t' \in T'$, n stands for the number of a scheduling cycle. Let $\gamma(t, t')$ represents the time node that we have known when the setup time and deadline would be in the timetable of scheduling model. And it's a simple feasible measure to get the accurate data of the progress of the departments.

$$\gamma(t, t' - \tau) = \begin{cases} (t, t' - \tau) & \text{if } t' - \tau \geq 0 \\ (t - \omega_1, \omega_1 n + t' - \tau) & \text{if } t' - \tau < 0 \wedge t > \omega_1 \end{cases} \quad (\text{I})$$

With the rule of Just In Time (JIT) in SCM, according to Amaro, Barbosa-Póvoa (2008) [1], Manoj, *et al.*, (2008) [7], Choi, Chiu, Fu (2011) [4], an organization planning to coordinate the related facilities needs to build an effective supply chain and keep a good rhythm with the end-customers. In the paper of Salema, Póvoa, Novais (2009) [8] the backward time operator can deal with the information of orders in a period and work out the point of setup time for each department. The backward time operator is defined as formula (I). Let τ be the time spent on a task of a department. The setup time can be described as $\gamma(t, t' - \tau)$, while the deadline as $\gamma(t, t')$.

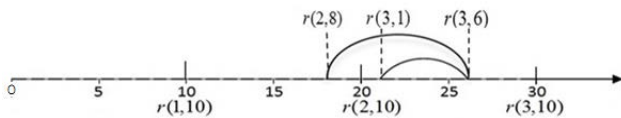


Figure 3. The time axis for backward time operator

In order to account for the situations of washery, a setup time point $\gamma(t, t' - \tau)$ is defined between the input

time and output time, (e.g., $\omega_1 = \left\lceil \frac{\tau - t}{n} \right\rceil$). The deadline of

upstream department is the same as the setup time of the interconnected downstream department in the coal supply chain. Let us consider an example through the time axis in Figure 3 which can help us to have a clear insight on formula (I). When $\gamma(t, t') = \gamma(3, 6)$, it means a task should

be completed in the 6th day in cycle 3. According to (1), if $\tau = 5$, it means a task need 5 days to complete, and $\gamma(t, t' - \tau) = \gamma(3, 1)$ since $t' - \tau \geq 0$. If $\tau = 8$, $\gamma(t, t' - \tau) = \gamma(2, 8)$ since $t' - \tau \leq 0$ and $\omega_1 = 1$. The time point $\gamma(2, 8)$ means the setup time is the 8th day in cycle 2.

$$\begin{aligned} & \sum_{t \in T} \sum_{y \in Y} f_I(t, y(x_1, x_2, x_3 \dots)) + V_{t=0} \\ & = \sum_{t \in T} f_O(t, y'(x'_1, x'_2, x'_3 \dots)) + V_{t=T} \end{aligned} \quad (\text{II})$$

These time points in a certain cycle relate quantities aggregated in time such as demand, commercial coal storage, production, raw coal inventory and purchase quantity with detailed coal materials flow. The constraints are defined for each aggregate quantity in a department, and the I/O balance control theory can account for the workload and manage the coal supply chain to complete the order on schedule.

As Wang, Cheng (2009) [12] and Angerhofer, Angelides (2000) [2] have analyzed, the I/O controlling adopted the system dynamics model. So, the formula (II) shows input is equal to output in a certain period. On one hand, the input consists of initial inventory $V_{t=0}$ and new added production $\sum_{t \in T} \sum_{y \in Y} f_I(t, y(x_1, x_2, x_3 \dots))$ in the time set of T , here the f_i represents the production capacity up to the time variable t , the processing volume y per day which is due to raw material supply x_1 , the production workshop x_2 , and the warehouse x_3 and so on. On the other hand, the output consists of final inventory $V_{t=T}$ and the delivered production to the next facilities, and the f_o represents the production delivered to different customers which is affected by the market.

3.2. Constrains of the Model

The scheduling model for a washery is driven by the orders from customers and thus the producing activities are arranged and planed as a backward operation flow. The model manages the internal department through activity analysis with relative expenses for different types of commercial coal during a fixed period.

Sub-process 1: the commercial coal logistics can deliver the commercial coal from inventory to end customers. The logistics department has to bring together adequate trucks to transport the product from warehouse to the target customers and complete the handover on time. One order from customer $c(c=1, 2, 3, \dots)$ have a definite delivery date $\gamma_c(t, t')$ and the tonnage $q_{ck\gamma(t, t')}$ of type $k(k=1, 2, 3, \dots)$ coal. Let the period of logistics sub-process from warehouse to end customer is τ_{uc} . The τ_{uc} consists of transit time $l_{uc}/\bar{v}_0$, loading time $q_{ck\gamma(t, t')}/\bar{q}_{u0}$, and unloading time $q_{ck\gamma(t, t')}/\bar{q}_{c0}$.

$$\tau_{uc} = \left\lceil l_{uc}/\bar{v}_0 + q_{ck\gamma(t, t')}/\bar{q}_{u0} + q_{ck\gamma(t, t')}/\bar{q}_{c0} \right\rceil \quad (\text{I})$$

$$\gamma_{uc}(t, t') = \gamma(t, t' - \tau_{uc}) \quad (\text{2})$$

Sub-process 2: the commercial coal inventory can supply sufficient commercial coal to satisfy the demands on the delivery time. The delivery time is equal to the deadline when the commercial coal has stored adequate

finished coal for all the orders in a scheduling period, and this condition can be assured by constraint (3). In other word, the inventory of type k coal is more than the quantity $q_{ck\gamma(t,t')}$ at the time of $\gamma_{uc}(t,t')$. What's more, the inventory of washery has a upper limit $\bar{u}$, as described in the constraint (4), which means the total quantity of inventory have to be less than $\bar{u}$ at any time.

$$u_{k\gamma_{uc}(t,t')} \geq q_{ck\gamma(t,t')} \quad (3)$$

$$\sum_{k \in K} q_{k\gamma(t,t')} + \sum_{k \in K} u_{k\gamma_{uc}(t,t')} \leq \bar{u} \quad (4)$$

Sub-process 3: the coal production center can process different types of commercial coal stored in the warehouse to meet the customers' demand. In period T , the total tonnage of machined coal $\sum_{t'=1}^t \sum_{k \in K} q_{k\gamma(t,t')}$ and initial commercial inventory coal on the time of $t = 1$, $\sum_{k \in K} u_{k\gamma(t,1)}$, is equal to the total tonnage of delivered coal, $\sum_{t'=1}^t \sum_{c \in C} \sum_{k \in K} q_{ck\gamma(t,t')}$, and commercial coal inventory on the time of t' , $\sum_{k \in K} u_{k\gamma(t,t')}$, as shown in the constrain (5). In the constrain (6), the tonnage of type k coal in the commercial warehouse at the delivery time $u_{k\gamma(t,t'_{uc})}$ consists of initial commercial inventory of type k coal on the time of $t = 1$, $u_{k\gamma(t,1)}$, and added tonnage of type k coal from workshop, $\sum_{t'=1}^{t'_{uc}} q_{kr}(t,t')$. Constrain (7) indicates that the production center can't suffer too much orders in a period. If constrain (7) does not hold any more, the problem can be solved through orders outsourcing as noted by flow B in Figure 2.

$$\begin{aligned} & \sum_{t'=1}^t \sum_{c \in C} \sum_{k \in K} q_{ck\gamma(t,t')} + \sum_{k \in K} u_{k\gamma(t,t')} \\ &= \sum_{t'=1}^t \sum_{k \in K} q_{k\gamma(t,t')} + \sum_{k \in K} u_{k\gamma(t,1)} \end{aligned} \quad (5)$$

$$u_{k\gamma(t,1)} + \sum_{t'=1}^{t'_{uc}} q_{kr}(t,t') = u_{k\gamma(t,t'_{uc})} \quad (6)$$

$$\begin{aligned} & \sum_{t \in T} \sum_{t' \in T'} \sum_{c \in C} \sum_{k \in K} q_{ck\gamma(t,t')} \\ & \leq \sum_{t \in T} \sum_{t' \in T'} \sum_{k \in K} q_{k\gamma(t,t')} + \sum_{k \in K} q_{k\gamma(1,1)} \end{aligned} \quad (7)$$

Let τ_{Mku} represents the time that customer c 's order, so, $q_{ck\gamma(t,t')}$ should be taken into the sub-process of production center. The binary variable Y_{mik} ($i=1,2,3$) can describe the choice of sites in the machine process if a step is necessary, e.g., $i=1$ stands for Sieving, $I=2$ stands for Washing and $i=3$ stands for Mixing. If $Y_{mik} = 1$, the step i should be taken; otherwise the step should be passed. Let q_{mi} represent the unit of output per day of workshop i . Therefore, we can calculate the τ_{Mku} by equation (8), so as the time point $\gamma_{Mku}(t,t')$ for the production center to start working to finish customer's order by the equation (9).

$$\tau_{Mku} = (q_{ck\gamma(t,t')}/q_{m1})Y_{m1k} + (q_{ck\gamma(t,t')}/q_{m2})Y_{m2k} + (q_{ck\gamma(t,t')}/q_{m3})Y_{m3k} \quad (8)$$

$$\gamma_{Mku}(t,t') = \gamma(t,t' - \tau_{Mku}) \quad (9)$$

The main goal of production center is taking advantage of different varieties of raw coal to produce commercial coal for coal customers. And there are three main sub-processes that have the maximum production capacity. Introduce a binary variable $Y_{Mk\gamma(t,t')}$, when $Y_{Mk\gamma(t,t')} = 0$, it means the production center is full-load or shut down and cannot machine out $q_{k\gamma(t,t')}$. This situation can be denoted by constrain (10).

$$q_{k\gamma(t,t')} \leq \min(q_{m1}Y_{m1k}, q_{m2}Y_{m2k}, q_{m3}Y_{m3k})Y_{Mk\gamma(t,t')} \quad (10)$$

Sub-process 4: There should be sufficient varieties of raw coal inventory to support the production center to machine commercial coal sustainably. The scale of raw coal inventory designed is purchased from coal mines in different areas and could meet production needs. For the reason of maximum aggregate stock $\bar{v}$ of the warehouse, it's essential to transport the right type and the right tonnage of raw coal to produce the right machined coal.

The raw coal that a washery generally needs is Anthracite coal—type A and Bituminous coal—type B. At the time $\gamma_{Mku}(t,t')$, we assume the production tasks $q_{k\gamma(t,t')}$ of the production center warehouse ask for getting $q_{Avk\gamma(t,t')}$ ton of anthracite and $q_{Bvk\gamma(t,t')}$ ton of bituminous, so constrains (11) and (12) can calculate the required tonnage of A and B. Let $v_{A\gamma(t,t')}$ represents the inventory of anthracite, $v_{B\gamma(t,t')}$ is the inventory of bituminous. Meanwhile, at the time $\gamma(t,t')$, the total tonnage of inventory cannot exceed the upper limit $\bar{v}$, as described in constrain (13).

$$q_{Avk\gamma(t,t')} = \sum_{t' \in T'} \alpha_k q_{k\gamma(t,t')} \quad (11)$$

$$q_{Bvk\gamma(t,t')} = \sum_{t' \in T'} \beta_k q_{k\gamma(t,t')} \quad (12)$$

$$\sum_{k \in K} (q_{Avk\gamma(t,t')} + q_{Bvk\gamma(t,t')}) + (v_{A\gamma(t,t')} + v_{B\gamma(t,t')}) \leq \bar{v} \quad (13)$$

Sub-process 5: the raw coal logistics can transport the raw coal from coal mine in a distant area to the raw coal warehouse of the washery. In this process the transport equipments, travel route, transit time with loading time and unloading time need to be considered both. The coal mines located in one district can supply the similar composition or same type of raw coal. But, it's hard to buy all kinds of raw coal a customer need from one supplier. In fact, the washery can purchase one kind of coal limited availability in one district far away from another coal district. It takes a measurable time in equation (14) and (15), τ_{Awv} and τ_{Bzv} , just as the same with the commercial coal logistics. And the starting time for the mines to upload and transport coal to warehouse can be calculated as the result of $\gamma_{Amv}(t,t')$ or $\gamma_{Bzv}(t,t')$ through equation (16) and (17).

$$\tau_{Awv} = \left\lceil l_{Awv}/\bar{v}_0 + q_{Aw\gamma(t,t')}/\bar{q}_{Aw0} + q_{Aw\gamma(t,t')}/\bar{q}_{v0} \right\rceil \quad (14)$$

$$\tau_{Bzv} = \left\lceil l_{Bzv}/\bar{v}_0 + q_{Bz\gamma(t,t')}/\bar{q}_{Bz0} + q_{Bz\gamma(t,t')}/\bar{q}_{v0} \right\rceil \quad (15)$$

$$\gamma_{Amv}(t,t') = \gamma(t,t' - \tau_{Awv}) \quad (16)$$

$$\gamma_{Bzv}(t,t') = \gamma(t,t' - \tau_{Bzv}) \quad (17)$$

Sub-process 6: raw coal procurement can buy raw mine in accordance with the warehouse from the proper supplier or mine. As to replenish and supply the shortage of special raw coal to ensure the production, the purchasing department proposes to choose the credible coal supplier in the perfectly competitive coal market, which means the price of raw coal with a similar quality is same and the washery tends to trade with the nearer raw coal supplier.

$$\sum_{t' \in T'} \sum_{w \in W} \sum_{k \in K} q_{Awk\gamma(t,t')} + v_{A\gamma(t,1)} \quad (18)$$

$$= q_{A\gamma(t,t')} + v_{A\gamma(t,10)}$$

$$\sum_{t' \in T'} \sum_{z \in Z} \sum_{k \in K} q_{Bzk\gamma(t,t')} + v_{B\gamma(t,1)} \quad (19)$$

$$= q_{B\gamma(t,t')} + v_{B\gamma(t,10)}$$

$$v_{A\gamma(t,1)} \geq \underline{v}_A, v_{A\gamma(t,10)} \geq \underline{v}_A \quad (20)$$

$$v_{B\gamma(t,1)} \geq \underline{v}_B, v_{B\gamma(t,10)} \geq \underline{v}_B \quad (21)$$

3.3. Objective Function of the Coal Scheduling Model

Leviakangas (2011) [6] has researched the value attribute of the facilities on a three level supply chain. Salema, Póvoa, Novais (2009) [8] have taken advantage of the Value Conformity Service (VCS) for manufacturing enterprise to make relevant decisions. The operating cost is primarily made up by the sub-processes like production, logistics, purchasing, distribution and storage resources. It's crucial to find out the concepts that can gain competitive strength among the sub-processes. Firstly, the cost of production depends on the level of technology and manufacturing process which can meet the requirement of customers. Secondly, the cost of logistics and distribution depends on the distance and oil prices. Thirdly, the relationship between supply and demand affects the price fluctuation of raw coal, even though the feasible business, like long-term procurement contracts and futures trading, can reduce risk to some extent. However the scheduling model can reduce the uncertainty of demand and remained the inventory costs at a lower level.

The cost of raw coal inventory in a scheduling cycle $C_{vt}B$ can be calculated by equation (22), let $\bar{c}_v$ is the unit cost per ton of raw coal inventory. Let $\bar{c}_u$ be the unit cost per ton of commercial coal inventory. In the same way, we can get the cost of commercial coal inventory by equation (23).

$$C_{vt} = \sum_{t' \in T'} \sum_{t' \in T'} (v_{A\gamma(t,t')} + v_{B\gamma(t,t')}) \quad (22)$$

$$C_{ut} = \sum_{t' \in T'} \sum_{k \in K} \bar{c}_u u_{k\gamma(t,t')} \quad (23)$$

Constrain (24) determine the cost of inventory, C is considered as an objective value. The scheduling model can get the optimal solution by MILP. These constrains above for solving C can be applied to real operating process to figure out a timetable for the washery.

$$C = \min(C_{vt} + C_{ut}) \quad (24)$$

4. Concludes

The related researches of SCM in the different fields has point out the demand of end-customers and the capacity of function nodes are the essential factors which can result in scheduling model for improving. The scheduling model for washery hardly focuses on internal process control to raise competitive strength, but the collaborative management of the coal supply chain can definitely reduce the uncertainty and time delay. The scheduling work should be developed based on SCM.

The design of scheduling model for the washery to manage the coal supply chain in which the operating process can be described in a linear relationship in a period. The orders sent by customers are managed at various points of the facilities on the coal supply chain, based on complex information that each department works and continuously updates. The fewer inventories can make the coal supply chain operating in a fast rhythm and keeping low cost without too much risk. Although the coal users' demand and orders can't be forecasted, the scheduling model can response as quick as possible to plan the works and deliver the machined coal on time to satisfy the end-customers.

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