An Optimization Grouping Method in A Multi-line Manufacturing System

By

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Submitted to the Department of Mechanical Engineering on August 18, 2010 in Partial Fulfilment of the Requirements for the Degree of Master of Engineering in Manufacturing

Abstract

A tailored product grouping method using binary integer linear program for optimization is developed for two production lines in a food packaging manufacturer. A mathematical model is created to assign products to the two dedicated production lines with an objective to minimize the total setup times. The optimization model is subject to capacity constraints on each line. With the demand of each product entered, the model is able to generate an optimal production grouping and sequence as well as the minimal total setup time required. Compared with CAS current fixed grouping method, this linear program grouping method reduces total setup time generally by 17% and prevents both production lines from overloading. Also, this grouping method allows the Make-to-Order food packaging manufacturer to respond to changes in demand volume and product mix by changing the product grouping accordingly.

Keywords: Make-to-Order, product grouping, optimization

Thesis Supervisor: Stephen C. Graves

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Chapter 1 Introduction

1.1. Organization of Thesis

This thesis is divided into six chapters. A general background of Company A is introduced in the first chapter. Problems with the current production system are described in Chapter 2. Besides the problem description, the objectives and scope of this project are also included in this chapter. Chapter 3 presents a literature review of studies on production systems and simulation techniques. Chapter 4 encompasses the methods used to identify and analyze the problem. In Chapter 5, results and discussion of this study are presented. Chapter 6 concludes this paper with findings and recommendations. Finally, Chapter 7 presents opportunities for further research.

1.2. Company Background

Company A is a multinational food processing and packaging company of Swedish origin. Founded in 1951, it is one of the largest manufacturers in the food processing and packaging industry. Company A provides integrated processing, packaging and distribution lines as well as plant solutions for liquid food manufacturing. Today, the business spans more than 150 countries with 43 packaging material production plants worldwide.

Company A, Singapore (CAS) was established in 1982. Once producing both finished and semi-finished packaging materials, now CAS manufactures finished packaging material for customers in 19 countries. CAS and Company A, Pune, in India are the production plants in the South and Southeast Asia Cluster. In year 2007, CAS received the Manufacturing Excellence Award (MAXA) for overall excellence in innovations, operations and sustainability as well as its World Class Manufacturing (WCM) approach to ensure operational improvement and downtime minimization.

Due to the increase in complexity of Company A's supply material plants worldwide and increase in both complexity and number of products, Company A has been focusing on improving their supply chain and production efficiency.

1.3. Company Products

Company A is one of the world's major packaging providers. It offers a wide range of packaging products, filling machines, processing equipment, distribution equipment and services. Figure 1 shows the major products of Company A.

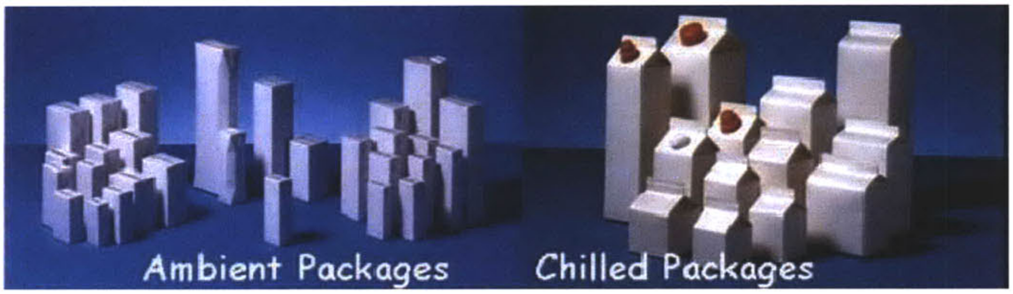

Figure 1: Major Products of Company A.

The packages in Figure 1 are used for food items like milk, juice and soy products. A design service is also available for customers. Each package is made of 6 layers of materials, including aluminum, paper and polyethylene, to prevent spoilage of the content. The base material for each package is paper that provides structure and support to each package. After the design is printed onto the paper, the paper will be coated with a layer of aluminum foil, which makes the pack aseptic and preserves the flavor of the content. Four layers of polyethylene will also be coated onto the paper. The outside layer prevents damage from moisture; the adhesive layer between the paper and aluminum foil provides structure support and two protective innermost layers seal the liquid content. The layers of the package and their respective functions are shown in Figure 2.

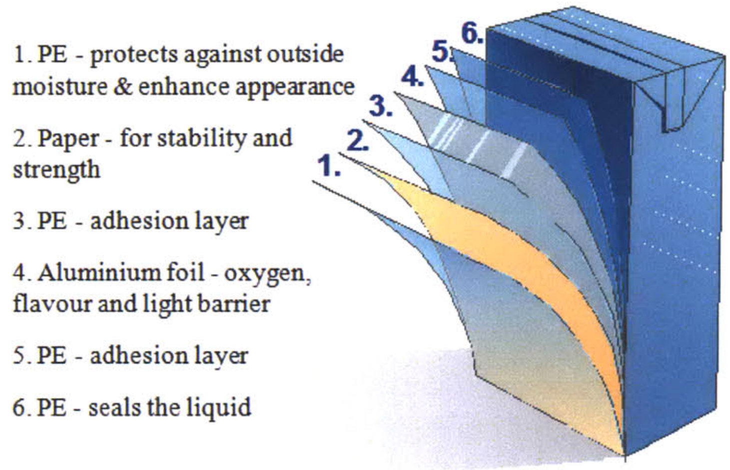

Figure 2: The Different Layers of a Package.

There are 10 classes of packages available. They are Brik, Brik Aseptic, Prisma Aseptic, Gemina Aseptic, Fino Aseptic, Classic Aseptic, Wedge Aseptic, Rex, Top and Recart. Different sizes are offered for each class of package, while the polyethylene layers are different for different carton content.

Currently, different products are distinguished by the system code, size code, quality code and design code. The system code defines the class of the package, which describes whether the carton is aseptic, refrigerated or ambient. Different classes require different creasing in the printing stage. System codes also have a suffix indicating the content of the carton (juice or milk), which would affect the laminating stage since different contents require different polyethylene formulations. The size codes indicate the volume of liquid contained by the package and its shape (slim, base, square). Thus it describes two attributes and affects the printing, slitting process and sorting on the laminator. Products with the same size code would have same overall width and therefore, same number of webs. Quality codes determine the type, thickness in grams per square meter and the brand of paper used. Lastly, design codes describe a single attribute that is the design of the product.

Compared with other factories of company A, CAS offers a large range of different CA pack products. Currently, around 20 different products of different package classes, carton sizes and polyethylene formulations can be produced in CAS.

1.4. Markets and Customers

Positioned in Singapore, CAS efficiently serves customers in the South and South East Asia cluster. There are also customers from Europe and the Middle East. In total, CAS ships its finished products to customers in 19 different countries, as shown in Figure 3.

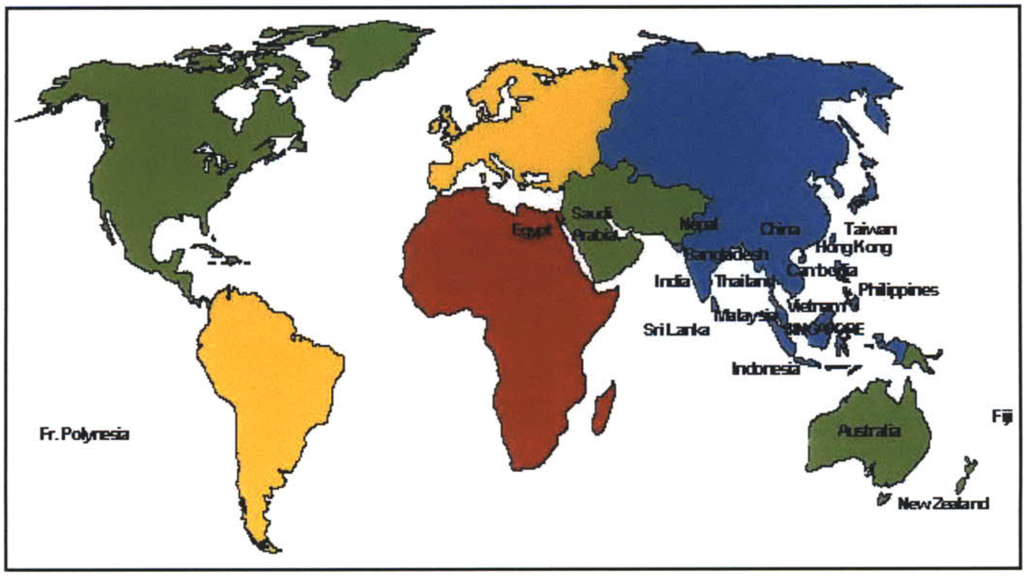

Figure 3: Markets Served by Company A.

The customers of CAS currently need to place their orders through a Tetra Pak market company. The market company has a sales office in the customers' respective country. They take orders from beverage producing companies and then receive and distribute the finished products to the customers.

Currently, the Thailand market is the largest by volume, followed by Malaysia, Indonesia and Vietnam. Most of the products are shipped to the customers by sea. At the moment, only the Malaysia market is being served by truck freight. For most shipping routes, the containers are only picked up from Singapore ports twice a week and the shipping dates are fixed. For example, for the case of the Thailand market, finished goods are shipped out on every Tuesday and Saturday. For the Malaysia market, the freight truck delivers orders from CAS everyday. The details are documented in Table 1.1 below.

Table 1: Shipping Schedules.

Country	Shipping Dates	Country	Shipping Dates
Australia	Thu, Sun	New Zealand	Tue, Thu
China	Mon, Thu	Pakistan	Mon
Hong Kong	Tue, Sat	Philippines	Tue, Sat
Indonesia	Thu, Sun	Saudi Arabia	Tue
Japan	Sat	Sri Lanka	Fri
Korean	Mon, Fri	Taiwan	Mon, Wed
Malaysia	Daily	Thailand	Tue, Sat
Nepal	Mon	Viet Nam	Mon, Wed, Thu

From Table 1.1, one can see that the shipping to most markets is twice a week. For Malaysia market, daily delivery is done by truck freight.

1.5. Company A, Singapore, Operations

The core corporate functions of CAS are the design, production, planning and purchasing departments. There is also a market company operating in CAS' premises and this is an independent entity from CAS. The market company is responsible for order management and customer service. CAS' warehouse and delivery operations are outsourced to a third party logistic company. An order flow diagram is illustrated below in Figure 4 to aid in the explanation of the process of orders in CAS.

Figure 4: Order Flow Diagram.

1.5.1. Design Department

After the customers' designs have been submitted to CAS's design department, the design department reviews and adapts these designs to suit CAS's production systems. When faced with difficulty, the customers do receive assistance from the design department in designing the carton. Once the design is confirmed, the design is broken down according to the component colors. The process colors are Cyan (C), magenta (M), yellow (Y) and black or key (K). Special or spot colors may also be used to obtain specific shades of color. The number of spot colors can vary from none to seven. A sales order can only be made once the design is confirmed.

1.5.2. Planning Department

The planning department at CAS is responsible for materials planning and production planning.

1.5.2.1. Materials Planning

Materials Requirement Planning does the ordering of the raw materials needed for production. The base materials ordered are paper, polyethylene and aluminum foil with many types of variants in terms of grade and size. The purchasing department is responsible for acquiring the additional materials such as water based inks, pallets and tapes that are used for production as they are relatively low volume and low cost.

Company A International (CAI) is the parent body of CAS. CAI issues the annual global forecasts for number of packs and marketing directives. CAI's Global Supply places blanket orders on the basis of the annual forecast for each of the converting factories with the suppliers in order to obtain economies of scale and to pool the variation in demand. The converting factories then place the actual orders with the suppliers to withdraw from the blanket order placed initially.

In addition, monthly forecasts are also issued and updated regularly. As the lead time of raw materials is very long, the ordering is done well in advance. The ordering is done on a weekly basis as this time period coincides with the frequency of dispatch. A continuous review method is used to determine the order quantities. The re-order point is set at approximately 40% of the monthly demand while the order up-to point is around 60% of the monthly demand.

1.5.2.2. Production Planning

The production system of CAS is a make-to-order one. The production schedule is drafted only upon receipt of a production order from the sales department. The scheduling is done on the SAP based CAS computer planning P2 system and the current production lead time is around 12 days. Planning is based on the delivery due date. . CAS uses three core machines for their processes. They are the printer, laminator, and slitter. On each of type of machines, the orders are grouped together based on certain criteria to minimize setups. The grouping for the printer is done on the basis of size and shape. The criterion for the laminator is the overall width of the roll. Lastly, the slitter orders are arranged based on pack width.

A block scheduling system is used to plan the production schedule. In this collaborative planning, the planning department generates a weekly production schedule with blocks according to width of the paper rolls. This is to reduce the number of setups at the laminator. Customer orders are then fit into the blocks. The latest order date for the customers is 4 days before the production cycle starts. The production cycle starts on every Monday. Thus, the customers must place their orders by Thursday of the previous week. The estimated delivery date is 3 days after the end of the production cycle. Therefore, the products will be ready on the Wednesday after the production cycle. The customers will be able to place orders many weeks earlier. However, when the orders are placed too early, the orders would be kept in the system and be produced in the subsequent production cycles. An illustration of the block planning system in days is shown below in Figure 5.

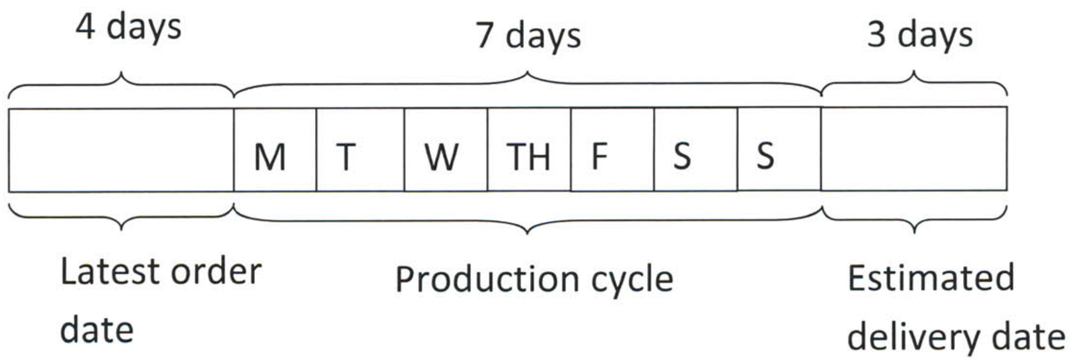

Figure 5: Block Planning System.

However, some customers tend to place rush orders. These orders are urgent orders that are placed within 1 to 3 days before the start of the production cycle in which it needs to be produced. Rush orders create disruptions to the planned production schedule. These last minute orders are rush orders which lower equipment efficiency. Also, when the current production schedule has been completed ahead of time, the planning department would also bring forward some orders to fill up the empty block in the block schedule. By doing this, the equipment efficiency is improved but advanced production will also result in higher work in process (WIP) and finished goods inventory.

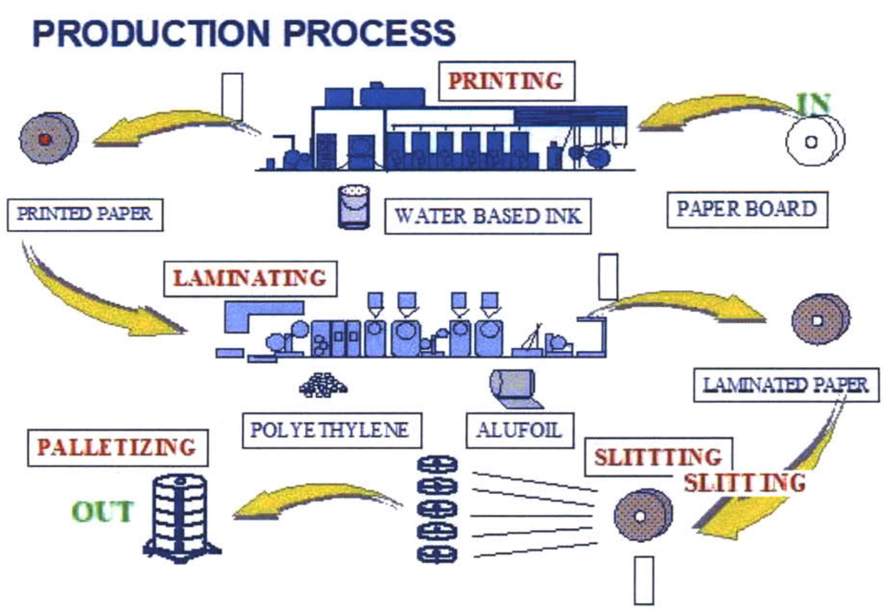

Figure 6: An Overview of the Manufacturing Processes.

1.5.3. Production Department

The Production Department performs the major manufacturing processes to produce the packing materials. The 3 major processes in CAS are printing, laminating and slitting. Before printing, a pre-press process has to be carried out, and after slitting, a doctoring process sometimes needs to be done. An overview of all the production processes is shown in Figure 6.

1.5.3.1. Pre-Press Process

This is the first stage in the production process. In the pre-press stage, the clichés for printing are prepared from the negatives. The clichés are polymeric stamps with elevated portions for the areas to be printed. These clichés are prepared on photopolymer plates through a process of controlled exposure to UV light. There will be a cliché prepared for each color used for printing. After which, the clichés are mounted onto a sleeve with a rotating spindle. The number of clichés mounted on one sleeve depends on the width of the individual pack and the paper roll. This corresponds to the number of webs. A cliché used for printing is shown below in Figure 7. Figure 8 shows the mounted sleeves.

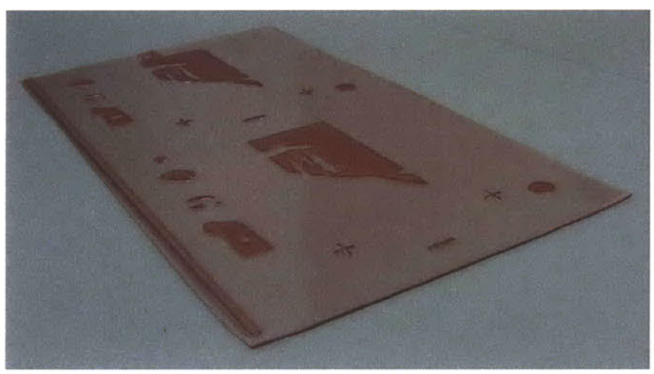

Figure 7: Cliché Used For Printing.

Figure 8: Mounted Sleeves.

1.5.3.2. Printing Process

In the printing stage, the flexography method is used. This is a method of direct rotary printing that uses resilient relief image plates of photopolymer material. The design pattern on the clichés is reproduced onto the paper board by rotary contact of the paper roll with the stamp. Water based ink is used. The incoming paper roll is loaded on the un-winder, which opens it up and feeds it to the printing stations. An illustration is shown in Figure 9.

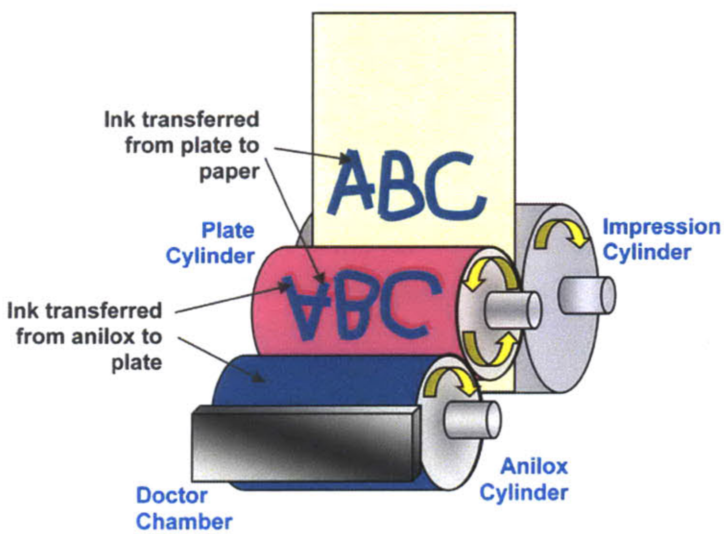

Figure 9: The Printing Process.

There are seven stations on the printer. Each station holds the sleeves and the water based inks for one of the colors of the design. Depending on the design colors, some of the stations may be idle for a design as not all colors are used for every design. A colored image is formed by 4 process colors, Cyan (C), magenta (M), yellow (Y) and black or key (K). The different colors are then superimposed one over the other to get the complete final printed design.

Fold creases for the produced cartons are also formed during the printing process. The purpose of creasing is to enable proper folding of the pack during the filling stage at the customer site. The tool is used to form creases and also to punch the holes for straws. For routine printing, flexographic technology is used. For higher resolution designs, CAS uses offset printing, which is more expensive compared to flexography.

Machine Speeds

There are two printers in CAS, Printer 13 (P13) and Printer 18 (P18). The 2 printers are identical and hence have the same operating machine speeds. Both printers can run from 300m/min to 600m/min.

Failure Rates

The mean time between failures (MTBF) and average mean time to repair (MTTR) in minutes for January to April 2010 are shown below in Table 1.2.

Table 2: Printer Failure Rates.

	MTBF (Minutes)	MTTR (Minutes)
P13	13,964	61
P18	12,570	63

Setups

Setups at the printing process occur for every order that requires a change of the sleeves at the different print stations. A change of sleeves is needed for each change in design. The old sleeves must be taken out first, followed by the mounting of the sleeves with the new designs. The average time to change a sleeve is 14.3 minutes. The sleeves at different color station could be changed concurrently. In addition, a setup also has to be done whenever there is a change in the packaging system of the product. For this, there needs to be a change of the creasing tool. The average time to change a creasing tool is 33.5 minutes.

Sequence

The optimum sequence of the products being printed is planned based on size and shape. This is to reduce the amount of setups due to the change of creasing tools which take a relatively long time.

1.5.3.3. Laminating Process

Laminating involves the coating of aluminum foil and polyethylene (PE) layers onto the printed paper. A roll is first unwound at the unwinder. It then goes through three stations for the coating process. The last step is to rewind the laminated paper into a roll. In the first station, a layer of aluminum foil is layered onto the printed paper. After which, PE film is coated in the inner surface of the packaging material to prevent contamination and leakage. The final station adds another layer of PE on the outer surface of the packaging material to protect the paper. This process is shown in Figure 10.

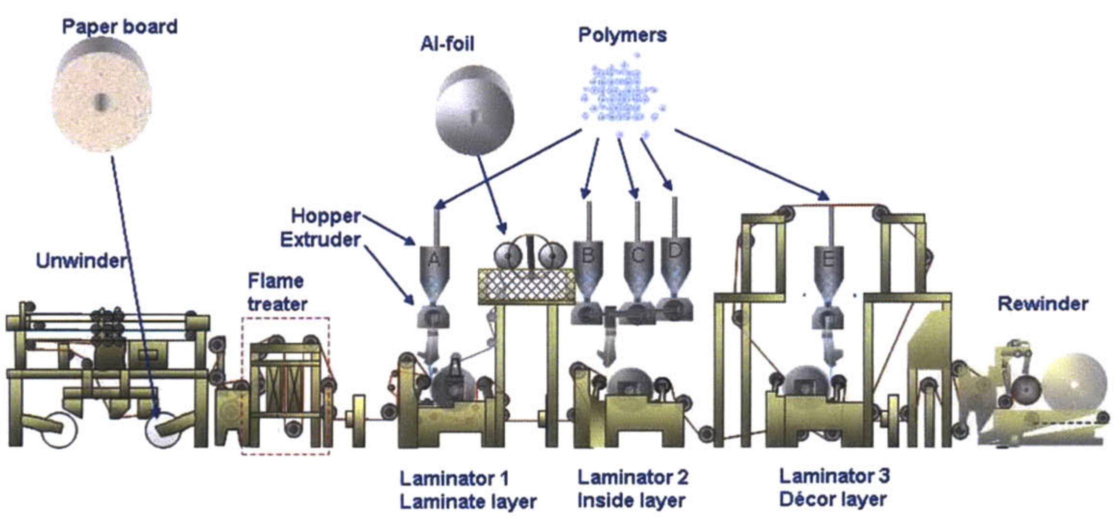

Figure 10: The Laminating Process.

Machine speeds

There are two laminators in company A. Laminator 21 (L21) and laminator 22 (L22) have different operating machine speed. The two laminators can only run at a specific range of speed in order to produce quality layers. L21 can run from 300m/min to 430m/min while L22 can run from 350m/min to 600m/min. The laminators are not run at the fastest speed as CAS wants to keep the laminator on continuously until a breakdown or a planned maintenance occurs. This is because starting up a laminator incurs a huge drooling waste cost of approximately S$8,820 each time. This drooling waste cost is the cost of wasted PE that is not used until the machine stabilizes. Therefore, the laminators are run at a speed corresponding to the amount of orders to be processed each week, to prevent the laminators from being idle at anytime.

Failure rates

The mean time between failures (MTBF) and average mean time to repair (MTTR) in minutes for January to April 2010 are shown below in Table 1.3.

Table 3: Laminator Failure Rates.

	MTBF (Minutes)	MTTR (Minutes)
L21	13,011	57
L22	11,185	65

Setups

There are two major product families – juice and milk. They account for about 97% of all the products. L21 can only produce juice products while L22 can produce both juice and milk products. Low density PE is used for milk products while high density PE is used for juice products. Within a product family, the laminator could use the same setup as the materials used for the layers are the same. When there is a change in the product family, a major setup change is required to change the type of layers used. This setup would take 40 minutes. A minor setup is required within a product family due to the different width of coating required. The setup time required for the change in width is sequence dependent. When the width is changed from narrow to wide, the setup time is 30 minutes. When the width is changed from wide to narrow, the setup time is 20 minutes.

L22 has the ability to do a setup in approximately 0 minutes when the width change is from wide to narrow and the width change is less than 20mm. This is called the flying setup. The flying setup permits the changeover without having to stop the machine. It only requires the machine to reduce its run speed, change the size of extruder and sleeves, then ramp up the run speed again. Thus, there is negligible time lost in the setup. The setup time is shown in Table 1.4. The PE is made to flow continuously during the setups so that the layer can reached the required quality. However, the PE is wasted during the setup since the PE is not coated onto the paper. The wasted PE is called drooling waste. The drooling waste is 48.90 Singapore dollars per minute.

Table 4: Setup Time on Laminator 21 and Laminator 22.

Type of setup	L21 Setup time (minutes)	L22 Setup time (minutes)
Product family	40	40
Width (narrow to wide)	30	30
Width (wide to narrow, >20mm)	20	20
Width (wide to narrow, <20mm)	20	0 (flying setup)

Sequence

The sequence of the production is planned to minimize the setup in the laminating stage. This is due to the high cost of drooling waste. The printer and slitting stations do not have setups that have significant costs. The production sequence is to first group the product families together. Secondly, within the product family, the products are arranged from the widest to the narrowest. The printing and slitting stations production sequence follow this laminating sequence.

1.5.3.4. Slitting Process

The paper roll can have 4, 5, 6, 7, 8 or 9 webs (columns) depending on the product size. The slitting process cuts the entire roll into reels of a single pack width so that they can be fed into the filling machines at customer production plant. The rolls are unwound, slit using a row of knives and counter-knives and then rewound to form reels. The reels are then grouped into defective reels and non-defective reels. Defective reels are reels that consist of at least one defect and these reels need to go through the doctoring process to have the defects removed. A schematic diagram of slitting process is shown in Figure 11.

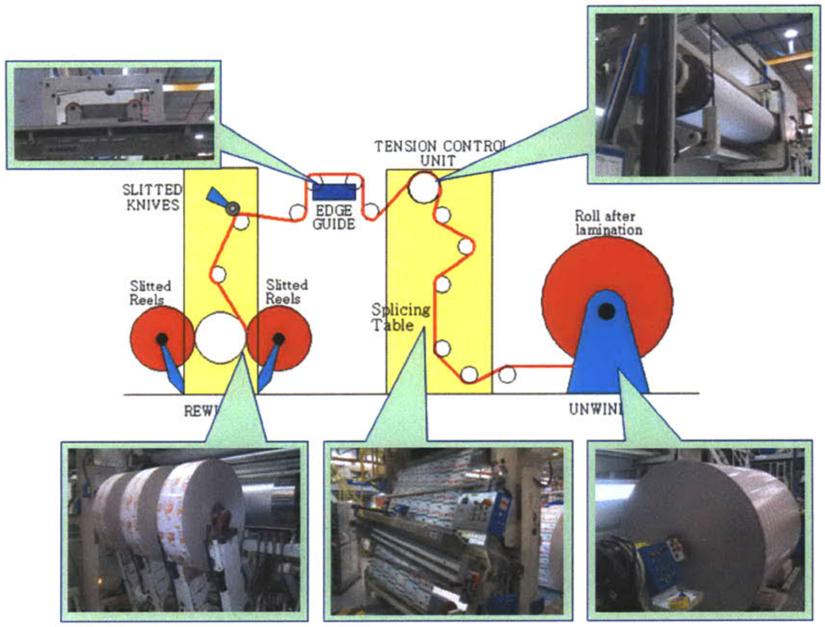

Figure 11: Process of Slitting Station.

Machine speeds

There are 4 slitters in Company A. The minimum, maximum and the current average run speed is shown in Table 1.5. The machine speed of the slitters is much faster as compared to that of the printing and laminating stations. However, the current average run speeds are much lower than their maximum speeds. The slitters are not run at the maximum speeds at all times because there is a need to ramp-up and ramp-down the slitters during the slitting process. Hence, at certain times the slitters are running at a high speed, and certain times at a lower speed. This is a requirement for the slitters to work.

Table 5: Machine Speed for Four Slitters.

	S52	S53	S54	S55
Minimum speed (m/min)	30	30	30	30
Maximum speed (m/min)	1000	800	1000	1200
Current Average run speed (m/min)	232	227	240	251

Failure rate

The mean time between failures (MTBF) and average mean time to repair (MTTR) in minutes for January to April 2010 are shown below in Table 1.6.

Table 6: Slitter Failure Rates.

	MTBF (Minutes)	MTTR (Minutes)
S52	15,982	11
S53	18,548	9.5
S54	19,403	9
S55	18,001	6.5

Setup

The types of products that can be slit by each of the four slitters are shown in Table 1.7. Slitter S54 and S55 can slit any type products. However, there are some limitations on slitter S52 and S53. A highlighted cell means that the slitter is able to produce that particular product.

Table 7: Type of Products that can be Slit by Each Slitter.

Products	S52	S53	S54	S55
250 Mini				
125 Slim				
1000 Square				
200 ml				
250 ml				
300 Slim				
330 Slim				
200 Mid				
250 Slim				
1000 Slim				
200 Slim				
375 Slim				
200 Mini				
250 Mini				

1000 Square				
200 ml				
250 ml				
330 Midi				
500 Midi				
1000 Slim				
200 Slim				
375 Slim				
1000 Carton Bottle				

Two types of setup can occur at the slitter stations and the setup time is the same for any slitter. The first is the change of the number of webs to be slit. This would involve the positioning of unwinder and rewinder arms, changing of knives and counter-knives and it would take 60 minutes. The second type of setup is due to the difference in the stiffness of paper board. This would involve the positioning of knives, counter-knives and rewinder arms and it would take 15 minutes.

Sequence

The optimum sequence of the slitting process is to have products of the same width grouped together to minimize the setup. The sequence dictated by the laminating process has already grouped products of the same width together from widest to narrowest. Thus, there is no conflict of the optimum sequence between the laminating and the slitting stage.

1.5.3.5. Doctoring Process

After the slitting process, the defective and non-defective reels are separated. The non-defective reels would be kept at the shop floor and the defective reels would be doctored. Doctoring or rework is the process of removing the packs with defects from the reels. Approximately 30% of the reels require doctoring. These defects are due to any of the upstream processes and they are removed collectively at this stage. There are 14 doctoring stations after the slitting process. Each doctoring station would have an operator to find the defects and remove them using a machine. If a defect is spotted at any point along the length of a reel, the defect would be removed together with parts of the reel within 5 meters in length on either side of the defect. One reel could be doctored every 24 minutes on average by an operator. However, as it is more of a manual process, the doctoring of a reel could take up to 2 hours.

1.5.3.6. Palletizing Process

The doctored reels would join the good reels to be palletized. Palletizing is the process of stacking reels together on a pallet and wrapped with a plastic layer. There would be 6 reels on the pallet on average. The palletizing time is 8 minutes. The palletized reels would be transported to the warehouse and await delivery. These palletized reels are handled solely by a third party logistics company from this point onwards.

1.5.4. Storage and Warehousing

CAS' in-house warehouse is shared among raw materials; work in process (WIP) and part of total finish good inventory (FGI). Currently, the in-house warehouse is managed by a third-party logistics company.

The current daily FGI level is around 1000 rolls (converted from pallets), among which up to 600 rolls are stored in the internal warehouse. Each roll is approximately 5513 meters long and it takes up about 3 pallets. The current daily FGI level of about 1000 rolls is approximately equal to about 6 to 7 days of inventory as CAS produces approximately 130 to 150 rolls per day on average. The external warehouse is engaged when there is not enough space. The floor layout and capacity for each category of inventories are illustrated in Figure 1.12. As we can see from the figure, the full capacity for WIP is approximately 500 rolls only. Yet currently, average WIP levels can reach over 1000 rolls, not including raw material rolls. The raw material rolls are stored in a huge container yard beside the warehouse and it can hold up to 800 rolls of raw material.

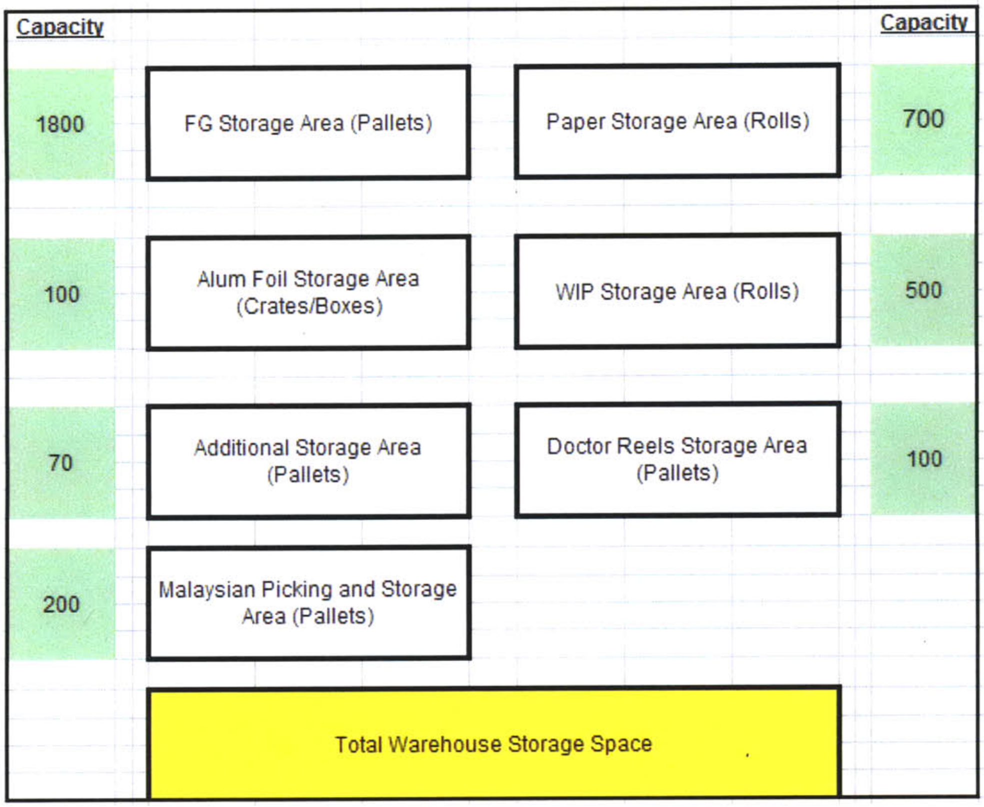

Figure 12: Capacity of Warehouse.

The movement of raw material, WIP and FGI between the production floor and in-house warehouse is facilitated by the laser guided vehicles (LGVs). These vehicles can move a roll at a time and they are programmed to follow a specific route. Forklifts and clamp trucks are used for the movements of the rolls within the in-house warehouse.

1.5.5. Purchasing Department

The purchasing department at CAS is responsible for the purchase of additional materials and indirect services. Examples of additional materials include inks, pallets, cores, straws etc. Indirect services mainly refer to equipment maintenance, electricity, and water utilities. The base materials comprise 60% of the total monetary value spent by the purchasing department, while additional materials and indirect services make up the remaining 40%. There are more than 10 suppliers for the additional materials and more than 500 providers for indirect services. The purchasing department reviews all the suppliers regularly and will provide assistance when the suppliers are underperforming. The purchasing department has a well-established system to source for alternative suppliers. Hence, suppliers who consistently underperform will be substituted.

Chapter 2 Problem Statement

2.1. Problem Description

High WIP

Due to increase in demand, CAS has been producing over 4800 rolls per month since March 2010. CAS' marketing company has projected that sales will be growing at 12 percent annually. Therefore, CAS needs to produce over 5300 rolls by March 2011. Due to the increasing throughput, CAS' WIP has been continuously increasing. Currently it has an average WIP inventory of 4 days between the printing process and laminating process. The WIP between the laminating process and slitting process is around 2 days inventory on average. All the WIP is stored in CAS' internal warehouse. Apart from storing WIP, CAS' internal warehouse also stores part of the raw paper and finish goods. Fixed space is assigned for each inventory categories. However, due to the increase in the WIP level, the in-house warehouse has already reached its full capacity. Therefore, CAS needs to modify its production system in order to reduce its WIP level to be able to accommodate all its inventories.

Long Lead Time

Currently, there is a total customer lead time of 12 days. The production lead time takes up about 10 of these 12 days. This long lead time is mainly due to the long waiting time between processes. The current practice at CAS is to transport all WIP into the warehouse to be stored after each process is completed. Only when the next process is ready to be carried out would the WIP then be transported back onto the factory floor. An illustration of the lead time is shown below in Figure 13.

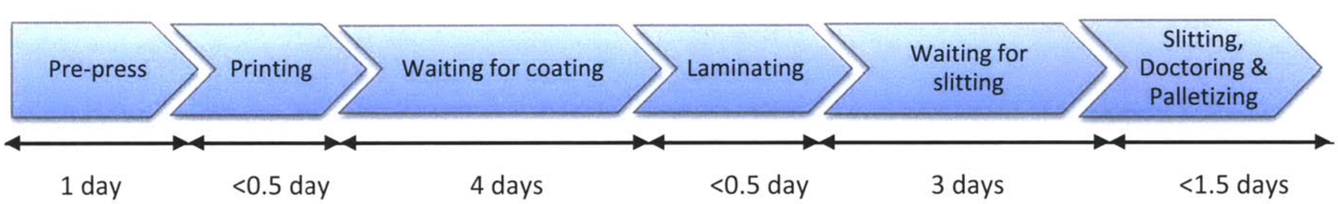

Figure 13: Production Lead Time.

Furthermore, there is a high risk of customers switching to competitors for their shorter lead time. Hence, this long customer lead time of 12 days is a problem for CAS.

Complexity

The products are highly customized. Thus, there are many different kinds of products. The current production process is a mixed flow process such that a product can flow to almost any station downstream. This mixed flow production process is shown below in Figure 2.2. The boxes represent machines, the triangles represent WIP inventories and the arrows represent where the products can flow after each process and after being stored as WIP. Thus any sequence of machines is possible.

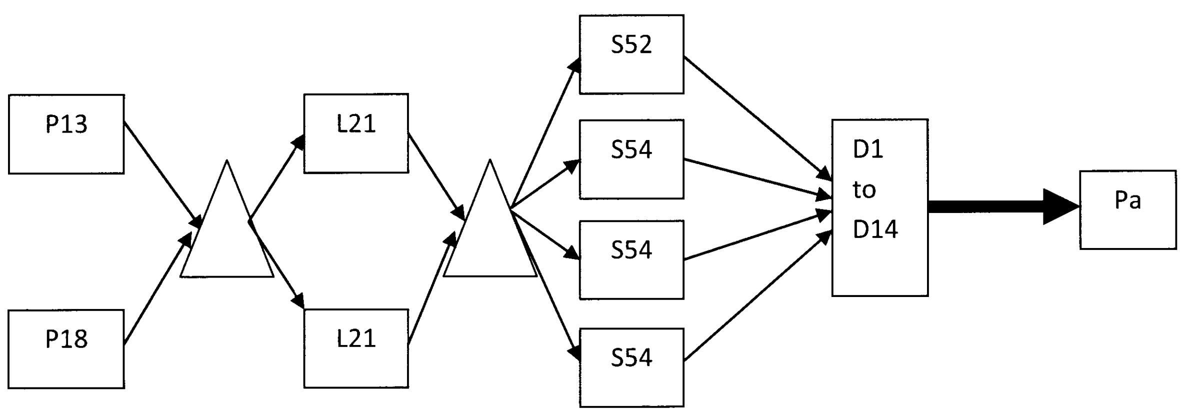

Figure 14: Current Mixed Flow Production Process

The allocation and sequencing of the products is a manual process. It is highly dependent on the judgment of the planner. There would be cases where customers placed rush orders and these orders have to be inserted into the planned sequence. It is difficult to insert such orders as the planner has to plan a new production route for these orders. Since it is a mixed flow production, the rush orders affect the production of other orders.

2.2. Project Objective

In this project, the author aims to improve the manufacturing system of CAS by the following means:

- Reduce the high level of WIP to a suitable level which the CAS' internal warehouse can accommodate.

- Improve the customer lead time so that CAS can stay competitive in this aspect.
- Reduce the complexity of the production system so that easier planning can be done.

2.3. Scope of project

This project only concerns CAS and is only aimed to benefit CAS. All data provided by the author are pertaining to manufacturing in the CAS factory alone. The project consists of 2 parts. The first part is done together as a group of 3 authors. The second part will consist of each of the authors' own individual projects.

CAS has recently redesigned their production system. The new production system is composed of two dedicated production lines. They have restricted products flow between the lines. Different sizes of packaging products will be assigned to one production line only. Therefore, a good resource allocation plan and product grouping are needed to maximize the benefit of the new production system.

Currently, CAS has designed a production grouping to ensure the key sizes packaging products have smooth production. Therefore, sizes 200 Slim, 250 Slim, 200 Mid and 1000 Slim which are ordered by CAS's key customers at fairly constant rates will be produced on the production line with fewer changeovers. All the remaining sizes of packaging products and rush orders will be produced by the more flexible production line. The grouping designed by CAS is fixed and CAS does not intend to modify it regularly. Therefore, the grouping will stay the same for each production cycle even though the demand volume and product mix might change. Without the optimization process, it is hard for the fixed grouping to achieve minimal total setup time. Also, as the grouping is determined based on experience, it is possible the fixed grouping could overload the production lines.

It is necessary to design an effective product grouping method to cater to fluctuating weekly demand and allow for regrouping when needed. Through this grouping method, setups should be minimized while production lead time remains constant. In this thesis, the author reviews the state-of-the-art product grouping methods (Chapter 3) and proposes a linear program to group the products grouping for CAS and achieve minimal total setup time for given demand mix (Chapter 4).

Chapter 3 Literature Review

3.1. Production in Make-to-Order Manufacturing

Different from make-to-stock manufacturer, a make-to-order (MTO) manufacturer only produces when it receives an order from customers. Therefore, make-to-order manufacturers do not carry uncommitted finished goods inventory to meet demand. However, one common challenge a MTO manufacturer might encounter would be adjusting the level of work-in-process (WIP) [1].

In MTO sector, it may be difficult to make accurate demand forecasts. It is also not easy to come up with the optimal product grouping, particularly because the demand mix is not accurate during the planning stage [2]. At the meantime, MTO manufacturer needs to keep its lead time as short as possible to remain competitive.

Production planning is the activity of making the aggregate plan for utilizing resources and material to meet customer orders. Planning and scheduling determine the flow of material and allocation of resources in order to fulfill future demand and orders [3]. Traditional production planning is usually based on lead time estimation and Material Requirements Planning (MRP) [4]. Estimates are based on past experience rather than the actual orders. Therefore, it is particularly difficult for MTO manufacturer to make optimized production plan due to hard-to-predict demand and numerous product families. Here, the resources usually refer to machine or human resources that are shared by different production activities.

Scheduling is responsible for making detailed schedules set by production plans. Apart from satisfying various resources and timing constraints, the solution should be designed to minimize the maximal tardiness and cost associated with production. If global optimal scheduling method is hard to achieve, a close-to-optimal heuristic solution should be proposed and followed.

CAS offers a wide range of products. It has more than twenty different sizes of products. At the meantime, due to different lamination formulation, there could be over forty different types of products for the laminating process. For CAS, its numerous product groups and fluctuating demand for each production cycle make it hard to follow a unique strict grouping method. Currently, CAS is quoting a 12-day lead time to customer by estimation and past production experience though weekly demand and machine load fluctuation. Since CAS has adequate labor resources, we will only take machine resources into consideration as constraints for the proposed scheduling method.

3.2. Production Grouping Models

Production grouping has been studied by many researchers. K. L. Mak and Y. S. Wong [5] have discussed product grouping and resource allocation in their research. They studied product grouping in a Make to Stock context where multiple production lines were used. One kind of product can only be produced on one line. With a goal of minimizing total production cost, they developed a mathematical model to determine the optimal number of product groups that should be formed and the composition of each product group. A genetic-based algorithm was proposed to solve the product grouping problem. However, Mak and Wong did not extend their study into MTO context. Also, if there are numerous product groups, it may take a substantial amount of time for the genetic-based algorithm to search for the global optimal grouping.

Maria Antonia Carravilla and Jorge Pinho [6] de Sousa studied complex production planning in a Make-to-Order company with three production lines. They developed a mathematical model to determine the optimal production grouping with the goal of minimizing setups and production lead time. They designed a Decision Support System composed of a package of software products employing algorithms. However, the developed prototype is not available for CAS to use. Also, with no sub-contractor, the Decision Support System may not be appropriate for CAS.

William M. Feld proposed an alternate way of product grouping [7]. The product demand data should be gathered and analyzed. The source of information usually comes from business plan forecast and should be compared with actual customer order sales data. The products could be sorted by their associated volumes or the alignment characteristics. The alignment characteristics include volume, customers, target markets, common manufacturing processes, configuration commonality and engineering content. If the products are sorted by volume, they could be categorized as runners, repeaters and strangers. Runners have stable demands, frequent customer orders and take up large part of the total volume. Dedicated flow lines/cells with segregated resources should be set up for them. Repeaters have lower volume, variable order frequency category and do not require a dedicated flow line. Strangers have very low volume or infrequent demand pattern and could be produced once or twice per month. In this thesis, Feld method was applied and a grouping tree will be developed for CAS. The grouping result would be compared with the method developed in the thesis.

3.3. Linear Programming

Linear programming is a mathematical method widely used for finding optimal outcome in a model with list of constraints represented as linear equations. It is extensively used in business and economics. Linear programming could also be employed in manufacturing problems including planning, routing, scheduling and assignment to find best result for the objective function when all the requirements are linear. The first linear programming problems were developed by Leonid Kantorovich in 1939. However, for complex network flow and multi-commodity flow problems, specialized algorithms have been developed for their solutions.

Chapter 4 Methodology

The aim of this study is to develop an efficient yet simple method for CAS to group its products for production. The method aims to generate the optimal product grouping with the minimum total setup time in production. Therefore, the cost associated with setup will also be minimized when optimal production grouping is achieved.

CAS production system is divided into two dedicated production lines. Each line is composed of one printer and one laminator. Four slitters are assigned with specific product sizes. Therefore, the slitting process will not be affected by the product grouping. As a result, slitters are not considered in this model. Compared with printing setups, the setups in lamination are longer and more costly. According to CAS costs for WCM Costs / Benefits Analysis TG2010 [8], polyethylene and aluminum foil wasted during setups in lamination account for around 40% of the total annual waste. With this in mind, we will determine the production sequence and grouping to minimize the total lamination setup time. The production grouping and production sequence for both the printing process and the slitting process will be the same as those of lamination.

In the lamination process, changeover from a wider paper roll to a narrower paper roll requires less time than changeover from a narrower paper roll to a wider paper roll. Therefore, the product groups used in both the mathematical model and the grouping guidelines are arranged according to paper roll width descending order. This is the same as CAS current planning practice.

4.1. System Modeling

In this paper, we took the constraint-based approach [9] to model the CAS grouping problem. A resource-constrained grouping mathematical model was constructed.

The planning cycle used in the model was set as one week, same as the production cycle. The two laminators have different capabilities and capacities. In the two-dedicated-line production system, laminator 21 was assigned to line 0 and laminator 22 to line 1. Due to machine capability limitation, milk products and odd size products can only be produced on laminator 22. Therefore, only juice product groups were considered in the grouping model. Since the product groups were arranged according to paper roll width descending order, the setup times in the model only include changeovers from wider paper roll to narrower paper roll. The average running speed for both laminators is used in the model to account for the effects of speeding up and down due to setups.

4.1.1. Assumptions for the model

Assumptions for the grouping model include:

1. All laminators are considered stable and the machine failure rates are considered constant.
2. The operators on both lines have the same level of operating skills and will not affect machine performance.
3. There is no rush order entertained.

4.1.2. Mathematical model

The following notations are used for the formulation of the model:

Indices

$i \in [1,2, \dots, J]$ – size group of product

$j \in [2,3, \dots, J]$ – size group of product

$g \in [0,1]$ – production line g

Variables

D_i – demand for each size of packaging products

C_g – available production capacity for production line g

$J -$ number of size groups ordered in that production cycle

Process dependent parameters

$T_{i,j}^{g}$- Setup time between size groups on production line g

Decision Variables

$x(i,j)$- binary variable that specifies the sequence of product groups on line 0

$y(i,j)$ – binary variable that specifies the sequence of product groups on line 1

Constraints

Each size of the packaging products is only processed on one production line.

$$\sum_{j>i}^{J}[x(i,j) + y(i,j)] = 1, i \in [1,J). \quad (1)$$

Workload on each production line cannot exceed the capacity of the line.

$$C_0 \geq \sum_{i=1}^{J-1} D_i \, [\sum_{j=i}^{J} x(i,j)]. \quad (2)$$

$$C_1 \geq \sum_{i=1}^{J-1} D_i \, [\sum_{j=i}^{J} y(i,j)]. \quad (3)$$

The flow on each production line must be consistent. Inflow should equal to outflow on each line.

$$\sum_{k<i} x(k,i) = \sum_{j>i} x(i,j), \; i\epsilon(1,J). \quad (4)$$

$$\sum_{k<i} y(k,i) = \sum_{j>i} y(i,j), \; i\epsilon(i,J). \quad (5)$$

Both production lines need to be utilized. There must be at least one product produced on both production lines. Variable number of product groups on both lines is allowed since there is no constraint. Also, there is no maximum setup limitation.

The inflow and outflow of production line 0 should be 1.

$$\sum_{j>0}^{J} x(0,j) = 1. \quad (6)$$

$$\sum_{j>0}^{J} x(j,J) = 1. \quad (7)$$

The inflow and outflow of production line 1 should be 1.

$$\sum_{j>0}^{J} y(0,j) = 1. \quad (8)$$

$$\sum_{j>0}^{J} y(j,J) = 1. \quad (9)$$

4.1.3. Objective function

The objective function minimizes the total lamination setup time.

$$\textbf{\textit{Minimize}}: \sum_{i=1}^{J-1} \sum_{j>i}^{J}[x(i,j)T_{i,j}^{0} + y(i,j)T_{i,j}^{1}] \quad (10)$$

By changing the demand and the product mix, values of respective terms in the objective function will change accordingly and we will get different grouping results. This model allows CAS to modify product grouping when different order pattern is received every planning cycle.

Since all the decision variables are binary and all constrains are linear, this makes our problem a binary integer linear program. The Solver in Microsoft Excel 2007 will be used to search for the optimal result for our model.

4.1.4. The production sequencing

The sequencing problem is also addressed in the model. Since the product groups were arranged in paper roll width descending order, the output of the model is the final production sequence.

4.2. Data Extraction

The data used in this thesis was obtained from CAS planning department and lamination production department. In the analysis, the real demands received from week 5 to week 8 year 2010 were used.

The demands were grouped into juice, milk and odd size packaging products. The milk and odd size packaging product orders were assigned to production line 1 due to machine capability limitation. Then the juice packaging products were arranged according to size and descending paper roll width.

Chapter 5 Results and Discussion

5.1. Mathematical Model Grouping Results

We used the past order data from week 5 to week 8 to test the mathematical model. The optimal grouping results obtained were discussed and compared with current grouping used by CAS.

5.1.1. Excel 2007 Solver and data extraction

Since all constraints in the mathematical model are linear and all the decision variables $X(i,j)$ and $Y(i,j)$ are binary, our problem is a binary integer linear program. Microsoft Excel 2007 Solver was used to solve this optimization problem.

Excel 2007 Solver allows users to solve a linear optimization model by creating the target cell, the changing cells and the constraints. [x] The target cell is set to be our objective function—the total setup time. The changing cells are the decision variables in our mathematical model. When setting the constraints, apart from the constraints we listed in Chapter 4, all the decision variables need to be set as binary variables. This could be achieved by setting all the variable cells as binary variables with the "Add Constraints" option. The Excel 2007 Solver allows an optimization model to have 200 decision variables and 400 constraints maximum. Since we shall have no more than 13 sizes of juice packaging products, the numbers of the decision variables and constraints will not exceed Excel 2007 Solver's limit. The optimization model was set to be "Linear" and "Not negative" under solver option since our optimization model is linear and positive.

The setup time data between different product groups on different lines were acquired from CAS lamination department. Although the setup times are random variables, we assume they are constants in this model and use their average values. The full setup time table for all juice packaging products could be found in Appendix B.

The available line capacity for each production line is calculated using the following formula:

$Available\ line\ capacity\ =$
$average\ laminating\ speed\ \times production\ time\ in\ one\ production\ cycle -$
$capacity\ assigned\ to\ other\ products$

The average laminating speed for laminator 21 is taken as 350 meters per minute while the average laminating speed for laminator 22 is taken as 550 meters per minute. The capacity assigned to other products refers to the capacity needed to produce milk and odd size products, and is different for every production cycle.

Actual line capacity was used in the model to take in the effect of the production line operating efficiency. In real production, it is often not possible for machine to be operating at its full capacity. Therefore, it is necessary to consider the line operating efficiency. Actual line capacity is calculated as:

$$Actual\ line\ capacity\ for\ one\ production\ cycle = Available\ line\ capacity\ \times Line\ efficiency$$

Here is an example of the available line capacity and actual line capacity calculation for line 0 with laminator 21. The average laminating speed is 350 meters per minute. The operating time in one production cycle is 10,080 minutes. The capacity assigned to other products is 0 meters. The production line operating efficiency is taken as 0.9.

$$Capacity\ for\ Line\ 0 = 350\ \frac{meters}{min} \times 10080\ \frac{min}{cycle} - capacity\ assigned\ to\ other\ products = 3528000\ meters$$

$$Actual\ line\ capacity\ for\ Line\ 0 = 3528000\ meters\ \times 0.9 = 3157200\ meters$$

5.1.2. Grouping Results

Demand for week 5, week 6, week 7 and week 8, 2010 was studied using the linear programming grouping model. The results obtained were studied and compared with CAS current grouping and grouping tree method (Section 5.2.).

For week 5, 12 different sizes of juice packaging product groups were ordered. The demand and capacity are in terms of meters as shown in Table 8. The production line operating efficiency for line 0 is 0.9 and for line 1 is 0.85. Line 1 has a lower operating efficiency due to the fact it has to entertain rush orders. This may slow down the production speed. The demand data were input into Microsoft Excel. The optimized production sequence and the minimal setup time were generated by the Solver. For week 5, the optimized setup time is 210 minutes. Product size 375 Slim and 200 Slim would be produced on line 0, taking up around 20% of the total demand of the week. The other 10 sizes of juice packaging products together with milk and odd size packaging products would be produced on line 1 through laminator 22.

Table 8: Week 5, 2010 Demand and Capacity

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	1,140,862	3,175,200	3,528,000	0.9
Line 1	3,612,132	3,999,941	4,705,813	0.85

Table 9: Week 5, 2010 Production Sequence

Week 5, 2010						
Size code	375 Slim	200 Slim	1000 Slim	200 Mid	250 Slim	300 Slim
Paper Size	1597	1574/6	1533	1512	1512	1506
Demand	89,286	1,051,576	591,367	271,489	900,206	551,779
Line 0	89286	1051576	0	0	0	0
Line 1	0	0	591367	271489	900206	551779
Size code	330 Slim	250 ml	200 ml	1000 Square	125 Slim	250 Mini
Paper Size	1506	1504/6	1504/6/8	1468	1466	1448
Demand	16,697	533,054	230,437	151,996	360,838	4,269
Line 0	0	0	0	0	0	0
Line 1	16697	533054	230437	151996	360838	4269

For week 6, 2010, only 6 different sizes of juice packaging products were ordered. The demand and capacity are shown in Table 10. The production line operating efficiency for line 0 is 0.9 and for line 1 is 0.85. After running the linear program model in Excel Solver, the minimal setup time obtained is 170 minutes. The production sequence and grouping results are shown in Table 11. Only size 200 Slim products are assigned to line 0 while the other five sizes are assigned to line 1. Line 0 would carry around 21% of the total demand while line 1 would carry around 79%. From Table 10, it is obvious that without further increase in capacity or line operating efficiency, line 1 can cater 100% of week 6 demand. If we allow production lines stay idle, we could obtain a 140 minutes total setup time and a total lower setup cost by assigning all the orders to line 1. By not operating production line 0, the startup cost for laminator 21 could also be saved.

Table 10: Week 6, 2010 Demand and Capacity

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	779,297	3,175,200	3,528,000	0.9
Line 1	2,591,415	4,483,037	5,274,161	0.85

Table 11: Week 6, 2010 Production Sequence

Week 6, 2010						
Size code	200 Slim	1000 Slim	200 Mid	250 Slim	1000 Square	125 Slim
Paper Size	1574/6	1533	1512	1512	1468	1466
Demand	779,296	471,825	211,200	963,480	135,660	809,250
Line 0	779,296	(0)	0	0	0	0
Line 1	0	471,825	211,200	963,480	135,660	809,250

In week 7 there were 11 different sizes of juice packaging products ordered. The demand of the week, line capacities and operating efficiency are shown in Table 12. The minimal setup time obtained in Excel Solver is 190 minutes. The production sequence and grouping results are shown in Table 13. Size 1000 Slim products would be produced on line 0 while all the other groups are assigned to line 1 with the paper roll width descending order. From Table 12 we can see that for week 7, the total amount of juice orders is 4,048,513 meters, which is smaller than the available capacity of line 1 (4,253,374 meters). As long as the line 1 operating efficiency is larger than 0.95, line 1 could entertain all the orders of week 7, 2010. This would generate a shorter total setup time of 150 minutes for week 7. If we allow production line 0 to stay idle and ensure an operating efficiency of 0.95 for production line 1, setup cost could be saved further.

Table 12: Week 7, 2010 Demand and Capacity

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	692,550	3,175,200	3,528,000	0.9
Line 1	3,355,963	3,615,368	4,253,374	0.85

Table 13: Week 7, 2010 Production Sequence

Week 7, 2010						
Size code	375 Slim	200 Slim	1000 Slim	200 Mid	250 Slim	300 Slim
Paper Size	1597	1574/6	1533	1512	1512	1506
Demand	-	2,441,883	692,550	155,520	613,645	397,575
Line 0	-	0	692,550	0	0	0
Line 1	-	2,441,883	(0)	155,520	613,645	397,575
Size code	330 Slim	250 ml	200 ml	1000 Square	125 Slim	250 Mini
Paper Size	1506	1504/6	1504/6/8	1468	1466	1448
Demand	20,880	512,857	523,600	73,017	1,051,050	7,818
Line 0	(0)	(0)	(0)	-	(0)	(0)
Line 1	20,880	512,857	523,600	73,017	1,051,050	7,818

Only 3 different sizes of juice packaging products were ordered during week 8. The demand of the week, line capacities and operating efficiency are shown in Table 14. After running the optimization model in Excel Solver, the minimal setup time obtained is 140 minutes. The production sequence and grouping results are shown in Table 15. Size 200 Slim products would be produced on line 0 and the other two sizes on line 1. We can see from Table 14 that the total demand of juice packaging products of week 8 is 2,432,151 meters. This is smaller than the actual capacity of either line. Therefore, if we allow one line to stay idle, all the orders could be produced on one line to achieve minimum setup time and startup cost. Since changeovers on laminator 22 take less time than those on laminator 21, we could assign all the orders to line 1 with paper roll width descending order. This would generate a total setup time of 110 minutes.

Table 14: Week 8, 2010 Demand and Capacity

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	1,961,765	3,175,200	3,528,000	0.9
Line 1	461,386	3,950,953	4,648,181	0.85

Table 15: Week 8, 2010 Production Sequence

Week 8, 2010			
Size code	200 Slim	1000 Slim	200 Mid
Paper Size	1574/6	1533	1512
Demand	1,961,765	370,575	90,811
Line 0	1,961,765	(0)	0
Line 1	0	370,575	90,811

5.1.3. Comparison between linear program and CAS current grouping

CAS has assigned product groups 200 Slim, 250 Slim, 200 Mid and 1000 Slim to line 0. All the other sizes of juice packaging products, milk and odd size packaging products are assigned to production line 1. CAS designed the grouping to ensure the four key sizes have smooth production. Since laminator 22 has greater capacity and capability, line 1 is designed to handle vast kinds of packaging products product and rush orders. Laminator 21 requires longer setup times and cannot coat milk and odd size packaging products; therefore, line 0 is designed to handle fewer sizes with larger order volume.

From the demand tables for week 5 to week 8, we see that the orders from customer are not consistent. Both the demand quantity and sizes ordered varied greatly. This is also suggested by the study of the past orders from week 1 to week 13 of year 2010, only 3 sizes have weekly coefficients of variation less than 0.6. (Section 5.2) If CAS strictly follows its current grouping, it is very likely they will not achieve the optimal setup time since following a strict split product grouping might cost more on changeovers and machine startups.

Table 16 shows the comparison between setup time and machine loads using our mathematical grouping model and CAS current grouping. As we can see from Table 16, apart from week 8, the linear program grouping model results in shorter total setup time.

For week 8, there would be zero juice workload on laminator 22. However, the 60 minute setup time for the first product on laminator 22 cannot be eliminated as milk and odd size packaging products need to be produced on line 1. Therefore, the effective total setup time for week 8 with CAS grouping method would be 180 minutes, which is longer than that for mathematical model grouping. Also, for week 7, CAS grouping would overload laminator 22 as 4,631,105 meters exceed the capacity of 4,253,374 meters.

Table 16: Comparison between Linear Program Model and CAS Grouping

	Setup Time (Minutes)		Juice Workload Laminator 21		Juice workload Laminator 22 Load	
Grouping Method	Mathematical Model	CAS Grouping	Mathematical Model	CAS Grouping	Mathematical Model	CAS Grouping
Week 5	210	300	1,140,862	2,814,638	3,612,132	1,938,356
Week 6	170	180	779,297	2,425,801	2,591,415	944,910
Week 7	190	230	2,954,740	1,859,290	3,535,655	4,631,105
Week 8	140	120	1,961,765	2,423,151	461,386	-

Therefore, as Table 16 illustrates, we can say that the linear program model gives better product grouping compared with CAS current grouping. For each week we have examined, the linear program grouping results in shorter total setup time and prevents the machines from overloading.

From our analysis, we could also see that for week 6, 7 and 8, line 1 could entertain all the customer orders with a line operating efficiency higher than 0.95. Therefore, it is also possible for CAS to let line 0 stay idle in some of the weeks. Therefore, since CAS takes orders from customer on a weekly basis, it is better to allow for a more flexible grouping and update the production grouping on a weekly basis.

5.2. Grouping tree guidelines

We proposed a simple grouping tree guideline for product grouping. This guideline aims to give CAS a fast grouping method. The grouping guideline is introduced in the following section. Then the grouping results generated by the grouping tree method are compared with the grouping results generated by the linear program grouping method.

5.2.1. Categorization of products

CAS products have many unique characteristics. The grouping guidance is developed based on sorting the products by their demand volume and alignment characteristics [7]. The alignment characteristics we chose are manufacturing configuration and paper roll width. Therefore, the products were grouped firstly by the manufacturing configuration, then by their demand volume, machine capacity and lastly by the paper roll width.

5.2.1.1. Manufacturing configuration

Currently CAS offers milk packaging products, juice packaging products and odd size packaging products. Each product category requires different lamination configuration and coating formula. The two laminators CAS owns have different capabilities and capacities. Milk packaging products and odd size products can only be coated on laminator 22. Therefore, all the milk and odd size products were assigned to production line 1 with laminator 22. The juice packaging products will be split and assigned to both production lines according the demand volume and paper roll width.

5.2.1.2. Demand characteristics

Products could be categorized as runners, repeaters and strangers. Runners have stable demands and take us large part of total production volume. Dedicated flow line should be set up for them. Repeaters have lower volume, variable order frequency category and do not require a dedicated flow line. Strangers have very low volume or infrequent demand pattern and could be outsourced for production.

5.2.1.3. Machine capacity

Laminator 21 and laminator 22 have different capacities. Laminator 21 runs at 350 meters per second on average while laminator 22 can run at 550 meters per second on average. If running fulltime, laminator 21 can process around 3,528,000 meters of packaging products per week when there is no machine breakdown. On the other hand, laminator 22 can process around 5,544,000 meters of packaging products per week without machine breakdown. Since milk and odd size packaging products can only be produced on laminator 22, the available capacity for juice packaging products would be the full capacity of laminator 22 less the capacity needed for milk and odd size packaging products. The product grouping created should not cause machine overload in any circumstances.

5.2.1.4. Paper roll width

For laminator 22, when the width difference of the two consecutive orders is less than 20mm, the changeover could be done without machine stoppage. Therefore, to minimize total setup time for laminator 22, the products assigned to laminator 22 should be arranged in paper roll width descending order to minimize the changeover time. Currently, CAS assigns all the juice packaging products among which the width differences are less than 20mm into a planning block to facilitate the planning process.

5.2.2 Grouping Tree

The grouping frame is illustrated by the Grouping Tree in Figure 15: Grouping Tree Diagram. Manufacturing configuration constraint has been used as the first tier criteria. Therefore, milk and odd size packaging products will be assigned onto laminator 22. The demand characterization acts as the second tier grouping criteria. Products will be categorized as runners, repeaters and strangers according to their demand data and coefficient of variation. Runners will be assigned to the dedicated line to ensure a smooth production. Repeaters and strangers will be processed on laminator 22 since the changeover time is shorter compared with laminator 21. Machine capacity should also be considered so that the grouping will not cause machine overload. Lastly, the product groups assigned to laminator 22 should be arranged in the paper roll width descending order to take advantage of the "0 setup time" on laminator 21 (5.1.2.4).

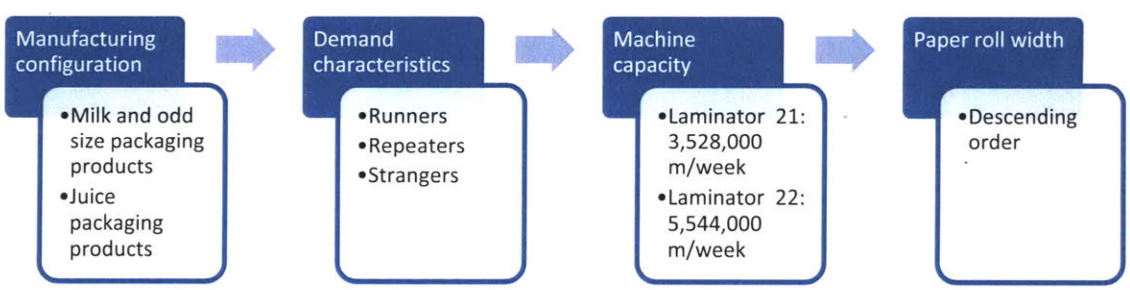

Figure 15: Grouping Tree Diagram.

5.2.2 Grouping Tree Results

To sort the products by their demand volumes, CAS past demand data from week 1 to week 13 year 2010 was studied. There were total 13 different sizes of juice packaging products ordered during the period. Their average weekly demand, standard deviation, coefficient of variation and average percentage are shown in Table 17. Average demand and the standard deviation were in meters. For COV (coefficient of variation), those higher than 1 were labeled with red; those between 0.5 and 1 were labeled with khaki and those below 0.5 in green. For the average percentage of each product size, those below 1% were labeled with red; those above 1% and below 10% were labeled with khaki and those above 10% in green. The sizes which were categorized as the "runners" are in green, the "repeaters" are in khaki and the "strangers" in red.

Table 17: COV and Demand Study of Juice Packaging Products.

Size	375 Slim (630)	200 Slim (465)	1000 Slim (813)	200 Mid (466)	250 Slim (565)	300 Slim (585)	330 Slim (600)
Average Demand (m)	22,889	1,452,105	556,543	171,581	789,631	218,846	26,179
Standard Deviation (m)	32,686	671,148	307,763	107,987	317,849	213,664	49,411
COV	1.43	0.46	0.55	0.63	0.40	0.98	1.89
Average Percentage	0.4%	28.1%	10.8%	3.3%	15.3%	4.2%	0.5%
Size	**250 ml (560)**	**200 ml (460)**	**1000 Square (811)**	**125 Slim (350)**	**250 Mini (567)**	**130**	**Total**
Average Demand (m)	314,975	175,774	73,204	487,134	4,538	26,095	5,169,362
Standard Deviation (m)	206,478	188,340	82,066	339,858	6,351	63,360	1,308,296
COV	0.66	1.07	1.12	0.70	1.40	2.43	0.25
Average Percentage	6.1%	3.4%	1.4%	9.4%	0.1%	0.5%	83.6%

From Table 17, we can see that the average weekly demands of product sizes 200 Slim (465), 1000 Slim (813) and 250 Slim (565) are 28%, 11% and 15% respectively. These three types of products took up above 50% of the average total weekly demand. Also, their coefficients of variation are relatively low, which indicates the demands were stable. Therefore, sizes 200 Slim (465), 1000 Slim (813) and 250 Slim (565) were categorized as the "runners" (labeled with green in Table 17). For product size 200 Mid (466), 300 Slim (585), 250 ml (560), 200 ml (460) and 125 Slim (350), the coefficients of variation are not high (between 0.5 and 1.1). The demands for these product sizes were not as high as for the runners, yet somehow stable. Therefore, 200 Mid (466), 300 Slim (585), 250 ml (560), 200 ml (460) and 125 Slim (350) were categorized as the "repeaters" (Labeled with khaki in Table 17). Lastly, product size 375 Slim (630), 330 Slim (600), 1000 Square (811), 250 Mini (567) and 130 all had less than or equal to 1% of the average total weekly demand. The coefficients of variation of these product size groups are also all above 1. This indicates that the demands for product size 375 Slim (630), 330 Slim (600), 1000 Square (811), 250 Mini (567) and 130 were not stable and fluctuate drastically. Therefore, they are the "strangers" (Labeled with red in Table 17).

The coefficient of variation of total average weekly demand for CAS is only 0.25 (Appendix B). This indicates that the total demand for CAS is rather stable. Therefore, it is safe to make the grouping decision based on the historical demand data.

From Table 17, juice packaging products took up around 83% of the total demand. Milk and odd size packaging products took up around 17% of the total demand. The runners group took up around 54% (1,296,760 meters) of the total demand and the rest took up 46% (1,104,647 meters).

From the results we acquired, a general grouping could be constructed. Line 0 with laminator 21 will produce product size 465, 813 and 565. All the rest juice packaging products, milk and odd size packaging products should be produced on line 1 with laminator 22. As 1,296,760 meters and 1,104,647 meters are far from both machines' capacity, the general grouping satisfies the machine capacity criteria.

5.2.3. Grouping results for individual week

Past demand data of week 5 to week 8 2010 was examined to test the grouping tree. For week 5, there were total 12 sizes of juice packaging products ordered. According to the grouping we developed, product size 200 Slim, 1000 Slim and 250 Slim should be assigned to the dedicated line 0 with laminator 21. The remaining 9 sizes of juice packaging products, milk and odd size packaging products should be assigned to production line 1 with laminator 22. Table 19 shows the allocation result, where line 0 products are in green and line 1 products in blue. From Table 18 we learn that both lines will not be overload. The total setup time would be 250 minutes. This is 40 minutes longer compared with the total setup time of the grouping result generated by linear programming in section 5.1.2.

Table 18: Week 5, 2010 Demand and Line Capacity.

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	2,543,149	3,175,200	3,528,000	0.9
Line 1	2,209,845	3,999,941	4,705,813	0.85

Table 19: Week 5, 2010 Production Grouping and Sequence

Week 5, 2010						
Size code	375 Slim	200 Slim	1000 Slim	200 Mid	250 Slim	300 Slim
Paper Size	1597	1574/6	1533	1512	1512	1506
Demand	89,286	1,051,576	591,367	271,489	900,206	551,779
Line 0	0	1051576	591367	0	900206	0
Line 1	89286	0	0	271489	0	551779
Size code	330 Slim	250 ml	200 ml	1000 Square	125 Slim	250 Mini
Paper Size	1506	1504/6	1504/6/8	1468	1466	1448
Demand	16,697	533,054	230,437	151,996	360,838	4,269
Line 0	0	0	0	0	0	0
Line 1	16697	533054	230437	151996	360838	4269

For week 6, 2010, there were only 6 sizes of juice packaging products ordered. According to the grouping we developed, product size 200 Slim, 1000 Slim and 250 Slim should be assigned to the dedicated line 0 with laminator 21. The rest 3 sizes of juice packaging products, milk and odd size packaging products should be assigned to production line 1 with laminator 22. Table 21 shows the allocation result, where line 0 products are in green. Both lines will not be overload. The total setup time would be 210 minutes. Again, this is 40 minutes longer compared with the total setup time of the grouping result generated by linear programming in section 5.1.2.

Table 20: Week 6, 2010 Demand and Line Capacity.

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	2,214,601	3,175,200	3,528,000	0.9
Line 1	1,156,110	4,483,037	5,274,161	0.85

Table 21: Week 6, 2010 Production Grouping and Sequence.

Week 6, 2010						
Size code	200 Slim	1000 Slim	200 Mid	250 Slim	1000 Square	125 Slim
Paper Size	1574/6	1533	1512	1512	1468	1466
Demand	779,296	471,825	211,200	963,480	135,660	809,250
Line 0	779,296	471,825	-	963,480	-	-
Line 1	-	-	211,200	-	135,660	809,250

For week 7, 2010, there were 11 sizes of juice packaging products ordered. According to the grouping we developed, product size 200 Slim, 1000 Slim and 250 Slim should be assigned to the dedicated line 0 with laminator 21. The remaining 8 sizes of juice packaging products, milk and odd size packaging products should be assigned to production line 1 with laminator 22. Table 23 shows the allocation result, where line 0 products are in green. However, as we examine Table 22, it is obvious that this grouping will over load line 0 since the actual capacity of laminator 21 is smaller than the total demands of product groups 200 Slim, 1000 Slim and 250 Slim. Therefore, the grouping tree method will not work for week 7. This indicates a fixed grouping based on historical data might not be viable in case of demand surge or demand mix change. It is necessary to propose new product grouping when demand quantity and mix changes.

Table 22: Week 7, 2010 Demand and Line Capacity.

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	3,748,078	3,175,200	3,528,000	0.9
Line 1	2,742,317	3,615,368	4,253,374	0.85

Table 23: Week 7, 2010 Production Grouping and Sequence.

Week 7, 2010						
Size code	375 Slim	200 Slim	1000 Slim	200 Mid	250 Slim	300 Slim
Paper Size	1597	1574/6	1533	1512	1512	1506
Demand	-	2,441,883	692,550	155,520	613,645	397,575
Line 0	-	2,441,883	692,550	-	613,645	-
Line 1	-	-	-	155,520	-	397,575
Size code	330 Slim	250 ml	200 ml	1000 Square	125 Slim	250 Mini
Paper Size	1506	1504/6	1504/6/8	1468	1466	1448
Demand	20,880	512,857	523,600	73,017	1,051,050	7,818
Line 0	-	-	-	-	-	-
Line 1	20,880	512,857	523,600	73,017	1,051,050	7,818

For week 8, 2010, there were only 3 sizes of juice packaging products ordered. According to the grouping we developed, product size 200 Slim and 1000 Slim should be assigned to the dedicated line 0 with laminator 21. Product size 200 Mid, milk and odd size packaging products should be assigned to production line 1 with laminator 22. Table 25 shows the allocation result, where line 0 products are in labeled in green and line 1 products are in blue. From Table 24 we learn that both lines will not be overloaded. The total setup time would be 150 minutes, which is 10 minutes longer compared with the total setup time of the grouping result generated by linear programming in section 5.1.2.

Table 24: Week 8, 2010 Demand and Line Capacity.

Production Line	Demand (meters)	Actual Capacity (meters)	Available Capacity (meters)	Efficiency
Line 0	2,332,340	3,175,200	3,528,000	0.9
Line 1	90,811	3,950,953	4,648,181	0.85

Table 25: Week 8, 2010 Production Grouping and Sequence.

Week 8, 2010			
Size code	200 Slim	1000 Slim	200 Mid
Paper Size	1574/6	1533	1512
Demand	1,961,765	370,575	90,811
Line 0	1,961,765	370,575	0
Line 1	0	-	90,811

5.3. Comparison

It seems that mathematical model generates better grouping compared with the grouping tree method. From Table 26, we see that for all weeks from week 5 to week 8, 2010, mathematical model grouping generates shorter total setup time compared with the grouping tree grouping. It is also possible for the grouping tree method to fail when product demand surges or the demand mix changes. Therefore, the mathematical grouping model is a better choice for CAS.

Table 26: Comparison between Linear Program Method and Grouping Tree Method.

	Setup Time (Minutes)	
Grouping Method	**Linear Program Method**	**Grouping Tree**
Week 5	210	250
Week 6	170	210
Week 7	190	Not Viable
Week 8	140	150

Chapter 6 Recommendations and Future Work

6.1 Recommendations

The following three recommendations are made to CAS based on the study of the linear program grouping results, the comparison study between CAS current grouping practice and the linear program grouping as well as the comparison study between the linear program method and the grouping tree method.

Firstly, CAS should also consider updating the grouping assignment weekly rather than following a fixed grouping. Since their production cycle is one week, the demand volume and product mix would change weekly. A fixed grouping may not be suitable for weekly production as it may overload production lines and result in longer total setup time. A weekly updated grouping according to the current orders would give a shorter total setup time and prevent the machine from overloading.

Secondly, CAS should not keep a production structure with two dedicated lines due to fluctuating orders from customers from week to week. When the total demand of the production cycle is less than the capacity of laminator 22, all the orders should be produced on line 1 as setups on laminator 22 are shorter. This could also save laminator 21 startup cost. When the weekly total demand equals to or exceeds the capacity of laminator 22, the both production lines should be operating.

Last but not least, CAS could also consider setting up a deadline for taking in rush orders or a better way to manage these rush orders. Since rush orders may need to be produced immediately, they can disturb the weekly production schedule and bring longer setups on both laminators. The larger the volume of rush orders CAS accepts, the less useful the optimized grouping and schedule are. Therefore, it is in CAS's best interest if they set up a better rush order management system.

6.2 Future Work

In this thesis, we only considered the setup times on the laminators. In future work, mathematical models could be developed to incorporate the effect on the setups for the printing process and for the slitting process. Genetic algorithms or more complex algorithms could be employed to perform more efficient searches for the optimal grouping solution since the objective function is likely to be more complex.

Chapter 7 Conclusion

This thesis proposed a product grouping method for CAS weekly production planning. With minimizing the total setup time on laminators as the objective, this grouping method generates a production grouping whenever needed and also prevents machines from overloading.

The main advantage of this method is that it allows the company to change and modify the current grouping when the demand or constraints changes. As currently CAS follows a fixed production grouping, it is likely that one or both production lines could be overloaded with sudden demand surge for certain product sizes. When demand mix or customer order pattern changes, the linear program grouping method could allow immediate change in grouping to cater to the changes.

The method gives the planning department an effective tool to generate a weekly production plan which effectively cuts production cost. Based on limited testing, the linear program grouping method generates better grouping assignments compared with alternative approaches, such as grouping tree method. The total setup times are reduced on average by 17 percent (Table 16).

The new grouping method also introduces a quantitative measure for the total setup time. While the current grouping is simple and based on experience, there has been no previous effort to optimize and verify the production grouping. The linear program grouping method could allow CAS to see the total setup time in the planning stage. They could arrange or change production schedule accordingly to achieve their target total setup time.

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Appendix A1: Setup Time Matrix for Laminator 22

This table is the setup matrix used in Chapter 5 for total setup time calculation. The product sizes were arranged in the paper roll width descending order. The widest size is 375 Slim (630) and the narrowest is 250 Mini (567). They were labeled with numbers from 1 to 12. "0" indicates the starting of the production. For instance, from roll "0" to column "1" indicates the first product size being produced on laminator 22 is size 1 –375 Slim (630) The first roll resembles all the values of "i" in the term $y(i,j)$ and the first column resembles "j" in the term $y(i,j)$. Therefore, the time shown in the table at the cross grid of roll i and column j is the setup time required for the changeover from product size i to product size j on laminator 22. The startup time for laminator 22 is 60 minutes for all sizes of juice packaging products. The setup time matrix is also not symmetric. Setup time for changeover from size i to size j is not the same that from size j to size i.

Juice		1 (630)	2 (465)	3 (813)	4 (466)	5 (565)	6 (585)	7 (600)	8 (560)	9 (460)	10 (811)	11 (350)	12 (567)
	Size code	**375 Slim**	**200 Slim**	**1000 Slim**	**200 Mid**	**250 Slim**	**300 Slim**	**330 Slim**	**250 ml**	**200 ml**	**1000 Square**	**125 Slim**	**250 Mini**
	Paper Size	**1597**	**1574/6**	**1533**	**1512**	**1512**	**1506**	**1506**	**1504/6**	**1504/6/8**	**1468**	**1466**	**1448**
0		60	60	60	60	60	60	60	60	60	60	60	60
1	**1597**	0	0	30	30	30	30	30	30	30	40	40	40
2	**1574/6**	0	0	30	30	30	30	30	30	30	40	40	40
3	**1533**	0	0	0	20	20	20	20	20	20	40	40	40
4	**1512**	0	0	0	0	0	0	0	0	0	30	30	30
5	**1512**	0	0	0	0	0	0	0	0	0	30	30	30
6	**1506**	0	0	0	0	0	0	0	0	0	20	20	30
7	**1506**	0	0	0	0	0	0	0	0	0	20	20	30
8	**1504/6**	0	0	0	0	0	0	0	0	0	20	20	30
9	**1504/6/8**	0	0	0	0	0	0	0	0	0	20	20	30
10	**1468**	0	0	0	0	0	0	0	0	0	0	0	20
11	**1466**	0	0	0	0	0	0	0	0	0	0	0	20
12	**1448**	0	0	0	0	0	0	0	0	0	0	0	0

Appendix A2: Setup Time Matrix for Laminator 21

This table is the setup matrix used in Chapter 5 for total setup time calculation. The product sizes were arranged in the paper roll width descending order. The widest size is 375 Slim (630) and the narrowest is 250 Mini (567). They were labeled with numbers from 1 to 12. "0" indicates the starting of the production. For instance, from roll "0" to column "1" indicates the first product size being produced on laminator 21 is size 1 –375 Slim (630) The first roll resembles all the values of "i" in the term $x(i,j)$ and the first column resembles "j" in the term $x(i,j)$. Therefore, the time shown in the table at the cross grid of roll i and column j is the setup time required for the changeover from product size i to product size j on laminator 21. The startup time for laminator 21 is 60 minutes for all sizes of juice packaging products. The setup time matrix is also not symmetric. Setup time for changeover from size i to size j is not the same that from size j to size i.

Juice		1 (630)	2 (465)	3 (813)	4 (466)	5 (565)	6 (585)	7 (600)	8 (560)	9 (460)	10 (811)	11 (350)	12 (567)
	Size code	**375 Slim**	**200 Slim**	**1000 Slim**	**200 Mid**	**250 Slim**	**300 Slim**	**330 Slim**	**250 ml**	**200 ml**	**1000 Square**	**125 Slim**	**250 Mini**
	Paper Width	**1597**	**1574/6**	**1533**	**1512**	**1512**	**1506**	**1506**	**1504/6**	**1504/6/8**	**1468**	**1466**	**1448**
0		60	60	60	60	60	60	60	60	60	60	60	60
1	**1597**	0	30	40	40	40	40	40	40	40	40	40	40
2	**1574/6**	0	0	30	40	40	40	40	40	40	40	40	40
3	**1533**	0	0	0	30	30	30	30	30	30	40	40	40
4	**1512**	0	0	0	0	0	30	30	30	30	40	40	40
5	**1512**	0	0	0	0	0	30	30	30	30	40	40	40
6	**1506**	0	0	0	0	0	0	0	15	20	40	40	40
7	**1506**	0	0	0	0	0	0	0	15	20	40	40	40
8	**1504/6**	0	0	0	0	0	15	15	7.5	10	40	40	40
9	**1504/6/8**	0	0	0	0	0	20	20	10	5	40	40	40
10	**1468**	0	0	0	0	0	40	40	40	40	0	30	30
11	**1466**	0	0	0	0	0	40	40	40	40	40	0	30
12	**1448**	0	0	0	0	0	40	40	40	40	40	40	0

Appendix B: Demand Coefficient of Variation Analysis for all Sizes of Juice Packaging Products

To sort the products by their demand volumes, the past demand data from Week 1 to Week 13 in Year 2010 was studied. There were totally 13 different sizes of juice packaging products ordered during the period. Their average weekly demand, standard deviation, coefficient of variation and average percentage are consolidated in Appendix B. The average demands and standard deviations were measured in meters. For COV (coefficient of variation), those higher than 1 were labeled with red; those between 0.5 and 1 were labeled with khaki and those below 0.5 in green. For the average percentage of each product size, those below 1% were labeled with red; those above 1% and below 10% were labeled with khaki and those above 10% in green. The sizes which were categorized as the "runners" are in green, the "repeaters" in khaki and the "strangers" in red.

week	375 Slim	200 Slim	1000 Slim	200 Mid	250 Slim	300 Slim	330 Slim	250 ml	200 ml	1000 Square	125 Slim	250 Mini	13 (130)	Juice Total	Total
1	53100	1048195	413100	120960	642320	53010	0	179664	48440	0	97500	3909	0	2660198	3755985
2	0	1902131	502200	144000	980685	164331	36539	364552	150768	0	361400	0	0	4606606	4698726
3	15930	929400	684450	69120	911865	42408	5220	329928	54320	135660	516750	11727	0	3706778	4666372
4	0	1943897	0	138240	1087902	0	0	0	0	0	463150	0	0	3633189	4532076
5	89286	1051576	591367	271489	900206	551779	16697	533054	230437	151996	360838	4269	0	4752994	5587914
6	0	779296	471825	211200	963480	0	0	0	0	135660	809250	0	0	3370711	3640550
7	0	2441883	692550	155520	613645	397575	20880	512857	523600	73017	1051050	7818	0	6490395	8160505
8	0	1961765	370575	0	0	0	0	90811	0	0	0	0	0	2423151	3317850
9	0	0	1356417	51860	1244495	418779	31320	425406	39480	182610	515450	19545	8266	4293628	5768451
10	10620	1876138	662175	420640		413478	5220	556295	63700		716300	0	0	4724566	5111060
11	74340	1906126	696600	185140	579235	0	0	148957	393540	199500	453700	11727	198549	4847414	5774882
12	0	1808881	441450	238240	756997	342445	182697	426574	332360	0	987350	0	0	5516994	5721144
13	54280	1228081	352350	224140	794737	461187	41759	526576	448420	0	0	0	132422	4263952	5828903
Average Demand (meter)	22889	1452105	556543	171581	789631	218846	26179	314975	175774	73204	487134	4538	26095	4253121	5120340
Standard Deviation (meter)	32686	671148	307763	107987	317849	213664	49411	206478	188340	82066	339858	6351	63360	1114392	1265008
COV	1.43	0.46	0.55	0.63	0.40	0.98	1.89	0.66	1.07	1.12	0.70	1.40	2.43	0.26	0.25
Average Percentage	0.45%	28.36%	10.87%	3.35%	15.42%	4.27%	0.51%	6.15%	3.43%	1.43%	9.51%	0.09%	0.51%	0.83	