Optimization of Labor Allocation at a Syringe Production Facility Using Computer Simulation

by

Sze Sen Liaw

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Signature of Author: ______________________________
Department of Mechanical Engineering
August 19, 2008

Certified by: ______________________________
Brian W. Anthony
Lecturer, Department of Mechanical Engineering
Thesis Supervisor

Accepted by: ______________________________
Lallit Anand
Professor of Mechanical Engineering
Chairman, Department of Committee on Graduate Students

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Abstract

Optimization of the current labor resources at a Singapore pharmaceutical company is necessary to control the labor cost effectively without affecting the production capacity. Two new labor allocations were proposed. They featured higher labor flexibility to reduce the response time to machines failures, as well as more focused job scope to reduce work interruptions. The labor tasks were also categorized based on skill levels to facilitate the implementation of skill-based pay system in order to motivate employees. Computer simulation was used to study the performance of the new labor allocation proposals. While Proposal 1 had a lower productivity than the current labor allocation, proposal 2 showed an increase as compared to current labor allocation. The financial analysis predicted a total annual benefit of S$320,246 in the form of labor cost reduction and increased productivity from the implementation of proposal 2 with the current number of production technicians.

Keywords: Labor Allocation, computer simulation, optimization

The content of the thesis is modified to protect the identity of the attachment company. The name of the company and confidential information are omitted.

Thesis Supervisor: Brian W. Anthony
Title: Director, Manufacturing Systems Technology Program, Singapore-MIT Alliance

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Chapter 1: Introduction

The concept of Lean manufacturing has been embraced by many of today's most successful companies in various industries and labor resource management is an important element of a lean production system. Optimization of labor resource is directly related to profitability through production output and running cost. Therefore, an effective strategy to manage the labor resources is essential for an organization to operate at its peak efficiency.

Businesses in Singapore are facing increasing pressure from escalating labor cost. At the Syringe production line in MD Medical's Singapore manufacturing facility, the annual cost of labor amounts to more than S$2 million in 2007 [from internal source] and it is expected to increase in coming years due to high inflation and a tight job market. Therefore, MD must control its labor cost effectively without affecting the production capacity in order to stay competitive. The labor resource at the Syringe production line is current facing a high turnover rate of about 65% for workers with 1 to 3 years of services [from internal source], and this has affected the morale of the production workers as well as the production output. This translates to higher cost from increased hiring activities, training and loss of productivity. With the Syringe value stream already facing constraint on labor cost, a possible solution will be to optimize the existing labor resources with a reallocation of job scope. A new labor structure can facilitate fairer reward system and career advancement.

1.1) Skill-based Pay

A skill-based pay system rewards employees based on their level of competencies and recognizes skills that bring value to the organization [1]. This approach gives all employees clearly defined requirements for different skill levels and motivates them to improve themselves by progressively learning more advanced skills. Companies that have technical and operator jobs can benefit the most from a skill-based pay system and organizations that adopt such a system can expect a reduced workforce with more competency and job satisfaction [2].

At MD, in the Syringe value stream, the current pay structure pays a production technician (PT) according to his/her educational qualifications and years of related experience. A PT's salary progression is based on the annual appraisal exercise. However, the criteria for promotion are subjective and tend to be biased toward seniority. Therefore, a senior PT may be paid much more than a younger but more competent PT and this is a weakness in the system, leading to resignation of several promising PTs. Currently, there is no existing scheme in place to motivate a PT to learn new and more difficult skills.

The Syringe value stream stands to benefit from the implementation of a skill-based pay system that creates a skill-based career path that is clear and well-defined to all PTs so as to motivate them to acquire more skills and enhance their technical competency. A workforce that is technically flexible and has less reliance on the technical support crew can operate the production line more efficiently with less machine downtime and higher productivity. In addition, a more transparent and fairer pay structure can also improve the morale of the PTs and hence, address the issue of high turnover rate. However, an obstacle that hinders the implementation of the skill-based pay system is the similar job scope for both new and experienced PTs. Therefore, the first step is to reallocate the tasks in the current job scope of the PT based on their capabilities. This can better utilize the skills of the experienced PT by involving them in more difficult tasks, while creating a less intimidating job scope for the new PTs by starting with easier tasks. The PTs can then be paid accordingly to their level of competence.

1.2) MD Medical and MD Tuas Plant

MD Company is a global biomedical technology company that focuses on improving drug therapy, enhancing the diagnosis of infectious diseases and advancing drug discovery. MD manufactures and sells a wide range of biomedical products that includes medical supplies, devices, laboratory instruments, antibodies, reagents and diagnostic products. It serves healthcare institutions, life science researchers, clinical laboratories, industry and the general public.

MD Tuas plant manufactures cannula, needle, and syringe products. These products are first shipped to the various MD's distribution centers (DC), which then supply the products to their respective clients. The plant is organized into value streams (VS). There are currently 7 VS, each producing a different product family. Each VS is managed by a Value Stream Leader (VSL) and operates independently with its own equipment and workforce. This project focuses on the VS that produces syringes and is referred to as the Syringe Value Stream.

1.3) The Product

A syringe is a medical device that is used to inject fluid into or withdraw fluid from the body. Figure 1 shows an example of a syringe manufactured at MD. A syringe typically consists of 4 parts: barrel, plunger, stopper and needle. MD supplies syringes of six different sizes. The barrels also come with different types of tips: A, B and C. These different tips will determine how the needle is attached to the barrel. Other customizations of the syringe products include the choice of having needle, using different length of needle, as well as blister packaging or bulk packaging of the syringes. Each specific product configuration is referred to by its stock keeping unit (SKU). In general, there are three major categories of syringe product SKUs: AS, DN and DS. AS refers to products that are bulk packed in large bags instead of packing individual syringes into blisters and then into cartons. DN refers to SKU that comes with needle while DS are SKU that does not come with needle.

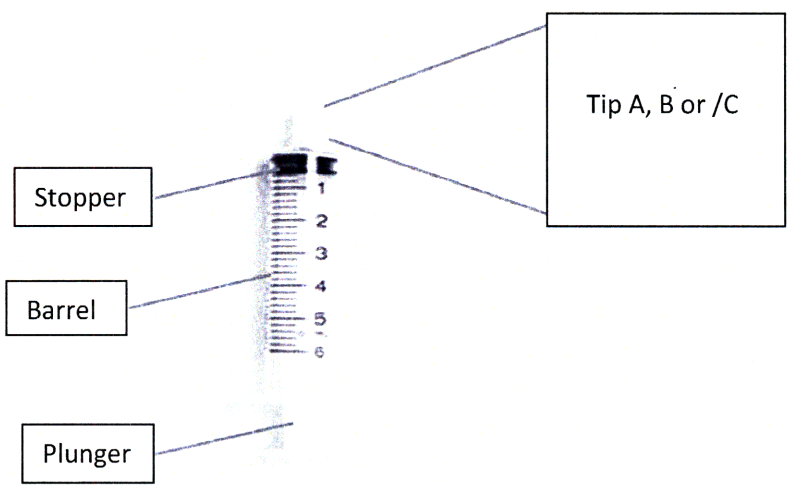


Figure 1: Different parts of a medical syringe

1.4) Process Flow

Figure 2 summarizes the process flow of the syringe line. The syringe manufacturing process was designed for one-piece flow where products move continuously along the line. The various parts of the syringes are transferred between machines via a conveyor. The production floor is split into the controlled environment area (CEA) and the normal area. The processes inside the CEA can be divided into four stages: M, P, A and PP. SP is done outside the CEA to prevent the contamination of paper fibers from the carton boxes. S using ethylene oxide (ETO) is done in a gas chamber. For selected products, an alternative method of sterilization using gamma ray can also be done in external facility.

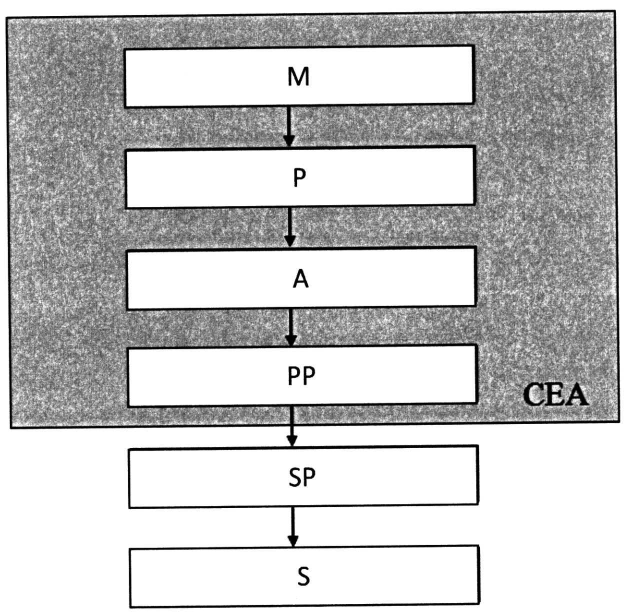


Figure 2: Process flow of syringe production

1.4.1) Process M

Injection molding produces plastic parts. There are two types of plastic parts being molded: barrels and plungers. Every barrel molding machine is designated to a specific barrel size. Barrels of different tips can be produced by changing the mold. The changeover of different tip can typically takes up to X hours. There is only one type of plunger for each size of syringe, so there is no changeover for the plunger molding machines.

1.4.2) Process P

The next stage of the process is to print the scale and label on the molded barrels. The molded barrels are first transferred from the molding machines, also known as M machines, through air vents into the hoppers. These barrels are then channeled into a printing machine for printing.

1.4.3) Process A

Syringe assembly is performed by a complex assembly machine, also known as the A machine, which assembles the printed barrel, molded plunger, stopper and needle together into an assembled syringe. The printed barrels are channeled from the printing machine via conveyor, while plungers are transferred from the molding machine via air vent. The stoppers and needles are manually replenished into their respective hoppers.

The assembly process starts by attaching the stopper to the plunger. This is followed by having the plunger sub-assembly push-fit into the barrel. Finally, the needle is attached to the tip of the barrel to complete the assembly.

A changeover is required between assemblies of SKU with different needle options. A typical changeover takes a PT X hour, on average, to complete.

1.4.4) Process PP

The assembled syringes are packed in blisters in primary packaging machines, also known as PP machines. A blister consists of top and bottom web. The top web is a piece of paper that carries the label and information of the syringe. The bottom web is a nylon pocket that contains the syringe. The process begins by thermal heating of the bottom web to form pockets in the gage. The assembled syringes are then picked and placed into each gage. The gage runs through a computerized vision system to detect any missing parts of the syringes. Finally, the bottom web is sealed with the top web to form blister packs.

A changeover is required for different product sizes as well as batch number. A typical changeover takes a PT X hours, on average, to complete.

1.4.5) Process SP

The blisters of syringes are transferred out of the CEA into the secondary packaging machines. They are then packed in cartons and labeled before sending for sterilization.

1.4.6) Floor Layout

Confidential

Figure 3: Floor plan of syringe production lines

Figure 3 illustrates the layout of the syringe production lines. There are a total of X plunger molding machines and X barrel molding machines. There are X different lines that create different syringe sizes: Aster, Cone, Beech, Daisy, Fern, Gray, Haw, Iris I and II. Production of Iris I and II syringes shares the same line and changeover between the two sizes can take up to X hours.

1.4.7) Cone Line

Cone is a unique syringe production line with a different process flow. The process consists of assembly stage using a different machine, followed by primary and secondary packaging using the machines from the Aster. The assembled syringes are sourced from an external supplier. The process of the assembly machine begins by first removing the plunger from barrel. A small metal clip is added before the plunger is refitted into the barrel. The reassembled syringes are then packaged into blisters.

1.5) Current Allocation

1.5.1) Job scope and tasks

In the Syringe Value Stream, production floor technical workers are classified as production technicians (PT) or technical specialists (TS). PT's are responsible for the day-to-day operation of machines, minor machine issues, as well as manual tasks and in-process inspections. TS's, on the other hand, are more involved with higher skilled tasks that include repairing machines following major breakdown, doing maintenance on molds and machines, implementing engineering improvements, and training and deployment of PT's.

While PT's have seemingly identical job scopes, they differ in experience, ability to perform minor troubleshooting, preventive maintenance and changeover, skills, and ranks, the latter namely, PT 1, PT 2 and PT 3. Promotion from one rank to another involves appraisal that takes into consideration a number of factors, some of which measures a PT's attitude instead of skill level. Hence, a PT 2 is not necessarily more apt at handling machine issues than a PT 1. PT's can be assigned to any machine. On the other hand, a new hire would not usually handle Machine P until he or she has been certified to run the Process A and PP. Certification on a particular machine takes about two months, after which the PT would be allowed to run basic operations on the other two machines in the line as well.

At the start of a shift after the morning shift meeting (SSU), PT's start up the machines and perform housekeeping by cleaning the machines and their surrounding area. The machine input parameters are also checked against standards. Once the machines are in operation, the PT's are free to conduct hourly in-process inspections on the machines they are in-charged of; samples are collected and checked for defects in accordance to the quality plan. Further action is required if critical defects are found. Hourly in-process inspections allow defects from any process to be identified within an hour.

PT's also replenish materials such as stoppers, needles, Cone syringes and clips, top web and bottom web at the start of a shift and whenever they are available to ensure that production is not interrupted from a lack of material. Nonetheless, it is still common for production to be delayed when the upstream molding processes fail to supply plungers or barrels directly. Sometimes these molded parts are poured into the line from bags of WIP (work-in-process) that have been built in advance to give the molding machines more time for changeovers. Both the packing of these WIP into bags, and their subsequent entry into the line requires manual packing and manual pouring on the part of PT's. Manual packing of assembled goods is also necessary if the line is running a bulk order.

Of all tasks a PT performs, clearing machine stoppages and jams, as well as resolving minor machine breakdowns, are given the highest priority since these issues instantaneously halt production. In such cases, PT pause activities of lower priority and resume only when the machine issue is settled or handed over to a TS. Major machine breakdowns are handled by TS and PT3, who is essentially a TS trainee not engaged in line operation.

A compiled list of tasks is shown in Appendix A and B, and discussed further in Section 1.5.3 Utilization.

1.5.2) Manning

Each adjacent pair of full lines are manned by three PT's, while the Daisy and Cone assembly utilize an overtime (OT) PT and a full-time PT respectively (Figure 4). These add up to 10 or 11 operators on the floor. Typically within a line-pair, one PT is in charge of two Machine P's, while the two remaining PT's are each in charge of Machine A and PP within a line. There are a meal break and a tea break lasting 40 minutes and 20 minutes respectively per PT per shift. During breaks when only two PT's are available on a line-pair, they share all tasks related to machine downtime and thus could be seen working beyond their designated machines. Since Cone and Daisy do not belong to any particular line-pair, they join the Aster-Beech lines and Fern-Gray line-pair respectively. Sharing of work between the three PT's also happens whenever a PT could not manage his workload for a significant amount of time.

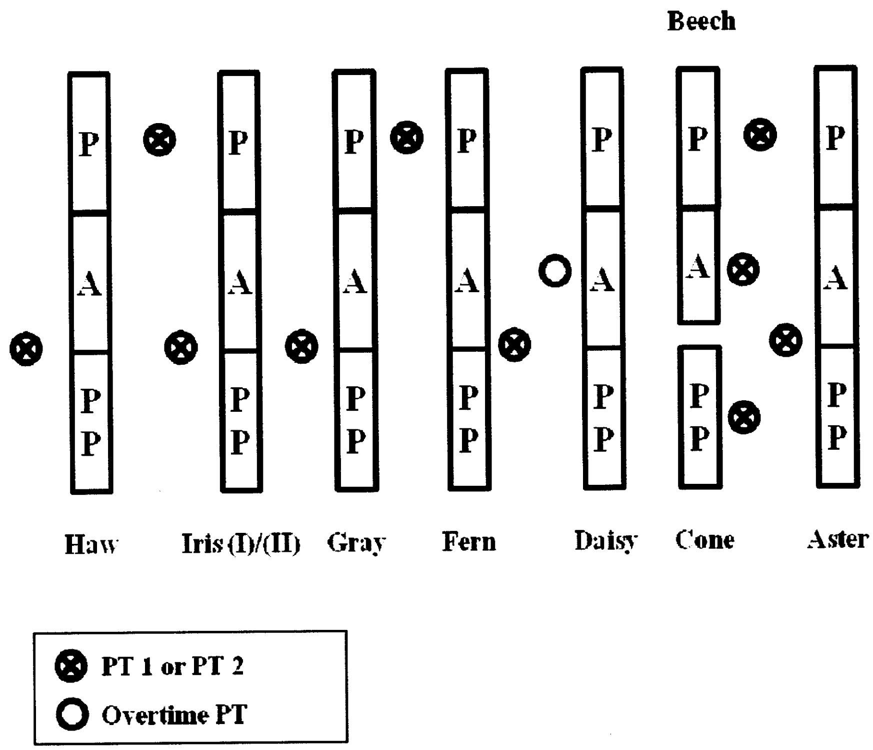


Figure 4: Production floor plan with current manpower allocation

Changeover occurs when product type switches between tip types, AS, DN and DS orders, and needle lengths. Two of the three PT's will be involved in changeovers with one PT left to run the adjacent line (Figure 5). With the exception of Iris(I)/(II) line which takes up to 24 hours, changeovers take up to a maximum of 3 hours on other lines.

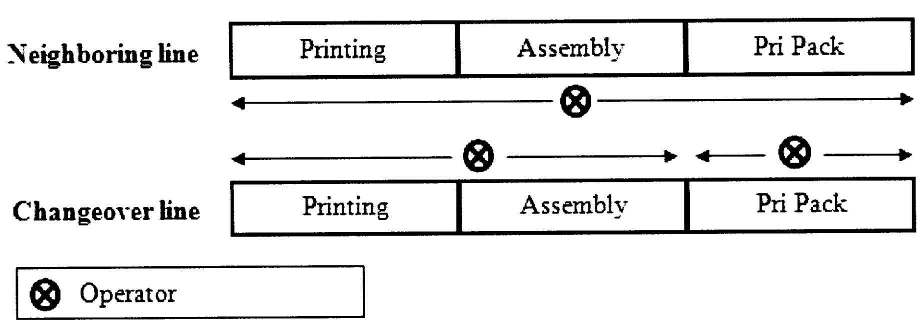


Figure 5: Labor arrangement during changeover

Preventive maintenance (PM) is performed on all lines every month on a rotational basis; at any one time only one line would be shut down for PM. One out of the three PT's is involved in PM of one machine while the remaining two PT's run the adjacent line; three OT PT's are brought in to do PM on the remaining machines on the PM line (Figure 6).

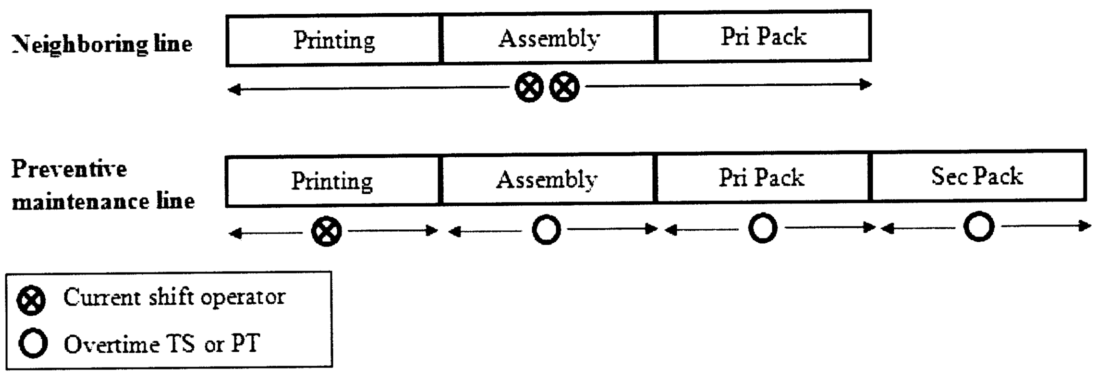


Figure 6: Labor arrangement during preventive maintenance

1.5.3) Utilization

To gain an insight on the nature of the PT's' tasks and workload, a systematic approach was taken to obtain the frequency and duration of each task for all production lines.

Tasks can be classified as deterministic or stochastic; the nature of these two classes of tasks differs in their predictability. Deterministic task occurs with certain regularity and consistency, while stochastic task occurs randomly. The durations of tasks were recorded and averaged from five shifts of observations on the production floor. The estimation of task frequencies, on the other hand, depends on the nature of the task.

Frequencies of deterministic tasks such as in-process inspection, machine startup and preventive maintenance are readily known since they are regular. Changeover counts were found from the production schedule by looking at product types. Average material replenishment frequencies were calculated as follows:

$$\textit{Number of bags of material replenished per shift} = \frac{(\textit{Total amount of material consumed in last 6 months})}{(\textit{amount of material per bag})(\textit{total number of shift that requires the material in last 6 months})} \quad (1)$$

Since the most direct reason for manual packing is the difference in machine speeds between molding and line, the difference in their daily outputs divided by the number of molded parts a bag can contain equals to the number of bags packed. The average of this figure over two months is taken as the average frequency of manual packing and pouring. Frequency of bulk order packing is, similarly, the confirmed production output for bulk order divided by capacity of a bag and averaged over six months.

Machine breakdown are random events. Frequencies of stochastic tasks must be derived from records of machines downtime since they are highly varied and observational results would not be representative. Despite having an APRISO system in place for tracking downtime, downtime logs in APRISO reports are unable to realistically reflect actual downtime reason and duration; a single downtime event could be registered as several downtime events of shorter durations. Nevertheless, certain types of "Downtime Reasons" in APRISO can be taken as actual root causes of downtime and used to count the number of downtime. The selected set of "Downtime Reasons" were counted for occurrence and averaged over the total number of shifts in six months to estimate the average number of machine stoppages. A different set of "Downtime Reasons" were used for each type of machines and they are listed in Appendix C. Similarly, frequencies for minor troubleshooting were derived from APRISO via the same method. Major troubleshooting could not be captured accurately by APRISO and were estimated from the lines' manual records.

The average duration and frequency of each task are summarized in Appendix A and Appendix B respectively.

Average task durations have been grouped under the broad categories of stochastic tasks and deterministic tasks. Tasks related to machine issues decrease in duration down the lines from Machine P to Machine PP. For each machine, tasks duration increase with the severity of machine issue, being the shortest for machine stoppages and the longest for major troubleshooting diagnosis. Since PT's do not currently perform major troubleshooting, but rather attempt to troubleshoot or diagnose a machine before handing it over to a TS, a fixed duration of 15min is approximated for such diagnosis. Deterministic tasks duration varies over a wider range, from 0.2 minutes to 30.2 minutes. Machine startup, housekeeping and administrative work take about 15 minutes or longer, while hourly visual in-process inspections and parameter checking take between 4.2 and 5.2 minutes. Manual packing and pouring of molded or assembled parts require 1 to about 2 minutes per bag, while replenishment of assembly parts takes up to 1.3 minutes only. On the other hand, replenishments of top and bottom web need more time since these rolls of web are heavy, and loading them into the packaging machine involve a more complex procedure than the pouring of assembly parts into hopper bins.

The trend for frequencies of stochastic machine issue-related tasks is opposite that of their task duration trend. Frequencies of machine stoppages and minor troubleshooting increase down the line from Machine P to Machine PP. Within each machine, the frequency of machine issues decrease from stoppages to major troubleshooting diagnosis. For deterministic tasks, task frequencies are fixed for the categories of hourly visual in-process inspections and parameter checking, as well as machine startup, housekeeping and administrative work. There is no distinctive trend across lines for manual packing, pouring and replenishments, except for manual packing of bulk order; larger syringes necessitate more packing since each bag could accommodate less big syringes.

The average total man-hours needed by the tasks, per 8-hourly shift, were calculated by multiplying durations of tasks by their frequencies. These values were divided equally among the number of PT's available to convert total man-hours to percentages of a PT's shift time. Summing all these percentage values gave the utilizations of PT's during non-break periods. These values were then scaled up to mimic the effect of redistributing a PT's workload over remaining PT's during break period. An average break time scenario would consist of one PT working on Gray, Haw and Iris(I)/(II) lines each, one PT working between Daisy and Fern, and two PT's sharing work on the Aster, Beech and Cone lines. The entire break period lasts three hours for the Haw and Iris(I)/(II) line-pair and two hours for all other lines. Both non-break and break utilizations were weighted and summed to obtain the average utilization of a PT over the entire shift.

Percentage utilizations of PT were calculated for all lines under a selected scenario and tabulated in Table 3. The chosen scenario corresponds to the productions of bulk order Daisy and Iris(II) lines, packaged syringes without needle (DS) at Beech line, and packaged syringes with needles (DN) at all other lines (Table 1).

Table 1: Production order for each line in selected scenario

Aster	Beech	Cone	Daisy	Fern	Gray	Haw	Iris I	Iris II
DS	DN	Operation	AS	DN	DN	DN	NIL	AS

As a basis for selecting the scenario, relative dominance of production order types on each production line per month was calculated and averaged over a six month period. The proportions of time, in number of shifts, dedicated to DS, DN and AS orders were tabulated from the production schedule. A simplification was made to merge DS and DN categories since both involve similar tasks; the combined category was represented by DN to give a more conservative model at later stages. It was found that most lines produce only one out of the three production types. Proportion of production types, given that lines are running, is shown in Table 2.

Table 2: Relative proportion of shifts dedicated to production types by lines

Aster		Beech	Cone	Daisy	Fern	Gray	Haw		Iris I/II	
AS	DS	DN	Cone	AS	DN	DN	AS	DN	AS (50ml)	DS
21.4%	78.6%	100%	100%	100%	100%	100%	12.8%	87.2%	27.4%	72.6%

Table 2 shows that Beech, Haw and Iris (I)/(II) lines have a significant proportion of AS orders on top of the dominant DS or DN order. Variation in production scenario thus arises from a combination of these orders. Since production type on one line does not affect that of other lines, they are taken to be independent. The probability of encountering a particular scenario was obtained by multiplying relevant percentages across the lines.

It was found that the production order combination, from Beech to Haw, which corresponds to the scenario in Table 1, has a probability of about 70% occurring. Out of this 70%, about 50% is contributed by Iris (I)/(II) DS order while the remaining 20% is due to Iris (II) AS order. There are six other unique scenarios which make up the remaining 30% probability. Due to such variation in possible scenarios, scenarios vary in importance and not all could be considered in great depth. Though Iris (I)/(II) DS was more prevalent than Iris (II) AS, the latter entails a more intensive workload for the PT's. To be conservative without losing characteristic of the system in general, the scenario in Table 1 was selected as a representation of the system. Something that works for the Iris (II) AS would also work for Iris (I)/(II) DS.

Table 3: Summary of PT utilizations for 2 selected scenarios by lines

Resource designation*	No. of Resource	Non-break utilization (%)	Break utilization (%)	Average utilization for 8-hour shift (%)	Average Utilization for 8hour shift per line pair (%)
Aster & Beech P	1	61	128.0	70.6	75.4
Aster A&PP	1	71	128.0	79.1	
Beech A&PP	1	68	128.0	76.6	
Cone	1	55.5	128.0	65.9	65.9
Daisy	1	73.6	176.5	88.3	88.3
Fern & Gray P	1	63.2	102.8	68.9	76.9
Fern A&PP	1	68.2	176.5	83.7	
Gray A&PP	1	74.2	102.8	78.3	
Iris I/II P	1	62.4	103.4	74.1	78.8
Iris I A&PP	1	71.3	103.4	80.5	
Iris II A&B.pack	1	73.2	103.4	81.8	

* B= Bulk

From Table 3, break time utilizations are higher than that of non-break periods as a result of having less people working on the lines. All break utilizations exceeded 100%. The break utilizations for the Haw/Iris(II) line-pair PT's and half of the Daisy/Fern/Gray group PT's are about 103% and significantly smaller than others. One likely reason for this is that the PT's typically man one line each during break. For the Aster/Beech/Cone group, two PT's go for lunch each round and leave behind just two PT's for seven machines. Similarly, a smaller PT-to-machine ratio exists in the Daisy/Fern group where only one of the two remaining PT's attends to both lines during break.

Since 100% is the limit for utilization in practice, PT's are forced to complete jobs quicker, do a hastier in-process inspection, or respond slower to machine issues. Any attempt to increase average utilization of PT's is hence limited by the high break utilization that would be detrimental to productivity by making the PT's unavailable for machine issues. Despite having significant variation in break time utilizations, the lines (excluding Cone) actually have similar non-break utilizations in the range of 60% to 74%; combining break and non-break utilization widened this range to 70.6% to 88.3%. The average utilization for line-pairs increases from small syringes to big syringes, and stayed within a relatively small range of 3.4%. Cone and Daisy PT's have a utilization of 65.9% and 88.3% respectively.

A comparison between production orders reveals that, while both lines running AS orders have higher utilizations than most lines with DN and DS orders, utilization level could not be attributed to the production type alone. Running a packaged order instead of bulk order involves an additional Machine PP, which in turn consumes more man-hour in inspection and machine-related issues. On the other hand, running bulk order involves extra manual packing of finished goods into bags. Since the smaller Daisy syringes were packed less frequently than the larger Iris(II) syringes there ought to be a marked difference in their utilizations. The apparent closeness in their utilizations suggest that the time savings achieved, from not having to run Machine PP, is small in the Daisy line with respect to the Iris(I)/(II) line. Hence, the production order type does not exert the same level of workload on different lines; it is unfeasible to generalize line utilizations on the basis of production type. For individual big syringe lines, though, AS tends to give a higher utilization than DS.

A breakdown of tasks by the duration of shift time a task occupies would be useful for identifying opportunities for waste reduction. Average duration of a PT's shift time occupied by each task for Haw and Iris(I)/(II) lines is shown in Figure 7 and 8 in percentages and absolute time respectively. Unassigned time constitutes the highest proportion of a shift (21.2%), followed by 13.5% for machine stoppages. Unassigned time arises from high machine uptime, lack of material, or major machine troubleshooting. If all machine issue-related tasks were grouped, machine downtime forms the largest group with 26.8% utilization. In-process inspections do take up a significant portion of a PT's time since it takes about 14.7% to complete.

With this breakdown of tasks, a better understanding of the labor cost of various tasks could be formed. Further recognition of value adding and non-value adding tasks could uncover opportunities to streamline tasks and to reduce wastage.

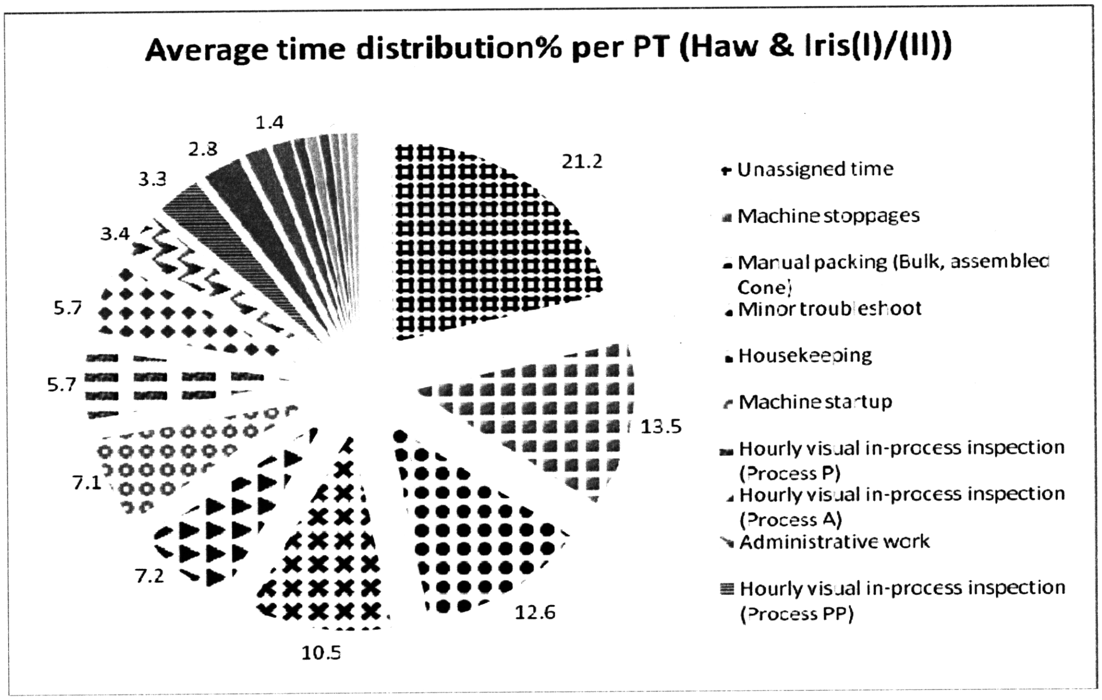


Figure 7: Pie chart of average time distribution of tasks per PT

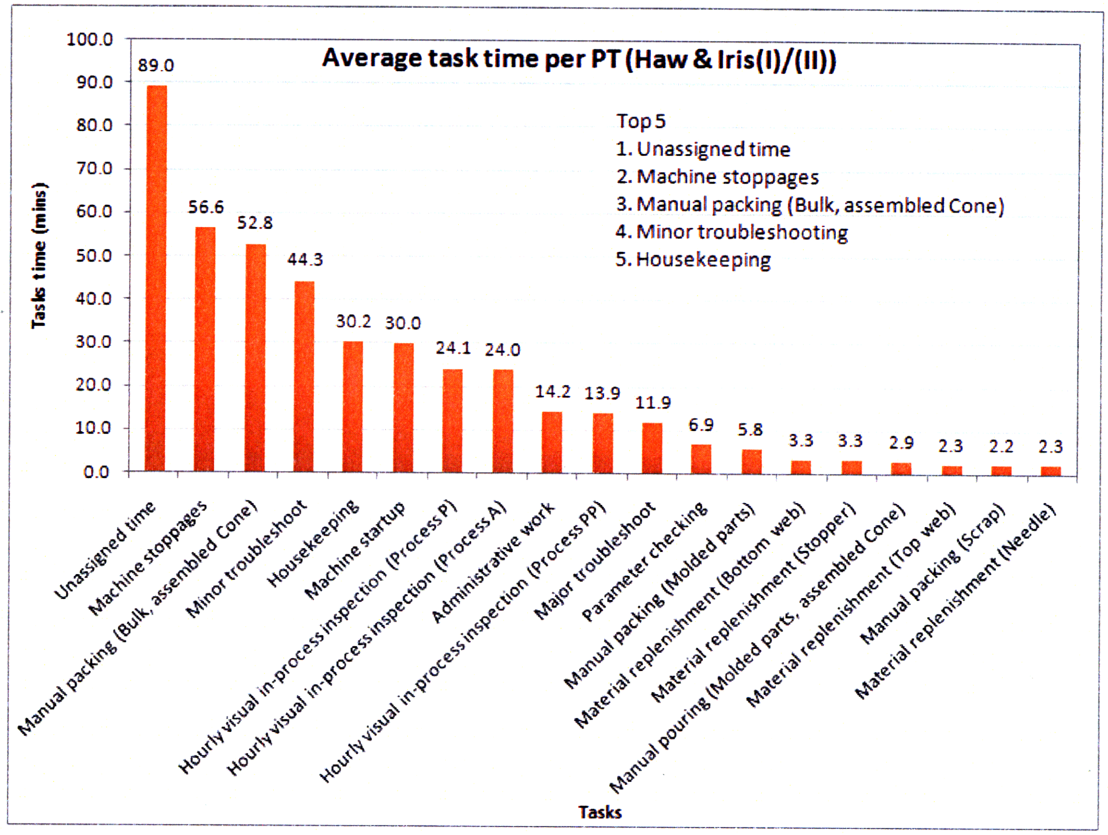


Figure 8: Pareto chart of tasks time per PT per shift

Chapter 2: Problem Statement

2.1) Limitations of current resource allocation

In the current resource allocation scheme, an increasing trend in PTs' average utilization from Aster and Beech lines to Haw and Iris(I)/(II) lines suggest that PTs working for big syringes lines were consistently more overworked than small syringe lines. The average utilization for PTs at all lines were also not maximized to the value of 90% (after giving an allowance of 5-10% for time in between work to avoid fatigue) as the BD management would normally expect to achieve.

The break arrangement in current allocation causes utilization during break and non-break period to differ significantly. While small syringe lines were able to keep their utilization within 100%, big syringe lines (Fern to Iris(I)/(II)) have overshot 100% utilization during break periods. This means that it is possible that PTs responsible for those lines are not completing all tasks during the total of three hour long break period. Hence, this break arrangement has also made it impossible to increase the average utilization without causing utilization during break to exceed 100%.

As the PTs at the syringe lines lined up their tasks according to their priorities, they were often observed to interrupt tasks that were of low priority and long service durations to work on tasks that were of a higher priority. A typical example was to interrupt a five minutes hourly in-process inspection on assembled syringes so as to clear a machine stoppage for about five seconds. These interruptions could be as frequent as three to four occurrences for a single task. Highly interrupted tasks also included manual packing and administrative work such as filling up of forms.

Although PTs did not reflect to the management that these interruptions have affected their quality of work, it was evident that these repetitive interruptions would divert the attention of a PT. Thus, the worker was more likely to lose focus and neglect some important details in the current task that was to be put aside or being hastily completed. A recent quality issue raised through a customer complaint leading to a recall on an entire batch of syringes has illustrated a case of ineffective hourly in-process inspections. Such quality issues are unusual and avoidable, as hourly in-process inspections would definitely not allow a whole batch of rejected parts to be packaged if they were done correctly. The quality and duration of hourly in-process inspections also depended very much on the experience, inspection skill and how meticulous each individual is. With ten PTs at the production lines in charge of this important task, there would be a certain amount of variability in the quality and duration of inspections.

In the current allocation, a newly hired PT is required to be both intellectually and technically competent so as to perform all tasks as specified in their job scope. These tasks extend to a wide skill range. They include non-skilled manual tasks such as pouring of needles into the hopper or manual packing of assembled syringes in bags, as well as skilled manual tasks such as minor troubleshooting and recovery of the machines. In addition, PTs need to understand and familiarize themselves with the operation of line machines in accordance to the production schedule, and the use of software used to input key information into the central computer database. However, mastering the ability to perform skilled manual tasks generally require a PT to have prior experience (of six months or more) with operating the machines and clearing basic machine stoppages. As a result of such a wide job scope, inexperienced PTs might be intimidated by the steep learning curve.

The current way of work sharing is perceived to be unfair due to BD's compensation system and work dynamics between PTs. Current sharing of tasks between all PTs in a line pair offers the flexibility for them to help one another when either one of them is temporarily absent during breaks or is too busy to attend to another task that occurred concurrently. This is critical to avoiding loss of productivity due to machines waiting for repair. However, lower skilled PTs would often be unable to share higher skilled tasks, whereas higher skilled PTs need to share tasks across the full range of skill levels. In general, PTs with broader capabilities, especially in resolving complicated machine problems, are expected to help out more. However, these PTs are paid based on an appraisal system that very much depends on seniority, attitude and commitment. BD does not monetarily reward PTs directly for their achievement in attaining skills of a higher level. As such, higher skilled PTs who might not necessarily be paid more will not be motivated to work harder than others.

Line pair sharing between PTs of different skill levels worsens the difficulty in surfacing the incompetency of PTs within the group, and this could also encourage more social loafing. Since PTs are obliged to share work, an incompetent PT could very well rely on other PTs in the line pair. Also, because the performances of PTs are measured together in groups of three that are each responsible for their line pairs, it is harder to quantify the performance of each individual PT.

2.2) Objective and scope

The main objective of this project is to propose an optimized resource allocation for the syringe value stream. Resource allocation will be optimized through a reallocation of job scope to achieve one or more of the following:

- Maximized and balanced utilization of PTs during working hours
- Stronger job focus by reducing or eliminating interruptions during work
- Better work sharing between PTs
- Improved learning curve for a newly-hired PT
- Motivation of PTs to learn new skills through a transparent and fairer pay structure

Furthermore, productivity of the syringe value stream should be maintained or increased through this optimization. The performance of this optimization will be assessed through its total cost savings in comparison to its current state. The feasibility of the optimized resource allocations will also be determined.

This project is only limited to optimization of PTs involved in printing, assembly and primary packaging process at all production lines in the syringe value stream. This project consists of three main portions. The first part will be limited to discussions on the design of optimized resource allocations as well as comparing their characteristics. The second part will discuss the use of computer simulation to evaluate the performance of each allocation based on selected criteria. The third part covers a work study done to investigate the feasibility of two new job scopes in Proposal 2. This thesis will present the second portion of the project.

Chapter 3: Literature Review

3.1) Computer Simulation

A computer simulation is an approach to study and understand how a system works by building a model that imitates a real-life or hypothetical scenario on a computer [3]. A model is built using a simulation software package and then experiments are conducted by running the model for a simulated time period. Predictions may be made about the behavior of the system by changing the input variables depending on the objectives of the computer simulation. Computer simulations are particularly useful for modeling systems where simple closed form analytic solutions are not possible.

Computer simulation has been used widely in the area of manufacturing and users have often reported satisfactory results [4]. Manufacturing companies develop and implement new innovative methods to further enhance their production capability in order to remain competitive. However, the introduction of new ideas can be risky and computer simulation provides a cost effective mean to test and refine the new methods before committing to any costly investment. The manufacturing company can then confidently move to implementation after having quantified the potential benefits on the simulation.

The use of visual interactive simulation (VIS) [5] can further enhance the capabilities of computer simulation. A visual display can allow users to understand the simulation better by showing parts and labor moving between jobs, while elements such as machines, conveyors and work centers can change appearance that reflects their state. Within manufacturing, simulation has been used to tackle a wide variety of applications. Felix and Bing have demonstrated how computer simulation can be used in an automotive company to test different labor allocations and determine the most optimal allocation and establish the labor resource requirement. Using utilization as criteria, the most optimal allocation reduces headcount by two without affecting the production throughput [6]. However, using simple resources to represent workers within these simulation models has the limitation of ignoring the potentially large impact of variability in human performance on system performance. This affects the predictive capability of simulation models, especially those with a high proportion of manual tasks [7]. The use of VSL that take into consideration of variability from machines and labor in terms of probability distributions can be a feasible approach for computer simulation of different labor allocations. The VSL allows companies to better understand the behaviors of the different possible labor allocations and determine the most suitable labor allocation for their operation.

Chapter 4: Methodology

4.1) Computer Simulation Study

The simulation study was focused on gaining an insight into the behavior of the entire syringe production line when using the current and alternative proposed labor allocations, by comparing the utilization of labor and machines, as well as the ability to meet production requirement. The details on the characteristics as well as the tasks reallocations among the PTs for the proposed labor allocations are presented in the first thesis of this project [8]. Therefore, the aim of the simulation was to determine the production figures of different labor allocations as well as to provide information on the utilization of the labor to determine the optimal labor requirement. The scope of the model was limited to simulating the activities from the printing machines to the primary packaging machines. The software chosen for this case study was SIMUL8® Version 11.0. It is a menu driven package that allows visual interactive simulation.

The first step of model development was to create the actual production lines on the computer simulation. Figure 9 shows a schematic of the simulation model for a normal production line and how the labor task modules interact with the production line.

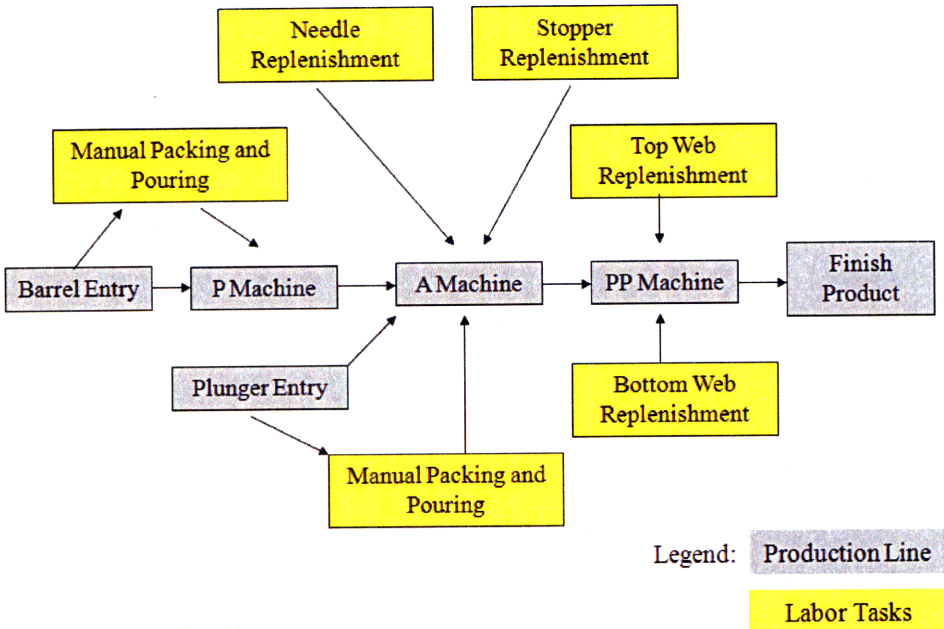


Figure 9: Schematic diagram of simulation model for normal production line

Figure 10 shows a schematic of the simulation model for a production line with manual (bulk) packing order. The syringes are manually packed by PTs in bags instead of packaging into blisters at the primary packaging machines. Therefore the top and bottom web replenishment tasks are replaced by the manual packing task.

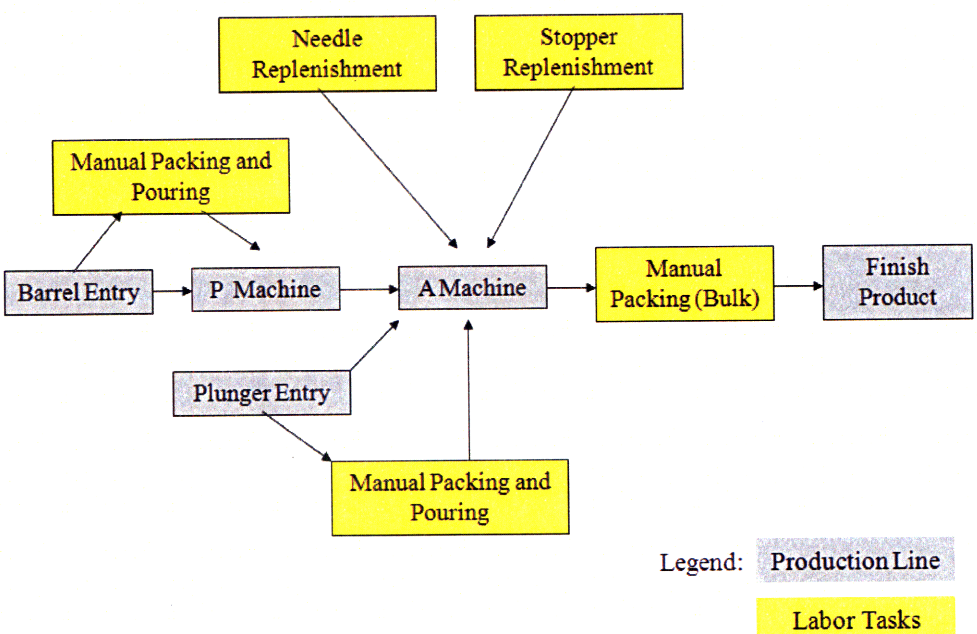


Figure 10: Schematic diagram of simulation model for production line with manual (bulk) packing

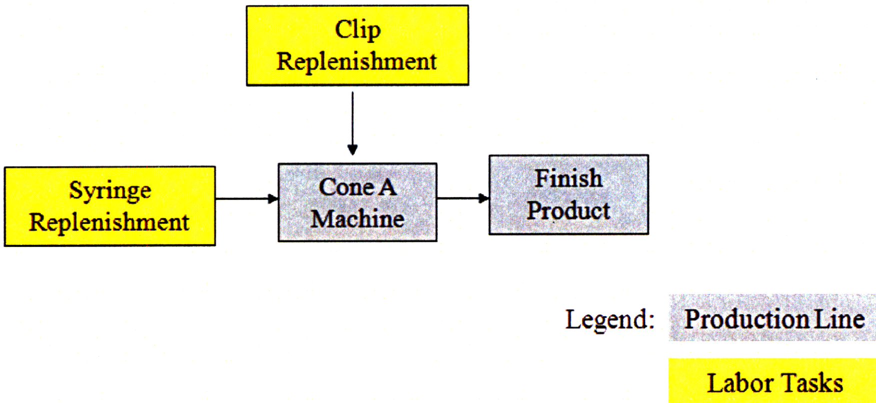


Figure 11: Schematic diagram of simulation model for SSLX line

Figure 11 shows a schematic of the simulation model for Cone production line. It is a unique line that consists of only an assembly machine. The labor tasks involved are syringes and clips replenishment.

Table 4: Legend for icons in computer simulation

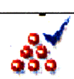
Icon	Name	Function
	Work item entry point	Register number of items entering simulation model
	Storage area	Represent buffer space between machines
	Work center	Represent machines or labor tasks
	Work item exit point	Register number of items manufactured
	Labor resource	Represent PTs used in simulation model

Table 4 presents and explains the different icons used in simulation modeling. Figure 12 shows a simplified model of a single syringe production line. The model was described in terms of different interrelated elements: work centers as different machines, queues, work entry and exit point, labor resources, process plans and factory layouts. The Syringe Entry point represents the arrival of molded parts from the molding machines while the packaged syringes exit point represents the supply of assembled syringes to the SP machine. The input parameters for the production line include the arrival rates distribution of the different product parts, the time distribution taken for machines to process the parts, the sizes of the queues and the number of labor resources required for the line.

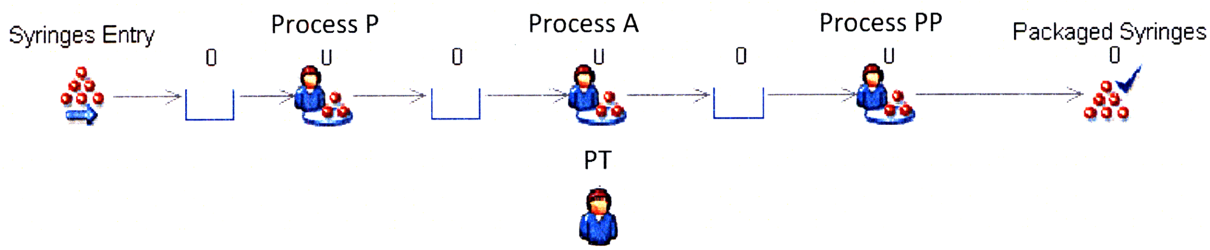


Figure 12: Model of a single syringe production line

Different types of breakdowns and their respective labor resources required were programmed directly into the work centers that represent the different machines. The types of breakdowns are machine stoppages, minor troubleshoot and major troubleshoot. The time distribution of mean time to failure and mean time to repair were specified at the work center object under the efficiency option.

The second step of the model development was to build different modules that represent the different tasks that the PTs are required to complete. These modules were designed to interact directly with the production line and influence the production output. The tasks that were modeled include material replenishment, manual packing and pouring of molded parts and bulk orders, as well as the diagnosis of troubleshooting that is immediately followed by an actual troubleshooting by a higher skilled PT. The travelling time of the labor resources between various working points was also being considered in the model.

Tasks that have no effect on the production output were simulated as isolated models as shown in figure 13. There was no interaction between the production lines and these models. These tasks include hourly visual inspection, housekeeping, parameter check and administrative work. The inter-arrival time for each task were defined at the work item entry point. The service time and labor resource required for respective tasks were defined at the work centers.

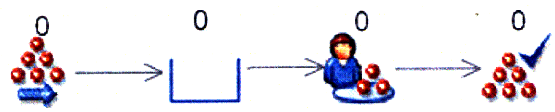


Figure 13: Simulation model for tasks not related to production output

4.1.1) Material Replenishment

The material replenishment module mimicked the replenishment actions by the PTs on the syringe production line. It was assumed that the PT will refill the materials when it reaches a pre-specified minimal level. Work items that require manual replenishment are needles and stoppers at the A machine, as well as top web and bottom web at the primary packaging machine.

Figure 14 shows how a needle replenishment module can be added to the A machine work center. The Base Level work center represents the minimal amount of needles before new needles are being added into the needle hopper. This minimal amount can be specified at the Routing In option using the Before Selecting Visual Logic as shown below. Visual Logic is a programming code used in SIMUL8® to give specific instructions to the various simulation elements.

```
Base Level Route-In Before Logic
↳ Set Collect Number    Needle Replenishment, N_Baselevel, Base Level
  //Set quantity of syringe for Base Level//
```

Base level refers to the work center that carries out the routing in, Needle Replenishment refers to the work center where materials are being routed in from, and N_Baselevel is a number variable that represent the minimal amount. The Needle Replenishment work center represents the amount of new needles added during each replenishment. This amount can be specified at the Routing Out option under Batching.

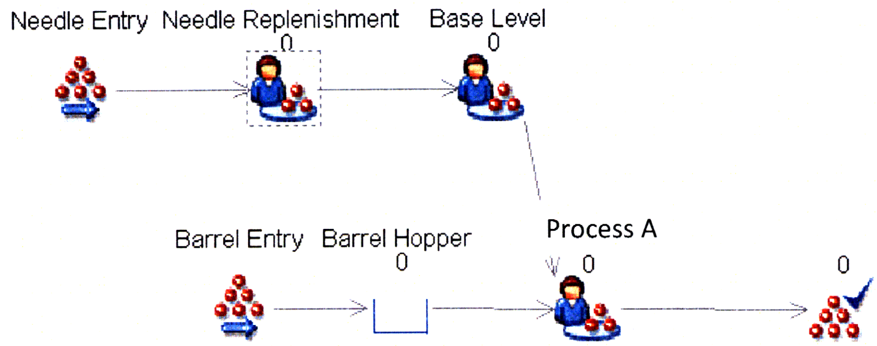


Figure 14: Needle replenishment module

4.1.2) Manual Packing and Pouring

This module mimics the task of PT packing and pouring molded parts manually before the P machine. The need for this task arises from the difference in speed between the molding machines and the rest of the production line. PTs will need to pack molded parts when the molding machines are faster and pour molded parts when the molding machine are slower.

Figure 15 shows how this behavior was being simulated in the computer simulation. Bottom Lvl Buffer refers to the capacity of the hopper before the printing machine. If the syringe arrival rate is higher than the P processing rate, this buffer will overflow, which in turn lead the extra syringes into the Overflow. Once the Top Lvl Buffer_Manual Packing collected the number of syringes for each bag, the PT will be utilized to simulate the packing action and the bag will be stored at the Manual Packed, which represents the buffer space on the production line. If the syringe arrival rate is lower than the P processing rate, the parts in the Bottom Lvl Buffer will be used up and the P machine will then draw parts from the Manual Packed buffer. The Manual Pouring work center will utilize the PT to simulate the task. The number of syringes for each pack was specified at the Routing In collect option of the Top Lvl Buffer_Manual Packing work center and Routing Out Batching option of Manual Pouring work center. In order to prevent the P machine from drawing parts from Manual Packed before the Bottom Lvl Buffer is empty, the programming code was written at Manual Pouring Routing In Visual Logic:

```
Manual Pouring Route-In Before Logic
 └► IF Bottom Lvl Buffer.Count Contents > 0
    //Check if Bottom Lvl Buffer is not empty//
     └► Block Current Routing
        //Block routing from Manual Pouring to Process P//
```

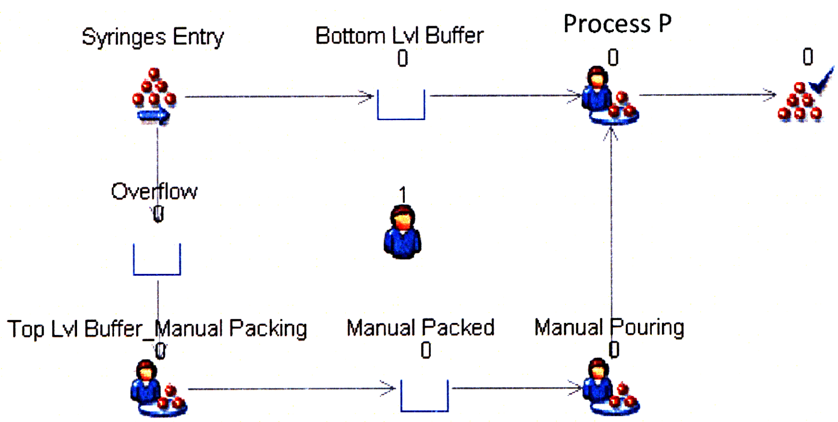


Figure 15: Module for manual packing and pouring of molded parts

4.1.3) Troubleshooting

The purpose of this module is to simulate the diagnosis of minor troubleshoot at the machine by a PT, which is immediately followed by an actual troubleshooting by a higher skilled technical specialist. Figure 16 shows that an additional work center MJTS was created to simulate the troubleshooting task for a P machine by the TS. The arrival rate distribution for mean time to failure and time distribution for mean time to repair for the major troubleshoot diagnosis were specified at the P machine under the efficiency option. Once the P machine detects a major troubleshoot diagnosis, MJTS will breakdown and utilize the TS. This can be written as an algorithm in Visual Logic code for the P work station as shown below.

```
Process P On Break Down
└► SET Time 1 = Simulation Time        //Set start time of breakdown//

Process P On Repair Complete
└► SET Time 2 = Simulation Time       //Set end time of breakdown//
└► IF Time 2-Time 1 = 15              //Check if duration = major troubleshoot
                                        diagnosis//
   └► Add Work To Queue    Main Work Item Type, Queue for MJTS
      //Initiate major troubleshoot task//
```

The following visual logic was also used to stop the P process from operating while MJTS was being serviced by the TS.

```
MJTS Route-In After Logic
└► BreakDown    Process P, 0     //Stop Process P at the
                                   start of major troubleshoot//
MJTS Work Complete Logic
└► BreakRestart    Process P     //Restart Process P at the
                                   end of major troubleshoot//
```

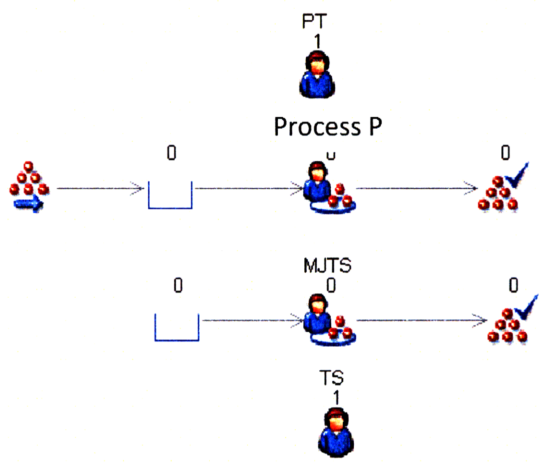


Figure 16: Module for diagnosis and troubleshooting

4.1.4) Minor and Major Troubleshooting Diagnosis

Additional tasks of minor and major troubleshooting diagnosis were built into the simulation models for proposed labor allocation 1. This is because in proposal 1, a low–skilled PT is assigned the tasks of handling stoppages, diagnosis of minor and major problems. The average times taken for the diagnosis of minor and major problems by low-skilled PTs were 5 and 6 minutes respectively. A high-skilled PT will handle minor problem and diagnosis of major problem. The average time taken for the diagnosis of major problem by high-skilled PT was 15 minutes. A TS will eventually handle the major problem.

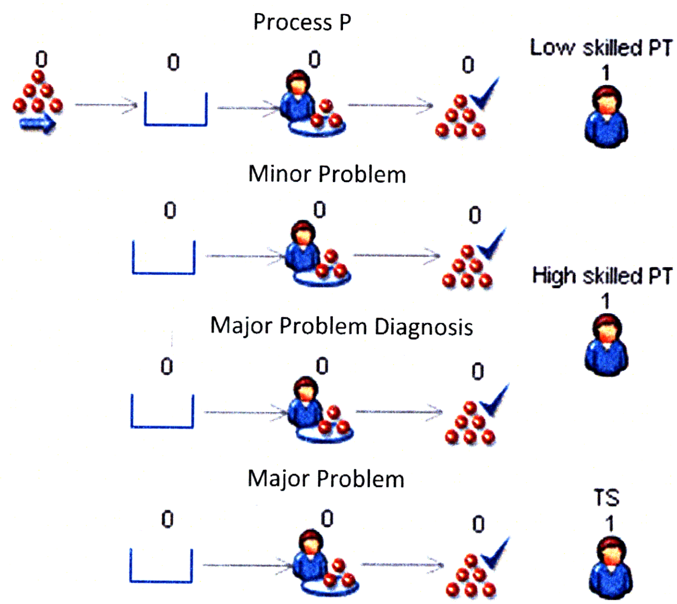


Figure 17: Additional work centers for machine problems and diagnosis for labor allocation proposal 1

Figure 17 shows the additional work centers created to simulate minor problem, major problem diagnosis and major problem for a printing machine. The services times for stoppages, minor and major problem diagnosis by a low-skilled PT were defined in the printing work center. Once the downtime for minor or major problem diagnosis was identified, a work item was added to the queue of minor problem or major problem diagnosis work center respectively. This can be written as an algorithm in Visual Logic code for the P work station as shown below.

```
Process P On Break Down
└► SET Time 1 = Simulation Time        //Set start time of breakdown//

Process P On Repair Complete
└► SET Time 2 = Simulation Time        //Set end time of breakdown//
└► IF Time 2-Time 1 = 5                //Check if duration = minor troubleshoot
                                       diagnosis//
  └► Add Work To Queue   Main Work Item Type, Queue for Process P Minor Troubleshoot
      //Initiate minor troubleshoot task//
└► IF Time 2-Time 1 = 6                //Check if duration = major troubleshoot
                                       diagnosis//
  └► Add Work To Queue   Main Work Item Type, Queue for Process P Major Troubleshoot
     Diagnosis
      //Initiate major troubleshoot diagnosis task for high-skilled PT//
```

At the minor troubleshoot work center, when a work item was initiated, the process P work center would breakdown and no parts was produced. The P machine was restarted only after the minor troubleshoot was completed. This was written in Visual Logic for the minor troubleshoot work center as shown below.

```
Process P Minor Troubleshoot Route-In After Logic
└► BreakDown Process P, 0            //Stop the P machine//

Process P Minor Troubleshoot Work Complete Logic
└► BreakRestart Process P            //Restart the P machine
```

At the major troubleshoot diagnosis work center, when a work item was initiated, the process P work center would breakdown and no parts was produced. Once the work item was completed, a new work item was then added to the queue of the major troubleshoot work center. The P machine was restarted only after the major problem was completed. The Visual Logic for these actions is shown below.

```
Process P Major Troubleshoot Diagnosis Route-In After Logic
↳ BreakDown Process P, 0            //Stop the P machine//

Process P Major Troubleshoot Diagnosis Work Complete Logic
↳ Add Work To Queue    Main Work Item Type, Queue for Process P Major Troubleshoot
      //Initiate major troubleshoot task//

Process P Major Troubleshoot Work Complete Logic
↳ BreakRestart Process P            //Restart the P machine//
```

The next step of the model development was integrating the different modules into the production machines to create the complete models for each production line as shown in figure 9-11. These models were then duplicated to represent the whole syringe production floor of 8 lines. The resulting layout was animated when the simulation was run, showing the movement of parts and resources with elapsed time. The simulation can be interrupted at any stage and a comprehensive reporting system can be viewed, either in graphical form or tabulated form.

After the model was developed, verification and validation were conducted. The movement of the work items and labor resources during the simulation were observed and no abnormality was observed. The simulation results of the current labor allocation, such as the production output and resources utilization, were also compared to the actual output and utilization for any significant discrepancy. The purpose of these was to ensure that the model behaves as intended. The last step was conducting the experiments and presenting the analysis results.

4.1.5) Computer Simulation Parameters

The uncertainty of the data and the manufacturing process was also considered with the stochastic influences on the models. Probability distributions were used to represent the random input and the process breakdown. The types of probability distributions for inter-arrival of stoppages and minor troubleshoot were determined using software StatFit® version 2.0. Table 5 summarizes the result of this analysis. The probability distributions for the inter-arrival of major troubleshoot were assumed to be normal and the mean and standard deviation were calculated from the company's record. The means and standard deviations are presented in table 6. The average service times and frequencies for various tasks used for the simulations were based on the timing presented in appendix A and B respectively. The machines' speeds used in the computer simulation were derived from the actual machines' capacity and presented in appendix D. Because the random input was used, replications of the simulation results were to find the average result which would be a better representation of the actual system.

Table 5: Distribution of inter-arrival time of machines stoppages and minor troubleshooting

Type of Machine Failures	Distribution	α	B
Process P Stoppages	Pearson 5	0.968	64.9
Process P Minor Troubleshoot	Pearson 5	0.968	277
Process A Stoppages	Pearson 5	1.52	16.8
Process A Minor Troubleshoot	Pearson 5	1.52	193
Process PP Stoppages	Pearson 5	8.86	73.6
Process PP Minor Troubleshooting	Pearson 5	8.86	1150

Table 6: Distribution of inter-arrival time for machine major troubleshoot

Type of Machine Failures	Distribution	Mean (min)	Std Dev
Process P Major Troubleshoot	Normal	465	184
Process A Major Troubleshoot	Normal	498	188
Process PP Major Troubleshoot	Normal	489	181

The current and proposed labor allocations were evaluated via simulation on this virtual model by changing the labor resources needed for different tasks accordingly. The details on how the various tasks were allocated to different types of labor resources for the various labor allocations are presented in the first thesis of this project [8]. Each task was also given a priority number as shown in appendix E. In the simulation models, the labor resources were allowed to stop an incomplete task to work on a higher priority task before returning to the original task. This was done by selecting the "interrupt other work if necessary" for each task under resource detail.

The walking time between production lines were considered in the simulation. These average times taken were determined from time trials on the production floor. Table 7 shows the average time taken to travel between different number lines.

Table 7: Average walking time for different distance

Travelling Distance (No. of lines)	Average Walking Time (min)
1	0.451
2	0.543
3	0.634
4	0.726
5	0.818
6	0.909

Chapter 5: Computer Simulation Results

Six sets of experiments were conducted for the three different labor allocations; current allocation, allocation 1, and allocation 2. The details on how the various tasks were allocated to the different types of labor allocations are presented in the first thesis of this project [8]. Each allocation has two variations. The first variation is the normal condition when all workers are working on the production floor. The second variation is the condition when some workers leave for break. The two variations were simulated in separate sets of experiments due to the software limitation of requiring fixed labor resource allocations for different tasks during simulation. Therefore, different models were required for the two variations in order to reflect the change in labor resource allocation. Each set of experiments consisted of 20 runs with a simulation period of 8 hours (1 shift) each.

A particular production scenario was chosen to test out the performance of the two proposed allocations as shown in table 8. AS refers to products that are bulk packed in large bags instead of packing individual syringes into blisters and then into cartons. DN refers to the SKU number that comes with needle while DS are SKU number that does not come with needle. The most common product type was chosen for each line. For a more conservative analysis, DN order was also chosen for all blisters packaging order except for Beech line, which does not produce such variations, as DN order requires higher labor workload. The same set of random numbers and experimental parameters were used for the different labor allocations to allow comparability of the results from different labor allocations. The results of the current allocation served as a basis for comparison for the two new proposed allocations.

Table 8: Production scenario for computer simulation study

Production Lines	Aster	Cone	Beech	Daisy	Fern	Gray	Haw	Iris II
Product Type	DN	SSLX	DS	AS	DN	DN	DN	AS

5.1) Productivity

The first results for comparison were the number of syringes produced by each labor allocation. Table 9 summarizes the average hourly productivity of each line for different labor allocations. In general, productivity during break condition was lower than normal condition because less manpower was available. However, the difference in proposal 1 was not significant since skilled PTs were made to stand-in for the operators who went for breaks. A more detailed discussion on the difference in the productivity between break and non-break condition for each labor allocation is presented in chapter 6.

Table 9: Comparison of average no. of syringe produced per hour between break and non-break

	Current State		Proposal 1		Proposal 2	
Production Line	**Non-break**	**Break**	**Non-break**	**Break**	**Non-break**	**Break**
Aster	14059	14099	13957	13854	14816	13537
Cone	9754	9463	9608	9599	9736	9593
Beech	7399	7477	7458	7450	8150	8052
Fern	17544	12901	15000	15175	17830	16380
Daisy	12823	13129	10749	10654	15062	14850
Gray	16957	16510	14901	14920	17591	16299
Haw	15579	14989	15735	15810	16470	15239
Iris II	2156	2143	2175	2173	2503	2421
Total	**96270**	**90710**	**89583**	**89634**	**102158**	**96371**

The projected combined productivity for each labor allocation was calculated by adding the average hourly productivity based on the number of break and non-break hours in an 8-hour shift as shown in table 10. Table11 presents the projected 8-hour shift productivity for each labor allocation. Proposal 2 had a higher number of produced syringes and proposal 1 had a lower number compared to the current labor allocation. A more detailed discussion on the difference in the average productivity between each labor allocation will be presented in chapter 6.

Table 10: No. of hours of break and non-break conditions in a shift

	Production Lines	No. of hours per 8-hour shift	
		Non-break	Break
Current Allocation	Aster, Beech, Cone, Fern, Daisy, Gray	6	2
	Haw, Iris II	5	3
Proposal 1	All	5	3
Proposal 2	All	4	4

Table 11: Average no. of syringe produced in 8-hour shift

Production Line	Current Allocation	Proposal 1	Proposal 2
Aster	105235	105580	100308
Cone	72333	70348	70730
Beech	55659	56385	56406
Fern	115324	107198	122541
Daisy	101037	85794	107333
Gray	120789	106419	121184
Haw	110571	116435	112145
Iris II	15897	16540	17063
Total	**696844**	**664700**	**707710**

5.3) Machine Performance

The percentage of failure induced downtime for the various machines at different labor allocations are presented in table 12. Proposal 2 has the lowest percentage of machine stopped time, followed by current state and finally, proposal 1. A more detailed discussion on the reasons for difference in the machines' stopped time between various labor allocations as well as its implications is presented in chapter 6.

Table 12: Average percentage machines' failure induced downtime

Line	Machine	Current Allocation		Proposal 1		Proposal 2	
		Non-break	Break	Non-break	Break	Non-break	Break
Aster	P	8.4	7.1	7.8	8.3	7.7	7.7
	A	11.8	11.5	13.1	12.0	12.0	12.7
	PP	21.8	18.6	21.3	18.5	17.5	22.1
Cone	A	13.4	12.1	13.4	12.0	12.6	12.8
Beech	P	10.1	11.9	11.0	13.3	11.5	10.6
	A	12.2	10.7	12.2	8.5	9.7	10.2
	PP	22.8	20.7	21.5	19.3	17.9	22.5
Daisy	P	6.7	8.7	9.9	11.0	8.4	8.5
	A	11.5	20.3	29.7	32.1	11.7	11.3
Fern	P	9.5	11.3	10.7	10.7	8.9	8.9
	A	18.1	20.2	34.2	28.6	12.9	12.4
	PP	26.8	41.0	27.6	18.9	21.7	25.4
Gray	P	10.4	10.9	10.5	10.5	6.8	9.3
	A	18.1	12.9	33.4	26.9	14.1	13.3
	PP	25.6	23.9	27.9	19.5	20.7	25.1
Haw	P	9.6	10.9	9.3	9.6	6.6	9.5
	A	15.9	13.5	17.2	13.4	13.8	14.0
	PP	22.4	25.6	23.2	20.0	21.3	25.1
Iris II	P	13.7	14.1	11.5	12.9	6.0	6.7
	A	12.8	12.3	14.3	12.4	13.5	13.4
Average		**15.1**	**15.9**	**18.0**	**15.9**	**12.8**	**14.1**

5.3) Labor Utilization

The utilization of the various PTs in different labor allocation is presented in table 13. The majority of the PTs have an average utilization of less than 90%, which is the acceptable limit for the company. However, the operator who is working on the Daisy production line as well as Fern assembly (A) and primary packaging (PP) machines in current allocation during break time had a utilization of 96.7%. These PTs were over-worked during break time and there was not enough work sharing to average out the workloads. However, the average utilization over the 8-hour shift was at a good level of 65.8% and 68.6%. In practice, these PTs will try to accomplish most of the routine tasks such as QA inspection and housekeeping during non-break. They will only handle those unpredictable machine related tasks during break so that they will not be over worked during break time.

The average utilization of skilled PT in proposal 1 was at a low of 30.8%. Therefore, they had additional capacity to take up more tasks such as preventive maintenance of machines or training of new-hires which were not captured in the computer simulation. However, the skilled PTs will take up a higher utilization when they stand-in for the operators when they go for breaks as the behavior was not captured in the computer simulation.

In proposal 2, the average utilization of the less skilled PTs, which included material handlers and QA inspectors, were higher than the more skilled PTs working on the machines. This had a positive effect since the higher utilization of less skilled PTs did not affect the productivity, as shown in table 11, but did free up utilization of skilled PTs which allowed them to respond to machine failure more quickly, hence reducing machines' down time.

Table 13: Average percentage of labor utilization of various PTs

	SIMULATION RESULTS						
	Resource	No. of Resource	Non-break utilization (%)		Break utilization (%)		Average utilization for 8hour shift (%)
			Working within line	Traveling between lines	Working within line	Traveling between lines	
Current Allocation	Operator – Aster & Beech P	1	43.0	Na	79.8	na	48.2
	Operator - Aster A&PP	1	57.2		79.8		60.4
	Operator - Beech A&PP	1	58.1		79.8		61.2
	Operator – Cone	1	39.2		79.8		45.0
	Operator - Daisy	1	60.7		96.7		65.8
	Operator – Fern/ Gray P	1	43.9		72.1		48.0
	Operator – Fern A&PP	1	63.9		96.7		68.6
	Operator – Gray A&PP	1	63.7		72.1		64.9
	Operator – Haw & Iris II P	1	46.8		70.7		53.6
	Operator – Haw A&PP	1	65.7		70.7		67.1
	Operator – Iris II A&B.pack	1	52.3		70.7		57.6
	Average						58.2
	Std dev						8.4
Proposal 1	Operator - Aster	1	58.2	0.0	55.4	0.0	57.2
	Operator – Cone	1	58.2	0.0	52.8	0.0	56.2
	Operator - Beech	1	59.0	0.0	55.2	0.0	57.6
	Operator - Daisy	1	57.2	0.0	53.2	0.0	55.7
	Operator - Fern	1	76.0	0.0	70.1	0.0	73.8
	Operator – Gray	1	75.2	0.0	69.4	0.0	73.0
	Operator – Haw	1	76.3	0.0	70.1	0.0	74.0
	Operator – Iris II	1	68.2	0.0	64.7	0.0	66.9
	Skilled PT	3	26.8	0.0045	37.6	0.0093	30.8
	Average						60.6
	Std dev						17.1
Proposal 2	Operator – Aster, Cone, Beech & Daisy	3	46.4	1.7	55.9	4.5	54.2
	Operator – Fern, Gray, Haw, Iris II	4	46.6	9.5	51.6	17.2	62.5
	QA Inspector	2	87.5	0.0	82.2	0.0	84.9
	Material Handler	2	72.0	0.1	68.2	0.1	70.2
	Average						65.7
	Std dev						11.0

The average utilization for 8-hour shift was calculated by adding the proportion of break and non-break utilization based on their number of hours in an 8-hour shift and the results are summarized in figure 18.

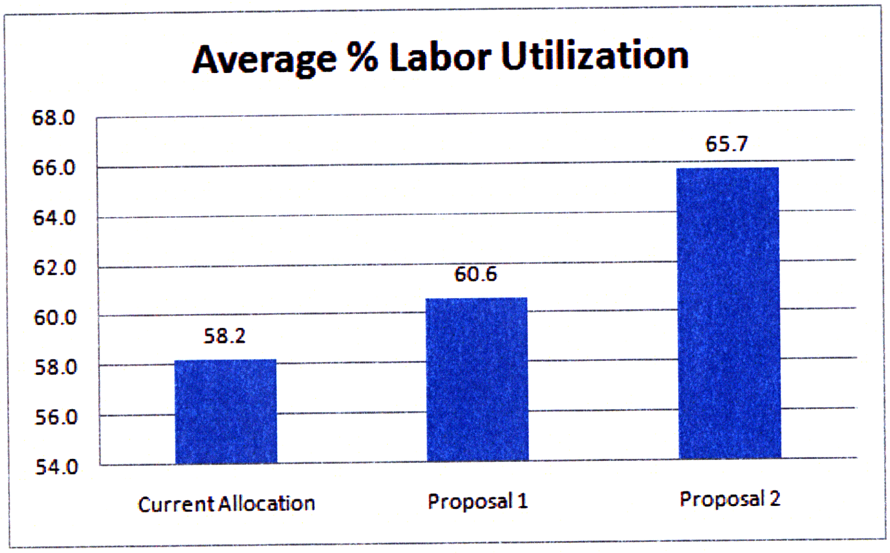


Figure 18: Comparison of average percentage of labor utilization

Proposal 2 had the highest average labor utilization of 65.7%. The higher utilization was caused by the increased travelling time of operators (Fern, Gray, Haw, Iris II). Proposal 1 has a slightly higher average labor utilization of 60.6% as compared to the current allocation of 58.2%. This increase was due to the additional diagnosis of machine failures done by the lower skilled operators before handling over to the higher skilled PTs.

Proposal 1 also had a higher standard deviation in average utilization. This reflects the difference in workload for different lines with higher utilization for larger syringe lines. Work sharing between lines for current state and proposal 2 helped in averaging the workload between PTs. A detailed discussion on the relation between the productivity and labor utilization is presented in chapter 6.

Chapter 6: Discussion

6.1) Productivity

A comparison in productivity between break and non-break conditions is presented in figure 19. Both current allocation and proposal 2 experienced a reduction in productivity during break. This was due to fewer PTs available to work on the machine failures which led to longer waiting time.

Proposal 1 has a design that mitigates the effect of fewer operators by having the skilled PTs to stand-in for operators during breaks. Therefore, there was no significant difference in productivity.

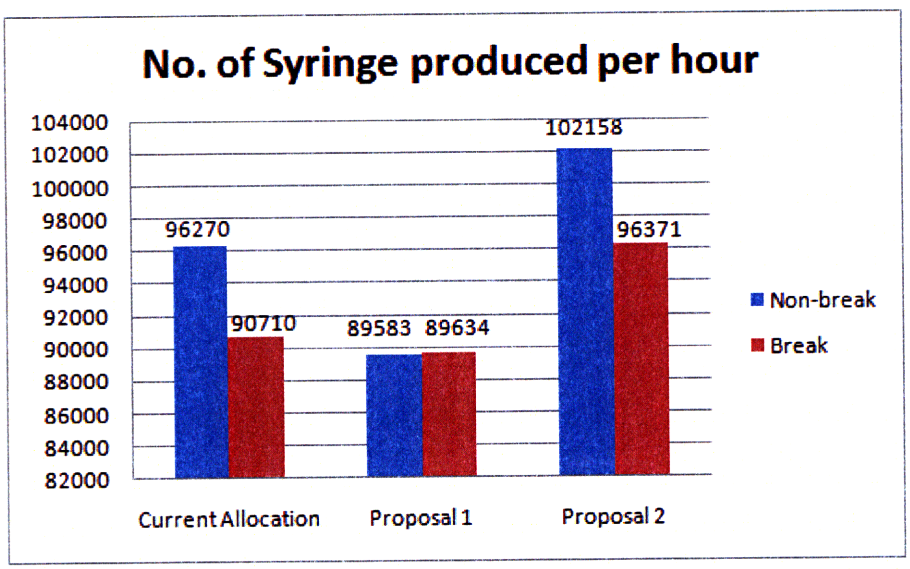


Figure 19: Comparison of productivity per hour between break and non-break conditions

The average shift productivity of the various labor allocations are summarized in figure 20. Proposal 1 has a productivity of 32000 syringes less than the current state. This is probably due to the extra downtime incurred by the operators who spent time on diagnosing the machine failures before handling over to the skilled PTs. Proposal 2 has a productivity of about 10000 syringe higher than current state with a confidence level of 95.98% using hypothesis testing. A student t-test was conducted and the calculation is shown in appendix F. This improvement is probably due to the reduction in labor response time by using a more flexible labor allocation. The reduction in labor response time can be validated by analyzing the machine downtime.

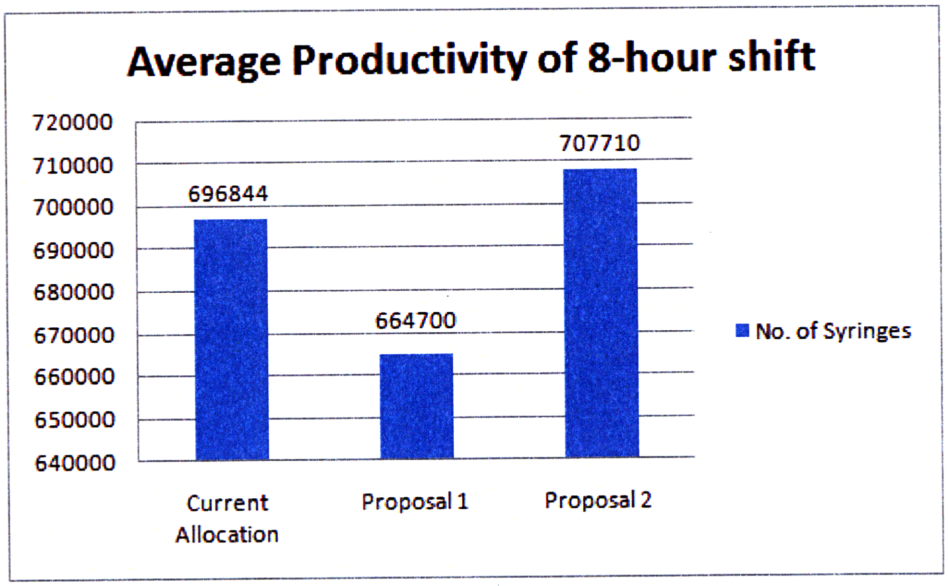


Figure 20: Comparison of average productivity of 8-hour shift

6.2) Machine Downtime

Figure 21 shows the average percentage of machine downtime in the various labor allocations. The difference in the machine downtime was due to the additional waiting time of the machines for the labor resource to arrive. This is because the machine parameters and the random number sets used for all the simulation runs are similar and thus, the machine downtimes less the waiting time for labor resource are expected to be similar. Proposal 2 had the lowest average percentage of machine downtime. Therefore, this reflects the shortest average labor response time of proposal 2 and validates the improvement in productivity due to the more flexible labor allocation.

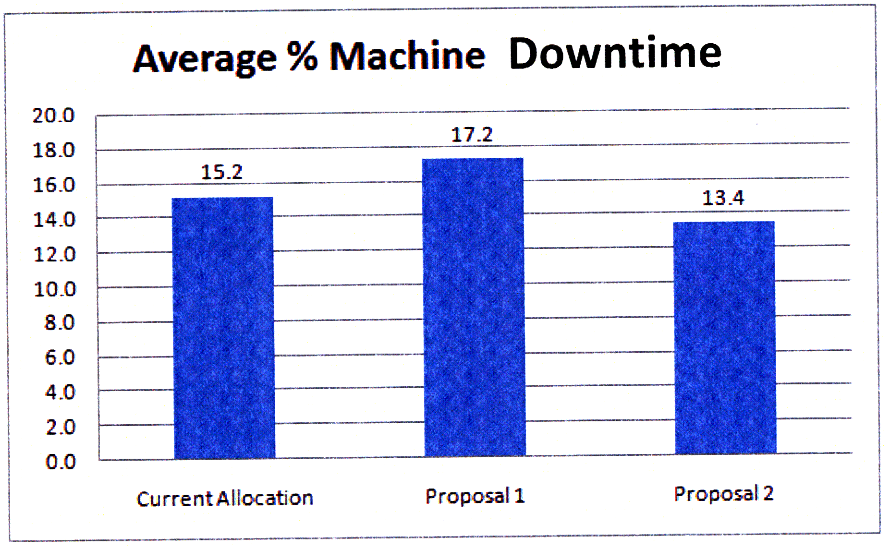


Figure 21: Comparison of average machines' downtime

6.3) Labor Utilization

Proposal 1 had a higher average utilization than the current allocation due to additional machines downtime. Hence, proposal 1 had a lower productivity. On the other hand, while proposal 2 also had a higher average utilization than the current allocation incurred from additional walking, the flexible labor allocation reduced the averaged labor response time to machine failures which increased the overall machine uptime. Hence, proposal 2 had a higher productivity. However, any strategy which can reduce the walking time of the flexible PTs in proposal 2 without compromising the effect of labor flexibility will further enhance the productivity.

6.4) Financial Analysis

A financial analysis was done for an overall comparison between the current labor allocation and the two proposed labor allocations in term of monetary value. The analysis comprised of two components: labor cost and value of productivity. The total labor cost was calculated for each labor allocations based on a new skill-based pay system. Currently, all PTs are categorized into three different levels: PT 1, PT 2 and PT 3. A new salary scale for skill-based pay system was developed for proposal 2. It was based on the assumption that the company would not incur additional labor cost with the new salary scale as compared to the current labor cost. The current average monthly labor cost for all PTs was S$ 15,345 as quoted from internal source. A contour plot, as shown in figure 22, was generated to determine the limit of maximum salary for each category based on equation (2).

$$(4 \times \text{PT 1 Salary}) + (3 \times \text{PT 2 Salary}) + (4 \times \text{PT 3 Salary}) = 15{,}345 \quad (2)$$

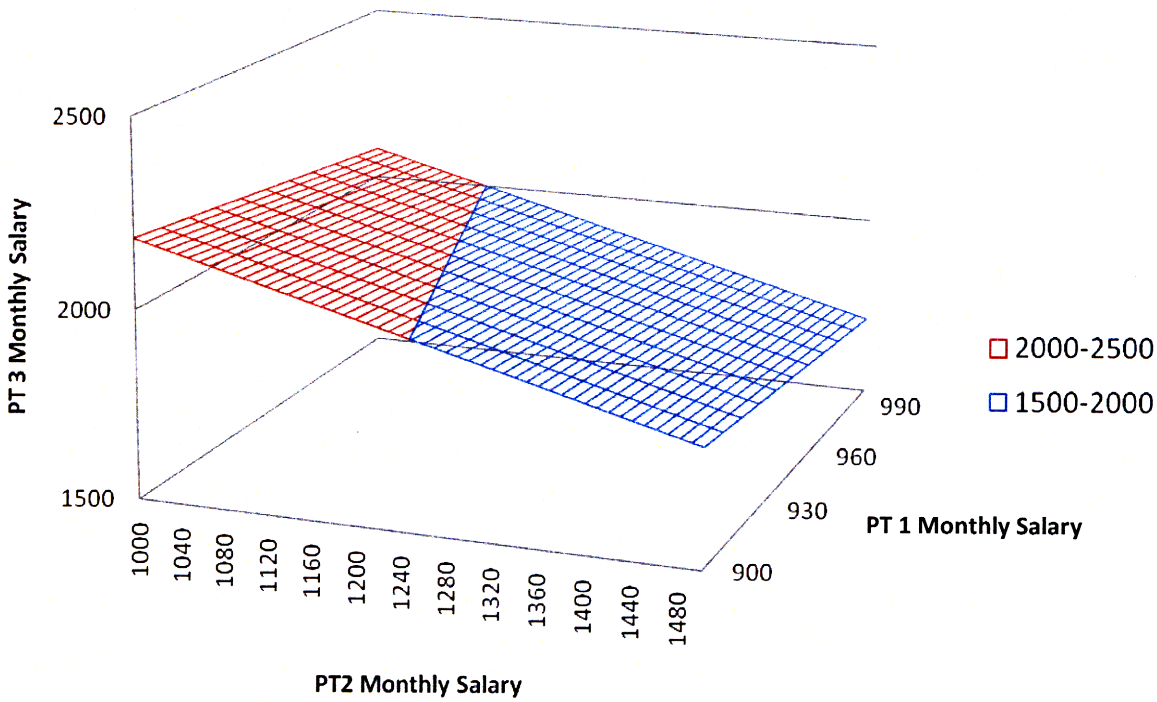


Figure 22: Contour plot of maximum monthly salaries

A set of values from the contour was chosen as the limits for the salaries of each category and the new salary scale is presented in table 14. PTs under the current salary scale will not be disadvantaged as their skills set will promote them to a higher category with a higher mean salary. The total labor cost of each proposal was calculated based on the new mean salaries as shown in table 15.

Table 14: New salary scale for skilled-based pay system

	Monthly Salary (S$)		
Category	**MIN**	**MAX**	**Mean**
PT3	1380	1820	1600
PT2	980	1380	1180
PT1	900	980	940

Table 15: Average monthly pay of various PTs

	Position	Monthly salary (S$)
Proposal 1	Skilled PT	1180
	Higher skilled PT	1600
Proposal 2	Material Handler	940
	Quality Inspector	940
	Skilled PT	1180
	Higher skilled PT	1600

MD is a cost center and any additional production above the targeted volume is considered as incremental recovery cost. A conservative value of S$20 for every 1000 syringes is used to calculate any additional productivity.

Table 16: Financial analysis of various labor allocations

	Current State (S$)	Proposal 1 (S$)	Value add (S$)	Proposal 2 (S$)	Value add (S$)
Labor costs	797,940	740,480	57,460	774,800	85,540
Incremental recovery cost			(694,310)		234,706
Total value added			**(636,850)**		**320,246**

Note: All values are per annum
() – Negative, not favorable

Table 16 shows the result from the financial analysis. Proposal 1 incurred a total loss in value of S$636,850 per annum due to the significant reduction in productivity which overrides the reduction in labor cost. On the other hand, proposal 2 has a potential total economical benefit of S$320,246 per annum due to cost saving from labor as well as increased productivity.

6.5) Sensitivity Analysis

A sensitivity analysis was conducted to explore the effects of different number of skilled operators in proposed labor allocation 2 on the overall productivity and monetary benefits. The simulations summarized in figure 19 show that having fewer skilled operators during break time reduced the productivity. The focus of this sensitivity analysis was the impact of increasing the number of skilled operators from the current 7 for proposal 2. Figure 23 shows the simulation results of average productivity of 8-hour shift for different number of skilled operators.

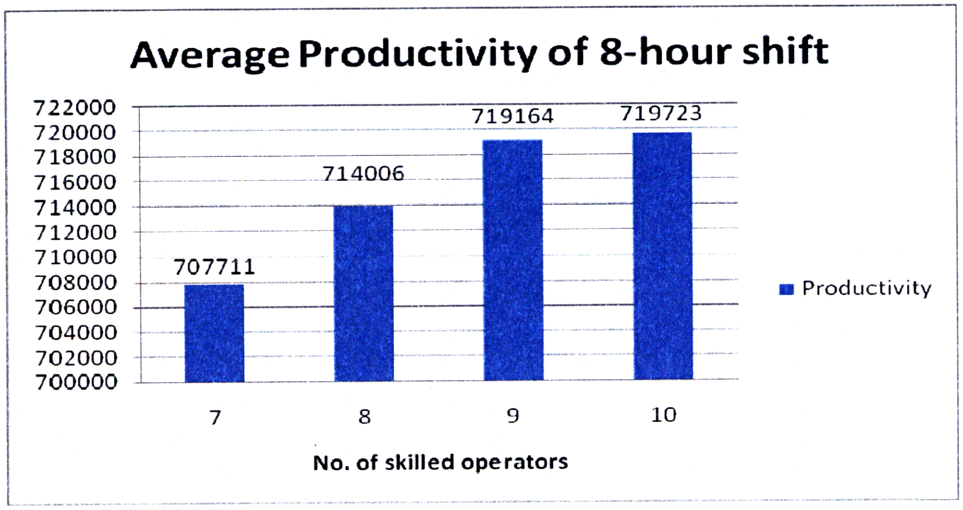


Figure 23: Average shift productivity of different number of skilled operators for proposal 2

A financial analysis was also done to evaluate the change in labor cost and recovery cost from additional productivity. The net monetary benefits of different number of skilled operators as compared to the current labor allocation are presented in figure 24. The largest monetary benefit of S$ 444,908 was achieved with 9 skilled operators for proposal 2. Increasing the number of skilled operators to 10 decreased the monetary benefit as the increase in labor cost overweighed the increase in productivity. Therefore the optimum number of skilled operators for proposal 2 is 9. Currently, the company's priority is to reduce labor cost while maintaining the current level of productivity. However, if the company is considering increasing their productivity in future, 9 skilled PTs could be deployed to yield the maximum economical benefits.

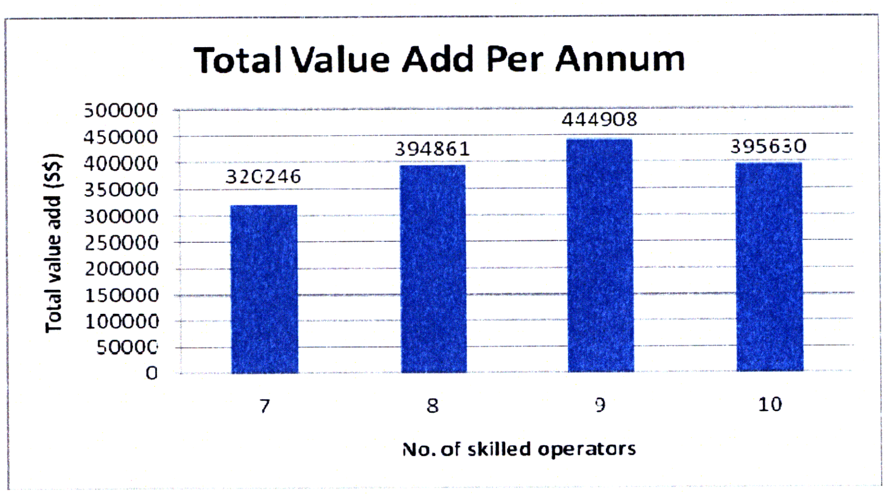


Figure 24: Net monetary benefit of different number of skilled operators for proposal 2

Chapter 7: Recommendations and Future Work

7.1) Recommendations

The result of computer simulation suggests that the optimum labor allocation for MD's syringe production is to have a team of flexible PTs to handle all the machine related tasks, while having specialized personnel for less skilled tasks, such as material handling and QA inspection as proposed in labor allocation 2. This labor allocation yielded higher productivity due to shorter machines downtime as a result of faster labor response time to machine failures. This was possible due to the higher labor flexibility and less utilization of skilled PT working on machine tasks.

The financial analysis also predicted a significant monetary gain of S$320,246 per annum for the company with the implementation of proposal 2. Therefore, it is recommended that the company embark on the transformation of the current labor allocation to the new allocation in proposal 2. The sensitivity analysis suggested that the optimum number of skilled operators for proposal 2 is 9. This is an increase of two workers to the existing number of workers, hence an increase in labor cost. However, the increase in productivity more than compensates for the increased labor cost. Therefore, the company can also consider increasing the number of workers to increase their average productivity.

The result of proposal 1 suggests that having fewer skilled PTs involved in machine related tasks is not desirable due to the extra downtime incurred during the transition from the less skilled PTs to the skilled PTs who can perform higher level of troubleshooting. Therefore, the company should ensure that they have a team of well-trained and skillful PTs to manage the machines.

7.2) Future Work

A possible area of study is to explore other strategy for labor flexibility in proposal 2 to reduce the utilization on walking. A chained flexibility strategy, which has comparable effect of a full flexibility arrangement but less travelling, can be explored [9]. This was not conducted in the present study due to the constraint of simulation software in defining the travelling time of pooled labor resources.

Another possible area for further investigation is the possibility of maintaining the non-break configuration throughout the shift. The simulation analysis shows the reduction in productivity during break periods. Depending on the labor allocation strategy, there are a substantial number of hours (3-4) in each 8-hour shift when the production floor is operating in break condition as the PTs rotate to go for their breaks. Figure 25 shows the expected improvement in productivity without any break condition. Therefore, it is worthwhile for the company to study the feasibility of having existing supporting TSs to stand-in for PTs during their break time. This will probably involve the scheduling of breaks for PTs and TSs.

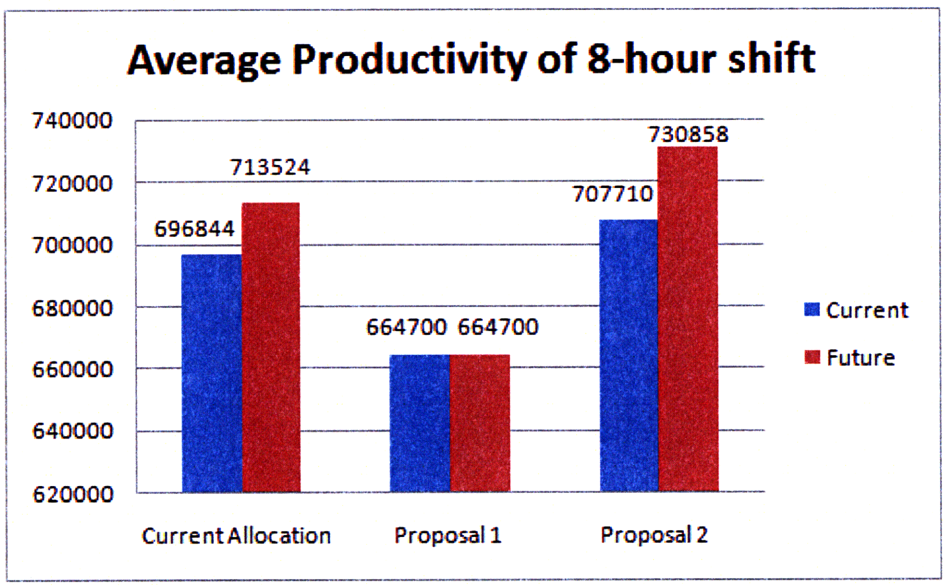


Figure 25: Comparison of productivity with and without break conditions

Chapter 8: Conclusion

This thesis use computer simulation to analyze labor allocations design alternatives. We explored different labor operating conditions in order to decrease cost and improve productivity.

This thesis presents the results of the computer simulation of MD's syringe production floor. The study concentrated mainly on predicting the performance of the current and two new proposed labor allocation strategies. The results enabled the company to gain a greater understanding of the behavior of the current and alternative labor operating strategies. The simulation study showed that of the three labor allocations, the proposed labor allocation 2 gave the best overall performance for the syringe production floor. It achieved the highest average productivity as compared to the current and the proposed allocation 1 with the same number of headcount. The improvement in performance can be attributed to the shorter response time of the PTs to machines' failures as a result of increased labor flexibility within the two teams of PTs in allocation 2, as well as separating less skilled tasks that has less effect on the productivity from PTs to specialized personnel. The financial analysis also predicted a monetary gain of S$320,246 per annum from proposal 2.

The reduction in productivity for allocation 1 can be attributed to the increase in machine downtime due to lower skilled PTs. This is a reflection of the penalty of using less skilled PTs to operate production machines and the importance of training for PTs. Therefore, the result of computer simulation suggests that the optimum labor allocation for MD's syringe production is to have a team of flexible PTs to handle all the machine related tasks, while having specialized personnel for less skilled tasks as proposed in allocation 2. The simulation analysis also shows the reduction in productivity during break periods and it is worthwhile for the company to study the feasibility of having existing supporting TS to stand-in for PT going for breaks.

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Appendix A: Duration of tasks

Task No.	Stochastic Tasks	Duration (mins)
1	P machine stoppages	3.7
2	P minor troubleshoot	14.5
3	P major troubleshoot diagnosis	15.0
4	A machine stoppages	0.9
5	A minor troubleshoot	7.4
6	A major troubleshoot diagnosis	15.0
7	PP machine stoppages	0.7
8	PP minor troubleshoot	6.8
9	PP major troubleshoot diagnosis	15.0

Task No.	Deterministic Tasks	Duration (mins)
10	Machine startup	30.0
11	Housekeeping	30.2
12	Administrative work	14.2
13	Parameter checking	4.2
14	Hourly visual in-process inspection (P)	4.5
15	Hourly visual in-process inspection (A)	4.5
16	Hourly visual in-process inspection (PP)	5.2
17	Manual packing (Molded parts)	2.0
18	Manual pouring (Molded parts)	1.0
19	Manual packing (Bulk, assembled Cone)	2.2
20	Manual packing (Scrap)	2.2
21	Material replenishment (Top web)	4.3
22	Material replenishment (Bottom web)	9.0
23	Material replenishment (Cone syringes)	0.4
24	Material replenishment (Cone clips)	0.2
25	Material replenishment (Stopper)	0.7
26	Material replenishment (Needle)	1.3

pendix B: Frequency of tasks

Stochastic Tasks	Number of occurrences per 8 hour shift									
	Average for one line	1cc LS	1cc LL	SSLX	3cc LCL	3cc (II)	5cc	10cc	20cc	50c
P machine stoppages	7.20	-	-	-	-	-	-	-	-	-
P minor troubleshoot	1.70	-	-	-	-	-	-	-	-	-
P major troubleshoot diagnosis	-	0.61	0.43	-	0.39	0.49	0.77	0.45	0.54	0.5
A machine stoppages	43.35	-	-	-	-	-	-	-	-	-
A minor troubleshoot	3.94	-	-	-	-	-	-	-	-	-
A major troubleshoot diagnosis	-	0.64	0.64	0.28	0.27	0.35	0.73	0.49	0.40	0.4
PP machine stoppages	58.30	-	-	-	-	-	-	-	-	-
PP minor troubleshoot	3.90	-	-	-	-	-	-	-	-	-
PP major troubleshoot diagnosis	-	0.67	0.62	0.67	-	0.26	0.48	0.51	0.65	0.6

Deterministic Tasks	Number of occurrences per 8 hour shift									
	Average for one line	1cc LS	1cc LL	SSLX	3cc LCL	3cc (II)	5cc	10cc	20cc	50
Parameter checking for a machine	8.0	-	-	-	-	-	-	-	-	-
P hourly visual in-process inspection	8.0	-	-	-	-	-	-	-	-	-
A hourly visual in-process inspection	8.0	-	-	-	-	-	-	-	-	-
PP hourly visual in-process inspection	8.0	-	-	-	-	-	-	-	-	-
Manual packing (Molded parts)	-	6.8	6.8	-	8.2	8.2	3.6	5.8	2.9	2
Manual pouring (Molded parts, assembled Cone)	-	6.8	6.8	-	8.2	8.2	3.6	5.8	2.9	2
Manual packing (Bulk, assembled Cone)	-	23.3	25.0	30.8	19.5	47.7	56.7	61.2	-	72
Manual packing (Scrap)	-	1.9	1.9	-	1.6	1.6	0.9	1.8	0.8	1
Material replenishment (Top web)	-	2.0	1.3	-	0.3	1.8	1.7	1.6	0.4	0
Material replenishment (Bottom web)	-	1.3	0.7	-	0.3	0.3	2.5	1.1	0.9	0
Material replenishment (Cone syringes)	-	-	-	51.3	-	-	-	-	-	
Material replenishment (Cone clips)	-	-	-	76.9	-	-	-	-	-	
Material replenishment (Stopper)	-	0.8	0.7	-	1.6	3.4	5.0	9.9	6.4	4
Material replenishment (Needle)	-	4.5	2.3	-	0.0	7.0	6.8	5.1	0.0	0

Deterministic Tasks	Number of occurrences per PT per 8 hour shift
Machine startup	1
Housekeeping	1
Administrative work	1

Appendix C: Machine downtime reasons captured using APRISO

Machine	Downtime Reason used in data collection via APRISO
P	Feeder low level Missing part
A	Barrel low level Plunger low level Stopper low level Needle jam Outfeed jam
PP	Film jam Wrong count Turret wheel jam Splice top web Fill cycle did not complete Synchronous no return signal Filling monitor No syringe supply

Appendix D: Machines speeds

Name of machine	Machine speed (min/part)
Aster P	1/300
Aster A	1/300
Aster PP	1/300
Cone A	1/200
Beech P	1/150
Beech A	1/150
Beech PP	1/250
Daisy P	1/300
Daisy A	1/300
Fern P	1/400
Fern A	1/400
Fern PP	1/400
Gray P	1/375
Gray A	1/400
Gray PP	1/400
Haw P	1/330
Haw A	1/340
Haw PP	1/370
Iris II P	1/45
Iris II A	1/45

Appendix E: Priority setting for different task in computer simulation

Tasks Description	Priority
P Breakdown	57
A Breakdown	56
PP Breakdown	55
Barrel Manual Pouring	54
Plunger Manual Pouring	54
Needle Replenishment	52
Syringe Replenishment	52
Top Web Replenishment	51
Bottom Web Replenishment	51
Manual (Bulk) Packing	50
Barrel Manual Packing	50
Plunger Manual Packing	50
QA Inspection	43
Parameter Check	42
Admin Work	41
Housekeeping	40

Appendix F: Hypothesis testing for simulation productivity results

Let $\mu_{current}$ be productivity mean for current labor allocation

$s_{current}$ be standard deviation for current labor allocation

$n_{current}$ be number of samples for current allocation = 20

μ_{p2} be productivity mean for proposal 2

s_{p2} be standard deviation for proposal 2

n_{p2} be number of allocation for proposal 2 = 20

From simulation results,

$$\bar{x}_{current} = 696844$$

$$\bar{x}_{p2} = 707710$$

$$s_{current} = 19314.02$$

$$s_{p2} = 17744.33$$

Pooled estimator = $s_p^2 = \dfrac{(n_{current} - 1)s_{current}^2 + (n_{p2} - 1)s_{p2}^2}{n_{current} + n_{n2} - 2}$

$$= \frac{(20-1)19314.02^2 + (20-1)17744.33^2}{20+20-2}$$

$$= 343946234.7$$

Using Student T-Test

Hypothesis Testing:

H_0: $\mu_{p2} = \mu_{current}$

H_1: $\mu_{p2} > \mu_{current}$

Test statistic:

$$t_{\alpha,38} = \frac{\bar{x}_{p2} - \bar{x}_{current} - (\mu_{p2} - \mu_{current})}{s_p\sqrt{\dfrac{1}{n_{p2}} + \dfrac{1}{n_{current}}}}$$

$$t_{\alpha,38} = \frac{707710 - 696844 - 0}{\sqrt{343946234.7}\sqrt{\dfrac{1}{20} + \dfrac{1}{20}}}$$

$$= 1.853$$

Using Excel function:

$$\alpha = \text{TDIST}(1.853, 18, 1)$$

$$= 0.04019$$

$$1 - \alpha = 0.9598$$

Therefore, with 95.98% confidence, the null hypothesis is rejected and the productivity mean of proposal 2 is higher than productivity mean of current allocation.