A Two-Phase Decision Support System for Optimizing the Steel Roll Cutting Problem

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Abstract—Cutting a large steel roll material into a small piece of sheet is an optimization problem for a steel sheet supply industry because of minimization of surplus materials. Due to having too much stock of leftover bits and pieces steel which come from the orders decreased, therefore the production schedule becomes very important for the industry. This study aims at how to optimize steel roll cutting problem by using the database decision support system to track the steel oxidized condition and find a flexible cutting schedule for production of steel sheet. The goals of this study are (1) optimizing cutting plane of steel sheet materials, (2) tracking and check the steel oxidized problem using database technology, and (3) establishing a decision support system (DSS). In addition, a heuristic method in the DSS helps in minimizing the waste of the cutting a steel roll into piece of steel sheet. At the same time, DSS helps in tracking the roll condition and optimizing the production schedule of the steel sheet cutting problem in the case study.

I. INTRODUCTION

Steel industry is a base industry for national construction; it’s called “mother of heavy industry” or “grain of industry”. It’s also a capital and technology intense industry. It needs much more capitals than other industries, but regains investments in a slow way and consumes much more than others. Steel industry includes smelting, founding, forging, rolling, pulling, stamping, cutting, grinding, welding materials producing and welding. Though there are many big scale steel factories, but the medium scales and small scales are the majorities in Taiwan.

In the situation of resource shorting, the cost of raw materials keeps raising up. Therefore, how to cost down became the most important theme of raising the competitive competence in steel industries. There are many cutting industry obeying the law of experience, operating there cutting with man power. Without accurate counting, only depending on the operators experiences to manufacture. In order of the operators’ main conscious and hobbits, there are many different ways of cutting, causing the reduction of using rate of the material, and many inventories of them.

It’s hard to avoid the remaining of the leftovers during the production. The leftovers can be reused over other orders. But according to some orders with special steel material and size, this order may produce many leftovers but cannot be used by other orders’ needs. In addition, the steel is easy to become rusty and these leftovers will become wastes. These orders look like benefits to the company’s business volume, but they are wastes indeed. Not only rising the manage cost but also raising the costs of material from accusing lost.

The business was overstocking with the leftovers, therefore, how to optimize the cutting steel becomes the prior issue. In the same time, with different steel nature from orders, how to construct an intelligence order taking support system becomes very important for the company to reduce operating and inventory costs. Therefore, the following tasks: a mathematical model to optimize the metal sheet cutting, the use of database technology for tracking the condition of metal sheet roll, and an intelligent decision support system will be built will be completed for this research as well as provide best control and management system for the cutting steel issues.

II. LITERATURE REVIEW

A. Decision Support System (DSS)

The concept of decision support systems can be traced back to the first Michael Scott Morton[3]. It was first proposed in the "management decision-making system" concept. Decision support system designed to be more than the other information systems analysis, its analysis of the data source for the transaction processing systems or management information system provides information within the organization, but sometimes also need external sources of information. Through its contraction of many modules to analyze data or to compile large amounts of data into a form of analysis for policy makers, and many a friendly user interface and user communication, users can easily change the assumptions made new issues or to receive new information [2].

Sprague [4] proposed an architecture of decision support system, the model from the database architecture it under a foundation. Sprague and Calson [5] proposed a decision support system model is divided into the following three subsystems. There are Dialogue Generation and Management System (DGMS), Data Base Management System (DBMS), and Model Base Management System (MBMS). Three subsystems provide decision support systems have the ability.

Turban and Aronson [7] proposed the framework of decision support system, apart from the user interface, data management and model management and other subsystems, adding more knowledge management subsystems order. Knowledge-based management sub-system can support any other subsystems, components, or play an independent role, providing intelligence to enhance decision-makers. It can be connected with the organization's knowledge base, knowledge can also be provided by the web server. Many methods of artificial intelligence has been the development of such networks in a similar JAVA implementation of the system can be easily integrated into other components within the DSS [8], shown in Fig. 1.
B. Cutting Stock Problem
Cutting Stock Problem related issues derived from trim loss problem, bin packing problem, container loading problem, nesting problem and so on. Focused on such issues of how best to approach from the larger size of the original compound, cutting the size to meet demand. Materials can cover one-dimensional cutting problems, two-dimensional and three-dimensional objects. Raw material size can be a single or multiple, the demand quantity can be fixed or have caps [6].

A broad range of applications due to such issues, and most of the NP-complete problems, so a long time to research on a wide range of cutting, of which there are many studies the problem of linear programming algorithms based on simplex method for solving techniques. One-dimensional cutting problems are often constructed by linear programming mathematical model was solved using slack integer constraints, column generation (column generation) is in the study cited the most frequently used or a solution techniques.

III. THE MATHEMATICAL FORMULATIONS OF OPTIMIZING CUTTING PLANE OF STEEL SHEET MATERIALS

A. Construct the mathematical model
The objective of mathematical models is to solve the problem of minimizing surplus materials, subject to limits of cuts and operation conditions, seeking the most economical cutting planning. The mathematical model based on operating procedures for steel cutting can help in planning optimization pattern to minimize the operation process.

The steel cutting operations can be divided into three phases: the first phase is focused on cutting a large steel coil into several small steel coils. The second phase is focused on cutting the rolled steel coils into a large flat steel to facilitate the subsequent cutting operation. The third phase is focused on the cutting of the length of steel sheet according to the order need. The piece unit of steel sheet is then become finished goods. The three phases of steel cutting processes are shown as in Fig. 2:

Fig. 2 The process of cutting steel
From the figure 2, it shows that the cutting operation is regularization procedure and large steel coil has a fixed thickness. It can not change the thickness of the finished good in the same batch, but it can only determine the length and width. It also shows that the same batch of processing operations after the cutting operation, the procedure step 1, is to fix the product width and then cut into the length of the product. The first cutting job is decided by length. Then, the second is decided by width. The steel cutting processes in step.1 and step.2 generate the surplus material. The purpose of this research will explore surplus material generated to construct an optimal mathematical model of cutting, so that the minimum surplus material and maximized re-utilization will be achieved.

The mathematical model in this study is Mixed Integer Linear Programming Model and it is solved mainly divided into two stages, the objective in each stage is not the same. In the first stage we solve the raw material cutting problem based on the order specifications, the processing of the raw materials required for the number of rolls in the step1. The steel coils need to be the same thickness and width in specification for the first stage of cutting. The purpose of this cutting job is to achieve the most savings for solving large raw material of steel coil cutting model, to solve the problem of excessive cutting of raw materials for steel rolls.

The objective function of the first phase is to minimize the amount of demand for steel roll. This approach also determines the total number of the material rolls needed in the step 3. The arrangement of the results of the mathematical model can maximize the utilization of raw steel and minimize the scrap of the raw material. The mathematical model assumes that the length the raw steels are the same and the length needed for each orders are independently of the demand. The mathematical models and symbols are defined as follows:

Phase.1 calculate the number of the steel rolls for demand

**Mathematical model :**

\[ \text{Min } \sum_{j \in MA} y_j \]  

Subject to

\[ \sum_{j \in MA} X_{ij} = 1 \quad \forall i \in ND \]  

\[ \sum_{i \in ND} WD_{ij} X_{ij} \leq LM_j \quad \forall j \in MA \]  

\[ \sum_{i \in ND} X_{ij} \leq M y_j \quad \forall j \in MA \]

Objective function (1) is the number of the minimum requirements for the steel rolls, said the restrictions in the cutting conditions, the raw material to make use of at least steel roll, steel demand can be cut to complete all orders, limit function of the type of steel cutting for the basic restrictions. Constraint (2) that the demand for any piece of steel plate, can only be discharged to the only block of raw material, that is a demand with the plate, not both at the same time by cutting different materials, where \( X_{ij} \) whether for the first i blocks of steel plate in the j blocks of raw material, Plate with a demand that can not be at the same time by cutting different materials steel, where \( X_{ij} \) is the first i block it in the j block of steel plate by cutting raw, if its value is 1, if and 0 otherwise. For example: suppose there are numbered 1 to 4 and plate number of raw materials demand for steel from 1 to 5, if the demand for raw steel plate 2 is cut out 4, the \( X_{24} \) the value is 1, \( X_{21}, X_{22} \) and \( X_{23} \) are all the values 0. At this point, decision variable \( y_j \) is the number of decision variables \( X_{ij} \) strain that \( y_j \) is reinforced material to be used, in terms of this case, \( y_4 \) of the value of 1, as shown in Fig. 3:

![Fig.3 The Schematic diagram of Constraint (2)](image-url)
Constraint (3) for a steel plate material of any form, from its demand for steel cutting out the total length of raw steel plate length of not more than itself. For example: raw steel as 20cm, demand steel as 4cm, 5cm, 6cm and 8cm. The demand for steel is greater than the sum of raw steel plate length 23cm. It is not possible to complete a batch cut, then it needs two batches to cut in order to meet the demand conditions. It means that the first piece of sheet material cut 4cm, 5cm, 6cm, then cut out a second plate of raw materials 8cm, and so on, there are three other models on the grounds the first piece of material cut the first steel cut 4cm, 5cm, 8cm, and then a plate by the second block of material cut out 6cm. And other conditions is that the first piece of raw steel from the first cut 4cm, 6cm, 8cm, then cut out a second plate of raw materials 5cm, and the first piece of raw steel from the first cut 5cm, 6cm, 8cm, then cut out a second plate of raw material 4cm.

Constraint (4) for the establishment of a decision variable’s relationship between Xij and yj. When demand for steel plates of any material in any one i j are cut out of steel, the Xij of the value of 1, then j yj corresponding to the value must be 1. The M is a great positive, and in this mode does not give the specific value. In the use, often giving a ratio of M to all other coefficients is significant for large values. Major limitation of this condition if the value of yj = 0, Xij the value will be 0, that is, if there is no raw material steel plate is cut in the case of the arrangements, there is a demand can not be discharged into any of the raw material steel plate.

Phase.2 According to the minimum number of material rolls, calculate the rate of the surplus steel roll which is re-utilization

The company often has long-term regular customers, and these customers purchase fix-specification orders in a period. Usually, these fix-orders must be cut number of fixed time and quantity. And these orders are often and large amount specification for cutting. In this phase, according to the phase.1’s result, and consider the width of common order, calculate the rate of the surplus steel roll which is re-utilization. The math model has two steps. The step.1 is calculating the surplus steel rolls after cutting this batch and cutting by the common order’s specification. This step’s target is the minimum surplus material amount as the Fig. 4. And step.2 is calculating the rate of the surplus steel roll which is re-utilization.

The mathematical models and symbols defined as follows:

Step.1 Calculate the surplus steel rolls after cutting this batch and cutting by the common order’s specification

Defined symbol:

\[ y_j : \text{the demand amount of steel rolls of phase 1} \]
\[ DW: \text{the width of steel piece for order} \]
\[ Mw: \text{the width of raw steel} \]
\[ SM: \text{the width of the surplus raw steel} \]
\[ C_r: \text{the width of the steel roll for the common order r} \]
\[ N_r: \text{the amount of the steel roll for the common order r} \]
\[ P: \text{the width of the surplus steel raw roll} \]

Mathematical model:

\[
\begin{align*}
\text{Min} & \quad P \quad (5) \\
\text{Subject to} & \\
Mw - DW \times y_j = SM & \quad (6) \\
SM - \sum C_r N_r = P & \quad (7)
\end{align*}
\]

Objective function (5) is calculating the minimum surplus amount. It is on behalf of the surplus steel after cutting by phase.1. The surplus steel can’t cut other specification, so surplus steel is the waste.

Constraint (6) for \( S_m \) is the surplus steel of raw steel roll \( M_w \) after cutting the total demand width by phase 1. Constraint (7) for the surplus material after cutting the total width of the common order \( (C_r \times N_r) \).

Step.2 Calculate the rate of the surplus steel roll which is re-utilization

The rate of the re-utilization = \( \frac{SM - P}{SM} \times 100\% \)

Fig. 4 The Schematic diagram of phase 2
If the steel roll can be further utilized by considering the remning material, indicating that the volume of raw materials required for steel roll cutting orders, the remaining re-utilization of waste roll can be higher, that is, the smaller the final waste. This information can be scheduled to provide production management reference for scheduling, but also provides business customers when the officers approached, the production of this order immediately after the operation the residual material benefits, which determine whether the benefit of this order, the decision whether the promised orders.

B. Experiments

The mathematical model was solved by Lingo and was tested on a simple case study shown in Table 1.

If not by the planning according to the order of cutting, demand for the 9 steel roll volume, scrap could include a piece of 1cm × 2cm × 2cm, a piece of 1cm × 2cm × 1cm, two pieces of 1cm × 2cm × 3cm, two pieces of 1cm × 2cm × 4cm and a piece of 1cm × 2cm × 11cm. The total length of the steel material is 162cm (18 × 9 = 162). And the total length of the surplus steel is 28cm. So the salvage rate was 17.28% (28/162 = 17.28%). The steel roll cutting plan as shown in Fig. 5.

After phase 1 operation, the calculated minimum requirement of steel roll is 8, the steel roll cutting plan as shown in Fig. 6, the waste generated by cutting plan for the two pieces of 1cm × 2cm × 2cm, a piece of 1cm × 2cm × 1cm and a piece of 1cm × 2cm × 5cm. The total length of steel material is 144cm (18 × 8 = 144). And the total length of the surplus steel is 10cm. So the salvage rate was 6.94% (10/144 = 6.94%).

As shown by the results of the above, salvage rate of 17.28% had never planned down to 6.94%, the minimum steel roll volume of demand planning has never been reduced to 8 volume from 9 volume, not only reduce the waste of the produce, but also saving the steel roll of raw material consumption.

Results through phase.1 that the minimum requirements of steel roll is 8, and the steel roll width 2 cm, so the need to cut the steel roll to the total 16cm, the width of a large raw material steel roll 25cm, so the steel roll remaining after cutting width 9cm, phase.2 model operation, the planning results can be used for the remainder of steel roll used in the volume 2 cutting of the steel roll width is 4 cm, respectively, the width of 4cm cut the steel roll, resulting 1cm of residual materials for the width of the steel roll, the steel roll that is waste. Finally, by mathematical calculation Phase.2 the Step2 re-use rate was 88.88%. This approach allows the waste generated by cutting operations to minimize, maximize utilization of the steel roll and then, as shown in Fig. 7.

<table>
<thead>
<tr>
<th>Order Number</th>
<th>Requirements Specification</th>
<th>Quantity demanded</th>
<th>Steel roll Specifications 1</th>
<th>Common Types</th>
<th>Common Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order 1</td>
<td>1cm × 2cm × 4cm</td>
<td>7</td>
<td>1cm × 25cm × 18cm</td>
<td>Specifications 1</td>
<td>1cm × 4cm × 4cm</td>
</tr>
<tr>
<td>Order 2</td>
<td>1cm × 2cm × 5cm</td>
<td>7</td>
<td>Specifications 2</td>
<td>1cm × 6cm × 7cm</td>
<td></td>
</tr>
<tr>
<td>Order 3</td>
<td>1cm × 2cm × 6cm</td>
<td>6</td>
<td>Specifications 3</td>
<td>1cm × 7cm × 9cm</td>
<td></td>
</tr>
<tr>
<td>Order 4</td>
<td>1cm × 2cm × 7cm</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 5 Schematic diagram of cutting test samples (before planning)](image)

![Fig. 6 Schematic diagram of cutting test samples (after planning)](image)
After two phases by the mathematical model of planning, the utilization rate improved significantly steel roll and reduce waste generation, not only save raw materials and inventory costs, but also more efficient technologies to enhance crop. The re-utilization of the data also provide business people in the business contact, the order under this pen after cutting the residual waste material is causing too much affect the company's profits, thus making it promised orders.

IV. DECISION SUPPORT SYSTEM

After users log into the DSS system, he/she can choose to use the system in accordance with its function of demand. The function contains not only inquiring the inventory, order and machine but also cutting decision. User must enter the type, thickness, width, and length of the steel if he/she chooses the inventory inquiry function as the Fig.8. The logical relationship between conditions are "And". The result of the inventory inquiry is shown as the Fig.9.

<table>
<thead>
<tr>
<th>The Number of the Steel Roll</th>
<th>The Name of the Steel Roll</th>
<th>Thickness</th>
<th>Width</th>
<th>length</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD0297011679</td>
<td>Light Board 0.80x1080.0x2438.0mm</td>
<td>0.8</td>
<td>1080</td>
<td>2438</td>
<td>10501080</td>
</tr>
<tr>
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<td>Light Board 0.80x1150.0x220.0mm LW 40&quot;</td>
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<td>1150</td>
<td>220</td>
<td>1220</td>
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<td>1219</td>
<td>2438</td>
<td></td>
</tr>
<tr>
<td>SD0296122351</td>
<td>Light Board 0.80x1219.0x2438.0mm</td>
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<td>1219</td>
<td>2438</td>
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</tr>
<tr>
<td>SD0297011574</td>
<td>Light Board 0.80x1219.0x2438.0mm</td>
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<td>1219</td>
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</tr>
<tr>
<td>SD14290900973</td>
<td>Light Board 0.80x1219.0x2440.0mm CG2 33&quot;</td>
<td>0.8</td>
<td>1219</td>
<td>2440</td>
<td>A bit rusty</td>
</tr>
<tr>
<td>SD0297031414</td>
<td>Light Board 0.80x1219.0x2440.0mm</td>
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<td>2440</td>
<td></td>
</tr>
<tr>
<td>SD1199061094</td>
<td>Light Board 0.80x1219.0x2440.0mm CG2 45&quot;</td>
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<td>1219</td>
<td>2440</td>
<td></td>
</tr>
<tr>
<td>SD0929912085</td>
<td>Light Board 0.80x1219.0x2440.0mm</td>
<td>0.8</td>
<td>1219</td>
<td>2440</td>
<td>A bit rusty</td>
</tr>
<tr>
<td>SD4199091482</td>
<td>Light Board 0.80x1222.0x2440.0mm CG2 41&quot;</td>
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<td>1222</td>
<td>2440</td>
<td></td>
</tr>
<tr>
<td>SD0359043201</td>
<td>Light Board 0.80x1230.0x2440.0mm</td>
<td>0.8</td>
<td>1230</td>
<td>2440</td>
<td></td>
</tr>
</tbody>
</table>

Back to the main screen

Fig.8 Search inventory information

Back to the main screen

Fig.9 The result of inventory information
The result of the cutting plan is shown in Fig. 10. According to the result, more effective use of the material if the re-utilization rate of the surplus material is higher. In this sample, the third material that which number of the steel roll is SD02X96091259. It has a higher re-utilization rate and the lower rate of the surplus material, so it can result in higher benefits. User can be based on re-utilization rate to assess the value of this order. The system can provide the reference to promise the order by the re-utilization rate of the surplus material.

V. CONCLUSIONS

According to the surplus material problem, we construct a mathematical model with the efficient algorithm for cutting problem and find out the optimal cutting mode of reducing the surplus material in order to having a workable mode. In this study, through building this database, using more database technology to control and manage customer relationships, materials, orders, and products is efficient in handling the status of all kinds of information, and even more in tracking and evaluating proposal. The features of DSS includes (1) to provide managers to track the inventory, machine and order information, (2) to combine the optimal cutting mathematical model with heuristic method to upgrade their cutting technologies, not only significantly reduce the waste and increase the utilization rate of steel but also reduce the operation, inventory and management costs, (3) to provide an operation for user interface, users can easily master the use of the system state, with more-friendly and high-interacted characteristics, (4) to introduce Web-based technology to construct this system, it’s convenient and approachable to users with browsers to work and it can let salesmen make the appropriate decision, no matter where they are, except that they can’t go on line, and (5) to provide timely planning cutting which could let the scheduling staff save the computing and management. Finally, under consideration to the effectiveness of orders, procedures and non-quantifiable benefits, this study builds an intelligent decision support system which provides managers a basis of making decision and is good at making decision as having the orders and production scheduling.

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