Value Stream Mapping and WIP and lead time Optimization for a Make-to-order System

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ABSTRACT

Value Stream Mapping of the Singapore operations of a multi-national food products packaging company was carried out with the objective of streamlining production in accordance with the World Class Manufacturing philosophy. An opportunity for reduction in WIP and lead time was identified. Simulation models were used, on the make- to-order, serial production system to test three potential solutions to the problem. The models used showed great promise for reduction in WIP and the lead time for both the priority and ordinary products. The role of design as a sorting criterion on the printer was also investigated by a fundamental integer programming model using the Travelling Salesman approach. Results confirming the significance of design in the printer setup process were obtained in the trial run.

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1 Introduction:

1.1 Background:

This thesis is a documentation of a seven month long internship at Company X, Singapore. Company X is a multinational food packaging and processing company of Swedish origin. Company X Singapore began operations in the Jurong island in 1982 as a part of the South and South-east Asia cluster. It produces packs for a variety of food and beverages. These packs are shipped to the customer locations, folded into cartons and filled using special machines. The range of products produced by Company X is shown in figure 1. [1]

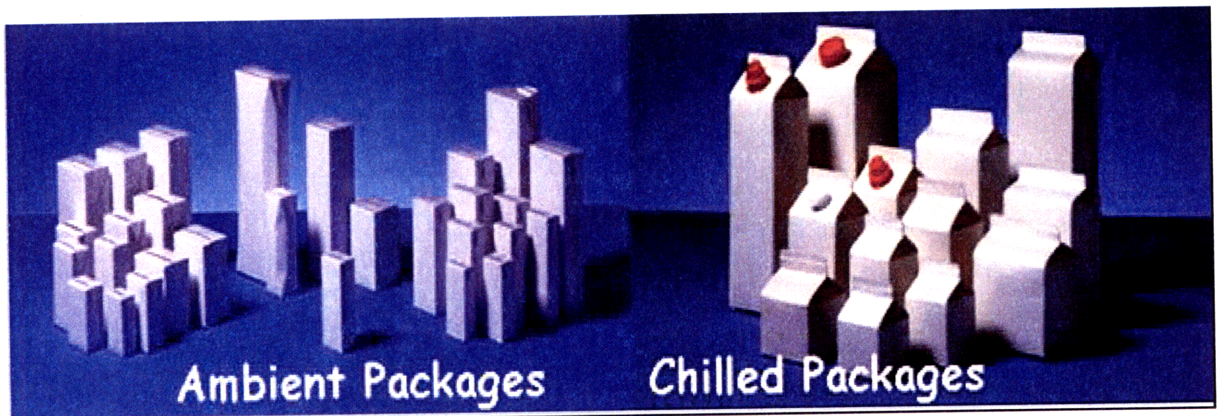


Figure 1: Range of products

Company X, Singapore began its World Class Manufacturing campaign in 2000 and has crossed the WCM Special milestone. As a consequence of these efforts, the plant received the MAXA Award for overall excellence in innovations, operations and sustainability in 2007 from the Economic Development Board of Singapore. Our project was under the WCM umbrella- more specifically under the supply chain pillar.

1.2 Motivation for the internship:

In accordance with the WCM ideology, the plant is on a continuous quest for improvement. As Company X, Singapore aims for the WCM Special Advanced certification, a need to streamline the processes was felt. A complete picture of the system helps in understanding the flow of both material and information through the various processes. It also facilitates the identification of gaps and loopholes through the observation of the productive and non-productive aspects of the flow. Diagrammatic representations of only a few segments of operations were in place in Company X, Singapore. So the first objective of our internship was to prepare a visual sketch of the system. Since the system was large, we focused on different segments of the map. I studied design, planning and production while my team mates Dafei Han and Jin Yi reviewed logistics and order handling respectively. Once this map was ready, we identified some areas of improvement:

1) Reduction of work in process between the stages of production (WIP)
2) Evaluation of the material ordering policy
3) Lead time for a priority product

I worked on the first project while my colleagues Dafei Han and Yi Jin worked on the second and third one respectively. WIP and lead time reduction was the subsequent objective of the internship. With this end in mind, I looked at the WIP between the different stages of production, the cause and the remedy for the problem. A consequence of reducing WIP is lead time reduction which was a measuring parameter

1.3 Organization of the thesis:

The thesis is divided into six chapters. Chapter1 is a broad overview of the scope of the work done. Chapter 2 is a description of the operations of the company. The system, product and processes are explained in this section. Chapter 3 is a description of the value stream mapping process, the indicators and the flow of material and information. Chapter 4 is a documentation of the solution to the more specific problem of WIP between the different stages of production. It includes the methodology followed and the changes made. It also includes the investigation of design as an important criterion for sorting on the printer. Chapter 5 summarizes the recommendations and the results. Chapter 6 deals with the scope for future work in this area.

2 Company X, Singapore Operations

2.1 Facility:

Company X, Singapore is spread over 55000 sq.m in the Jurong Island of Singapore. The factory, office space and the warehouse are all housed within the same premises. There is a soy processing facility in the block as well. Apart from the on-site warehouse, there is also an external warehouse.

2.2 Product:

Company X, Singapore manufactures packs for food items like milk, flavored milk, fruit juice and soy products. Assistance is also provided for the design of the carton. Each Company X pack is made with 6 layers of aluminum, paper and polyethylene to prevent spoilage of the contents. Paper is the base material for each pack and provides structure and support to the package. The carton design is printed on the paper. The paper is coated with a layer of aluminum foil to make the pack aseptic and preserve the flavor. In addition, there are four layers of polyethylene: one on the outside to prevent damage from moisture; an adhesive layer between the paper and aluminum foil; and two protective innermost layers to seal in the liquid. The several layers and their respective functions are shown in figure 2. [1]

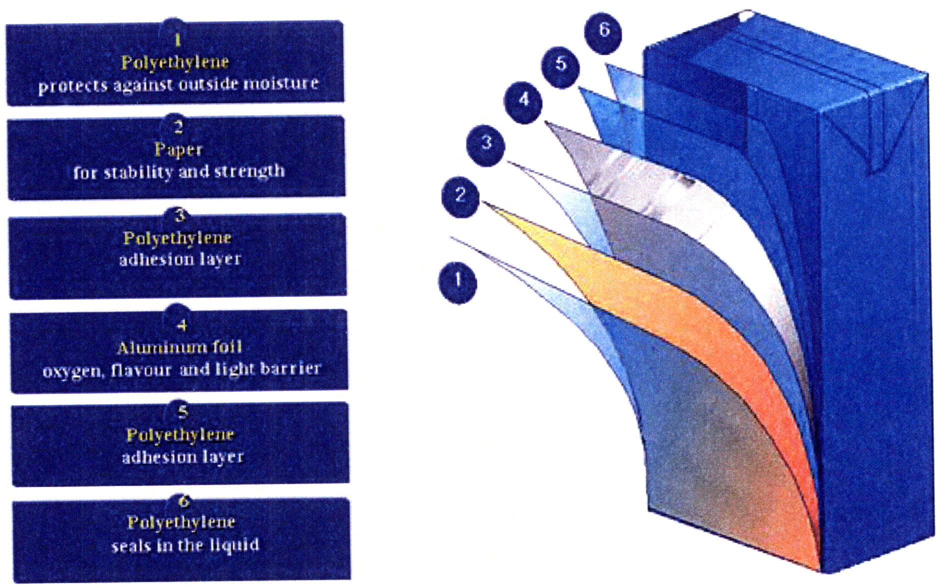


Figure 2: Different layers of a carton

A unique feature of the product portfolio handled by Company X, Singapore is its diversity. Compared to other Company X plants, Company X, Singapore produces a wide variety of products, some in very small volumes. Metalized packs are also manufactured here.

Each product is defined by a few attributes:

1) System code: This code defines one single attribute- the class of the package. More explicitly, it describes whether the carton is aseptic, refrigerated or ambient. This has an impact on the creasing tool used on the printer. Often this code is suffixed with the grade i.e. milk or juice specification of the package. So, it determines the type of PE used in the package and is important for the sorting on the laminator.

2) Size code: The volume of liquid contained by the package and its shape (slim, base, square) determines the size code. Thus it describes two attributes. It is important for classification on the printer. All the products with the same size code have the same overall width (for same number of webs). But some product families with different size codes may have the same overall width and can be grouped together on the laminator. So, sorting on the laminator is partially determined by the size code.

3) Quality code: This code describes multiple attributes. It determines the type, thickness in gsm (grams per square meter) and the brand of paper used. It is also different for every system, size and grade. Since it describes many distinct characteristics of a product, it is very difficult to use it as a basis for sorting.

4) Design code: It describes a single attribute – design of the product. It may also feature information on the revisions of the design in use. It also provides information the colors used for the design.

2.3 Customers:

The packs once ready are shipped to the customer site where they are folded into cartons and filled with the help of special filling machines. With the domestic market almost non-existent, one hundred percent of Company X, Singapore's production is exported. Singapore is conveniently located to cater to the needs of the Asia Pacific belt. But Company X, Singapore has customers in Europe and the Middle East as well. The largest customer countries by volume are Thailand, Vietnam and Taiwan. The countries served by Company X, Singapore are shown in figure 3. [1]

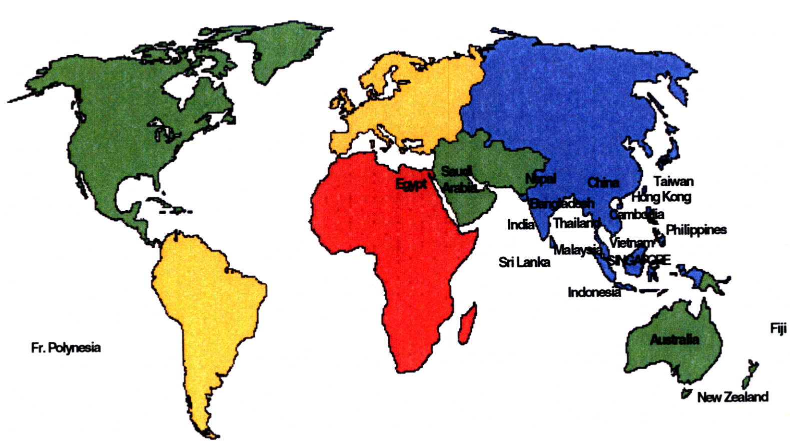


Figure 3: Markets served by Company X, Singapore

2.4 Processes:
A market company is a wholly owned subsidiary of Company X, located in each country which serves as a customer representative for that country. It facilitates order collection and allocation to different plants, based on capability, capacity and cost. Once the order is received by Company X, Singapore, a capacity evaluation exercise is performed to ratify if the order can be met on time and in full volume. Once the order is confirmed, the sales order is converted to a production order. The production order is the go-ahead for production. So, it is a make to order system. The manufacturing process in Company X, Singapore is serial in nature. All products flow through each of the following key steps one after the other, with no omission of steps or change in sequence of operations.

2.4.1 Design and Pre-Press:
The design department reviews the customer's design and modifies it to suit production. Assistance is also provided to customers in designing the carton. Once the design is confirmed, the designs are broken down into the component colors. Cyan (C), magenta (M), yellow (Y) and black or key (K) are the process colors. They are common to many designs. Apart from these, special or spot colors may be used to obtain specific shades of color. The number of spot colors can vary from none to seven. The negatives for each color are prepared.

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. One cliché is prepared for each color used for printing. The clichés are prepared on photo-polymer plates through a process of controlled exposure to UV light. A cliché used for printing is shown in figure 4.

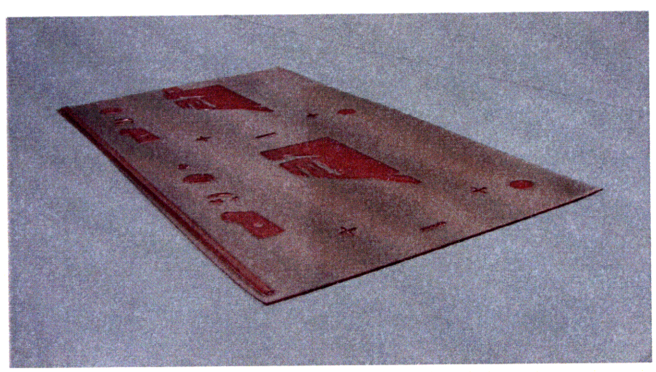


Figure 4: Cliché used for printing

A number of clichés are then mounted on a sleeve. The sleeve is a rotating spindle that is fitted into the printer. The number of clichés mounted on one sleeve depends on the width of the individual pack and the paper roll and is called the number of webs. In figure 5, there are five webs mounted on the sleeve. [1]

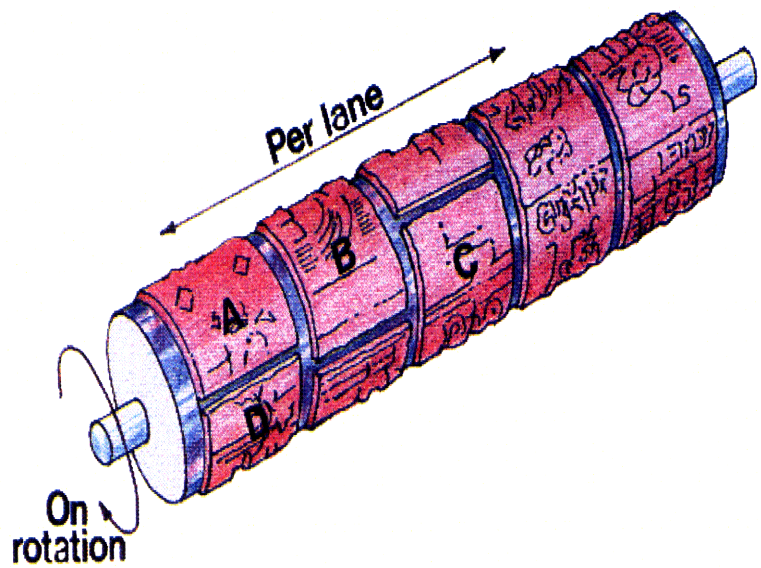


Figure 5: Clichés mounted on a sleeve for printing

2.4.2 Printing:
Printing is the process of reproducing the design on the paper roll by rotary contact with the stamp. There are three printers in the factory. Two of the printers, P17 and P18, are of the flexographic (flexo) type and are used for routine printing. The third printer, P19, is of the offset type, which is used for special, high resolution orders. The maximum speed of the flexo printers is 600m/min and the average run speed is around 500m/min.

The incoming paper roll is loaded on the un-winder, which opens it up and feeds it to the printing stations. 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 color scheme, some of the stations may be idle for a design. The different colors are superimposed one over the other to get the complete final picture as shown in figure 6. [1]

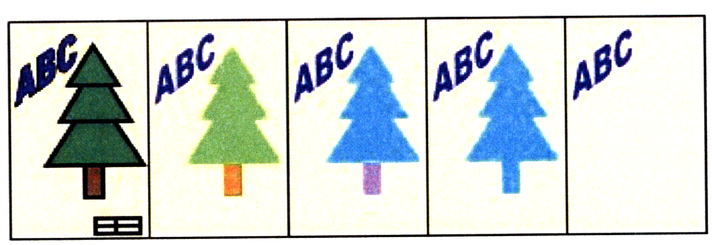


Figure 6: Colors being superimposed during printing

The roll once printed, is creased into the appropriate shape. The creasing is done using a special tool, specific to the shape of the carton. The purpose of creasing is to enable proper folding of the pack during the filling stage at the customer site. The creasing tool also punches the holes for the straws. The printed and creased paper is then rolled back on the re-winder. It is wrapped by a layer of paper to prevent contamination and is sent to the warehouse to wait for its turn on the laminator.

If the incoming roll is a continuation of a running design, it is joined to the previous roll. This process is called splicing and it is done using the splice tool which holds the paper roll in the correct tension and then tapes it to the preceding roll. This tool is located at the unwinding stage. There is an online inspection system after the printing and creasing stations to check for defects. The several portions of the printer are shown in figure 7. [1]

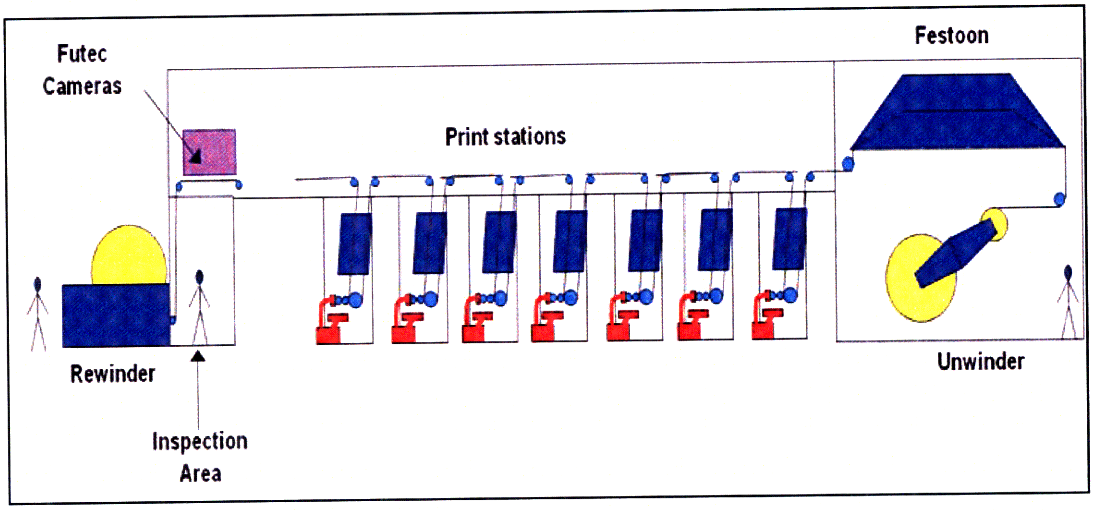


Figure 7: Schematic diagram of printing

2.4.3 Laminating:

Laminating is the process of coating the packs with polyethylene (PE) and aluminum foil. There are two laminators in Company X, Singapore – Lam 21 and Lam 22. They are very different in operation. Only Lam 22 can handle the metalized and offset orders. But the common orders can be handled by both. The first stage of the laminator is the un-winder for the paper and the splice tool which are similar in nature to the printer. The aluminum foil is fed in the form of rolls of appropriate sizes to the laminator at the foil un-winder. The low density polyethylene (LDPE) is supplied in the form of pellets to the hoppers where it is melted and extruded as a viscous film. There are three stations in the laminator that add the different layers to the pack:

1) The first station coats the paper with the aluminum foil with the adhesive layer binding the two together.
2) The second station coats the inner surface with two layers of PE.
3) The last station adds the décor or the outermost PE layer.

The pack is heat treated before the coating to remove excess moisture. There is an on-line inspection system to detect missing material and other defects. Once the lamination is done, the roll is wrapped and sent to the warehouse. The stages of the lamination process are depicted in figure 8. [1]

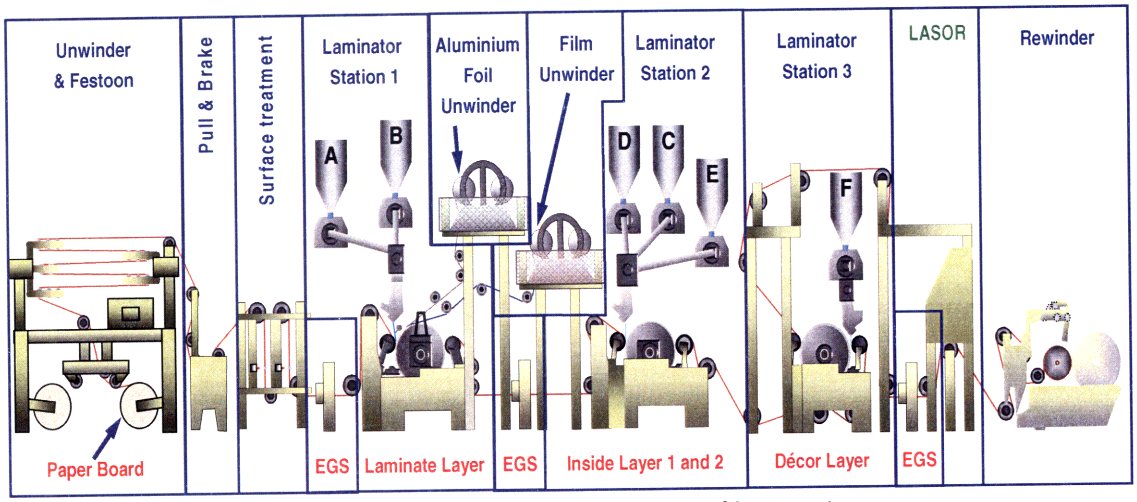


Figure 8: Schematic diagram of laminating

2.4.4 Slitting:

Each paper roll is made up of several webs or lines or packs. Slitting is the process of cutting up the roll into reels of one pack width. The first stage in slitting is the un-winder and the splice tool. The coated paper cut by the knives into reels. To prevent distortion, the reel is cut into portions of shorter length called sets. Each reel is divided into two and a half sets approximately. During the slitting process, the defects are marked with a paper tab to facilitate removal at a later stage. The stages of the slitting process are shown with a schematic diagram and photographs in figure 9. [1]

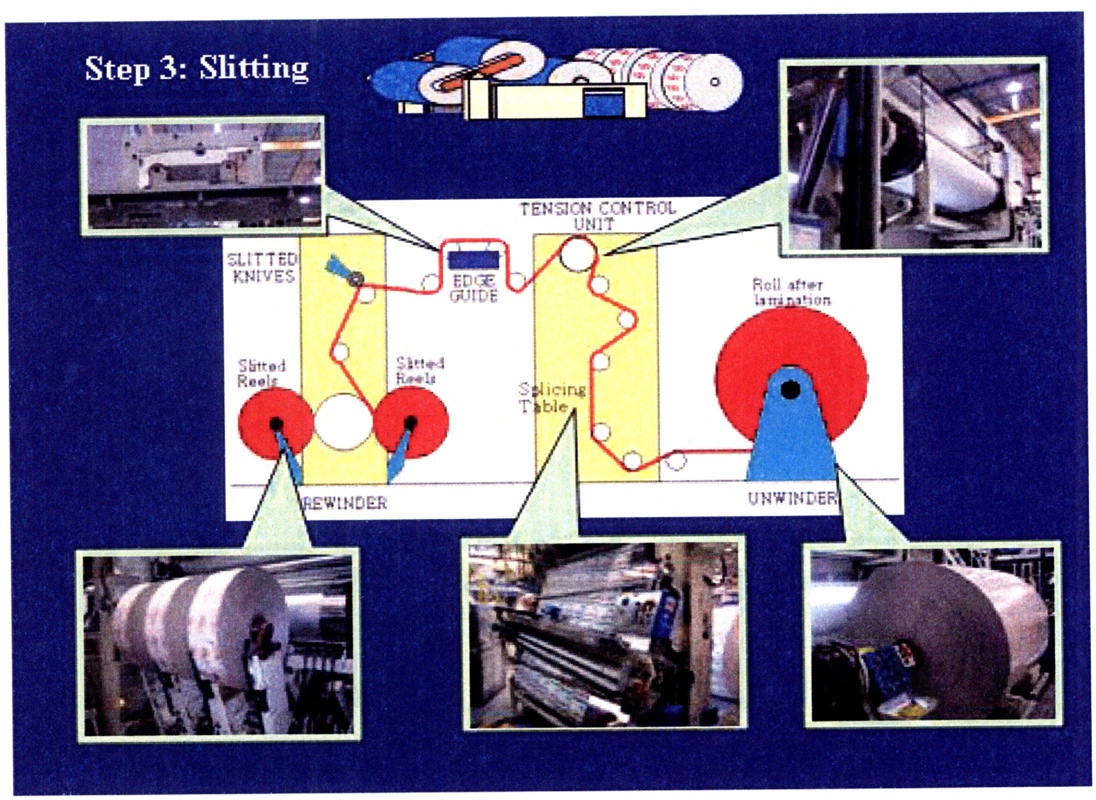


Figure 9: Schematic diagram of slitting

2.4.5 Doctoring:

Doctoring is the process of removing the portions with defects from the sets. After slitting, the sets with defects are sent through the roller conveyor system to the doctoring area. The set is unwound and the defective areas are removed. The reel is re-wound and sent on the conveyor to the next stage. Here, the sets are shrink wrapped in the oven and palletized in stacks of seven on wooden or plastic pallets. The reel is now ready for delivery and is transported to the warehouse to await delivery. A palletized and stretch wrapped set of reels is shown in figure 10.

Figure 10: Palletized and stretch wrapped reels

A schematic diagram of the entire production process, with the inputs at every stage is as shown in figure 11. [1]

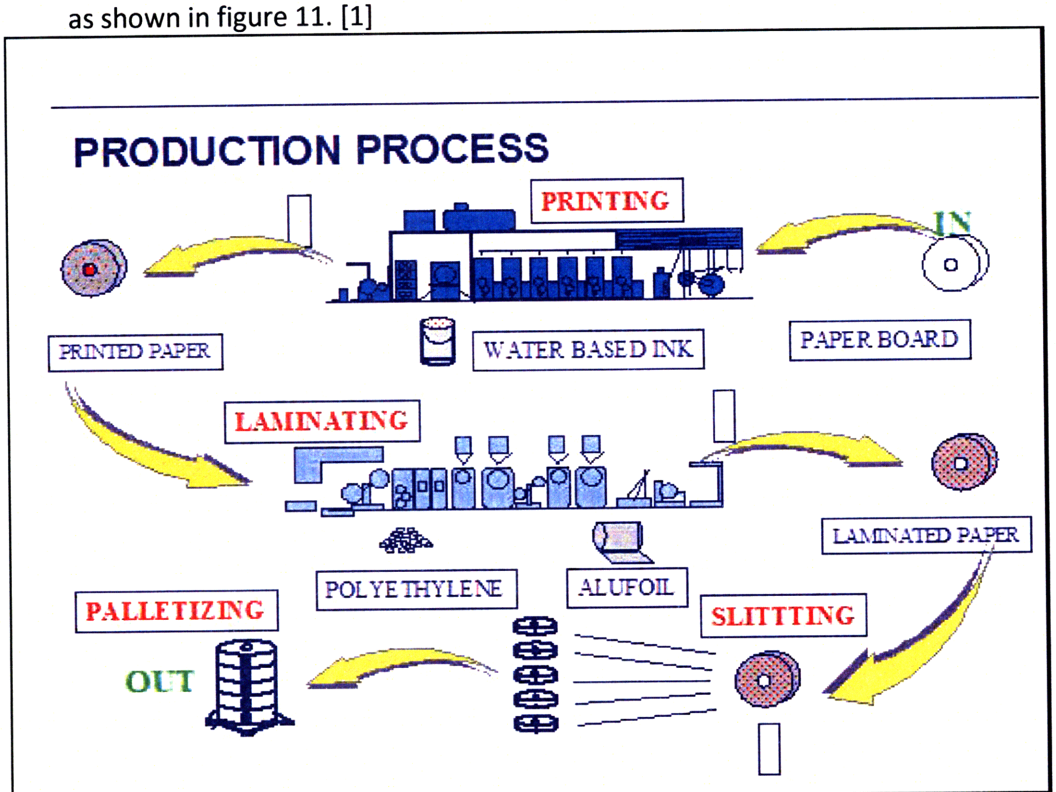


Figure 11: Schematic diagram of the Company X, Singapore production system

2.5 Setup process on the machines:
The setup processes on the machines is a very important part of the machine characteristics of the machines. It influences the sorting, grouping and planning of orders.

2.5.1. Setup on the printer:
On the printer, there is a minor setup for every design which involves change of the sleeves and the colors. The old sleeves are taken out of the machine and the sleeves with the new designs mounted on them are affixed. The color or anilox rolls are cleaned or replaced and the inks for the colors of the new design are loaded. The major setups occur for changes in system (shape of the package) and size (volume of liquid contained). In a major setup, in addition to the change in design, the creasing tool is also changed. The creasing tool creases the package along the folding lines based on the shape and size. This operation also provides the perforations and holes for the straw and caps. The orders can be run in any order. There is no specified sequence. The changeover process for the printer is displayed in the table x

2.5.2 Setup on the laminator:
On the laminator, each paper roll is coated with an Al foil of the same width and PE. So to change over to a product of a different size require the movement of the jaws of the extruder for the PE, the holders and guides for the materials and a change in the Al foil roll. The Al foil roll is larger in size than the paper rolls. One Al foil roll can be used for roughly 10 paper rolls. The Al foil roll has a short lifespan within which it must be utilized to prevent creasing and contamination.

So the important criterion for determining the need for a setup is the width of the roll. The overall width is a function of both the width of the individual pack and the number of webs. Since the number of webs is being standardized for a given size, it is a constant for every size. But the overall paper width may be the same for a few sizes. So, these sizes with the same width are grouped together. When a narrow order is run, the outer extremities of the sleeves on the laminator are exposed to dust. If a wider order were to be run in succession, the sleeves would have to be cleaned to avoid contamination. But in case of the transition from a wider to a narrower order, the portions of the sleeve in contact with the paper have been covered by the larger width paper of the preceding order. Hence the orders are always arranged from widest to narrowest.

The grade of the product i.e. milk or juice determines the quality of PE used for laminating the inner layers. To coat the inner layer, LDPE is used for milk specification, while HDPE is used for juice specification. The cleaning of the PE from the hoppers and the extruder is a laborious task. So to minimize the changeover time, all the milk orders and the all the juice are grouped separately and are run once a week. Among the juice orders and the milk orders, the products are run from widest to narrowest.

A unique specialization of Company X, Singapore is the flying setup. This allows a changeover on the laminator without shutting down the machine. For the flying setup, the machine is slowed down from its average run speed and then the size change on the extruder and the sleeves is effected. The change requires only a fraction of the time and cost of a conventional setup. But the flying setup can only be performed if the difference in width between the two orders is less than 6mm. An additional condition is that the diameter of the Al foil roll, which has to be greater than the width of the holder.

2.5.3 Setup on the slitter:

The setup on the slitter is a time consuming process. It takes much longer than either the printer or the laminator. As a consequence of this and process limitations, each slitter runs only a few product families. The need of a setup on the slitter depends on the width of each individual package and the number of webs. Both of these are functions of size. Hence the size code is the only criterion for sorting on the slitter.

2.6 Planning:

Planning is broadly divided into two segments.

2.6.1 Materials Planning:

Materials Requirement Planning deals with the ordering of the raw materials needed for production. The raw materials ordered are paper, polyethylene and aluminum foil with many variants in terms of grade and size. The other items that are used for production like water based inks, pallets, tapes and cores are ordered by the purchasing department as they are relatively low volume and low cost.

Company X International is the parent body of Company X, Singapore and it issues the global forecasts for number of packs and marketing directives. Company X 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. These numbers are interpreted in terms of length of material consumption. The lead time for the raw material is very long. Hence the ordering is done well in advance. But as the orders are received the orders for the subsequent periods is updated.

The ordering is done on a weekly basis as this time period coincides with the frequency of dispatch. A continuous review method is followed. 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.

2.6.2 Production Planning:

The Company X, Singapore production system is a make-to-order one. The production schedule is drafted only on receipt of a production order from the sales department. The scheduling is done on the SAP based P2 system. The production lead time is around 12 days. The basis for planning is the due date.

Although there are two laminators, efforts are made to accommodate all the orders on one laminator. This is because operation and changeover on laminator is expensive. The schedule on the printer and the slitter are prepared on the basis of the laminator scheduling. On each of the three machines, the orders are grouped together based on some 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. The slitter orders are arranged based on pack width.

The production is not continuous. The material is sent to the warehouse in the time between the processes. This creates the work in process (WIP) inventory. The WIP serves as a buffer between the machines to prevent any down time from propagating downstream. The waiting time between printing and coating is around 4 days while the interval between coating and slitting is of the order of 2 days. The year to date average of the stocks of WIP inventory at the different stages is shown in table 1. The doctoring stock is abnormally high owing to some production anomalies.

JAN - JUN 2008		YTD Ave
WIP		
	Printed Rolls	421
	S53 (7Webs&Offset)	41
	S52 & S54	121
	Laminated Rolls	186
	Doctoring Stock*	2021

Table 1: Year-To-Date average of WIP stocks

The orders are displayed on the planning board in the warehouse and factory floor. The production is carried out in the specified sequence and the warehouse replenishes the material accordingly. Often, rush or urgent orders are placed and have to be fulfilled in a short time. This causes disruption of the schedule as these orders have to be accommodated. The pie chart in figure 12 illustrates the distribution of the order time. The data is from January 2007 till June 2008.

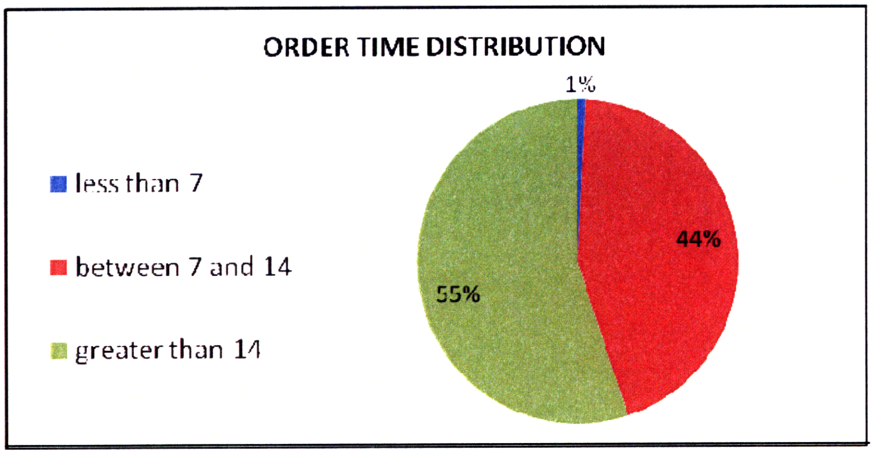


Figure 12: Pie chart of order times

2.7 Storage and material handling:

The Company X, Singapore warehouse is large in size and stores the finished goods and the WIP. The external warehouse and the storage in the ports are used for the raw material.

The movement of raw material, WIP and finished goods between the factory and the Company X, Singapore warehouse is done by a set of laser guided vehicles (LGVs). These vehicles are pre-programmed to follow a specific route and are summoned by the calling switch. They can carry a roll at a time. They are battery powered and are sent to the dock to recharge the batteries, every alternate shift.

Fork-lifts and clamp trucks are also used for internal movements of the rolls. Trolleys are used to move the inks and clichés. Belt conveyors are used in the packaging area. Small movement of the rolls is done by using Easy Mover which is a pneumatic roller.

2.8 WCM campaign:

World Class Manufacturing (WCM) is an ideology that manages all efforts continually to reach excellence. It aims at building a culture to maximize production effectiveness and people capability. Company X, Singapore began its WCM campaign in 2000 and reached the Total Productive Management (TPM) Excellence milestone in 2004 and TPM Special in 2006. It was also awarded the MAXA Award for excellence in manufacturing, operations and sustainability.

The WCM team in Company X, Singapore follows an eleven pillared structure working to improve and standardize the system. The pillar is an intelligence structure which supervises one aspect of system performance. Kaizen or continuous improvement teams are launched by the pillars to eliminate any sources of waste.

3 WCM philosophy and Value Stream Mapping:

3.1 World Class Manufacturing (WCM):

World Class Manufacturing (WCM) is a set of concepts and techniques for the management and operations of a company. It is not restricted to manufacturing alone, but extends to the all the activities of an enterprise- quality management, labor relations, training, staff supplier management, sourcing, transport and maintenance. WCM emphasizes intrinsic management at all levels of the organization, rather than domination by a separate group of managers. The complete utilization of resources- manpower and equipment is stressed on. Employee involvement and strong relations with suppliers and customers are the cornerstones of this philosophy. [2] The WCM philosophy was pioneered by the Japanese manufacturing revolution. It focuses on continuous improvement in quality, cost, lead time, flexibility and customer service. [3]

According to the WCM philosophy, elimination of waste or muda is important for the creation of a lean organization [4]. The seven key wastes are:

1) Over production or early production
2) Inventory
3) Unnecessary manual movement
4) Waiting time
5) Unnecessary movement of parts
6) Over processing
7) Scrap, rework and defects

The first step for achieving a lean system is the identification of wastes in the company's practices. A prerequisite, therefore is a complete visualization of the system with the key indicators of the company's performance highlighted at each stage. This is done by means of Value Stream Mapping (VSM), an important tool in WCM. The indicators reflect performance in the seven areas mentioned above and help in finding the inefficient segments and practices.

3.2 Value stream:

A value stream is the sequence of all the actions that are required to bring the product from concept to launch. [5] It traces the conversion of the product from raw material to its final form and also the customer order from placement till fulfillment. A value stream includes the value adding and non value adding actions. The Company X, Singapore value stream consists of the process from the time the order is received by the sales department till the actual shipping of the order. The intermediate stages include design, planning, production and logistics as shown in figure 13. [1] Although there are several hundred different products belonging to many different product families, they all follow a common, identical path. Therefore, this common course that is followed is defined as a single value stream.

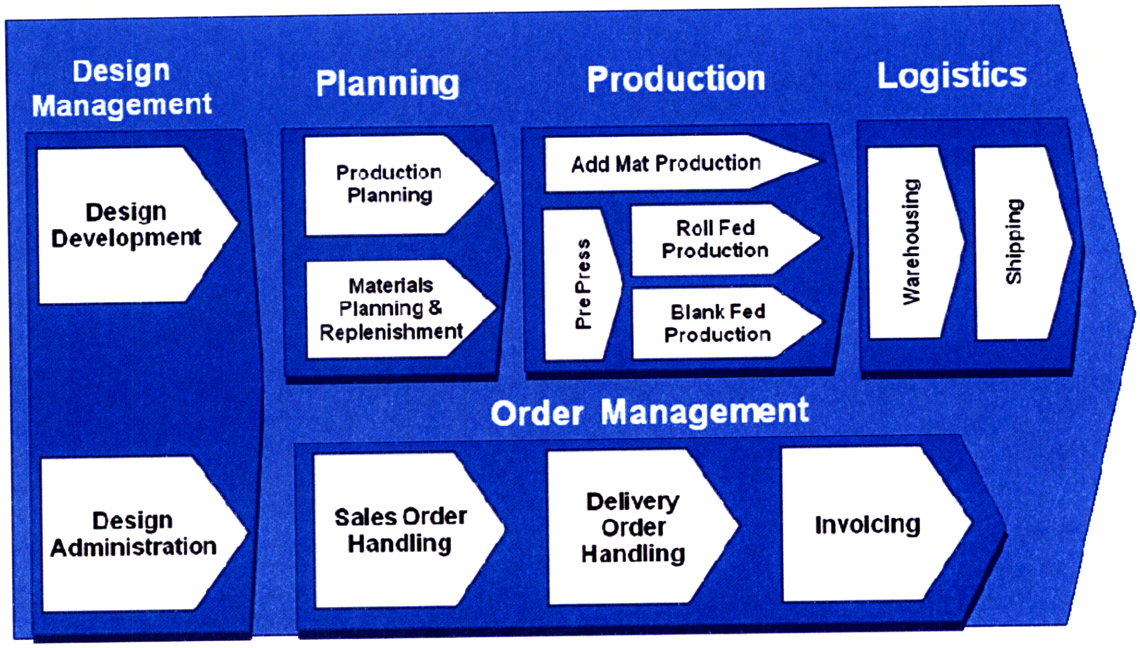


Figure 13: Different segments of Company X operations

3.3 Value stream map:

A value stream map is a visual tool that helps observe the flow of material and information as the product makes its way through the value stream. It helps trace the product's path from supplier to customer. A value stream map can be drawn for both the present state and the future state. The present state map is a snapshot of the processes as it is at present while the future state map is an ideal picture of how the processes should be. The use of the two maps concurrently can help in providing a starting point for the improvements and a vision or a target to be achieved. It helps in completely defining the path of change and improvement. [5]

For Company X, Singapore, only the current state map was prepared. The definition of the ideal state was not done beforehand and the developments were to be gradual and continuous. The map was divided into the segments as shown in figure 13:

1) Order Management
2) Design Management
3) Planning
4) Production
5) Logistics

This discussion will be limited to design, planning and production.

The investigation of the processes was done by studying the literature and by verifying by observations on the shop floor. Each process was perceived as the customer of the preceding process. All flows are indicated by arrows, the direction being from tail to head. The processes are laid out from left to right and top to bottom in sequence.

3.4 Benefits:

The advantages of using value stream mapping as an essential tool are:

1) It helps visualize the flow of material and information.
2) It provides information at a system level rather than at a process level.
3) It helps in the identification of waste and the sources of waste.
4) It depicts the linkages between material and information flows.
5) It provides a quantitative estimate of the key parameters at every stage.
6) It helps in decisions regarding flows which are very difficult to determine and evaluate otherwise. [5]

3.5 Symbols:

The symbols used in the value stream map and their explanations are provided in table 2.

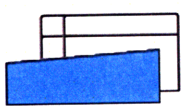
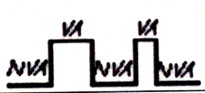
NO	SYMBOL	EXPLANATION
1		Material flow
2		Information flow
3		Blanket order
4		Forecast information consumption update to supplier
5		Production schedule shared to shop floor and warehouse to P2 system
6		Shipment
7		Decision box
8		Event box
9		Process
10		Warehouse/ storage space
11		Information from other phases
12		kaizen burst
13		Supplier
14		timeline showing value added and non-value added time

Table 2: Symbols used in the value stream map

3.6 Overview:

An overview of the entire process is provided in figure 14. The blocks are further explained in the subsequent diagrams.

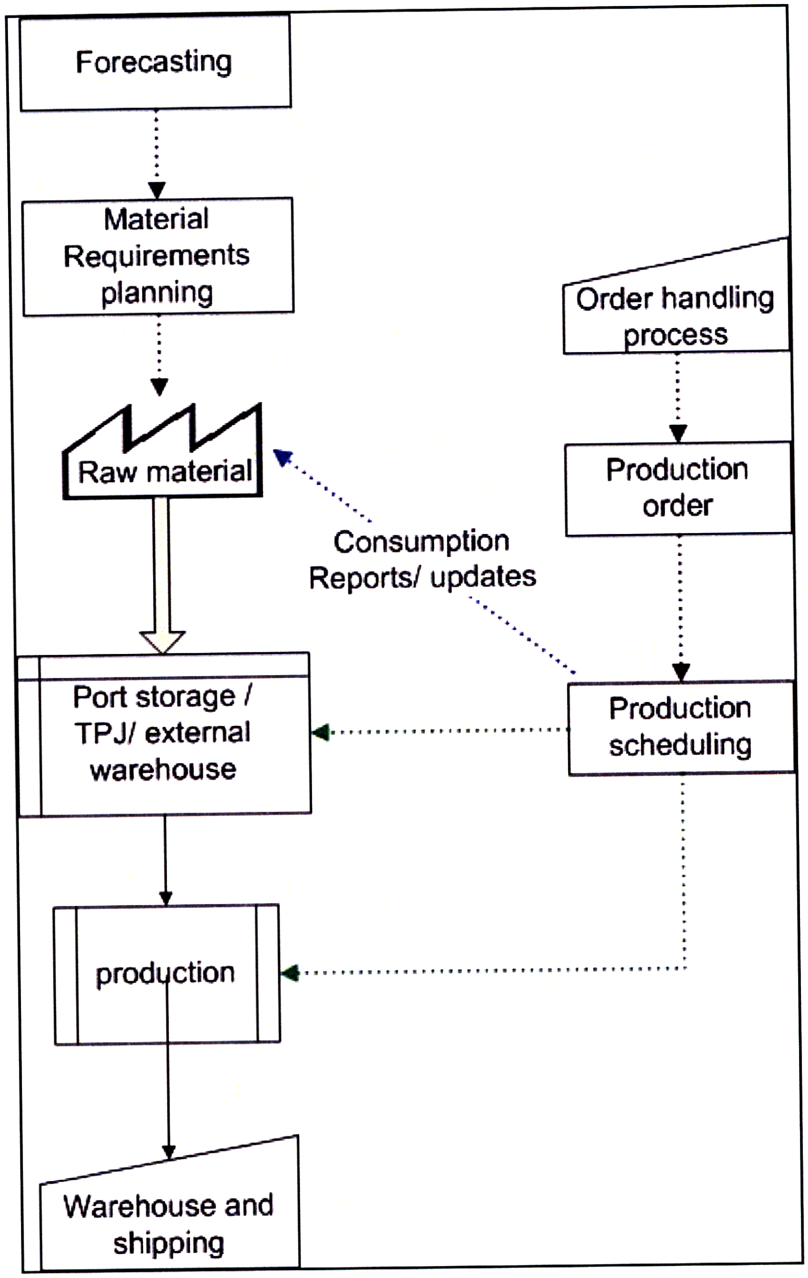


Figure 14: Overview of planning, production and design

3.7 Design and Pre-press:

Once the design department reviews and approves of the design it is sent to the pre-press section. Here, the clichés are prepared and mounted on sleeves for the printing stage. The important metrics are the time for the preparation of the sleeve and the number of sleeves prepared every shift because they contribute to the lead time for the product and also is the precedent for the downstream operations. A detailed process flow and analysis of the pre-press is as shown was performed to determine the capacity, flow time, manpower and material handling equipment. The information is tabulated in table 3.

	QS/Product:	ordering plates from warehou...	order verification	film preparation	back exposure	main exposure	punching holes	inspection	processing	oven	finishing	cutting	inspection	plates transported to mounting	prepare sleeve	trimming	taping	preparation	mounting
BASIC INFORMATION	description	operator from previous shift orders 1 pallet	if plates in condition (<20 rolls /5 uses) reuse old one	existing design- use old modify /new- obtain from design	no film	with film	holes for attachment	short and without stoppage	some portions etched away	curing	drying	rough cutting	final thorough inspection	based on schedule	removal of old designs	accurate cutting to exact shape		marking /sorting /clip-off	
	Process time (mins)	10		3 (new /modify)	1.17	12	0.33		5-old 10-new	150	12-UVC 15-UVA	2	2	5	10	10	7	5	10
	Target level (/person/shift)	1 pallet /shift			22 cliches/person/shift (3 shifts/day, 3-4 persons/shift)									40 orders		60 colours /person /shift	64 colours /person /shift		32 sleeves /person /shift
	Setup time (mins)	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Material Handling,	forklift		hand	hand	hand	hand	hand	hand	hand	hand	hand	hand	trolley	trolley	hand	hand	hand	trolley
	# of people involved			co-ordinat	4									1	1	2		2	
VOLUME	machines				6		2	on line	3	4 machines, 2 plates/ drawer		1 cutting m/c & scissor	4 tables			hand	hand	hand	hand
										5	1 drawer								

Table 3: Pre-press process flow

3.8 Production:

The production section includes information about the printing, laminating, slitting and doctoring processes. The map of production is shown in figure 15.

The key parameters indicated for each machine are:

1) The number of machines:

2) OEE (overall equipment efficiency): OEE is an important figure that provides information on the return on investment. It indicates the utilized fraction of the full potential performance of the machine. Equation x and y provide the mathematical formula used in the derivation of OEE.

   $$OEE = \frac{total\ up-time \times average\ actual\ run\ speed}{total\ run\ time \times maximum\ run\ speed}$$

   total up-time = total run time – setup time – idle time – time for maintenance – breakdown time – repair time

   OEE discounts the time that the machine is unutilized. This is to prevent penalizing the plant with efficient utilization if there is a lack of orders. But the OEE figure is an important characteristic for Company X, Singapore as it is a continually monitored performance indicator.

3) Inspection: The inspection systems locate and mark the defects directly on the production line. The defective portions are then removed before dispatch to the customer. This helps in maintaining the quality of the products. Apart from the quality check, the inspection systems act as a real-time indicator of machine capability. Defects are first signs of any technical problems on the machine and identification of defects may serve as an indicator of the machine condition. Defectives are a waste of resources – machine time, material and worker effort. Through the use of these systems, any problem can be detected and rectified quickly before a large number of defectives are produced, curtailing the wastage.

4) Manpower: The number of technicians manning each machine is important as it provides an indication of the work load during setup and the resources required for running the machine.

5) Setup time: Although the changeover time varies largely with the machine specification and the products involved, the average range of changeover time is mentioned.

6) Cycle time: The cycle time is the average time to process one roll on each machine. It is useful because it helps estimate the time that it takes for a machine roll to be processed.

7) Up time: The up time is the fraction of time that the machine is up and running. It discounts speed and quality loss and includes maintenance and setup in the productive time of the machine.

   The kaizen burst in the figure highlights the need for the WIP optimization project.

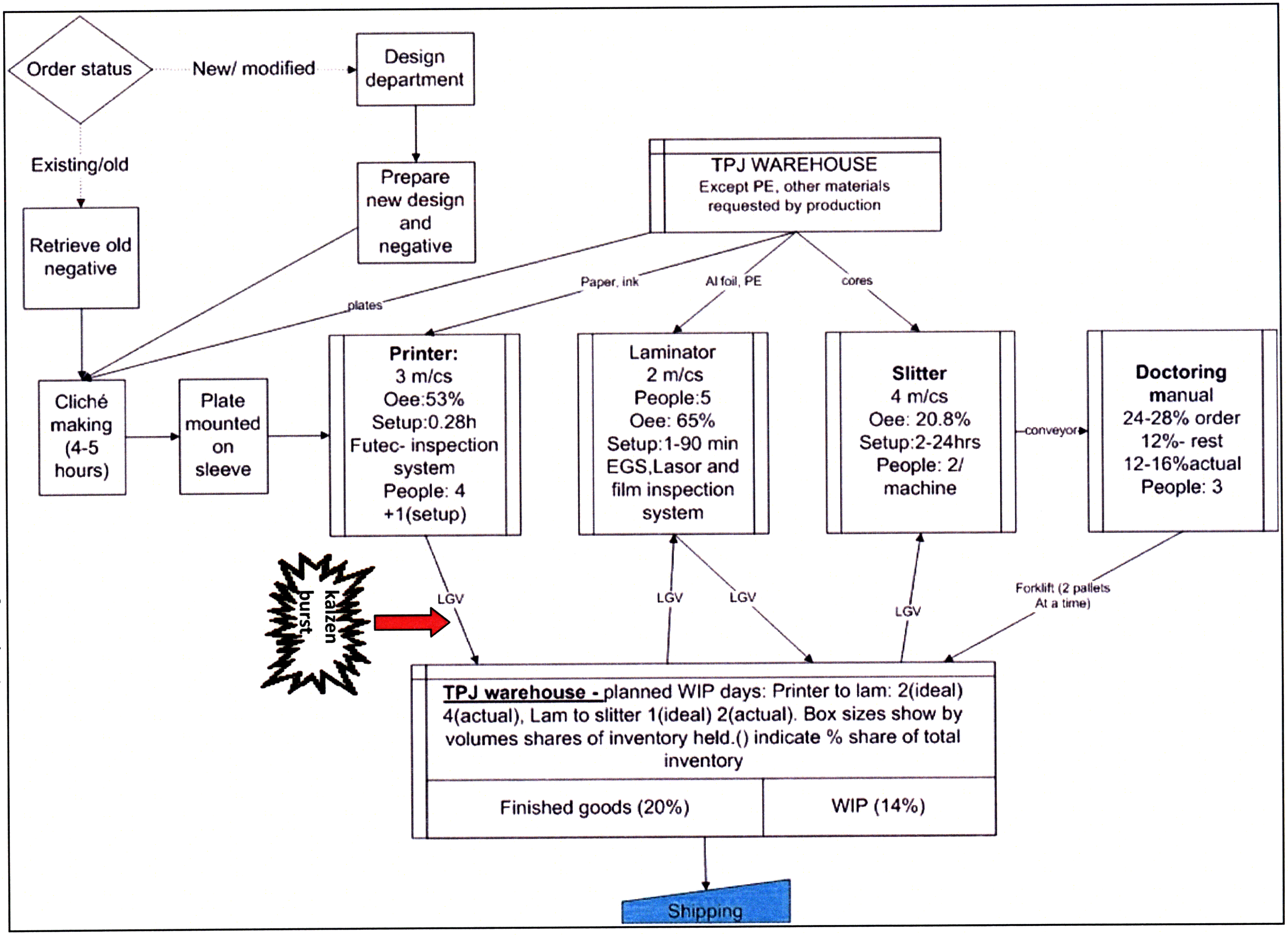


Figure 15: Value Stream Map of Production

3.9 Planning

This section covers the forecasting, material resource planning, capacity planning and the production scheduling.

For the map of material requirements planning shown in the figure 16, the key metrics are:

1) Planning policy: The policy is the set of guidelines followed for the planning and ordering of the raw material. The policy in use in Company X, Singapore is a continuous review model where the level of raw material is checked on a continuous basis. Once the level of material falls below the re-order point, an order is placed to replenish the raw material until the order up-to point. The forecasts for each time period is proved by Company X International and the blanket orders are placed by Company X Global Supply which are the international regulatory bodies in the Company X layout.

2) Stocks of raw material: The level of stocks for each of the raw materials is an important number as it reflects the portion of the cash flow tied up as inventory.

3) Planning horizon: The planning horizon is the period of time for which the planning and placement of orders are done. It reflects how far into the future the order extends.

The map of Production planning and scheduling is displayed in figure 17. The key metrics for this segment are similar in nature to material requirements planning and are as follows:

1) Planning Policy: The policy is the set of guidelines followed for the scheduling the order on the machine. The criteria used to determine the sequence of orders on each machine

2) WIP inventory: The WIP inventory between any pair of machines represents the portion of time spent by the roll waiting for products and consequently the increment in lead time because of non productive time.

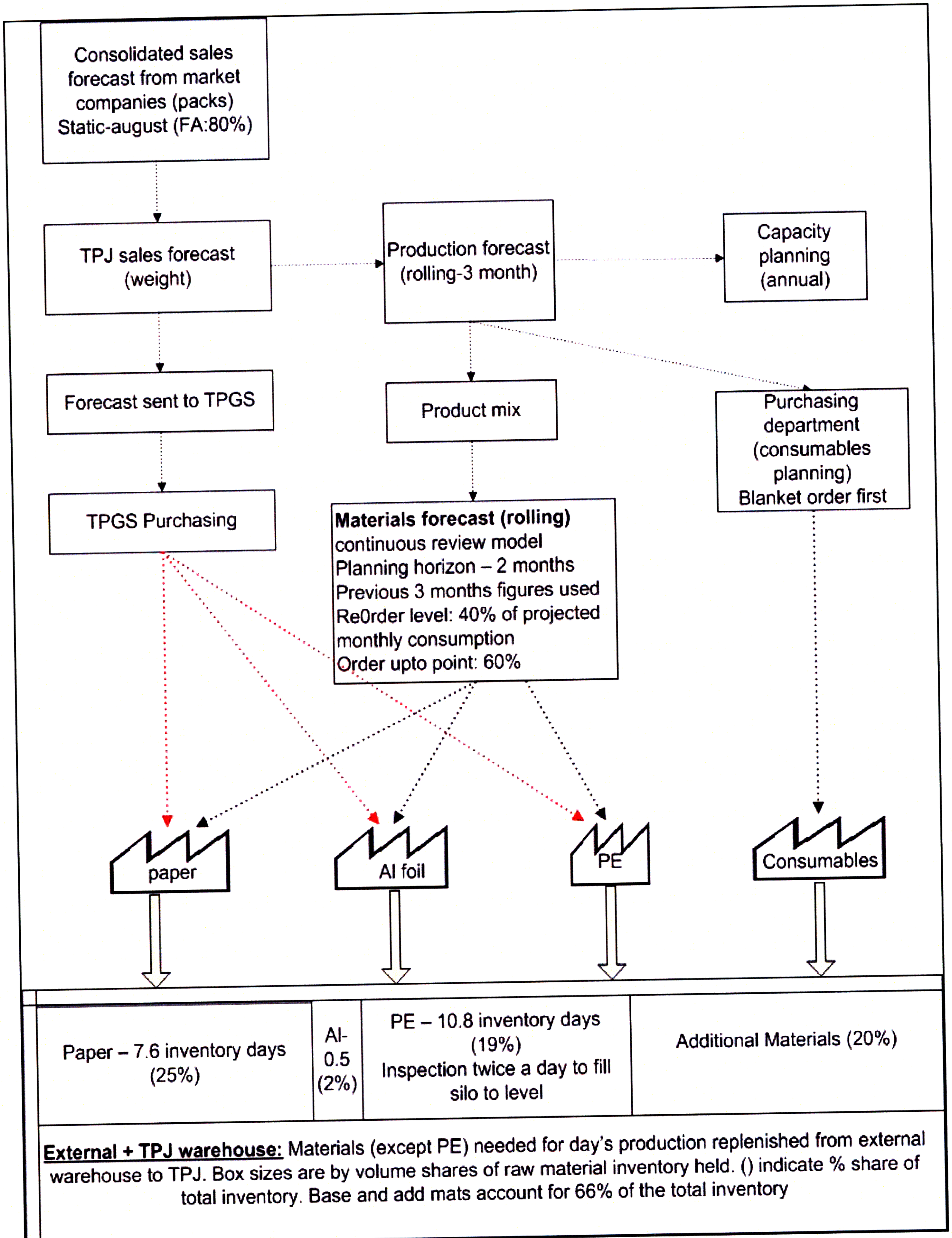


Figure 16: Value Stream Map of Materials Planning

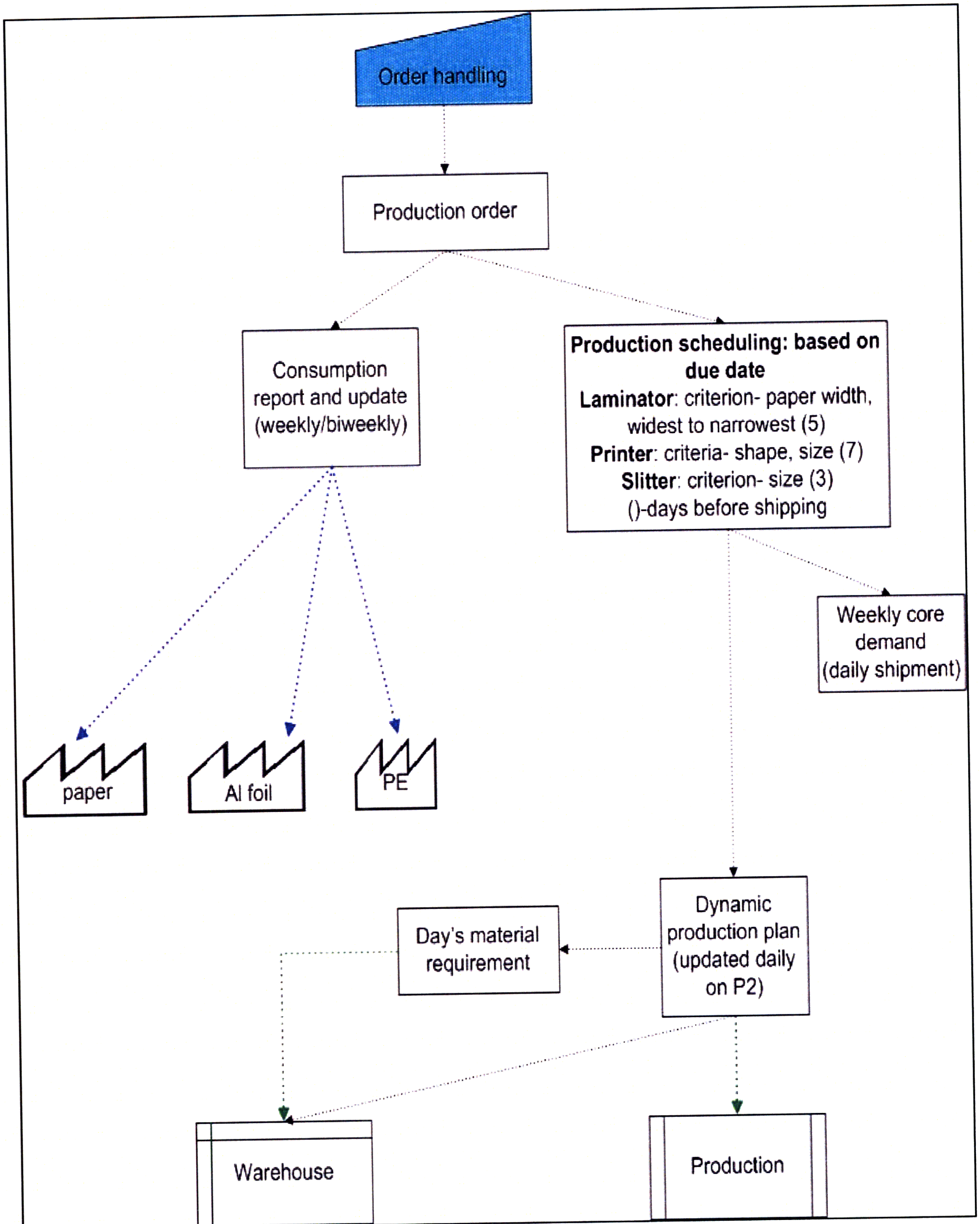


Figure 17: Value Stream Map of Production Planning

On the basis of the value stream mapping, the problem of excess WIP inventory between printing and laminating and between laminating and slitting was identified. This was then addressed in the focus project.

4 Methodology

Cause of WIP:
There are two main causes for the WIP in Company X, Singapore:

1) Different grouping criteria for the machines: In the Company X, Singapore factory, the printer, the laminator and the slitter have their own individual set of criteria for sorting the orders. On the printer, there is a minor setup for every design, which involves change of the sleeves and the colors. The major setups occur for changes in system and size. So, in order to minimize setups, the orders are grouped by size and system. On the laminator the orders are grouped by the grade – milk or juice specification. The laminator also incurs a setup for every change in the overall width of the roll. Product families with the same overall width are grouped together. So, within the milk and juice specification, the groups are run from widest to narrowest because of machine considerations. The setup on the slitter is similar to that on the laminator. It depends upon the width or the size of the pack. In order to group the orders according to the criteria for each machine, sufficient WIP is built up. This ensures that the number of setups is kept low.

2) Difference in machine speeds: The run speeds of the printer, laminator and slitter are very different. The laminator is the fastest and is almost 1.5 times as fast as the printer and about twice as fast as the slitter. The laminator is also the bottleneck machine. So sufficient WIP is built of the print stock to ensure that the laminator will not starve in case of a printer breakdown. This is essentially a buffer to decouple the laminator from any disruptions upstream. Between the laminator and the slitter, the disparity between the rate at which the laminator produces a coated roll and rate at which the slitter slits that roll is responsible for the WIP. This WIP mainly consists of rolls waiting for their turn to be slit.

To tackle the problem of WIP three solutions (Plan A, B and C) are investigated. The plans are introduced in the ascending order of the quantum of change suggested to the system i.e. Plan A is the most conservative while Plan C is the most revolutionary. Apart from this, the role of design in the printer setup is also investigated.

4.1 Plan A: Continuous flow for the top products

4.1.1 Deployment:

Company X, Singapore belongs to the South and South-east Asia cluster. Each year the cluster management issues a list of "must-win battles" which is a compilation of the priority initiatives for the cluster. One of the six priority initiatives issued for this year was to grow the share of business in the three major dairy customers – F, V and N. The production share of the customers is illustrated in figure 18 with the three key customers highlighted.

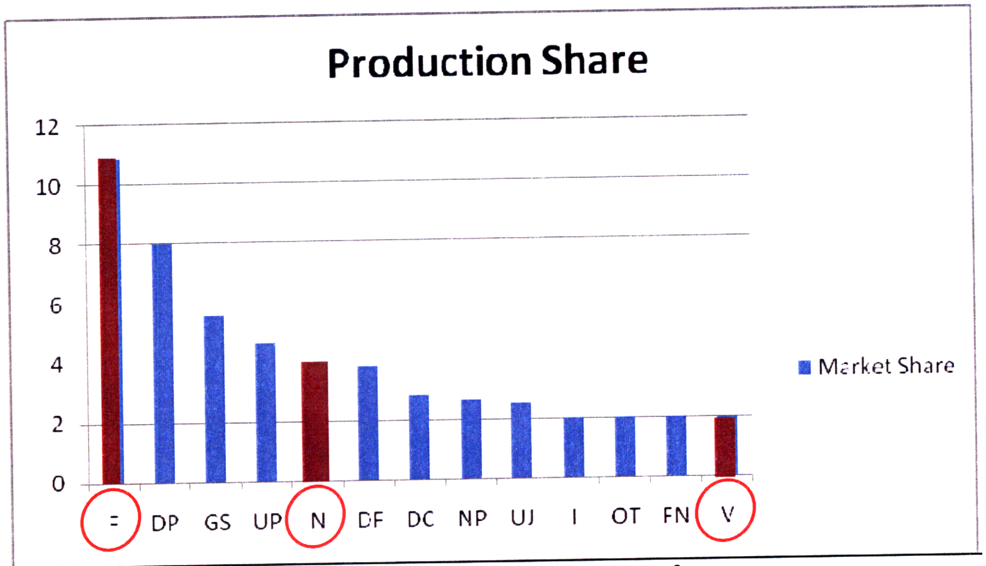


Figure 18: Production share of customers

Although N and V do not have a large market share presently, they harbor a large potential for more volume. If the service rate was improved Company X, Singapore could hope to acquire the remainder of these customers product line-up. Hence they are placed on the high priority list. For each of these 3 customers, the top products were identified on the basis of current volume of sales. The list of the products, their specifications and the market share as a fraction of the customer's product account with Company X, Singapore are listed in table 4.

	Customer F		Customer DL		Customer N		Customer V		
Country	Vietnam		Vietnam		Malaysia	Philipines	Vietnam		
% of country					33%	39%			
QS	7369-465	Product Family A	7369-465	Product Family A	7427-565	Product Family B	7369-465	Product Family A	
Design	53-785	Flavored Milk	53-8480	Milk	53-B624	53-7928	53-B228	53-B627	53-B626
Share of Customer	83%		63%		64%	85%	78%		
Share of QS	68%		69%		77%	60%	27%	25%	17%

Table 4: Information about Priority products

4.1.2 Method:

In Plan A, the changes to the production plan are kept to a minimum. The priority products belong to the Product family A and Product family B families which are two of the largest product families in the Company X, Singapore portfolio. Hence the time for which the machines run the product families is very long. The weekly run time on the laminator for the large product families is listed in figure 19.

Quality-Siz	Size	Web	Denomination	Widt	Hours
7037-465	200S	9	TWA/jl FP CD H	1,574	1.94
7038-465	200S	9	TWA/jl F CD-H	1,574	1.59
7073-465	200S	9	TBA/jl FP CB	1,574	4.88
7173-465	200S	9	TWA/jl FP CD	1,574	0.80
7178-465	200S	9	TWA/jl F CD	1,574	0.97
7369-465	200S	9	TBA/jl FP CD	1,574	38.85
7406-465	200S	9	TBA/jl F CD	1,574	0.23
7072-813	1000S	5	TBA/jl F CB	1,531	1.96
7073-813	1000S	5	TBA/jl FP CB	1,531	4.88
7468-813	1000S	5	TBA/jl-H F CD H	1,531	2.10
7469-813	1000S	5	TBA/jl-H FP CD-H	1,531	14.71
7072-466	200M	8	TBA/jl F CB	1,512	0.23
7073-466	200M	8	TBA/jl FP CB	1,512	5.89
7369-466	200M	8	TBA/jl FP CD	1,512	1.39
7427-565	250S	8	TBA/jl FP CD-H	1,512	31.00
7429-466	200M	8	TBA/jl-H FP CB	1,512	0.26
7459-565	250S	8	TBA/jl F CD-H	1,512	0.29
7072-560	250B	7	TBA/jl F CB	1,506	0.55
7073-460	200B	7	TBA/jl FP CB	1,506	5.84
7073-560	250B	7	TBA/jl FP CB	1,506	2.29
7369-460	200B	7	TBA/jl FP CD	1,506	3.16
7369-560	250B	7	TBA/jl FP CD	1,506	6.66
7369-600	330S	7	TBA/jl FP CD	1,506	2.39
7406-460	200B	7	TBA/jl F CD	1,506	2.75
7406-560	250B	7	TBA/jl F CD	1,506	5.95
7427-505	300S	7	TBA/jl FP CD-H	1,506	0.62
7444-560	250B	7	TBA/jl-H F CD	1,506	1.05
7459-585	300S	7	TBA/jl F CD-H	1,506	0.69
7037-350	125S	9	TWA/jl FP CD H	1,466	2.09
7038-350	125S	9	TWA/jl F CD-H	1,466	0.37
7073-350	125S	9	TBA/jl FP CB	1,466	0.60
7173-350	125S	8	TWA/jl FP CD	1,466	4.39
7369-350	125S	9	TBA/jl FP CD	1,466	8.41
7406-350	125S	9	TBA/jl F CD	1,466	0.24

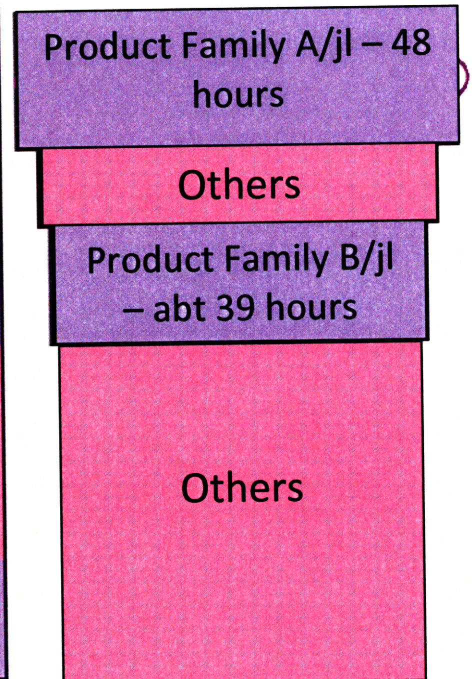


Figure 19: Weekly run hours of large product families

The 7 priority products are produced in the overlapping time segments for the same product family on the three machines i.e. the priority orders are produced at the time when Product family A products are running on any of the printers, laminators and slitters simultaneously. There is no change in the scheduling procedure or policy on any of the three machines. The overlap between the machines is not planned for but merely coincidental. Since the priority products are included in an already scheduled run of the product family rather than abruptly introduce the product, no extra setups are incurred.

The laminator is the bottleneck machine and hence the capacity of the laminator is a constraint. Usually the orders are completely printed about 4 days before coating. So, the continuous flow method where the coating is started before printing of all the rolls of the order was completed raised some concern. In case of a printer breakdown, although there would be no disruption on the laminator because of the inventory of other products built up, there is still the issue of the priority order not getting laminated on time. Either the laminator would have to wait for the printer to recover and print the remaining rolls of the priority orders; or the laminator would have to incur an extra setup to produce the product family again; or wait for the entire cycle to complete.

This problem is more pronounced if the priority order was scheduled for lamination at the end of the product family. Hence an effort is made to laminate the orders at the beginning of the lamination of the product family. This way even if the printer suffered the breakdown, the printer can be repaired in a few hours and the remainder of the rolls of the priority order can catch the laminator before the completion of lamination of the product family.

4.1.3 Simulation:

A simulation was run using the historical data for the months of April 2008 and May 2008. As mentioned in section 5.1.2, the overlap is an event occurring by chance. If the overlap did not occur on a regular basis, the priority order would have to wait for a long while for its turn. Although the run time would be short due to continuous flow of the order on the three machines, the waiting time for printing would be very long. But the analysis of historical data proved this to be rare, owing to the large volume of products belonging to the Product family A and Product family B families. Analysis of the historical production data was done to ensure that there is at least one overlap in a every 5 day period. Figures 20, 21, and 22 showing the timeline of production and the priority orders placement prove that the overlap is a frequent occurrence.

No	Symbol	Explanation
1		Production of 200 slim
2		Production of 250 slim
3		Production of other products
4		Non productive time
5	→	Flow of 200 slim
6	→	Flow of 250 slim

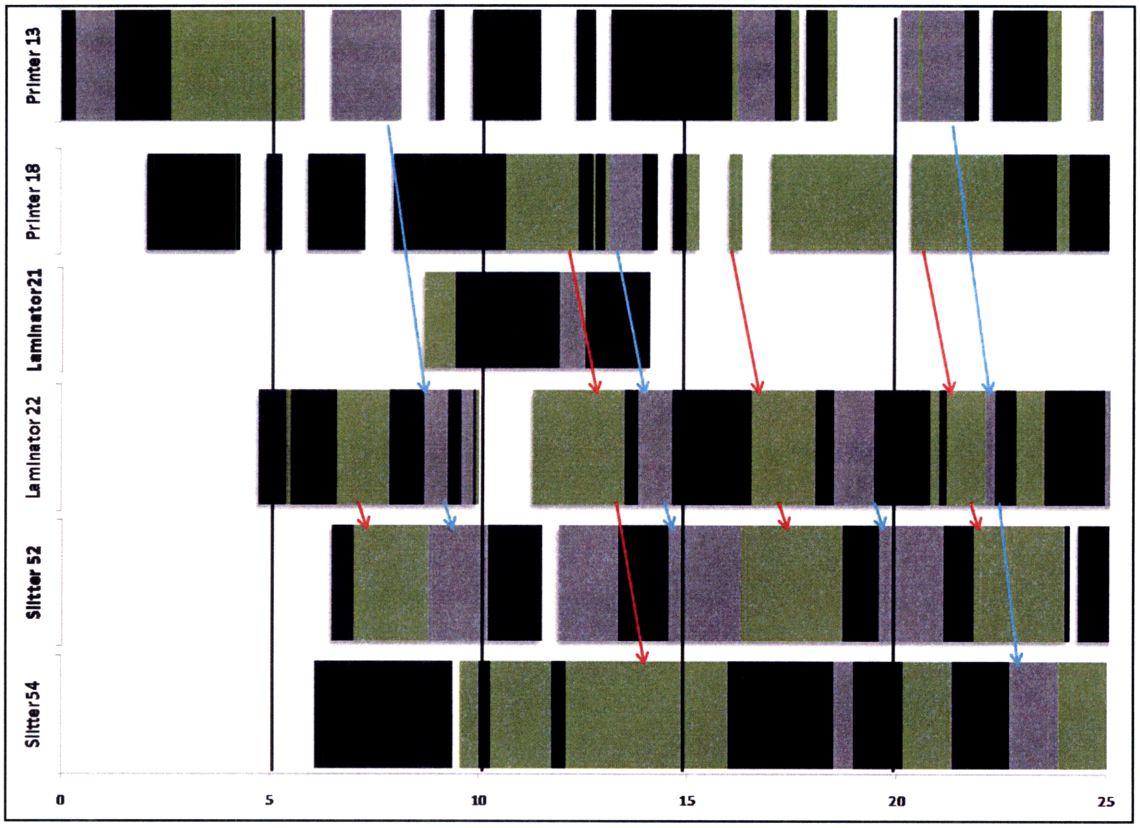


Figure 20: Production time for 25 days beginning 27/03/08 using Plan A

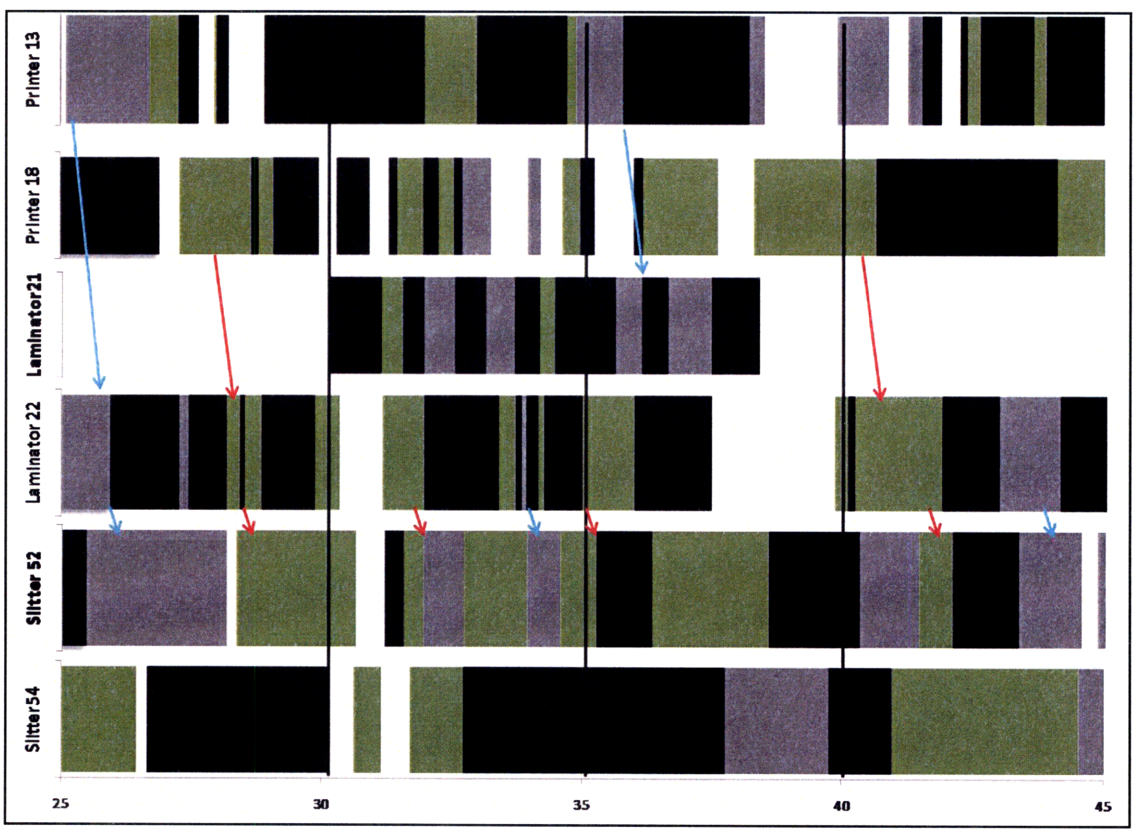


Figure 21: Production time for 20 days beginning 21/04/08 using Plan A

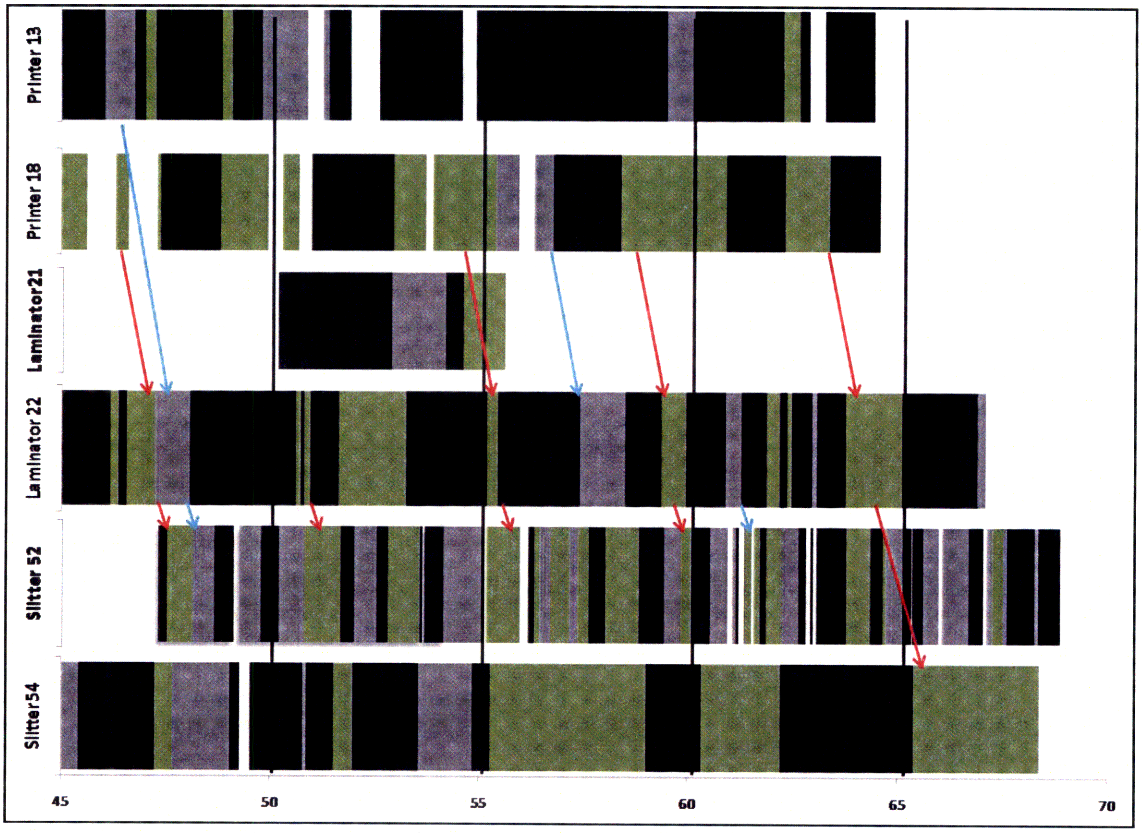


Figure 22: Production time for 25 days beginning 11/05/08 using Plan A

For the quality-size 7369-465, the length of one roll is 7100 m. After deducting the 120m used for setup, the effective length is 6980m. The average run speed of the printer is 500 m/min. So the time to print one roll is nearly 14 minutes. Taking into account variations in the figure, the printing time for one roll was taken to be 15 minutes for a conservative estimate. The run time for mean order volume for all the products on the three machines is listed in table 5. The run time on the laminator is 13 minutes while the run time on the slitter is 27 minutes. There is no changeover time considered as the priority orders are run within the same product family. The positioning of the priority orders with respect to the other products is as shown in figures 20, 21 and 22 for the different time periods.

The distribution of the weekly order sizes was assumed to be random. Using the mean and standard deviation for the weekly order sizes, the upper 2σ limit was calculated. This is the order size that would not be exceeded in 95% of the cases. The time for processing of orders of this size was calculated as shown in table 6. This exercise was performed to verify if there was a disruption in the orders that followed due to a large sized special order and also to determine the difficulties in the implementation on the factory floor.

The buffer rolls is the number of rolls that have to be processed before the start of the next operation to ensure uninterrupted flow. It is essentially the head start given so that the slower machine can catch up. In case of the printer and the laminator, since the machine upstream is slower than the downstream one, the buffer rolls is the number of rolls printed before the laminator starts the priority order. The laminator being faster will coat each roll more quickly than they can be printed. The buffer will slowly deplete and the laminator will catch up with the printer at the last order. Thus, printing and coating will be completed in the minimum possible time. For this stage, the buffer roll is roughly equal to the ratio of the run times of the two machines. A point to note is that run time for the printer includes the time to move the roll from printer to laminator.

In case of the laminator and the slitter, the machine upstream is faster than the downstream one. So, only one buffer roll is needed at this stage. Once the first roll is coated, the slitting can begin. The laminator will coat the rolls at a much faster rate and the slitter can slit them at its own pace.

The buffer rolls between the printer and laminator; and between the laminator and the slitter for the different products in the base case and worst case scenario are tabulated in table 5 and table 6.

					Printer			Laminator			Slitter
Product Family	Design No	Country	Customer	Mean	Run time	moving ti	Buffer rol	Run time	moving time	Buffer	Run time
A	53-9480/5	Viet Nam	DL	15.67	235.00	62.67	8.23	203.67	62.67	1.00	423.00
A	53-5785/13	Thailand	F	11.00	165.00	44.00	6.08	143.00	44.00	1.00	297.00
B	53-B624/3	Malaysia	N	5.00	75.00	20.00	3.31	65.00	20.00	1.00	135.00
A	53-B228/3	Viet Nam	V	15.00	225.00	60.00	7.92	195.00	60.00	1.00	405.00
A	53-B627/2	Viet Nam	V	16.00	240.00	64.00	8.38	208.00	64.00	1.00	432.00

Table 5: Buffer role calculation for base case

							Printer			Laminator			Slitter
Product Family	Design No	Country	Customer	Mean	std dev	max	Run time	moving time	Buffer rolls	Run time	moving time	Buffer	Run time
A	53-9480/5	Viet Nam	DL	15.67	2.89	21.44	321.60	85.76	10.90	278.72	85.76	1.00	578.88
A	53-5785/13	Thailand	F	11.00	6.03	23.07	346.00	92.27	11.65	299.86	92.27	1.00	622.80
B	53-B624/3	Malaysia	N	5.00	0.00	5.00	75.00	20.00	3.31	65.00	20.00	1.00	135.00
A	53-B228/3	Viet Nam	V	15.00	2.83	20.66	309.85	82.63	10.53	268.54	82.63	1.00	557.74
A	53-B627/2	Viet Nam	V	16.00	1.41	18.83	282.43	75.31	9.69	244.77	75.31	1.00	508.37

Table 6: Buffer roll calculation for worst case scenario

4.1.4 Results:

The WIP for the priority products between the printer and the laminator was reduced from 4 days to 0.06 days; and the WIP between laminator and slitter decreased from 2.1 days to 0.09 days. The WIP for the other products increased marginally because of the time spent waiting for the priority products to flow through the system. But since there is no scheduling change, it is just a case of a few products waiting longer while some others were being expedited. So the mean queue length and hence the overall system WIP remained unchanged.

The minimum cycle time (in minutes) for the priority orders for average number of rolls is listed in table 7.

Design No	Country	Customer	Order size	flow time
53-9480/5	Viet Nam	D L	15.67	695.0266
53-5785/13	Thailand	F	11.00	498.7208
53-B624/3	Malaysia	N	5.00	246.3276
53-B228/3	Viet Nam	V	15.00	666.9829
53-B627/2	Viet Nam	V	16.00	709.0484

Table 7: Production time for priority products

4.1.5 Practical considerations:

'Continuous flow' in the most technical sense of the term implies that the products do not go to the warehouse at any intermediate stage of production. They proceed from one machine to the next undergoing the several stages of the process before being moved to the warehouse as finished goods. But in the Company X, Singapore system, there is a huge disparity in the machine speeds. Since the printer is slower than the laminator, some inventory of printed rolls is necessary before coating begins so that the laminator can run uninterrupted. Since the slitter is also much slower than the laminator, the laminated rolls have to wait for their turn on the slitter. So even within the same order, there is some waiting time for the rolls.

The rolls of the order being processed can spend the waiting time on the factory floor. Alternately, allowing for some departure from the ideal, the rolls can be transported back to the warehouse. They can then be brought back to the factory after a short while, when they approach their turn on the next process. This way does not violate the conditions of continuous flow since the order runs on the three machines almost simultaneously. The layout of the Company X, Singapore site is shown in figure 23.

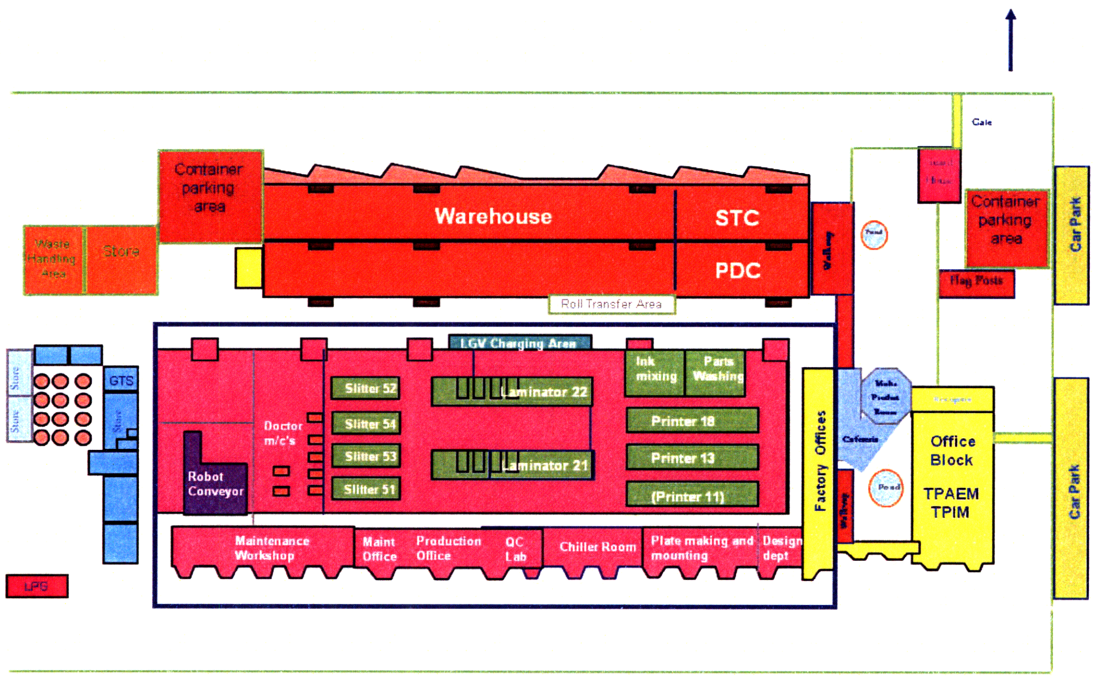


Figure 23: Layout of Company X, Singapore production facility

The choice of method depends upon the space available on the factory floor for the placement of the rolls. A 5 G study was carried out to investigate the potential for continuous flow in the factory.

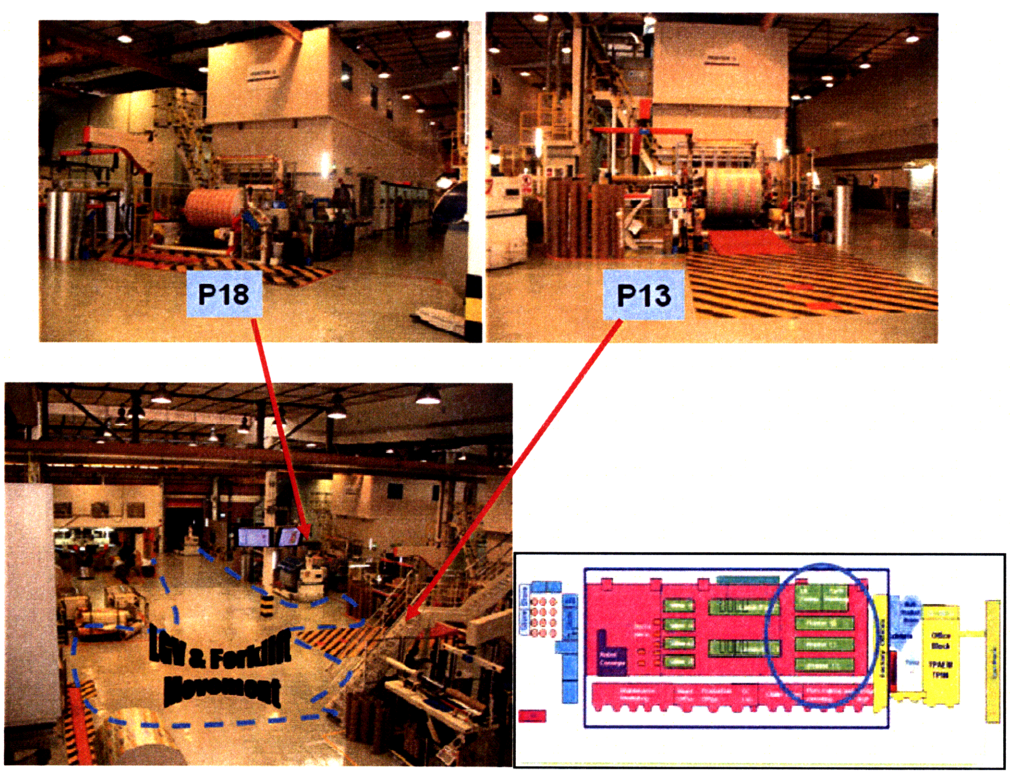


Figure 24: Analysis of space at the printer

Figure 24 shows a snapshot of the waiting space available between the printer and the laminator. A major portion of the space is allotted for the movement of the LGVs which ferry the raw material and WIP in and out of the warehouse. Safety protocol also plays an important role in the placement of WIP. Many portions of the factory floor are restricted due to the potential for injury to the workers. From figure 25, it can be seen that the authorized space available between the printer and the laminator is 5 rolls.

Figure 25: Analysis of space at the laminator

Between the laminator and the slitter, the space is scarcer. The primary storage space (adjacent to the slitter) is only for about 3 rolls. However with some modifications, secondary storage space (small material handling equipment have to be used to move the rolls) can be added. The blue line in figure 26 shows that a conveyor system can be built in and used to store the WIP.

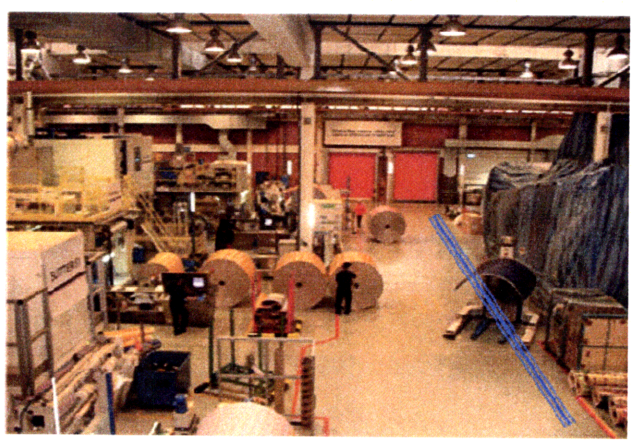


Figure 26: Analysis of space at the slitter

Another possibility is to make the air lock bigger. This will serve as a secondary holding area for the WIP as shown in figure 27. But all this requires an additional investment and re-routing of the LGVs along the new route which can be expensive.

Figure 27: Air lock at the Company X, Singapore production floor

4.2 Plan B: Waiting time reduction between printer and laminator and continuous flow for priority products

4.2.1 Background:

Each printed roll waits for about 4 days to be laminated. The reasons for this are the differences in the run speeds of the machines and the different sorting criteria. The analysis of the historical data from Jan 2007 to May 2008 as shown in figure 28 proved that 93 % of the rolls were printed 1 day or more before lamination. Another observation from the same data pool was that less than 1% of the orders were printed and laminated on the same day. This is evidence suggesting that the rolls wait between the printer and the laminator for longer than necessary.

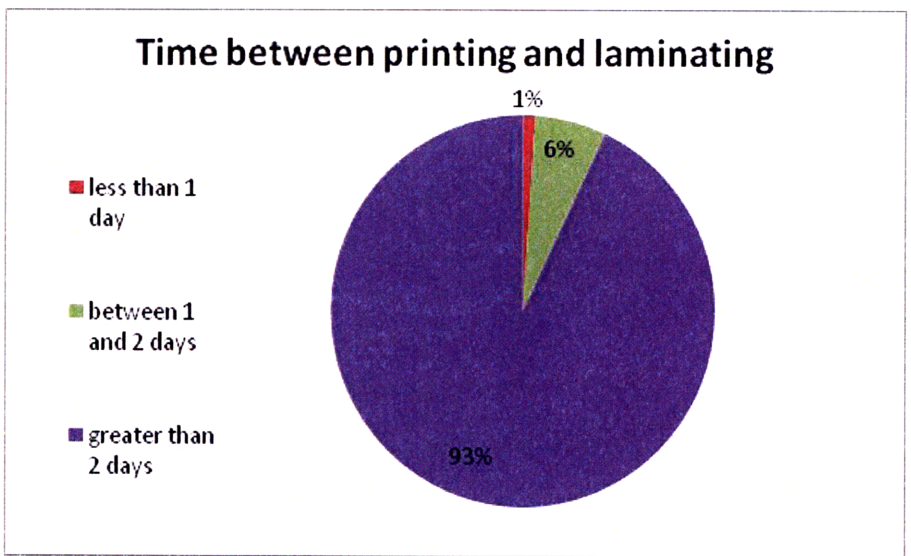


Figure 28: Pie chart of distribution of time between printing and slitting

4.2.2 Method:

According to Plan 2, the waiting time for the printed rolls is reduced by 1 day. This implies that all the orders are sent for lamination one day earlier. Or, if the lamination day is assumed to be fixed, the rolls are printed one day later. No change is made to the planning policy or the criteria for grouping on the machines. No extra setups are planned for any of the machines. The waiting span is reduced by 1 day and not more because change for a larger period implied more change to the system. This could not be accomplished without some change in the policy.

For the priority products, the continuous flow method described in section 5.1 is still adopted without any modifications. Overlapping time segments for the same product family on the three machines are identified after the offset is introduced. The priority products are produced in these time slots. No changes are introduced in the planning or placement of the priority orders. The run time calculations for the priority products are valid for plan B. To ensure that the orders are printed on time for lamination, the priority orders are placed at the beginning of the laminator's run of the same product family.

4.2.3 Simulation:

Using historical data from April 2008 and May 2008, plan B was simulated. The timelines from the simulation for the different periods are shown in figures 29, 30, 31. The time between printing and laminating was reduced by a day. So the printing was done one day later. The schedule was duplicated almost exactly for about 90% of the products. As mentioned earlier around 7% of the products couldn't catch the laminator after the waiting time reduction was introduced to the existing plan. These orders were shuffled on the printer such that the printing was completed before the start of the lamination. The shuffling was some minor change like swapping with another product family. Since the order of running is not of importance on the printer, this re-positioning of the product families didn't cause any additional disruption or waiting time.

In a few cases, the orders had to be re-positioned on the laminator. This shifting was only the re-arrangement within the same paper width. Again, no setups were incurred and the sequence on the laminator was not tampered with. The re-arrangement on the laminator was used only in cases where the change on the laminator would be trivial compared to the one needed on the printer to achieve the same end. So, any laminator change was done to primarily avoid unnecessary and excess shuffling on the printer. The priority orders were scheduled at the start of the laminator's run of the product family.

No	Symbol	Explanation
1		Production of 200 slim
2		Production of 250 slim
3		Production of other products
4		Non productive time
5	→	Flow of 200 slim
6	→	Flow of 250 slim

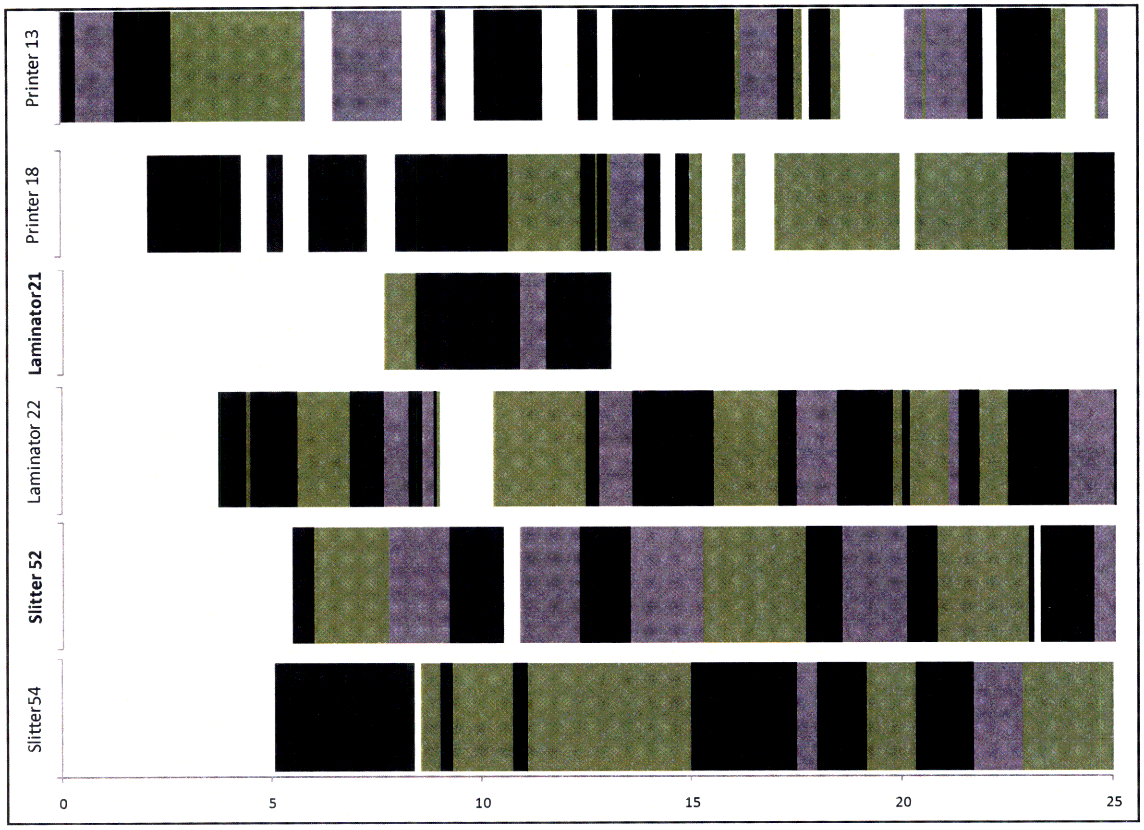


Figure 29: Production time for 25 days beginning 27/03/08 using Plan B

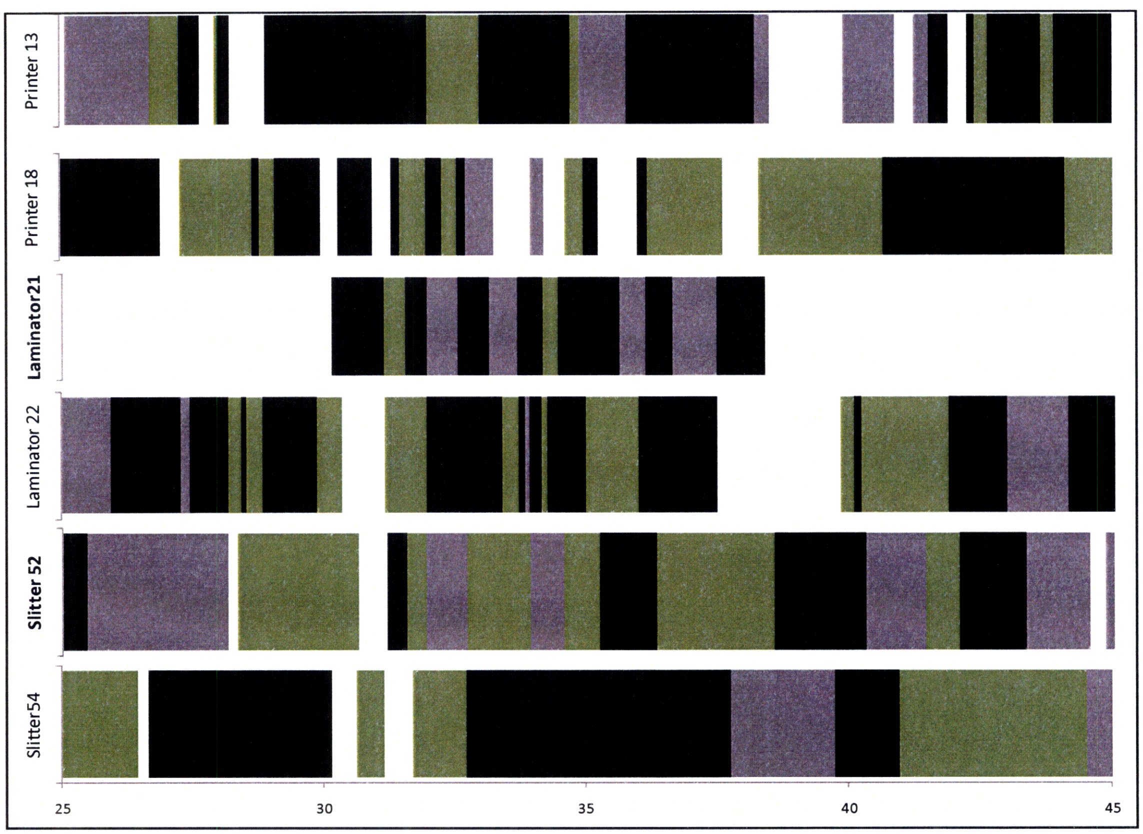


Figure 30: Production time for 20 days beginning 21/04/08 using Plan B

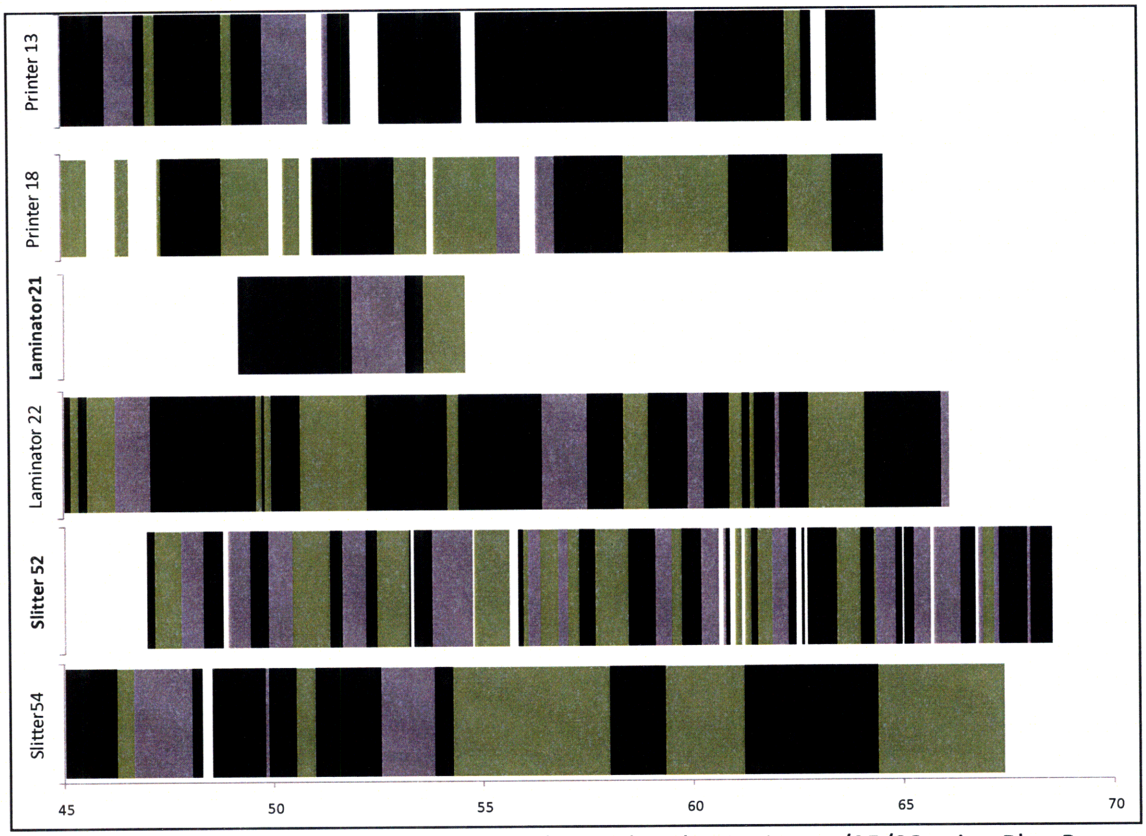


Figure 31: Production time for 25 days beginning 11/05/08 using Plan B

4.2.4: Results:

The results for the WIP of the priority products were the same as in plan A. The WIP between the printer and the laminator was reduced from 4 days to 0.06 days; and between laminator and slitter decreased from 2.1 days to 0.09 days. The notable change in the method is the reduction in the total system WIP from 3.8 days to 2.9 days. A one day reduction in WIP represents a saving of about 100 rolls.

4.3 Plan C: Change in planning policy on printer:

4.3.1 Background:

The basis for the planning presently in Company X, Singapore is the due date. The due date is the date that the order will be shipped from the factory. It is decided on the basis of the customer requirement and the shipping liner schedules. The orders are to be printed at least 7 days before the due date. The lamination is to occur 5 days prior to due date and the slitting is usually finished 2 days before due date. It is ensured this way that the orders are processed on time at the upstream stage.

Very often, the rolls are prepared well in advance for the next and wait as WIP inventory. This is because the schedule on the next machine is not taken into careful consideration during the process of planning. Only a rough estimate of the days left to dispatch is known. Even on the individual machine the orders are arranged by due date within the product family. But the final product finishing date is determined by the machine farthest downstream. So there is no reduction in lead time by using this policy on the upstream machines.

4.3.2 Method:

Since the laminator is the bottleneck machine, the planning for the laminator is done first. The present policy used on the laminator using weekly cycles and sorting by grade and paper width is retained. Due to the expenses of cold starting the laminator the possibility of cycles shorter than a week is ruled out. Changing the PE is a laborious task and there is also the problem of wastage of PE through drooling which enforces the need for the milk and juice specifications to run not more than once a week. The sequence from widest to narrowest is decided on the basis of least changeover time and trying to have the flying setup wherever possible. So the present planning for the laminator is optimal and hence is kept unchanged.

The slitter is also not modified because the introduction of the new slitter in the immediate future will ameliorate any problems in that area.

The major change occurs on the printer. The planning for the printer is done after the scheduling of the laminator. For every order, the scheduled lamination date is taken as the target date for the printer rather than the final due date. Each process is treated as the customer of the immediately downstream, instead of the final customer. This way, it is ensured that the printing is on time for the laminator. The processes upstream are decoupled from the final customer by the processes downstream. Each process bears a direct relation only with the operations directly upstream and downstream of it. Even if the printing sequence is organized by due date, the date at which the order is finally dispatched depends upon the dates of the processes downstream. So, the method ensures the dependence of the printer on only the process that directly influences it –lamination. WIP inventory at this stage is also reduced because the printer takes into account the schedule on the laminator and does not conservatively print orders in advance.

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4.3.3 Simulation:

To verify the effects of the new policy on the production and the WIP, a simulation was carried out using the order data from April 2008 and May 2008. The simulation was carried out on Printer 13 and Printer 18. The offset printer orders were not considered for the sake of simplicity. The Mean Time To Repair (MTTR) and Mean Time To Fail (MTTF) of the system was calculated from the data and is tabulated in table 8 in hours. The frequency and duration of downtime was distributed according to these numbers.

	p13 (hours)	p18 (horus)
MTBF (target)	80.00	80.00
MTBF (actual- apr)	112.15	117.10
MTBF (actual- may)	81.10	25.50
Productive time (apr)	17.00	15.00
productive time (may)	17.00	15.00
MTTR (apr)	32.71	43.91
MTTR (may)	23.65	9.56
MTTF (apr)	79.44	73.19
MTTF (may)	57.45	15.94

Table 8: Characteristics of printer 13 and printer 18

The orders were pooled together and arranged in the ascending order of date of lamination. They were then allotted almost alternately to the two printers. The printing and lamination processes were offset by 2 days initially. The offset helped the printers keep up with the laminators during the periods when both laminators operated simultaneously. The time for minor setup on the printer was taken as 15 minutes irrespective of the color combinations. The time for a major setup was assumed to be 25 minutes. These values are conservative estimates from the standard printing process data. There was no special treatment given to the priority products. They were part of the common flow through the system. The trial results are as shown in the timeline in figure 32 and figure 33.

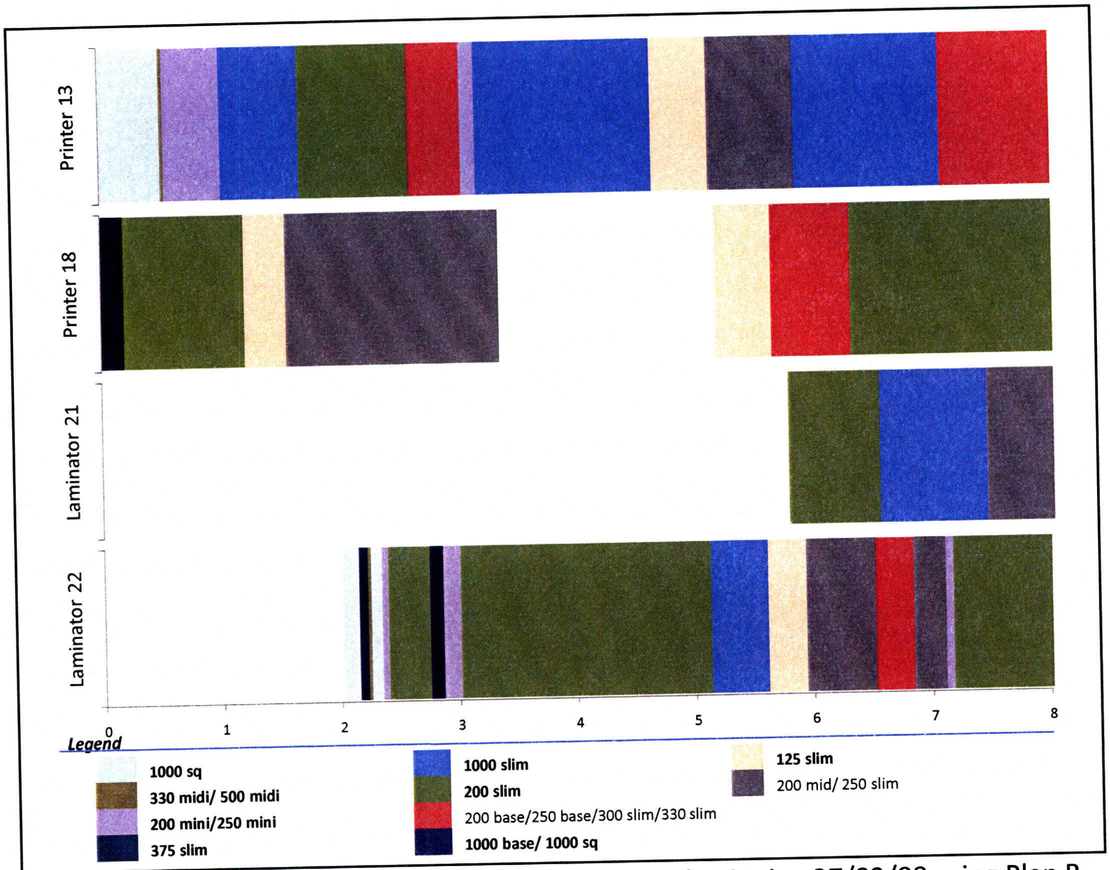


Figure 32: Production time for 8 days beginning 27/03/08 using Plan B

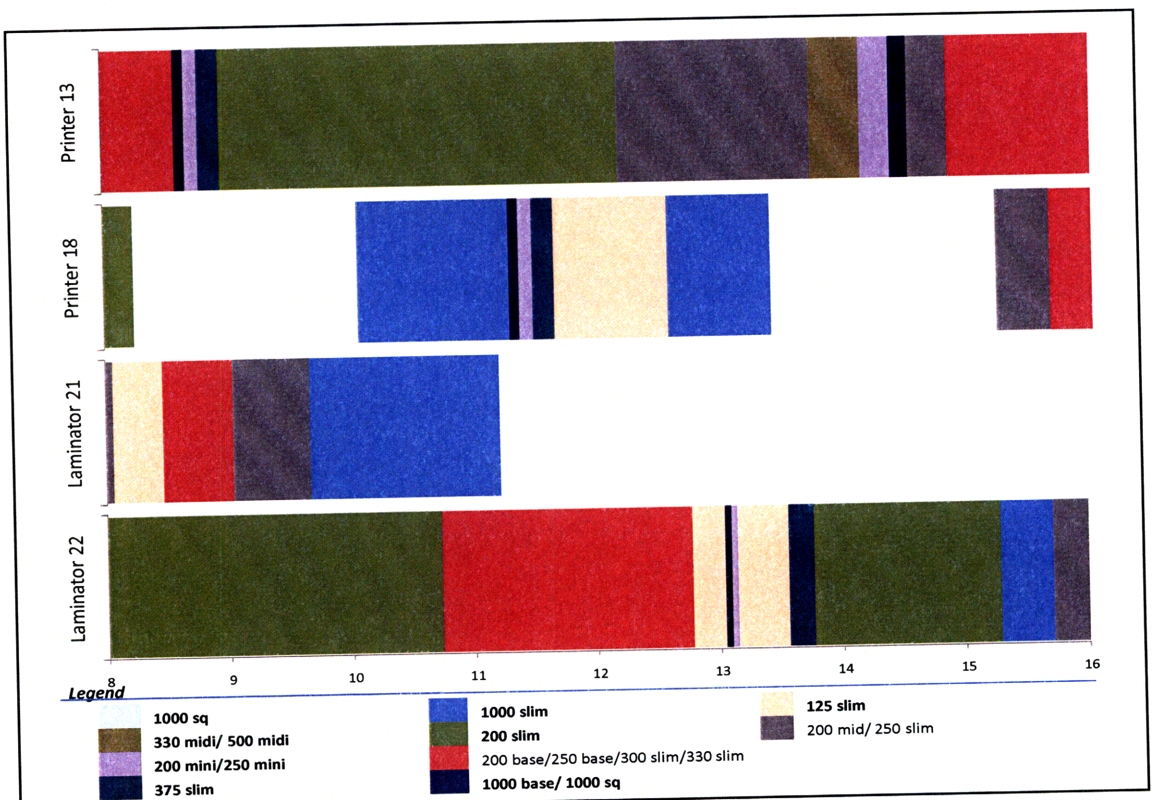


Figure 33: Production time for 8 days beginning 5/04/08 using Plan B

4.3.4 Results:

The simulation results for both the months were very promising. Although there was a little difficulty in the orders getting printed on time when both laminators ran simultaneously, it was a relatively rare occurrence. And the two day head start made up for these rough patches. The overall system WIP reduced from 3.8 days to 1.4 days. This also implied a reduction of 2.4 days in the lead time for all the products. The normal unreliability and down time of the printer was taken into account. But since the buffer between the printer and the laminator has been reduced in this plan, the laminator becomes more vulnerable to any sudden, untoward disruptions on the printer. This is a trade-off that is common to all lean systems. The decrease in the decoupling must be considered carefully.

4.4 Inclusion of design in sorting criteria on the printer:

4.4.1 Background:

Every design has a few component colors. The colors are divided into:

1) Process colors: These colors are the common colors used for the printers – cyan, magenta, yellow and key or black and are represented as C,M,Y,K. Most of the shades required in printing can be obtained using combinations of these colors.
2) Spot colors: These colors are special colors used to obtain a tone that is not reproduced with high fidelity using the process colors.

The designs consists some or all the process colors and often a few spot colors. Each color is run in one of the 7 printing stations. For every change in design, the sleeves with the clichés are changed. Along with that, the inks are replaced with those for the new design at each station in use. The change involves flushing out the old ink, changing the anilox rolls and cleaning the parts in contact with the color. In case of a common color between the two designs, only a sleeve change is necessary. If a color on one design is very close to a color on the next design, the cleaning and flushing process is simplified. Its easier to transition from a lighter to a darker shade.

On the printer, presently there is a minor setup for every design which involves change of the sleeves and the colors. The major setups occur for changes in system and size. So in order to minimize setups the orders are grouped by size and system. Design is not used as a sorting criterion. Within each product family, the orders are arranged by due date.

Studying the setup on the printer, it can be observed that there are two technicians in-charge of changing the color rolls. It takes roughly 10 minutes to change one station. Since the work in parallel, the changeover at the 2 stations is completed in 10 minutes. But if there is a third color that has to be changed, it would require an additional 10 minutes. A rough timeline of activities during setup operations is shown in figure 34. Also, if the changeover is to a color similar to the one running, the time required to change is reduced considerably. Another point of interest is that some stations may be unused during an order. The setup on these stations can be performed while the previous order is being run.

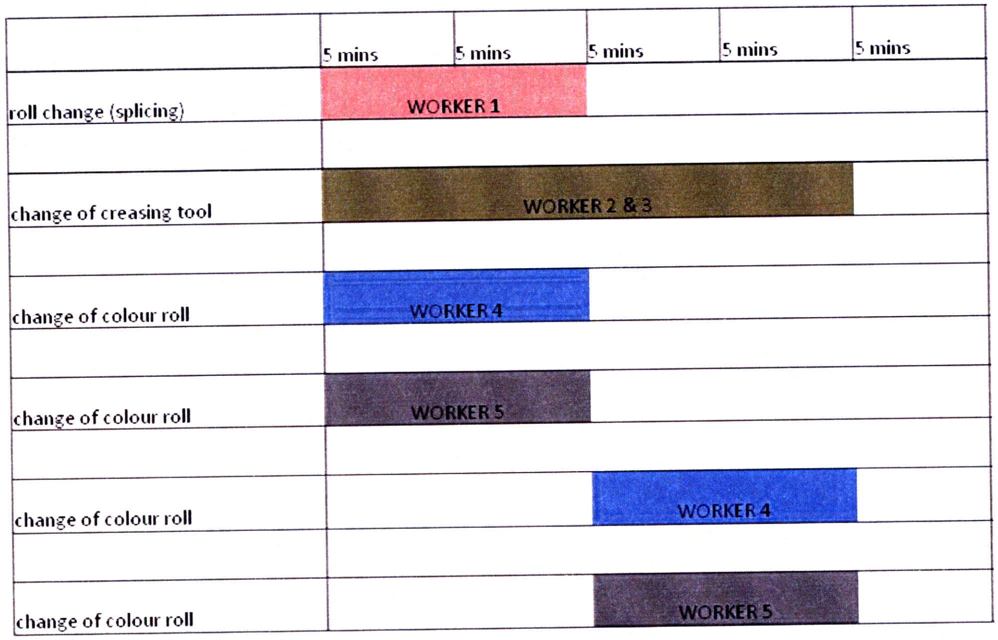
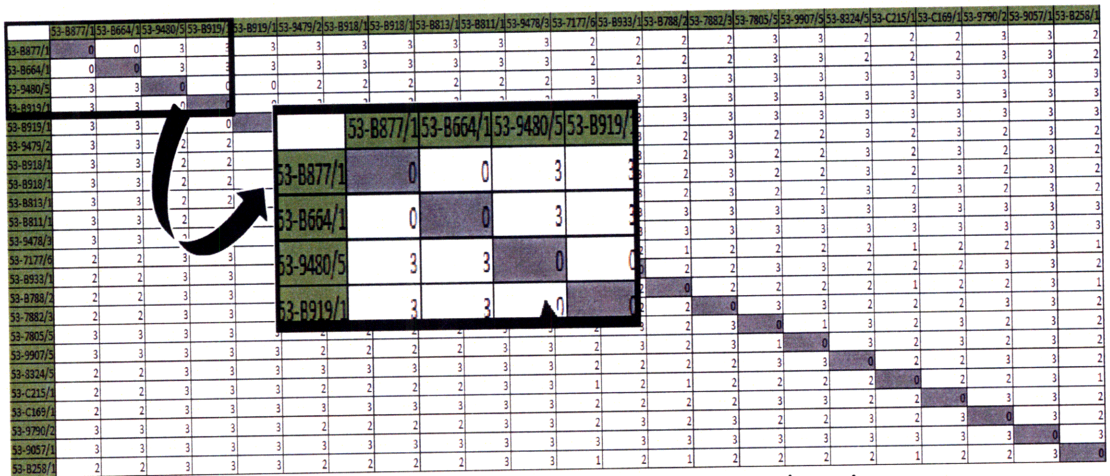


Figure 34: Gantt chart of printer setup operations

It was observed that 'stealing' of orders was a fairly common occurrence in Company X, Singapore factory. 'Stealing' is the process of shifting of orders by the factory floor technicians so that those with similar color schemes are produced in succession. This is done to primarily reduce setup time and effort by grouping orders with similar color schemes together. A notice requesting permission from planning personnel is sent up and on approval, the orders are re-arranged. This is an undesirable practice because it involves modification of the schedule just before execution rather than at the planning stage. Often, opportunities to save on setup time may be missed because the arrangement is not obvious. Also, an important order may be relegated to a later time erroneously. The process of asking for the go-ahead and the subsequent re-arrangement may be time consuming

4.4.2 Method:

A very rudimentary integer programming approach was used to solve the problem. The objective was merely to verify the validity of the suspicion. 23 designs belonging to the Product family A family were selected. Using the physical constraints of the machine, a matrix was prepared to tabulate the setup times from one design to all the others. The change between any two designs was considered commutative – the time for change from design A to design B was the same as the time for change from design B to design A. Since a very simple model was used, the shortening of changeover time between similar colors was not considered. Also, the use of empty stations was excluded from the model. Figure 35 is a diagram of the matrix with a section blown up.



	53-B877/1	53-B664/1	53-9480/5	53-B919/1
53-B877/1	0	0	3	3
53-B664/1	0	0	3	3
53-9480/5	3	3	0	0
53-B919/1	3	3	0	0

Figure 35: Matrix of setup times on the printer

Using this information, an optimization problem was drafted. The objective function was to obtain the best sequence to minimize the time taken by way of setup while running the designs. The only constraint was fulfillment of all the orders. This is analogous to the travelling salesman problem in which the shortest route is planned for visiting n cities with the time being the substitute for distance.

4.4.3 Travelling Salesman Problem:

The travelling salesman problem is one of the most widely used models in discrete, combinatorial optimization. It involves determining the shortest route for a salesman wishing to visit n cities. The input to the model is the distance between each pair of cities. [6] The solution to the model can be found by using optimal algorithms for finding exact solutions or using heuristic algorithms for suboptimal yet acceptably good solutions. Exact algorithms include the trial of all permutations, branch and bound methods and progressive improvement algorithms. The trial of all permutations is the most comprehensive of these and involves the listing of all the acceptable ordered combinations, evaluating each one and then selecting the minimum. But it works well only for problems of small sizes because of the computational effort involved. [7]

For obtaining the heuristic solutions, the nearest neighbor (NN) algorithm, Match Twice and Stitch method or pair wise exchange technique can be used. In the NN algorithm, the salesman starts from any city and chooses the nearest city that he has not yet visited as his next destination. He proceeds from that city to the next in the same way. Since this algorithm computes the values for a significantly smaller number of combinations, it is much faster than the exact methods. [8]

4.4.4 Mathematical Formulation:

To obtain the optimal sequence between n products, with indices i and j varying from 1 to n:

c_{ij} = time for changeover from the ith to jth product (determined from the changeover matrix)

x_{ij} = binary variable used to determine the location of the product in the sequence

$$= \begin{cases} 1 \text{ if the products } i \text{ and } j \text{ are in succession in the sequence} \\ 0, \text{ otherwise} \end{cases}$$

Objective function:

$$minimize \sum_{i=0}^{n}\sum_{j=1}^{n} xij\ cij$$

subject to:

$$\sum_{i=1}^{n} xij = 1$$

for j= 1 to n .... (1)

$$\sum_{j-1}^{n} xij = 1$$

for i= 1 to n .... (2)

xij = 0 or 1 for all i,j

The objective is to determine the optimal sequence in order to minimize the changeover time. Constraint equations 1 and 2 enforce the condition that for a circular sequence, each product has a product produced before it and one after it. They also ensure that all the products are produced in the sequence. [9]

4.4.5 Solution:

The programming language that was selected was Visual Basic. The problem was solved using an exact algorithm followed by a trial with a heuristic one.

For the exact solution, all the different possible sequences of running all designs were selected. Out of them, only the distinct sequences or permutations were retained. Since a symmetric system was assumed, the total number of distinct combinations is (n-1)!/ 2 = 22!/2. The total setup time for each sequence was calculated as a summation of the setup times between every successive pair of designs. The one with the minimum value was selected as the optimum sequence.

But a program with this logic had to evaluate all the combinations and this was tedious and time-consuming. So a modified version employing a heuristic algorithm was used. The approximation used was analogous to the NN algorithm. Each design in turn was nominated as a starting point. The next design was chosen such that it was one with the least changeover time from the running design. Once the design was selected, it was no longer considered for the subsequent designs in the same sequence. This ensured that each design featured only once in every sequence and avoided repetitive comparisons.

4.4.6 Results:

The problem yielded multiple optimal solutions. Hence, there was good convergence between the exact and the suboptimal method. One of the optimal sequences had been compared with the old one in table 9. It can be seen that the number of color changes seem to have reduced considerably. This will reduce the changeover efforts of the technicians, giving them more free time to do autonomous maintenance. The total setup time has also reduced significantly. This establishes the importance of design in the printer setup process. It proves the need to include setup as a criterion on the printer.

Sequence	No of changes	Setup Time	Sequence	No of changes	Setup Time
53-B877/1		0	53-B919/1		0
53-B664/1	0	0	53-B919/1	0	0
53-9480/5	3	20	53-9480/5	0	0
53-B919/1	0	0	53-9478/3	2	10
53-B919/1	0	0	53-B811/1	1	10
53-9479/2	2	10	53-B918/1	1	10
53-B918/1	1	10	53-B918/1	0	0
53-B918/1	0	0	53-9479/2	1	10
53-B813/1	1	10	53-B813/1	1	10
53-B811/1	2	10	53-9790/2	2	10
53-9478/3	1	10	53-7805/5	2	10
53-7177/6	3	20	53-9907/5	1	10
53-B933/1	2	10	53-B788/2	2	10
53-B788/2	2	10	53-7177/6	1	10
53-7882/3	2	10	53-C215/1	1	10
53-7805/5	3	20	53-B258/1	1	10
53-9907/5	1	10	53-B933/1	2	10
53-8324/5	3	20	53-7882/3	2	10
53-C215/1	2	10	53-8324/5	2	10
53-C169/1	2	10	53-C169/1	2	10
53-9790/2	3	20	53-B877/1	2	10
53-9057/1	3	20	53-B664/1	0	0
53-B258/1	3	20	53-B258/1	3	20
TOTAL	*39*	*250*	*TOTAL*	*29*	*190*

Table 9: Comparison of old and new sequence on printer

5. Summary of recommendations:

5.1 WIP Optimization and lead time reduction:

The changes to the production scheduling are listed as Plan A, Plan B and Plan C in ascending levels of quantum of change suggested. Plan A is very conservative and is only intended for continuous flow for the priority products. No change in scheduling is advocated and the chance overlap of product runs on the three machines is exploited. Plan B suggests a little more change. Continuous flow is still achieved only for the priority products. But the waiting time between the printer and the laminator is reduced for all the products. Plan C is more revolutionary than Plan A and Plan B. It involves significant change to the planning policy and planning criteria.

Plan A: Continuous flow for priority products:

In Plan A, there is no change in the scheduling procedure or policy on any of the three machines. The 7 priority products are produced in the overlapping time segments for the run of the same product family on the three machines. This overlap can be observed from plotting a timeline. For the priority products, the trials demonstrated that the cycle time and WIP decreased by 93% and 98% respectively. There was no significant change in the overall system WIP or lead time.

Plan B: Reduction in waiting time between the printer and the laminator:

In Plan B, the waiting time for the printed rolls is reduced by 1 day i.e. all the orders are sent for lamination one day earlier. No change is made to the planning policy or the criteria for grouping on the machines. Continuous flow is achieved only for the priority products by a method similar to Plan A. The overlap of product family runs on the three machines is again exploited to schedule in the priority products. In the simulation, it was noted that there was a 25% reduction in the WIP inventory days for the system. The reduction for the priority products was identical to Plan A.

Plan C: Alignment of orders on printer and laminator:

In Plan C, modifications to planning policy are suggested. Since the laminator is the bottleneck machine, the planning for the laminator is carried out first based on the due date. Then, the scheduled lamination date is taken as the target date for the printer rather than the final due date i.e. the process was treated as the customer of the process immediately downstream, instead of the final customer. With the use of this policy, the WIP between the printer and laminator was reduced by 65%.

There is no pre-requisite or concrete order for the plans. Any one or a combination of the plans may be implemented in any order. It is very difficult to make changes overnight to the system. At present, running the factory with less WIP can seem idealistic and risky. Testing the recommendations can be a difficult task given the expense of the cessation of an old policy and the start of a new one and also the probability of a failure. Bringing about any change requires the full support and co-operation of the work force and the management. Considerable modification of the methodologies and mindset is necessary. A good way to tackle this is introducing the modifications gradually, one step at a time. In view of these facts, it would be advisable to implement the plans sequentially from plan A through plan C. This will help the technicians become familiar with the concept of less WIP slowly and steadily rather than be overwhelmed by a drastic plan of action. It is also easier from the perspective of implementation.

5.2 Inclusion of design in the planning for printing:

The man machine work flow and the practice of 'stealing' orders suggested that color schemes may play a role in determining the setup time for the designs on the printer. From the integer programming results shown in the table 10, there seemed to be some evidence of the impact of the design colors on changeover times.

Sequence	No of color changes	Setup Time (mins)
original	39	250
revised	29	190

Table 10: Summary of comparison of old and new sequence

This highlights the need for consideration of design in the production scheduling on the printer. The design may not supersede size and system in importance for planning. But with each product family, it can be utilized as a criterion to arrange the orders.

5.3 Recommendations for data collection and classification:

The data for the simulations was obtained from the P2 system. The format of data storage of due dates and operation times is not consistent. It is a mixture of text, general, European date format and American date format. This is not very apparent from the data and can lead to errors if operations are performed directly without modifying the data to a common format. Changing multiple formats to a common one can often be a tedious task, especially given the volume of data. It is important that the values be stored in a consistent and clear format. A custom format with dd/mm/yy, hh:mm (date - 2 digits/month - 2 digits/year – 2 digits, hour-2 digits : minutes -2 digits) layout will be ideal as it will permit date and time operations to be performed on the data.

Each product is fully defined by 4 codes –design, shape, system and size. Often the system code is omitted from mention in the product specification. The quality code is used instead to determine the system. But since the quality code describes many attributes of a product, two products with different quality codes may belong to the same system. Thus it is not a clear and fool proof way of sorting. If it were ensured that the code defines only one important attribute or a combination of attributes pertinent for one machine, the coding process would become uncomplicated. Also, the use of such an independent code may help the automation of the sorting processes.

The products are arranged on the laminator based on overall width - from widest to narrowest. The size code determines the width of the package. But the numbers of the code do not reflect this actual width. The sequence in which the orders should be run is also not indicated in the numbering. Sequential coding may help comprehend at a glance the optimal order in which the products should be run. A hierarchical system would also enable more clarity in the planning even on other machines to understand the relative positioning of the product families.

Most of the information mentioned as necessary in the preceding paragraphs may be inferred from the existing codes. But this limits the scope of the work only to people with experience in the field. It may prove to be very tedious for people, less familiar with the system. Also, work by memory leaves room for error, especially considering the variety and the volume of the products.

This highlights the need for a fool proof, hierarchical, comprehensive and independent coding system for sorting the orders on the different machines.

6 Future Work:

Future work in this area includes some additions to the value stream map like a future state map, implementation issues and fine tuning of plans to reduce WIP and a sophisticated integer programming model for studying the effect of design.

The Value Stream Map prepared is only a current state map i.e. it is a snapshot of only the present state of the system. A future state map can be prepared to present the picture of the ideal system with the target values of parameters defined. This can help set the course for the changes and provide a benchmark for improvements. An ideal map can be prepared for regular time intervals to chart the gradual improvements in the system.

Three plans suggested to tackle the WIP and lead time problem were proposed. These plans were tested by simulations over short spans of time. The analysis can be extended to a longer period of time for greater certainty. A live trial on a small part of the system would be even more beneficial in identifying any potential practical problems in the solution. Plan C can be studied in more detail to evaluate the risks and benefits of implementation.

The integer programming model used to investigate the role of design in the printer setups showed positive signs of involvement. However the model used was rudimentary and limited to a specific set of orders belonging to one product family. This analysis can be extended to all the product families. A more comprehensive model can be generated to include all the occurrences like empty stations being set up during the previous run and similar colors requiring shorter changeover times.

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