Corrugation Software Development and Deployment: A Case Study

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Abstract

In this paper, we present a corrugation software features and its related development issues. Typically, in a paper corrugation factory, such a software is very important. The main features in the software is the paper roll inventory management and paper roll selection planning. The inventory management includes the stocking of the paper rolls. The roll selection plan involves creating a roll selection schedule, roll selection simulation and adjustment. The two features are related to each other. The plan generation considers the paper information and inventory. The plan simulation also suggests the inventory planning and reordering for future stocking. Thus, many related reports are produced from such a system. We present an example of user interfaces, database design, and an algorithm for plan generation. We also present an example case where the software is being used in a factory and can help minimize the paper wastes.

Keywords: Corrugation Process, Corrugation Software, Planning, Paper roll selection

1. Introduction

In a paper corrugation factory, a corrugation software is really important for controlling the paper roll inventory. Particularly, the software includes a roll selection planning and scheduling for corrugation jobs. Generating a good plan means the paper waste can be minimized, the employees are satisfied with their works, and stock levels can be maintained properly.

In this paper, we present a development of corrugation software. The software considers main features such as paper inventory and paper roll selection plan generation. The inventory includes paper roll information and their management. For a plan generation, the plan for feeding paper rolls to each mill stand is given. In the paper factory, the mill stand is fed with the sequence of the paper rolls for the corrugation. For a large factory, there are several mill stands and several workers. The worker needs to feed the roll to the mill stands. The sequence of paper rolls to be fed needs to be determined in advance. A planning algorithm which yields the sequence of roll feeding is also developed. The algorithm is integrated in the software which collaborates with existing database to determine paper rolls in a stock and help inventory planning. We present a software demonstration and its database design as well as the example plans and its evaluation after used.

Planning and scheduling in a factory is considered as an NP-hard problem. Mathematic models are often needed to find an optimal solution. Many researches are focused on heuristics to find an approximate solution in many manufacturing factories.

Several works have been done in cutting stock, scheduling and production planning. Most of them are solved using heuristic or linear programming approach. Nevertheless, very few of
these has focused on the corrugation process. Also, existing software for corrugation process or production planning is commercial and very expensive.

For example, the worked by Dyckhoff presented the use of linear programming to solve 1-D cutting stock which is NP-complete problem [5]. Afshar also used linear programming model to solve 1-D cutting stock with trim loss [1]. Cerqueira and Yanasse have given a good literature review on 1-D cutting stock problem [20].

For the scheduling problem, Ipsilandis used MOP in scheduling in project management [14]. His model attempts to minimize the overall time, idle time as well as cost. Lee and Asllani used linear programming to solve job-scheduling and compared with the genetic algorithm [16]. Chan, Muriel, and Simchi-Levi proposed the machine scheduling using linear programming and compared the approach with list scheduling [2].

The closest work in the paper mill is the worked by Robert Hasseler which attempted to solve the trim loss for the corrugation process [9, 13]. He modeled using 0-1 linear programming. The trim loss problem is not considered in the original scheduling model. However, he did not consider the amount of butt rolls in the inventory and the selection of the paper roll to balance the mill feeding.

Several heuristics have been studied for scheduling problem. Kops and Natarajan presented a scheduling algorithm for a single operation job flow [15]. The approach used both linear programming and dynamic programming and considered the due date and minimizing the work in process. Haessler [9] presented a heuristic to roll scheduling for cutting to minimize the setup cost, trim loss and total time based on the random solutions. Cruz, Sandstorm, and Wayne proposed the technique for corrugating for corrugate sheets [6]. Darley, Tessin, and Sandler used agents for corrugate boxes in the factory [7]. The agent analyzed the proper process to reduce inventory stock and considered the due date.

Many heuristics on the similar problem such as a cutting stock problem are such as Shen, Li, Yang, and Yu which used particle swarm [20]. Chiong and Beng compared genetic algorithm and evolutionary algorithms [3]. Many commercial software exists for cutting stock problem. The closet ones are from SolarSoft [21] which is for corrugate packing and from Mccullough [17] from CTI company which presented a DSS system for a corrugating box for the whole production cycle.

The paper is organized as follows: Section 2 presents some backgrounds on the corrugation process. Section 3 presents the overview of the software. Section 4 presents a plan generation process. Section 5 presents some example of the results and the discussion. Finally, we conclude our work in Section 6.

2. Backgrounds

In a corrugation box factory, corrugating is the most important process to save the cost. Normally, there are two types of corrugating boxes: Single wall and double wall corrugated boards as shown in Figure 1. In order to create the single wall board, 3 layers are needed while for the double wall board, 5 layers are needed.
In details the process will take the paper liner together with the paper medium and put together with the starch to become a piece of boards. Each paper is from the inventory which is in the roll as shown in Figure 2 (a). Each roll has a length of 4,000-6,000 meters. The unused roll is called full rolls while the already used one is called, butt rolls.
Each paper roll is put on the mill roll stand in Figure 2(b). For each machine, there is two paper roll heads. The other one is the spare roll using when the first roll is run out. Thus, while the first roll is feeding, the worker needs to prepare the paper in the other roll and preparing to lengthen the paper.

Each paper has attributes such as the paper grade which implies the paper weight in grams and the width the paper in Figure 2(a). To calculate the paper size, the dimension of the paper box is used together with the total boxed needed plus the size to spare.

Thus, in our work, to select a proper roll, we consider the following (in the order of preference).

1. Select the roll that can be put on the mill roll stand in reality. That is the following cases:
   - The length of paper in the roll must be long enough so that the employee can setup the paper on the machine.
   - The roll that is selected on the $i^{th}$ mill stand at time step $a$ cannot be in the mill roll stand $j$ at time $b$ where $b-a \leq 5$

2. Total waste should be minimized. In the factory, the roll with less than 300 meters is a waste since it cannot be used on the mill stand anymore.

3. The butt rolls should be minimized. We will attempt to minimize the use of the new rolls.

4. To feed the rolls, we consider the small rolls (the rolls with the less paper, more than 300 meters but not more than 1,000 meters) in the first priority.

5. For the rolls with the attributes, we will select the older rolls. We will attempt to use the old one in the stock first to prevent the inventory aging.

6. For the worker on each mill stand, the work on roll changing should be balanced. If the workers are assigned with the small rolls, he will need to change the rolls very often.

To solve such a problem optimally, linear programming may be needed. The problem may be modeled into a goal and a set of constraints. However, such the above constraints and
consideration are very difficult to model. Let us consider the simple model which is the subset sum problem. The problem is that given a set of integers $A = \{a_i\}$, and a number $S$. Is it possible to find a subset of $A$ which can sum to $S$? That is $\sum_{i} a_i x_i = S$, where $x_i$ is a binary variable. The general problem is known to a special case of the partition problem and known to be NP-Complete.

In our case, each job is the given number is the required paper length. We are going to choose the paper rolls from the stock to be cut so that the total waste is minimized. If the paper roll is infinitely long, then the problem is so trivial. However, in the real work, each paper roll has different remaining length while some has big and some is small. There are many required jobs at the same time. If we choose only the large rolls, we will end up with many small rolls that are not usable anymore. If we choose small rolls, the employee will have to change the paper roll very often. Thus, there are many criteria to go through which are sophisticated.

3. Software Overview

We gather the requirements from many related departments. We find that there are many activities that need to be considered to support the software functions. For example, the roll inventory management needs to support the production process and manage the paper by rolls. Figure 3 draws these related parts.

![Figure 3. Related Activities Needed for the Software](image)

In the figure, there is an inventory database which stores all paper rolls’ information. The planning department puts on the required jobs in the software. The planning department also involve the paper roll inventory management. The software generates the roll selection plan. There are support staff such as clamp employees who pickup and store paper rolls according the plans and after the rolls are used.

Thus, in general, the software has the scopes as following:

1. Paper roll selection/scheduling: The software can simulate the plan for verification.
2. Paper roll inventory management: The software has a database of paper rolls which can record the arrival of paper rolls to the stock, record the usage of the rolls, record
the waste paper and its sales, record the returned rolls, and search for transactions for update or checking.

3. Other data managements: The software has features in managing related data such as user information, information on rolls, grades, widths, roll defection, roll owner, roll locations, and mapping to proprietary data base.

4. Reports: There are 18 reports in this system. This includes the reports on roll inventory, on roll selection plan, on roll waste etc.

3.1 Database Schema

There are totally 26 tables in our database to store related information. The database server is implemented by Microsoft SQL Server 2008 R2. There are some examples of ER diagram shown in Figures 4-5.

Figure 4 shows the ER diagrams related to the part of paper rolls. Notice that tblMaster_Roll is a main entity for paper roll information. Table tblMaster_Owner records the owner of each roll. Table tblMaster_Location stores location information. Table tblMaster_Grade and Table tblMaster_Width store the grade and width information respectively.
Figure 5. Database Schema for Plan Generation

Figure 5 shows the ER diagrams related to the part of roll selection plans. For example, Table `tblTransaction_Plans_Items` keeps each row of the plan. Table `tblTransaction_Plans_Physical_Rolls` keeps the information for simulation.

3.2 User Interface Design: Main Process

First, the planning department gives job description using a proprietary software in Figure 6. Using these information, then our software produces a roll selection plan in Figure 7. The algorithm presented in Section 4 is used to create this plan. Also, the resulting plans can be exported to the excel file as in Figure 8.

From the resulting schedule, there may be the case in which the required paper rolls are not available in the stock. Thus, the plan may need to be simulated and rechecked. There could be a modification to a plan to change the paper rolls where appropriate. For example, one may need to substitute some defect rolls by the rolls in the stock that have the bigger paper width. Then, the selection plan may be edited as in Figure 9. After that the summary report is generated as in Figure 10.

Figure 6. Example of Job Description
Figure 7. The Example of Plan Output

Figure 8. Plan Generation in MS Excel Files
Figure 9. Plan Editor

Figure 10. Summary Report for Corrugation Plan
3.3 Data Entries

There are several data entries for the roll management such as in Figure 11, which is to record the rolls into the inventory. The information about each paper roll such as id, owner, grade, width, weight, length needs to be input for every paper roll in stock. If there is some defect for the rolls, it should be recorded so that the roll will not be considered for planning and may be treated appropriately. Figure 12 is to record the defect rolls in the stock. Once the paper is unusable, it may be sold. Figure 13 is to record the sales of the paper waste.

Figure 11. Data Entry for each Paper Roll Information

Figure 12. Data Entry for each Paper Roll Defect
Figure 13. Data Entry for each Paper Roll Waste Sales

For Figure 14, we show the data entry of other related information such as the user information.

Figure 14. User Information

A user may query the roll information shown in Figure 15.
Figure 15. Viewing Roll Information

Grade information is shown and may be edited in Figure 16. The grade code is used in the roll master table.

Figure 16. Grade Information
Also the location information is shown and may be edited in Figure 17. The location code is used in the roll master table.

![Figure 17. Location Information](image)

Several reports are as shown in Figures 18 to 20. Figure 18 shows the movement of paper rolls by grades. This is to show how each paper roll is used for each paper grade.

### 3.4 Report Design

Figure 19 shows the report for remainders for each butt roll. Figure 20 shows the summary of the paper roll usage by days. Figure 21 shows the summary of paper wastes for each roll in kilograms by days. Figure 22 shows a report for each roll for tracking purpose.

![Figure 18. Paper Roll Movement by Grades](image)
Figure 19. Butt Roll Summary Report

Figure 20. Paper Roll Consumption by Period
Figure 21. Paper Waste Summary by Period

Figure 22. Stock Card for each Roll

Figure 23 shows the changes of the number of full rolls and butt rolls over time in a graph. Figure 24 shows the comparison of the number of rolls received for each grade and the number of rolls having used. These graphs are useful for inventory planning.
4. Plan Generation Process

To model our problem, we assume that at time step $i$ at mill roll stand machine $j$ there is a need for a paper. We define the following variables:

- paper width is $w_i$
- paper grade is $g_i$
- required length is $l_i$
There are the following constants that are configured.

$c_1$ is the minimum length that can be on the mill stand machine e.g., 300 meters. If the roll has less length, it cannot be taken to the mill stand.

$c_2$ is the length that can be considered as the waste on the roll e.g., 10 meters.

$c_3$ is the threshold to determine big roll or small roll e.g., The paper roll that has length 1,500 meters or more is considered a big roll.

$c_4$ is the number of jobs to be apart when the same roll is used again in the different mill stand e.g., there should be at least 5 jobs apart to reuse the same roll in another mill so that the employee can have sufficient time to move the roll from one stand to another.

$s_1$ to $s_5$ is the total rolls accumulated at each mill stand for the whole plan, assuming there are 5 mill stands.

We create a schedule using a greedy approach. We use the following heuristic.

To search for a specific roll at time $i$ mill stand $j$, we do the following:

1. Search for roll $R_n$ that is in the ready for use. Its state does not have a status marked as return, or bad quality or in the $c_4$ job before at other mill stand. This is a query through the database.

2. From 1), select for the rolls that has the length exactly $l_{ij}$.

3. From 2), if not found, we search for the roll that has the total roll length $L_n$ where $L_n - l_{ij}$ is smallest (or optimal fit) and $L_n - l_{ij}$ is greater than $c_2$.

4. Alternative from 3), we try to find the roll that maximizes the value $L_n - l_{ij}$ (worst fit) so that the remainder can potentially be used.

5. Alternative from 4), check the previous roll if it is “big” roll or “small” roll using $c_3$ by trying to select the big roll alternates with the small roll until the whole required length $l_{ij}$ is obtained while maintaining $c_2 < \text{waste} < c_1$ and minimizing waste.

6. For all the above cases, if there are still more than 1 eligible rolls with the same specification, we select the roll that is the oldest by the manufacture date.

For the case that is no eligible roll, it is marked that the job $i$ cannot be accomplished due to the lack of the paper roll in the inventory. The notification report is sent to the manager that the certain paper roll is out of stock so that the re-ordering can be processed.

We run the above algorithm for each time sequence and each mill stand. However, in the above cases we have not considered to balance the load for each mill stand yet. Notice that this is supplement by step 5 which is the attempt to choose a big roll alternates with a small roll. To be more precise, we can add extra variables which are used to accumulate the number of changed rolls in each mill stand. The heuristic uses the combination of best fit and worst fit to select the roll (as in step 4 and step 5). From this algorithm, the big rolls will be selected in the beginning. In the later mill stand in the sequence, which may require the same kind of paper, it will get the smaller rolls. As a consequence, the employees at mill stands 3, 4, 5 on later jobs, may be complained due to the changing of the rolls. Thus, we have a little modification that counts the number of rolls at each mill stand to balance the roll selection. Then, the number of setup for each mill stand can be balanced.

Figure 25 shows the schedule results. The results are read as follows: Column “No” shows the job number. Thus, the same row implies the same job. Column “Width” is the width of the
roll. Five mill stands will require the same width since they process the same job at each row. Column “Grade#1” shows the paper grades needed for mill stand #1. Column “len#1” is the length required on mill stand #2 and so on. The empty entry in column “Grade” means there is no feeding at that sequence and the job uses the same paper grade as in the above row. For example, job no.3 at grade#3 “CA125” uses the same paper until job no.6. The whole length is 3,993 meters.

<table>
<thead>
<tr>
<th>Job sequence</th>
<th>Paper roll and length for each job</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Width</td>
</tr>
<tr>
<td>1</td>
<td>44.5-600037P1</td>
</tr>
<tr>
<td>2</td>
<td>202</td>
</tr>
<tr>
<td>3</td>
<td>221</td>
</tr>
<tr>
<td>4</td>
<td>55-204558A</td>
</tr>
</tbody>
</table>

**Figure 25. Example of the Plan Generation (I)**

From Figure 25, it is seen that at point 1 and point 2 at time step 6, the mill stand 2, 3 and 4 need the same type of paper. Then we check that which mill stand among these has the most accumulated load. Then mill stand 2 will get the big roll first where the mill stand 4 gets the small rolls. This way, the number of setup will be more balanced.

**5. Example Plan Results**

Since the application includes the database of the paper and their information, Figure 26 shows the example paper roll information from the inventory.
Consider the user interface example in Figure 26. We implement two methods our greedy and subset sum for comparison in the scheduling part.

Figure 27. Example of the Plan Generation (II)

Consider the details of the resulting plan description. Limit Time is the maximum total time used to find the answer in case of subset sum. The minimum length ($c_{ij}$) allowed is the minimum length of the paper (in meters) is required to take that roll on the mill stand.
Threshold is the value (in meters) to classify the big roll or small roll \((c_3)\). Waste Allowed (in meters) \((c_2)\) is the length that can be allowed as wasted in the roll. Initial Size is to specify whether the given Grade for each mill stand is big roll or small roll initially. The last three rows in the black area show the total number of roll changes, the total waste per mill stand, and the total number of unsolved job.

The figure shows the resulting plan from the subset sum approach. This is to check the answer with our heuristic results.

It is shown that the job number 3 and the roll mill stand 2 need the paper grade CA125 whose width and length are 221cm and 5,310 m. respectively. From the roll selection in the next lines, we found that the specified rolls and their remaining lengths are as follows.

<table>
<thead>
<tr>
<th>Roll</th>
<th>Grade</th>
<th>Remaining Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll 1</td>
<td>20-6-00002-GG</td>
<td>1,000m</td>
</tr>
<tr>
<td>Roll 2</td>
<td>18-9-25440-52</td>
<td>1,020m</td>
</tr>
<tr>
<td>Roll 3</td>
<td>33-4-11111-3G</td>
<td>1,400m</td>
</tr>
<tr>
<td>Roll 4</td>
<td>19-9-25540-01</td>
<td>1,890m</td>
</tr>
</tbody>
</table>

This sums up to 5,310m. which is according to what we require in the job. This is a perfect solution since there is no waste at all. The subset sum selection also corresponds to our solution since it sums up to the required length.

From the result, we classify the solution into four types.

1) Good solutions. In this case, the total waste is less than the threshold allowed \(c_2\) (Waste Allowed). This is as shown in the Figure 27 labeled 1).

2) Fair solutions. In this case, the total waste is more than the minimum length allowed. These rolls can be reused in the future. This is as shown in Figure 27 (labeled 2) ), in job number 6 which requires the total length of 4,850m but the selection produced the waste of 637m.

<table>
<thead>
<tr>
<th>Roll</th>
<th>Grade</th>
<th>Remaining Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll 1</td>
<td>44-5-22112-2S</td>
<td>2350m</td>
</tr>
<tr>
<td>Roll 2</td>
<td>22-2-22222-2C</td>
<td>2500m</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>4850m</td>
</tr>
<tr>
<td>Waste</td>
<td></td>
<td>637m</td>
</tr>
</tbody>
</table>

3) Bad solutions. It is the case where the roll selection results have the waste more than the waste allowed and the but less than the minimum length. In another case, it has no problem on the length but it has a problem of the sequence of the rolls in the plan. For example, the rolls need to be used in consecutive jobs of small rolls in Figure 28, labeled 3), job number 21. It needs the length 500m and after using the roll, it has the remaining length 14m. It is considered a small roll and is very consecutively.

4) Infeasible. This is shown as “---” in the plan (Figure 28, labeled 4). since there is no paper that is suitable for the job. The program cannot find the papers that have length summed up to the required job. The alternative solution may be to upsize the paper by finding the paper with the larger width or delay the job until the paper rolls are reordered.
From the previous data in last year in 2010, the total weight of paper waste per roll is 7.27 kg. In 2011, we started using the software. We measured the total weight of paper waste per roll is 5.38 kg. Thus, with the cooperation of the plan we can reduce the waste by 20.5%.

Despite of this, with the real operation, the provided schedule may not be applicable due to several stocking and handling reasons.

1) The specified paper roll may not be in placed as it needs to be. This is because the employee may misplace it after the earlier job.

   **Suggested solutions:** There should be a training session to the employees to place the rolls. Also, there should be signs to help employee place the rolls. This is to remind the employee to be careful before placing them.

2) The required roll is in the right place but it is stacked over by many other rolls. Then, it may be difficult to be picked up.

   **Suggested solutions:** There should be a proper way to organize the stocking rolls. For example, if there are too many rolls in the stocks, the number of rolls maintained in the stock should be reduced. This helps other problems such as aging rolls. Also, a better way to stack these rolls should be suggested.

3) The required roll is in place but its quality does not meet the standard due to some wrong handling (e.g., parts of it may be tore off.) or the high humidity.

   **Suggested solutions:** There should be a way to control the quality of rolls in the stocks, examining the rolls in the stock periodically and systematically.

4) The required roll is in place but its length is not as specified since the employee may perform a wrong cutting in the earlier job or measure the length incorrectly.

   **Suggested solutions:** There should be a strategy to check the length of the rolls in reality. This is to make sure that the length matches with the specification in the database.
Due to these above reasons, the required paper roll may be substituted with alternatives. Thus, the effectiveness of the plan is not so clear. However, what we have measured was the estimate and the comparison to the earlier operations that are without any plan at all. We still see the decrease in the waste. In the future, the software can be generalized and extended to handle these troubles by providing more alternatives to pickup the paper roll and etc.

6. Conclusion

We develop software for the corrugation process. The software integrates a paper roll inventory and a heuristic to create a schedule plan. The roll inventory contains paper roll information and their management with the database. The planning heuristic takes advantages of best fit and/or worst fit strategies. It creates a production plan for feeding a sequence of paper rolls for each stand mill. The algorithm considers many criteria in priority. Integrating with existing database, this will be advantages to the paper roll inventory planning. The previous applications show that using our planning software can reduce the waste by 20% in a prototype factory.

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References


