# Optimization of Labor Allocation at a Syringe Production Facility: Design Proposals

by

Xiangyong Su

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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**

At MD Medical (Singapore), the syringe value stream is facing escalating labor cost and high labor turnover. Therefore, optimization of the current labor resources is necessary to control the labor cost effectively without affecting the production capacity in order to stay competitive in the global context. A method used to design optimized labor allocations is outlined. Labor tasks were first categorized based on skill levels to form new job scopes. Following which, two new labor allocations were proposed. Both proposals feature flexible worker systems that reduce the response time to machines failures, as well as more focused job scopes to minimize work interruptions. New labor allocations facilitate the implementation of a skill-based pay system, which motivates employees to learn new skills. These two proposals can provide the benefits of higher production output and improved resource utilization.

**Keywords**: Labor allocation, design, optimization

Thesis Supervisor: Brian W. Anthony
Title: Lecturer, Department of Mechanical Engineering

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# 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.

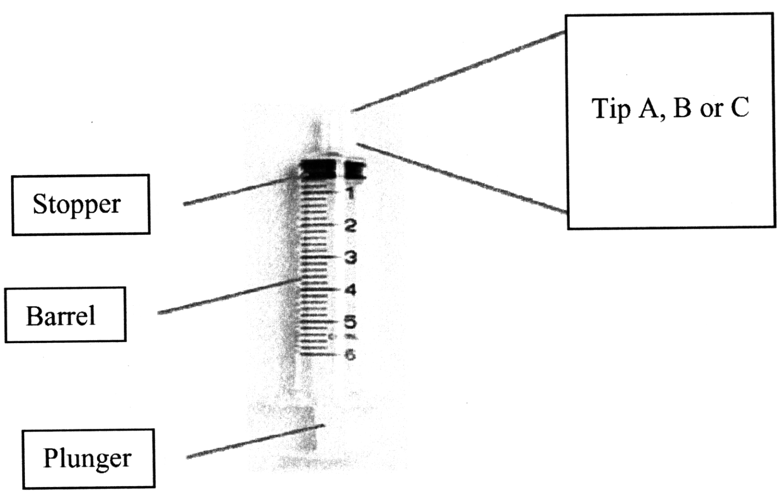



**Figure 1: Different parts of a medical syringe**

## 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: Process M, P, A and PP. Process SP is done outside the CEA to prevent the contamination of paper fibers from the carton boxes. Process 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.

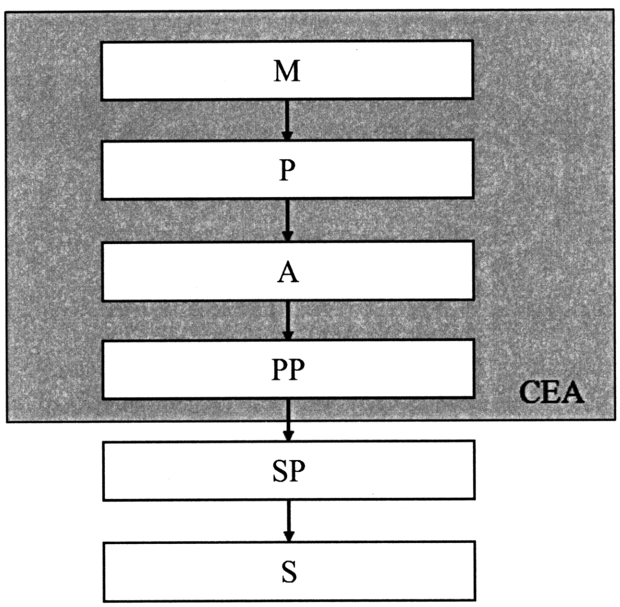



**Figure 2: Process flow of syringe production**

### 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 take 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 Machine Ms, through air vents into the hoppers. These barrels are then channeled into a Machine P for printing.

### 1.4.3 Process A

Syringe assembly is performed by a complex assembly machine, also known as the Machine A, 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 Machine PPs. 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 share 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). PTs 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 PTs.

While PTs 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. PTs 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), PTs 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 PTs are free to conduct hourly in-process inspections on the machines they are in-charge 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.

PTs 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 require manual packing and manual pouring on the part of PTs. 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 PTs, 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 Ps, while the two remaining PTs 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 PTs 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 PTs also happens whenever a PT could not manage his workload for a significant amount of time.

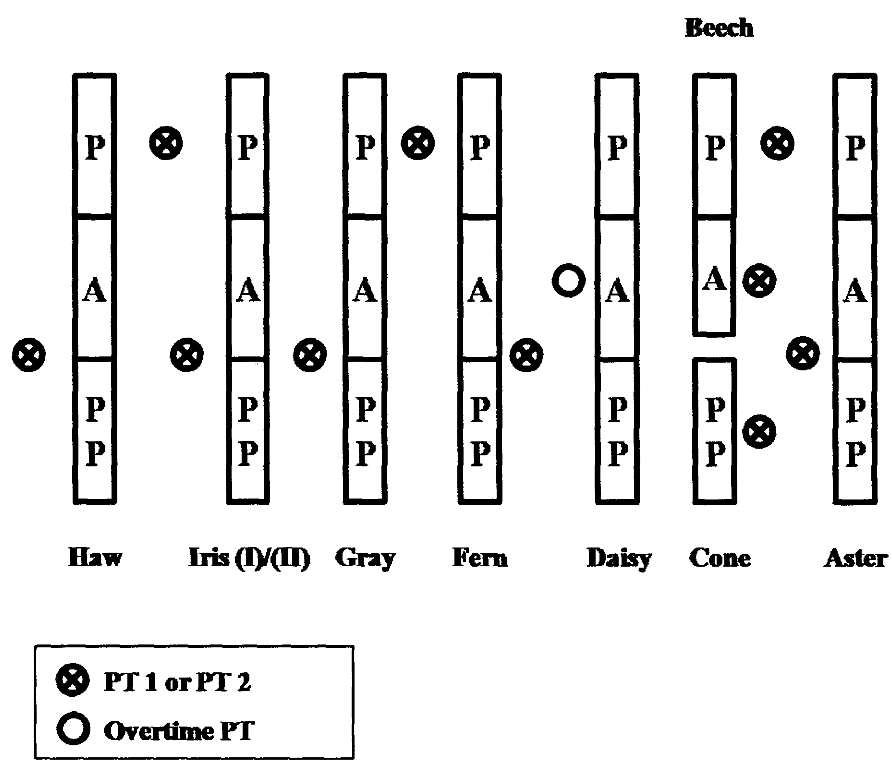



**Figure 4: Production floor plan with current manpower allocation**

Changeover occurs when product type switches between tip types, AS, DN and DS orders, and needle lengths. Two of the three PTs 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.

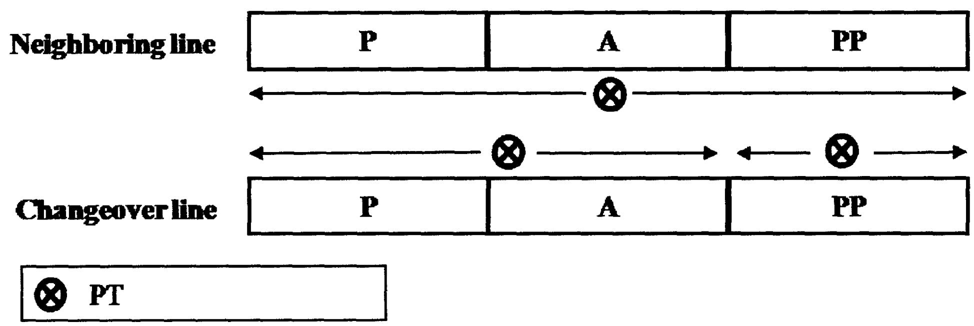



**Figure 5: Labor arrangement during changeover**

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 PTs is involved in PM of one machine while the remaining two PTs run the adjacent line; three OT PTs are brought in to do PM on the remaining machines on the PM line (Figure 6).

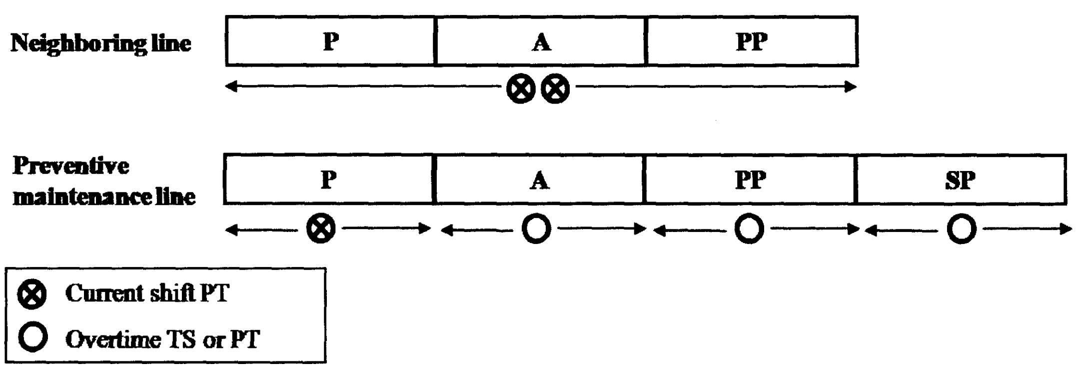



**Figure 6: Labor arrangement during preventive maintenance**

### 1.5.3 Utilization

To gain an insight on the nature of the PTs' 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:

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

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 PTs 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 PTs available to convert total man-hours to percentages of a PTs shift time. Summing all these percentage values gave the utilizations of PTs during non-break periods. These values were then scaled up to mimic the effect of redistributing a PT's workload over remaining PTs 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 PTs 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**

| Beech | Aster | 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. Relative proportion of the latter given the lines are running is shown in Table 2.

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

| Beech | | Aster | Cone | Daisy | Fern | Gray | Haw | | Iris(I)/(II) | |
|---|---|---|---|---|---|---|---|---|---|---|
| AS | DS | DN | Cone | AS | DN | DN | AS | DN | AS (Iris(II)) | 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 PTs. 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 | |
| **Haw & Iris(II) P** | 1 | 62.4 | 103.4 | 74.1 | 78.8 |
| **Haw A&PP** | 1 | 71.3 | 103.4 | 80.5 | |
| **Iris(II) A&B.pack** | 1 | 73.2 | 103.4 | 81.8 | |

* A=Process A, PP= Process PP, 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 PTs and half of the Daisy/Fern/Gray group PTs are about 103% and significantly smaller than others. One likely reason for this is that the PTs typically man one line each during break. For the Aster/Beech/Cone group, two PTs go for lunch each round and leave behind just two PTs for seven machines. Similarly, a smaller PT-to-machine ratio exists in the Daisy/Fern group where only one of the two remaining PTs attends to both lines during break.

Since 100% is the limit for utilization in practice, PTs 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 PTs is hence limited by the high break utilization that would be detrimental to productivity by making the PTs 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 PTs 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.

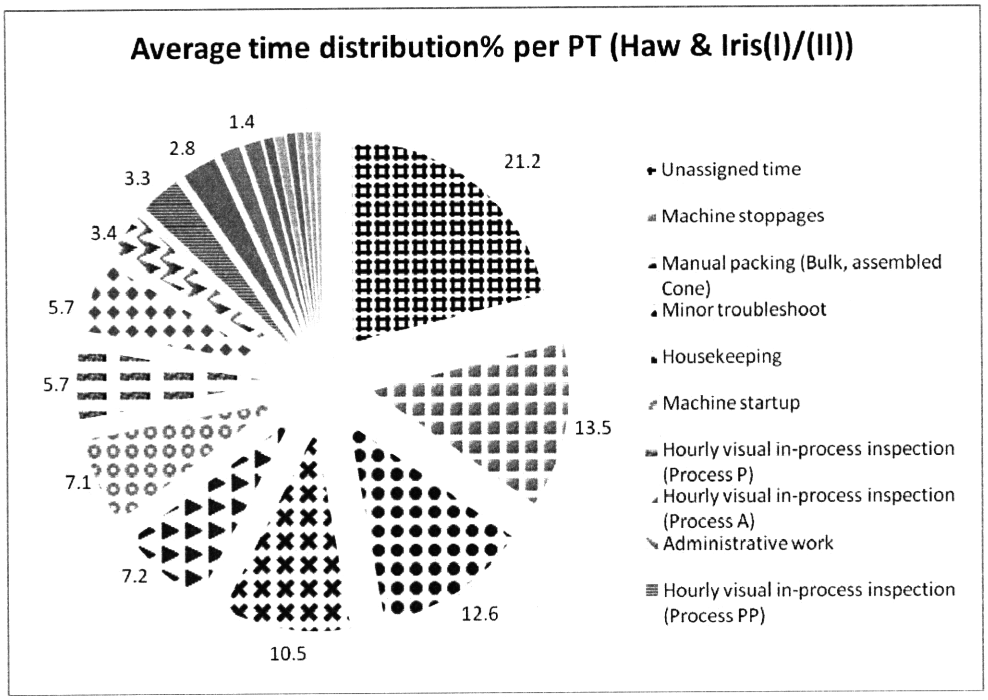



**Figure 7: Pie chart of average time distribution of tasks per PT**

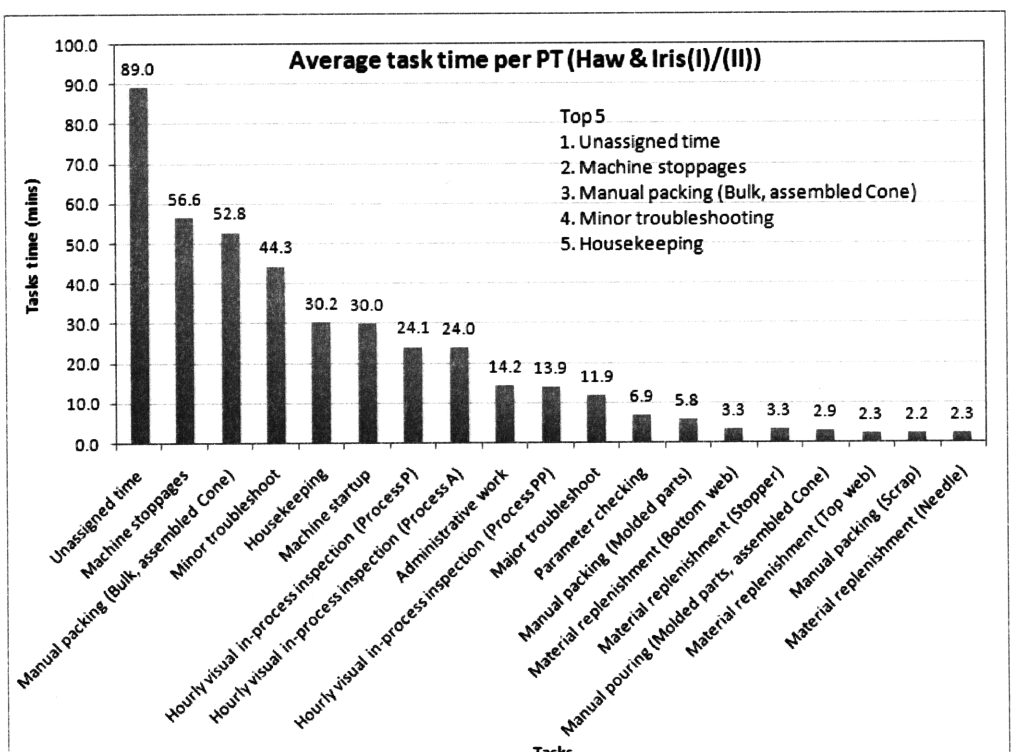



**Figure 8: Pareto chart of tasks time per PT per shift**

# 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, whereas the last part covers a work study done to investigate the feasibility of two new job scopes in Proposal 2. This thesis will present the first portion of the project.

# 3. LITERATURE REVIEW

## 3.1 Worker flexibility

Flexible work assignment has been used in the manufacturing environment as a tool to increase productivity by overcoming variations in workload. Variations arise due to many reasons. For example, changing over of equipment to change production type requires additional resources of different amount, depending on the changeover difficulty. Other causes could be machine failures, absence of resources, upstream material availability or quality issues.

Having flexibly trained workers benefits the manufacturing system because productivity can be improved by shifting resources and overcoming variations. Thus, these flexible workers are also known as variability buffers. In addition, they can also provide line capacity balancing abilities, resulting in higher operational efficiencies after capacity optimization.

Different strategies have been employed in the industry to achieve flexible worker systems. There has been considerable research being done on flexible workers. A type of flexible worker system mentioned by Schultz [3] and Sennott [4] was having flexible multi-skilled/cross-trained workers "float" around an area of workstations and support these workstations when the need arises. These floaters respond to needs such as taking over workstations that originally belong to specialists, when these specialists go for breaks and meals or are absent. In an actual manufacturing plant example given by Sennot [4], these floaters were highly skilled, experienced supervisors that serve in a supervisory role towards minimally skilled line operators. These floating supervisors were responsible for troubleshooting workstations when the line fails. Sennott [4] have further shown that even limited amounts of flexible workers can have an effect on line performance.

Schultz [3] also presented a common strategy in worker flexibility, where neighboring workers help one another by taking over unfinished tasks when their neighboring worker is unable to finish their work in an allotted time. Such a design could avoid idle time due to temporary or long-term bottlenecks.

Hopp [5] investigated a number of worker flexibility architectures for increasing efficiency in production lines. Strategies investigated included Cherry-Picking (CP), whereby capacity is picked from other stations to augment the bottleneck station. Picking of capacity would actually involve adding more skills to workers at low-utilization stations, thus increasing their flexibility to work at high-utilization stations. Another strategy investigated is via a skill-chaining pattern, whereby all workers can help the bottleneck station either directly or indirectly through the neighboring station. This chaining concept is in fact derived from Jordan and Graves [6], who first introduced it in the context of process flexibility for a single-stage manufacturing system.

A typical skill chaining can be as illustrated in Figure 9(a) [5], where a complete two-skill chain allows Worker 2 to help directly at bottleneck station 3, whereas Workers 1 and 4 can indirectly help by absorbing some or all of the work content at stations 1, 2 and 4.

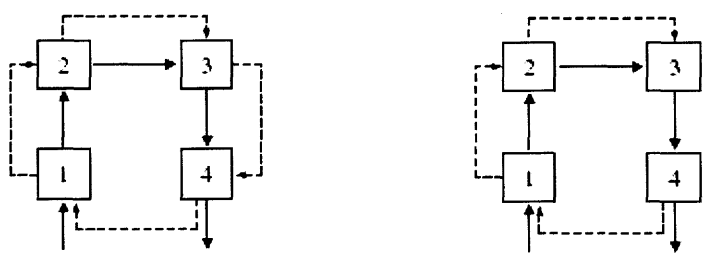



**Figure 9: Skill-Chaining strategies: (a) Two-skill complete chain (b) Partial Chain [5]**

A partial chaining strategy in Figure 9(b) [5] functions similarly to the former, except that Worker 3 would not be able to help station 4 if station 4 became a bottleneck due to variability. The authors concluded that the skill-chaining strategy outperforms CP as being more effective, less sensitive to the characteristics of the environment and much easier to implement. A complete skill-chain might not be easily implemented depending on the line layout since a complete chain for a single straight line would require one of its workers to service the first and the last station, hence incurring unnecessary worker movements (walking). Nevertheless, this limitation does not apply when parallel lines are present, as a complete chain can be easily achieved by linking neighboring heads and ends of both parallel lines together.

Although work flexibility promises benefits to the manufacturing system, Schultz [3] recognizes its many side effects, of both technical and behavioral nature. From the technical side, the authors have suggested that workers may lose efficiency by slowing down a machine to avoid mistakes when they relinquish a partially-finished operation to another worker. Extra movements out of their usual areas and moving back will also incur time. Furthermore, they have shown that moving between machines can cause a processing rate penalty beyond the time lost while moving. On the other hand, behavioral side effects include social loafing, which is possible since workers now depend on each other. Social loafing can also be interpreted as being caused by each worker's desire to have equitable division of labor. In the case of work sharing, performance feedback is weaker, thus workers may slow down their work pace to match their teammates, whom they assume to be not working hard [7]. Schultz [3] suggests that having real-time performance feedback on individual efforts would in fact help to negate this behavioral side effect by making individual efforts visible and allowing comparisons to be made between the workers in real time.

While there are several side effects for work flexibility, its benefits might still overcome the drawbacks. Therefore, the methodology in this project will take into account of work flexibility by looking at opportunities for the application of flexible worker systems mentioned by Schultz [3], Sennots [4] and Hopp [5].

# 4. METHODS

The subsequent two sections will first summarize the steps undertaken to create new allocations, whereas considerations used during the steps will be detailed in section 4.2.

## 4.1 Steps taken to design new allocations

There were four steps taken in designing new allocations: arranging all tasks in order with respect to skill, regrouping of tasks, designing manning arrangements for scenarios that might occur in a shift and finally computation and comparison of resource utilization.

Arranging all tasks in order with respect to skill was done based on the current On-Job-Training (OJT) modules that indicate the amount of active experience needed to learning a task, and on opinions gathered from technical specialists and engineers in the syringe value stream.

Having clearly identified the skills involved for these tasks, the next step was to regroup the tasks to form new job scope allocations. The third step was to design manning arrangements during non-break time, meal breaks, line changeovers and line preventive maintenance times. Finally, resource utilizations for each allocation was calculated for every line, which included utilization during break and non-break time, and the average utilization for the full 8-hour shift. These utilization values were also computed for different sets of scenarios selected to represent different production situations. Data used in calculations were collected and can be found from Appendix A and B. Resource utilization values were to be compared between job scopes within allocations as well as across allocations. This is to ensure that resources were not over-utilized and that resources for the various job scopes have suitable utilization values.

## 4.2 Considerations

Each task grouping (low, medium and high) represents a single job scope. One of the criteria for putting each individual task into a group was to allow for the creation of job scopes that specialize in a particular area. This would result in task groups that were of lesser task variety and of closer skill levels. Specialization allows a stronger job focus and enables faster performance on a higher number of similar tasks. As more learning opportunities arise from repeated occurrences of similar tasks, there would be more chances for recapping new knowledge and skills recently acquired. Naturally, learning would become more effective. This would eventually quicken the pace of learning and build up of experience such that overall efficacy in performing tasks would be heightened.

The second criterion for task grouping was to separate lower priority and long duration tasks from those that were of a higher priority. By separating them, opportunities for interruption of low priority tasks will be reduced.

Also, new allocations were designed to include work sharing only within each task group. This ensures that all workers within each group are capable and have equal opportunity to share all tasks within their similar job scopes. Worker flexibility, in the form of having cross-trained workers being able to support additional machines was incorporated in new allocations. However, the amount of flexibility was limited by spatial constraints, which were factored in as additional walking time for these flexible workers. In the new allocations, any requirement for additional labor and its source was to be accounted for during break periods, product changeovers and preventive maintenance.

In general, utilization was to be maximized for each worker in the new allocations. This involves a trial and error to determine the appropriate number of headcounts for each individual job scope. Utilization was intended to be maximized between 90 and 95%, allowing for 5-10% unallocated time between work to avoid fatigue.

## 5. RESULTS

Tasks were grouped into three categories: Low, medium and high skill level in Table 1. Each specific task listed in Appendix A and B was allocated to a general task description in Table 4. In addition to those tasks listed in Appendix A and B, "Machine preventive maintenance" and "Machine changeover" tasks were also included.

**Table 4: Task grouping into skill levels**

| Skill level | Task description | Task No. |
|---|---|---|
| Low | Manual packing | 17, 19, 20 |
| | Manual pouring | 18 |
| | Housekeeping | 11 |
| | Material replenishment (Stopper, needle, Cone syringes & clips) | 23, 24, 25, 26 |
| | Hourly visual in-process inspection | 14, 15, 16 |
| Medium | Administrative work | 12 |
| | Parameter checks | 13 |
| | Machine startup | 10 |
| | Machine stoppages | 1, 4, 7 |
| | Machine preventive maintenance – Simple | N.A. |
| | Machine changeovers – Simple | N.A. |
| | Material replenishment (Top and bottom web) | 21, 22 |
| High | Machine minor troubleshoot | 2, 5, 8 |
| | Machine major troubleshoot diagnosis | 3, 6, 9 |
| | Machine preventive maintenance – Difficult | N.A. |
| | Machine changeovers – Difficult | N.A. |

The following sections 5.1 and 5.2 each describe a proposal for resource allocation.

## 5.1 Proposal 1

In Proposal 1, tasks were regrouped to form two job scopes, namely, Operator (OP) and Skilled PT (S.PT). Eleven resources are required in this allocation. There are seven OPs, one overtime OP and three S.PTs. Each OP is assigned to a single production line and is responsible for running all machines in that production line, except for OPs of Aster, Beech and Cone, who share the responsibility for running the three lines. An OP from other shifts is called back on an overtime basis to operate the Fern line only when it is scheduled to run. S.PTs are not assigned to any particular line; they share among themselves the responsibility for all lines. The manning arrangement for Proposal 1 during non-break time is shown in Figure 10 below.

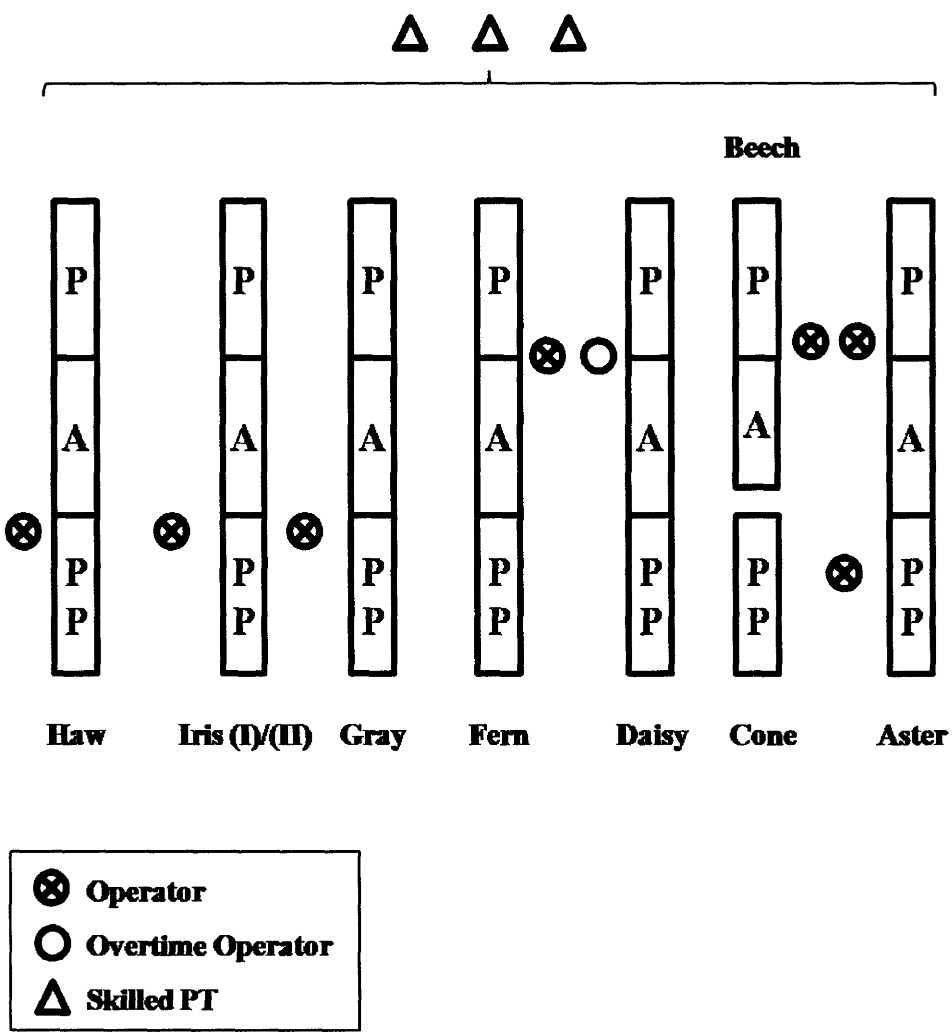



**Figure 10: Production floor manning arrangement for Proposal 1 during non-break time**

The job scope of each resource category in Proposal 1 is detailed below:

Operator (OP)

- Manual packing
- Manual pouring
- Housekeeping
- Material replenishment
- Hourly visual in-process inspection
- Administrative work
- Parameter checks
- Machine startup
- Machine stoppages
- Machine minor troubleshoot diagnosis
- Machine changeovers - Simple

Skilled PT (S.PT)

- Machine startup
- Machine minor troubleshoot
- Machine major troubleshoot diagnosis
- Machine preventive maintenance
- Machine changeovers - Difficult
- Training/Mentoring
- Stand-in for operator during breaks

During the start of a new shift, S.PTs will be involved in monitoring and expediting the machine startup for all lines. After machine startup, OPs are expected to request for S.PT to perform machine minor troubleshooting tasks if they are unable to resolve machine stoppages after five minutes of machine troubleshooting diagnosis. OPs are also expected to participate in machine changeovers together with S.PTs by performing simple machine changeover tasks. For newly hired OPs, S.PTs will also be responsible for a one to one on-production-floor practical training or mentoring.

### 5.1.1 Break arrangement

The manning arrangement for Proposal 1 during meal breaks is shown in Table 5. A similar manning arrangement is followed during tea breaks, but with every break period being 15 minutes.

**Table 5: Manning arrangement for Proposal 1 during meal break time**

| Break Period | Description | Cumulative no. of resources went for break | Breakdown of resources left |
|---|---|---|---|
| 1st 40 mins. | Three S.PTs stand in for three OP | 3 | 3 S.PT, 5OP |
| 2nd 40 mins. | Three S.PTs stand in for three OP | 6 | 3 S.PT, 5OP |
| 3rd 40 mins. | Two S.PTs stand in for one OP and one overtime OP<br>First S.PT goes for break | 9 | 2 S.PT, 5OP |
| 4th 40 mins. | Second S.PT goes for break | 10 | 2 S.PT, 5OP |
| 5th 40 mins. | Third S.PT goes for break | 11 | 2 S.PT, 5OP |

During break time, S.PTs are expected to stand in for OPs that went for break. When an OP requests for a S.PT to perform machine minor troubleshooting tasks at another line, swapping of the OP with the nearest S.PT occurs. This swap is done by exchanging the line responsibility for as long as the S.PT needs to complete the machine minor troubleshooting task. Appendix C, D, E, and F shows the production floor manning arrangements during the 1st, 2nd, 3rd, and 4th/5th hour of the break period respectively.

### 5.1.2 Line changeover arrangement

During a line changeover, one S.PT will be deployed to perform the changeover together with the changeover line's OP. The S.PT will be responsible for the relatively difficult changeover of Machine A and Machine PP whereas the OP will be responsible for simple changeover of the Machine P. Two S.PTs will be left to oversee the running of all remaining lines and support OPs with machine minor troubleshooting.

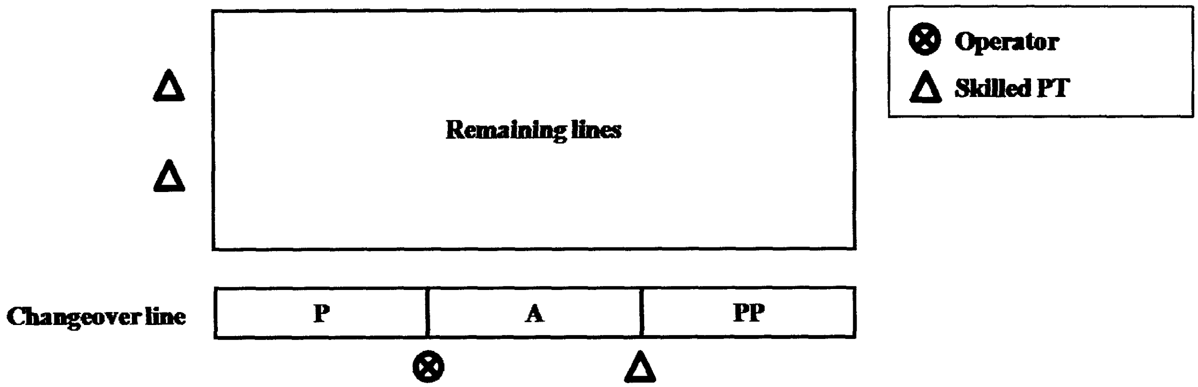



**Figure 11: Manning arrangement for Proposal 1 during changeover**

### 5.1.3 Line preventive maintenance arrangement

During a line preventive maintenance, one S.PT will be deployed to perform the preventive maintenance together with three overtime S.PTs. These overtime S.PTs can be filled in with S.PTs of another shift. In addition, since line preventive maintenances are prescheduled, there would not be any issue in gathering sufficient S.PTs for working overtime.

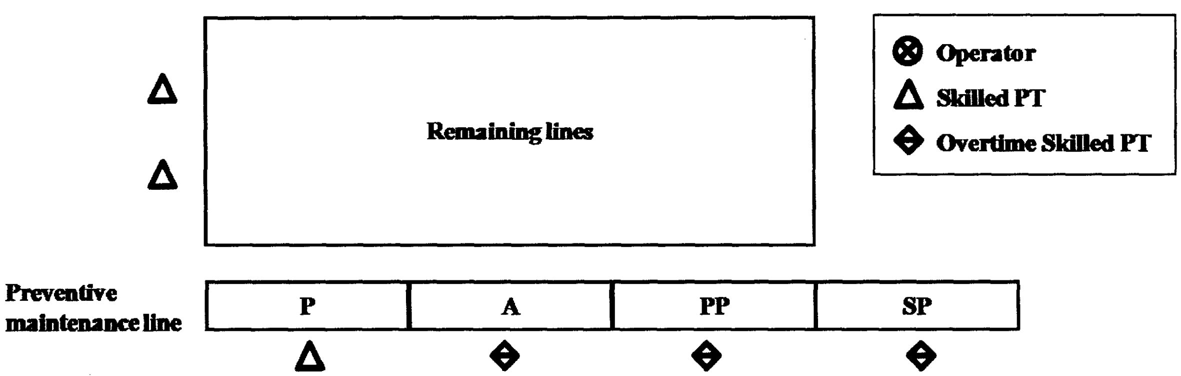



**Figure 12: Manning arrangement for Proposal 1 during preventive maintenance**

### 5.1.4 Resource utilization

Resource utilization for an eight hour shift was calculated for each job scope. For OP job scope, non-break and break utilization are similar since the responsibility of each OP remains to be the running of a single line. Depending on the production schedule, different product configurations will cause the OP to perform varying tasks types. Thus, OP utilization results for all three product configurations were calculated for each line. Since the utilization of S.PT depended upon the number of machine minor troubleshoot and major troubleshoot diagnosis tasks, two production scenarios were defined. The normal scenario refers to the commonly occurring production scenario described earlier in Table 1. The worst case production scenario for S.PT is defined to be as all machines running at the production floor. The utilization results are presented in Table 6 below.

**Table 6: Resource utilization for Proposal 1**

| Resource | Product config. | Non-break or Break utilization for 8hour shift (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Aster | Beech | Cone | Daisy | Fern | Gray | Haw | Iris(I) | Iris(II) |
| Operator | DN | 90.4 | - | - | - | 89.1 | 91.3 | 89.9 | - | - |
| | DS | 76.1 | 76.1 | 76.1 | 84.6 | 86.9 | 89.2 | 88.3 | 83.7 | 83.0 |
| | AS | 78.2 | 78.2 | - | 75.6 | 93.1 | 94.4 | 98.5 | - | 98.9 |

| Resource | Scenario | Utilization for 8hour shift (%) | | |
|---|---|---|---|---|
| | | Non-Break | Break | Average |
| Skilled PT | Normal | 84.2 | 87.1 | 86.2 |
| | Worst Case (21 machines) | 94.9 | 96 | 95.2 |

## 5.2 Proposal 2

In Proposal 2, resources were regrouped to form four different job scopes, namely, Material Handling PT (M.H.PT), Quality Inspector (QI), Skilled PT (S.PT) and Higher Skilled PT (HS.PT). Eleven resources are required in this allocation. There are two M.H.PTs, two QI, three S.PT and four H.S.PT.

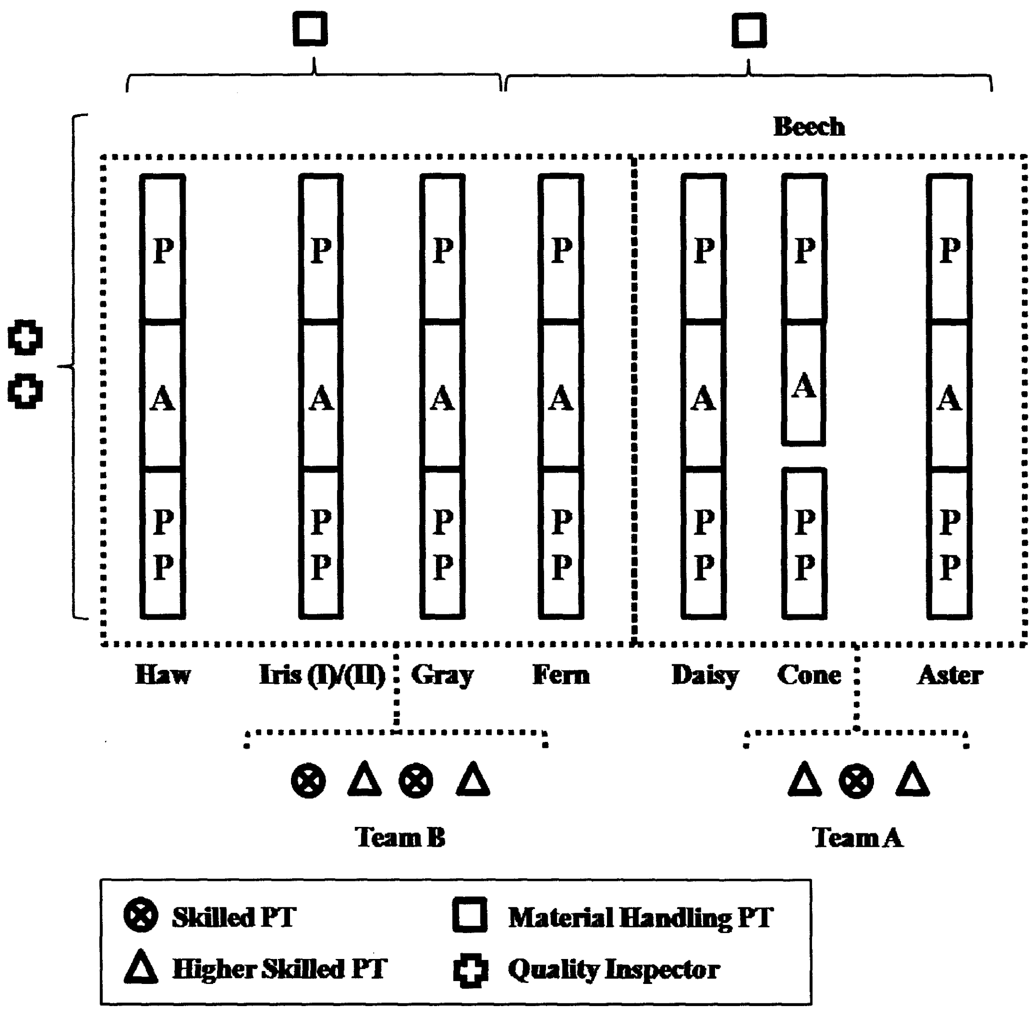



**Figure 13: Production floor manning arrangement for Proposal 2 during non-break time**

S.PTs and H.S.PTs are divided into two groups. The first group (Team A) consists of one S.PT and two H.S.PTs. This group is assigned to Aster, Beech, Cone and Daisy production lines and they share the responsibility for running all machines for those production lines. The second group (Team B) consists of two S.PT and two H.S.PTs. Similarly, this group is assigned to the rest of the production lines and they share the responsibility for running those lines.

Each of the M.H.PTs is assigned to either Gray, Haw and Iris(I)/(II) production lines group or the Fern, Daisy, Beech, Cone and Aster production lines group. Two QIs are responsible for hourly in-process visual inspection of all machines running.

For Proposal 2, the job scope of each resource category is as follows:

<u>Material Handling PT (M.H.PT)</u>

- Manual packing
- Manual pouring
- Material replenishment

<u>Quality Inspector (QI)</u>

- Hourly visual in-process inspection

<u>Skilled PT (S.PT)</u>

- Housekeeping
- Administrative work
- Parameter checks
- Machine startup
- Machine stoppages
- Machine minor troubleshoot
- Machine major troubleshoot diagnosis
- Machine changeovers - Simple

<u>Higher Skilled PT (H.S. PT)</u>

- Job scope of S.PT
- Machine changeovers – Difficult

- Machine preventive maintenance
- Training/Mentoring

During the start of a new shift, M.H.PTs will first perform material replenishment tasks and manual pouring of molded parts tasks such that the machines have all required materials to start production. S.PTs are expected to only perform simple machine changeovers together with H.S.PTs, who will perform difficult machine changeover tasks. For newly hired OPs, H.S.PTs will also be responsible for a one to one on-production-floor practical training or mentoring.

### 5.2.1 Break arrangement

The manning arrangement for Proposal 2 during meal breaks is shown below. A similar manning arrangement is followed during tea breaks, but with every break period being 15 minutes.

**Table 7: Manning arrangement for S.PTs and H.S.PTS in Proposal 2 during meal break time**

| Break Period | Description | Cumulative no. of resources went for break | Breakdown of resources left |
|---|---|---|---|
| 1st 40 mins. | One S.PT/H.S.PT each from Team A and B goes for break | 2 | 2 S.PT, 3 H.S.PT |
| 2nd 40 mins. | One S.PT/H.S.PT each from Team A and B goes for break | 4 | 2 S.PT, 3 H.S.PT, 2 M.H.PT |
| 3rd 40 mins. | One S.PT/H.S.PT each from Team A and B goes for break | 6 | 2 S.PT, 3 H.S.PT, 2 M.H.PT |
| 4th 40 mins. | One H.S. PT goes for break | 7 | 3 S.PT, 3 H.S.PT |

During break time, remaining S.PTs and H.S.PTs of each team are expected to share the responsibility for running their lines. The manning arrangement during the first break period is shown in Figure 14.

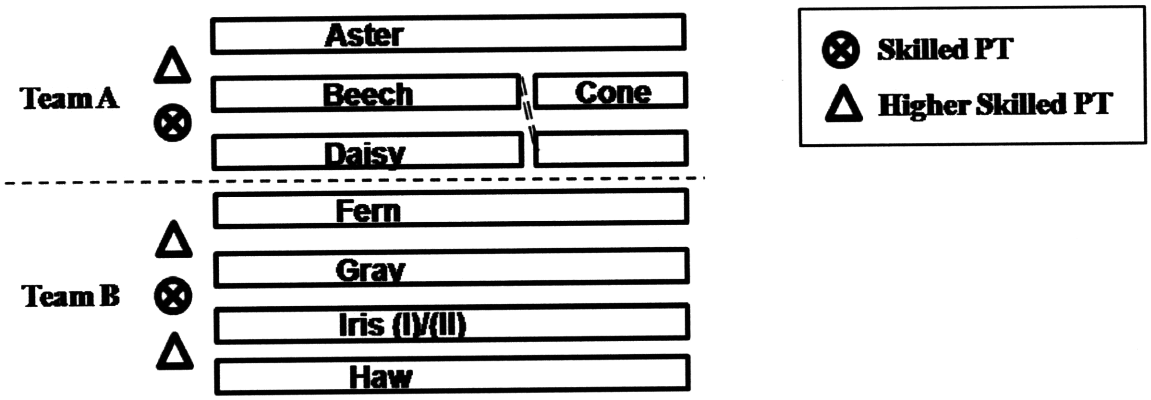



**Figure 14: Production floor manning arrangement for S.PTs and H.S.PTs in Proposal 2 during 1st break period**

Only one of the two QIs can leave for break at any one time, and the same case applies to the two M.H.PTs.

### 5.2.2 Line changeover arrangement

Depending on the scale of line changeover, one S.PT and one H.S.PT or two H.S.PTs will be deployed to perform the changeover. Figure 15 below shows a particular scenario where two changeovers take place simultaneously. For the minor changeover at Aster line, one S.PT and one H.S.PT will be deployed whereas two H.S.PTs will be deployed to perform the major changeover at the Haw line. One H.S.PT will be left under Team A to run two lines and two S.PTs under Team B will share the responsibility to run the remaining three lines.

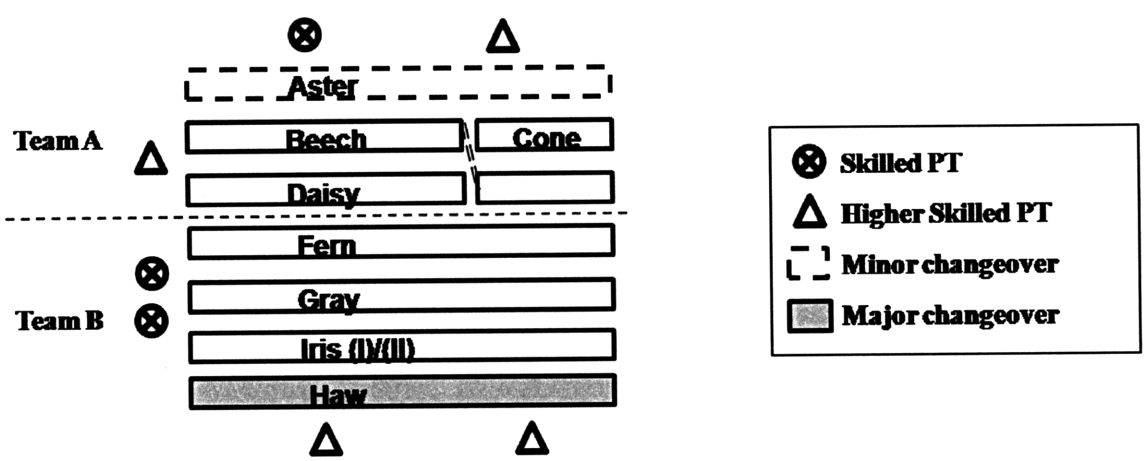



**Figure 15: Manning arrangement for Proposal 2 during changeover**

### 5.2.3 Line preventive maintenance arrangement

During a line preventive maintenance, one H.S.PT will be deployed to perform the preventive maintenance together with three other overtime H.S.PTs. Similar to Proposal 1, these overtime H.S.PTs can be filled in with H.S.PTs of another shift.

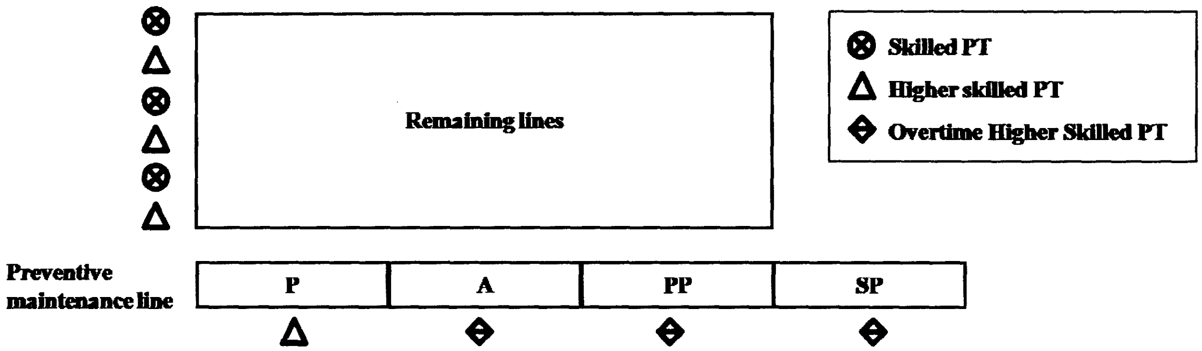



**Figure 16: Manning arrangement for Proposal 2 during preventive maintenance**

### 5.2.4 Utilization of resources

In Proposal 2, the worst case scenario for each job scope was defined separately, as one single scenario cannot yield conservative utilization results for every job scope. The worst case scenario for S.PT and H.S.PT is defined as shown in Table 8. Since the utilization of QI and M.H.PT depended upon the number of machine inspection points and material replenishment, the worst case production scenario for them is defined to be as all machines running. The utilization results are presented in Table 9 below.

**Table 8: Worst case scenario for S.PT and H.S.PT**

| Line | Aster | Cone | Beech | Daisy | Fern | Gray | Haw | Iris(I)/(II) |
|---|---|---|---|---|---|---|---|---|
| Product configuration | AS | Cone | DS | AS | DN | DN | AS | Iris(II) AS |

**Table 9: Resource utilization for Proposal 2**

| Position | No. of Resource | Scenario | Utilization for 8hour shift (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Team A - Aster, Beech, Cone, Daisy | | | Team B - Fern, Gray, Haw, Iris(I)/(II) | | |
| | | | Non-Break | Break | Average | Non-Break | Break | Average |
| S.PT. H.S.PT | Team A-3 Team B-4 | Worst Case | 64.9 | 97.4 | 74.2 | 64.4 | 85.9 | 73.6 |
| | | Normal Case | 58.8 | 88.3 | 67.2 | 60.6 | 80.9 | 69.3 |

| Position | No. of Resource | Scenario | Utilization for 8hour shift (%) |
|---|---|---|---|
| Quality Inspector | 2 | Worst Case (21 machines) | 101.2 |
| | | Normal Case | 91.3 |

| Position | No. of Resource | Scenario | Utilization for 8hour shift (%) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Aster, Beech, Cone, Daisy, Fern | | | Gray, Haw, Iris(I)/(II) | | |
| | | | Non-Break | Break | Average | Non-Break | Break | Average |
| M.H. PT | 2 | Worst Case (21 machines) | 69.5 | 150.8 | 81.1 | 81.4 | 150.8 | 91.3 |
| | | Normal Case | 73.2 | 131.4 | 81.5 | 58.3 | 131.4 | 68.7 |

## 6. DISCUSSION

### 6.1 Proposal 1

In this proposal, tasks were separated into two groups based on the skill levels required to perform them. The OP job scope includes low and medium skill level tasks, whereas the S.PT job scope includes only high skill level tasks during non-break periods. With this segregation, the level of skill for each job scope was distinguished. Since OPs are not required to perform high skilled tasks, an OP job scope does not require prior experience with machines; thus it is suitable for newly hired workers. Training OPs would be much faster compared to the current state allocation because of a reduced scope of task responsibilities. In addition, training would be easier with assistance from S.PTs during medium skilled tasks such as simple machine preventive maintenance and simple machine changeovers.

A stronger focus has also been incorporated for each job scope in this proposal. The focus for an OP job scope is directed at familiarizing the OP with daily machine running routine and picking up simple machine related skills. Having focus also benefits the OPs as they face a more gradual learning curve, making the OP suitable as an entry level job. On the other hand, an S.PT job scope allows the worker to specialize in minor machine repairs, as well as concentrate efforts to reduce machine failure frequency and machine repair time through machine preventive maintenance. An S.PT will also learn faster with a larger exposure to all machines on the production floor and have more opportunities for frequent task repetitions.

The job structure that follows this proposal provides a career progression path associated with skills upgrading. As such, it facilitates the implementation of a skill-based pay compensation system, where skills upgrading is encouraged through a monetary reward system. For example, a newly hired worker assumes an entry level job as an OP. After one year, having mastered all skills required as an OP, he continues upgrading his abilities with machine repair skills through training conducted by his employer to become qualified as a S.PT. Each time an additional skill is learnt by the OP, (skill deemed to be attained after tests), he will be rewarded with pay increments.

A flexible worker system has been used in this proposal in the form of S.PTs that float around the production lines to support the OPs through machine repairs. During other times, experienced S.PTs will take on a supervisory role towards the OPs, and provide support to them whenever the need arises. The S.PTs is also a flexible group that replaces OPs who have gone for breaks. Swapping of line responsibility between the S.PT and OP during machine minor troubleshooting is also an added flexibility that dynamically reallocates the resources based on needs. This replacement strategy during breaks has the advantage of retaining the number of workers attending to machine issues, thus it does not cause utilization to be raised during the break period. This further increases of average utilization for a working shift.

For the flexible worker system to be applicable to BD's syringe value stream, each OP will need to be competent in running all machines belonging to at least two lines. This is required so that each OP can swap with the neighboring line during minor troubleshooting.

Shown in Table S4, resource utilization for the OPs is between 76% and 99%, whereas the S.PTs experience utilization values of 84% to 96%. As compared to current state allocation, utilizations of workers do not exceed 100% for any production scenario. This ensures that workers have sufficient time to perform tasks at a manageable speed. Differences in utilization for S.PTs during break and non-break periods are also minimal.

However, there are two drawbacks in this proposed allocation. First, an additional five minutes are spent by OPs on the diagnosis of minor troubleshooting each time it occurs. Consequently for this proposal, machine minor troubleshoots are delayed by five minutes as compared to the current allocation. Machine major troubleshooting also suffers this additional five minute delay since any major troubleshooting needs to be passed through the chain of command: from being diagnosed as a minor problem by the OP, then being diagnosed as a major problem by the S.PT before being handed over to the TS. Since this delay adds on directly to the machine service time, it would reduce the overall productivity.

The second drawback in this proposal is additional travelling time incurred by the S.PT, to float around all production lines to supervise and render help when needed. Excess travelling time is considered a waste and opportunities to reduce unwanted travelling are sought. However, the nature of having flexible workers such as the S.PT requires them to move about randomly since machine reliability cannot be predicted. Nevertheless, the potential benefits of this flexible worker system could overcome the disadvantage of additional travelling time.

In this proposal and also in the subsequent proposal, it was assumed that a new inspection strategy was used such that inspection time could be reduced by half. This assumption was necessary in Proposal 1 in order that utilization of almost all OPs can stay below 100%. The feasibility of such a new inspection strategy will be further explored in part three [8] of this project.

## 6.2 Proposal 2

In this proposal, tasks were separated into four groups based on the skill levels. The M.H.PT and QI job scopes include only low skill level tasks, whereas the S.PT and H.S.PT job scopes include only medium to high skill level tasks. On top of segregating the level of skill for each job scope, this grouping also assigns all non-machine related tasks to M.H.PT and QI, whereas S.PT and H.S.PT deal with machine related tasks. Similar to Proposal 1, entry level jobs such as the M.H.PT and QI have been identified through this proposal. With no requirements for machine related skills, these two job scopes ask for minimal manufacturing experience for workers who need only to understand the production schedule well or who are meticulous and have a good eye for details. Having specialized QIs being in charge of inspection tasks will also assure higher consistency in quality checks, as well as inspection thoroughness since inspections are conducted by experienced workers.

In addition to the skills that M.H.PT and QI should have, the S.PT and H.S.PT are expected to operate and perform machine minor troubleshoots. As such, a higher pay scale for machine related skilled workers (S.PTs and H.S.PTs), would be reasonable and fair since a higher pay reflects and rewards them for possessing more advanced skills. H.S.PTs equipped with additional machine preventive maintenance and difficult changeover skills would command an even higher pay than the S.PT. This naturally leads to a requirement of defined pay steps, which are in line with concept of skill-based pay system.

This proposal has avoided combining high priority tasks with lower priority tasks together in a single job scope to minimize task interruptions. High priority tasks such as clearing machine stoppages, minor troubleshooting and major troubleshooting diagnosis have been assigned to S.PT and H.S.PTs. The only low priority and long service duration tasks assigned to them are housekeeping, administrative work and parameter checks. However, parameter checks and housekeeping occur during the start and end of a working shift, whereas administrative work lasts for fourteen minutes. Thus, reduced task interruptions and distractions can improve the overall focus and efficiency of the worker.

For this proposal, work is shared within the S.PTs and H.S.PTs in each of the two teams. Work sharing in this proposed allocation has been limited to sharing among similar skilled groups of workers. Since each worker in the group is equally capable of performing all tasks that fall within the scope of shared responsibility, fair and balanced sharing of tasks can occur. This promotes healthy team work and motivation amongst the team members. This is in contrast to imbalanced work sharing between workers with differing capabilities in the current allocation.

Work sharing within the two teams can bring about further optimization to improve resource capacity utilization and increased productivity. Three possible variations of worker flexibility can be applied to work sharing in this proposal. The first option is to allow full worker flexibility within each of the teams. This means that each worker in the team can perform any task arising from the production lines for which the team is responsible. The benefit of full flexibility comes about from providing the ability for any unoccupied team member to respond immediately to any task that arises. Within each team, all individual resource capacities are pooled together to fulfill total task demand. As such, productivity can be increased with reduced task waiting time. In addition, utilization of workers in the team can be balanced out. However, the drawback of the first option is more travelling time incurred due to workers walking long distances between production lines to perform a task. The longest distance that Team B workers can travel is across three production lines.

The second option is to allow limited worker flexibility, such that work sharing occurs only at some chosen machines. Each chosen machine act as a "link" that assigns task demands from one machine to one worker. These links form an incomplete "chain" of task demands and workers. This strategy (Chaining Strategy 1) is shown in Figure 17 and 18 below.

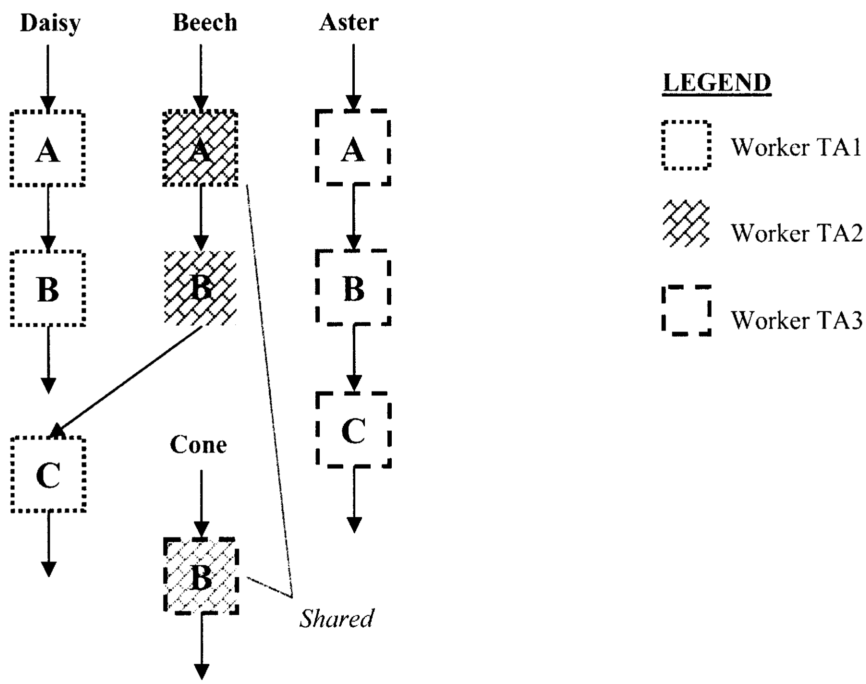



**Figure 17: Chaining Strategy 1 for Team A**

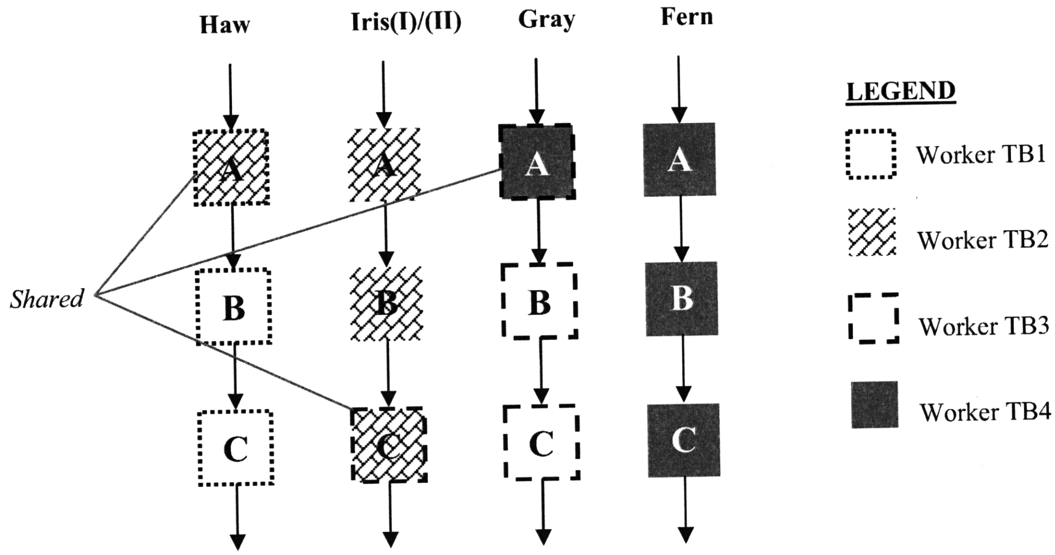



**Figure 18: Chaining Strategy 1 for Team B**

Figure 17 and Figure 18 show machines belonging to production lines for which each team is responsible. "A" represents a Machine P, "B" represents Machine A and "C" represents a Machine PP. Arrows represent the flow of products through the machines in the line. The machines are arranged in the diagram to provide a good estimation of the machine location on the production floor. The legend shows the pattern used to indicate each individual worker's responsibility for tasks arising from a machine.

In this chaining strategy, each worker is dedicated to task demands of a production line (e.g. Worker B1 dedicated to Haw line), but some workers are added with a flexibility to fulfill task demands from a shared machine at another production line. The resulting incomplete chain allows all team members to help one another directly or indirectly. For example, when two separate tasks arises at machine A and machine C of the Haw line, worker TB1 responds to task demand at machine C whereas worker B2 directly helps worker TB1 respond to task demand at machine A. Indirect help occurs when for example, four separate tasks arises at machine A and C of the Haw line, machine C of the Iris(I)/(II) line and machine A of the Gray line. In this case, worker TB1 responds to task demand at machine C (Haw) and worker TB2 directly helps worker

TB1 by responding to task demand at machine A (Haw). Worker TB3 and TB4 indirectly helps worker TB1 by responding to task demand at machine C(Iris(I)/(II)) and machine A(Gray) respectively.

Although the chaining strategy described above does not achieve full flexibility, limited flexibility has been shown in literature [6] to obtain almost all the benefits of full flexibility. Limited flexibility also mitigates the drawback of high travelling time in full flexibility. Workers in Chaining Strategy 1 travel lesser since the longest travelling distance possible for both teams is limited to crossing the neighboring production line.

The third option for work sharing is a limited flexibility with a different chaining strategy (Chaining Strategy 2). Chaining is done with an additional consideration of limiting the type of machines each worker is responsible for. Figures 19 and 20 below show how chaining is done.

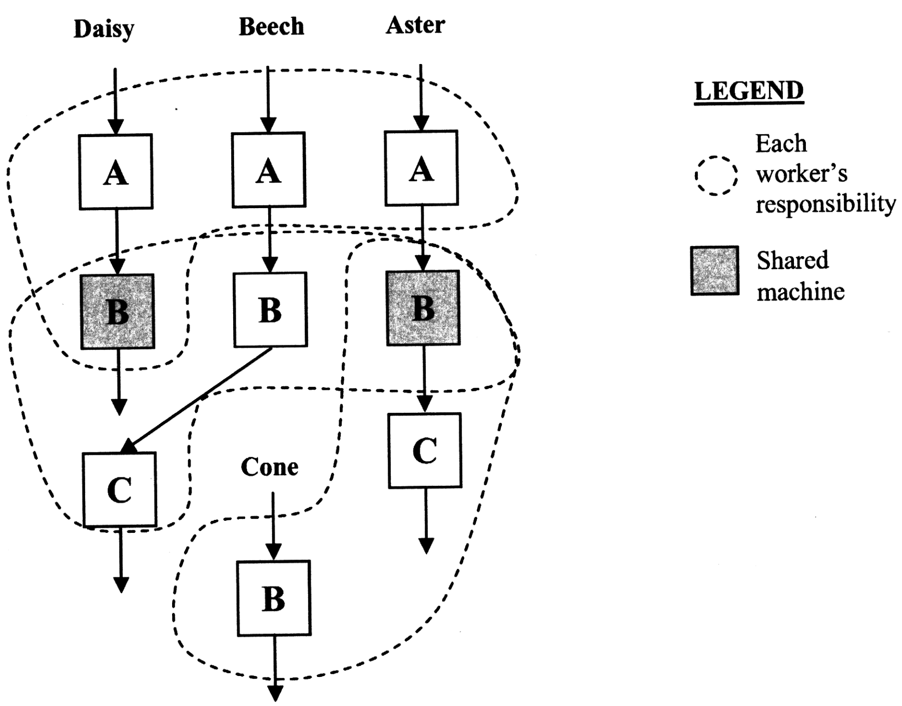



**Figure 19: Chaining Strategy 2 for Team A**

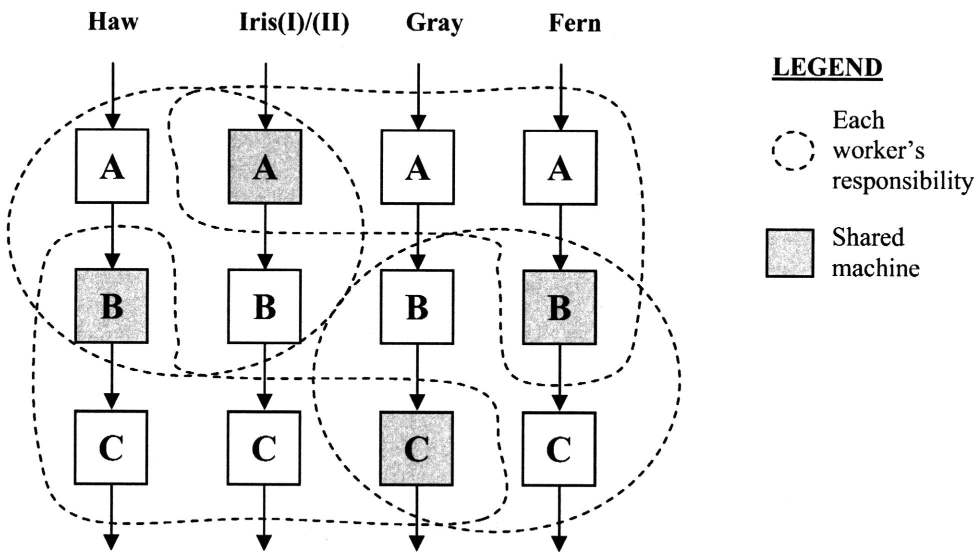



**Figure 20: Chaining Strategy 2 for Team B**

Chaining Strategy 2 works similarly as Chaining Strategy 1, with all team members being able to help one another directly or through an indirect way. However, each worker in Chaining Strategy 2 is only required to perform tasks arising from two types of machines. This arrangement provides the benefit of an improved learning curve for new S.PTs, since they need to learn only two types of machines rather than three machines as required in Chaining Strategy 1. In addition, a complete chain is possible for Team B, thus gaining more benefits through flexibility than the previous strategy. In comparison to Chaining Strategy 1, Chaining Strategy 2 would incur more travelling time as workers of both teams can travel the maximum distance of crossing two production lines.

As compared to current allocation, the difference in utilization of S.PTs/H.S.PTs between break and non-break periods has reduced significantly. While the utilization of QI in the worst case scenario slightly exceeds 100%, utilization in the normal case falls safely below 100%. As it is very unlikely that the worst case scenario of all machines running will occur, utilization values for QI were deemed acceptable. It is also to be noted that a new inspection strategy used here was necessary such that two QIs are sufficient to take care of all inspection tasks on the production floor.

As shown in Table 9, utilization values of the remaining M.H.PT during break period exceed 100%. This indicates that the remaining M.H.PT could not complete all tasks during the break period. As such, S.PTs/H.S.PTs are required to help out with uncompleted M.H.PT tasks during break period. Although such an arrangement would increase utilization values for S.PTs/H.S.PTs during break period, final utilization values were calculated and found to stay below 100%.

## 7. CONCLUSION

This report has outlined the method and considerations used to design optimized labor allocations. Two alternative labor allocation proposals were described and compared with the current state labor allocation. Tasks were separated based on skill levels and subsequently grouped them into new job scopes with a higher level of focus. Proposal 1 consists of two new job scopes, namely, OP and S.PT. The career progression path designed in Proposal 1 allows newly hired workers to start their career as an OP and progress towards S.PT through upgrading of their skills. On the other hand, Proposal 2 has four new job scopes, namely, Material Handling Production Technician (M.H.PT), Quality Inspector (QI), Skilled Production Technician (S.PT) and Higher Skilled Production Technician (H.S.PT). Newly hired workers can choose to start their career as a M.H.PT or QI and advance to S.PT, and subsequently, to H.S.PT. Job structures created in both proposals lead to an incremental pay and skill hierarchy, thus facilitating the implementation of a skill-based pay system. Motivation of workers to learn new skills can therefore be achieved with this pay system that acknowledges and rewards skills upgrading.

A stronger job focus has led to a reduced scope of responsibilities for entry level jobs, thus an improved learning curve for newly hired workers. Task interruptions are minimized, especially in Proposal 2, by separately assigning low priority tasks and high priority tasks to different job scopes. Both proposals also improved resource utilization by reducing break and non-break period utilization differences, as well as through maximizing overall resource utilization. More balanced work sharing has been incorporated in the proposals by limiting sharing to occur only between similarly skilled groups of workers. This further enhances teamwork and motivation amongst the workers.

Flexibility concepts have been applied in the proposals, to bring about greater productivity and improved resource utilization. Proposal 1 leverages on flexibility through floating S.PTs and a resource replacement strategy during break periods. Chaining strategies applied in Proposal 2, allow team members to help each other directly or indirectly, to reap the benefits of limited/full flexibility.

The final outcome of these two proposals depends on the validation of assumptions used and further analysis in the tradeoffs. Firstly, the effect of five minutes delay in Proposal 1 depends on the actual frequency of major and minor troubleshoot occurrence. This has to be assessed to determine its severity on overall productivity. Second, the feasibility of a new inspection strategy to reduce inspection time by half has to be explored. Third, the overall benefit from using a flexible worker system require further analysis, as productivity gains need to be traded off against time lost from additional travelling associated with increased flexibility.

# 8. RECOMMENDATIONS

The two labor allocation proposals presented above were shown to have clear benefits over the current allocation. However, the degree of productivity gains and feasibility of job scopes in each allocation have yet to be addressed. It is thus recommended that BD consider them together with the second [9] and third [8] part of this project to select the best optimized labor allocation for implementation.

Implementation of either one of the two proposals can be executed in three phases. The first phase involves an assessment of current resources in the syringe value stream. Every resource will need to be evaluated to determine skills that each possess because the current appraisal system does not capture such information. A compilation of these skills to form a skills inventory list will be valuable to BD to gain an insight on the current state. Thereafter, each resource can be suitably matched to the new job scopes as suggested by that proposal. The previous step would reveal to BD the discrepancy between current skills inventory and the required skills inventory for new allocation.

The second phase of implementation involves the training of workers to upgrade their skills to match new job scopes, and the hiring of entry level workers if necessary. This phase ends once the skills inventory of the Syringe value stream matches the requirements. The last phase would be an actual trial where production will be run using the new labor allocation. During the trial, productivity and worker utilization have to be closely monitored. This trial also serves as the period for BD to resolve any unexpected problems that might surface. An analysis after the trial period is necessary to evaluate the implementation outcome and decide on the continued use of new labor allocation.

# 9. FUTURE WORK

In addition to the two chaining strategies described in Proposal 2, other chaining strategies are possible. Alternative strategies can be investigated on their ability to bring about reduced travelling time and focused job scopes. For example, chaining similar machine tasks together allows the worker to train up faster with more task repetitions on a similar machine type, and this is particularly suited for entry level workers. In addition, we can further consider chaining tasks with negatively correlated demands together in the same chain such that task demands can be balanced out within the chain.

Another aspect not considered in the present study is how unexpected absence of workers would affect resource utilization and productivity for different allocations. As both allocations feature their own unique form of flexible worker system, it is worthwhile to study the performance of each allocation in scenarios where there is a reduction of worker from a different job scope.

A more thorough method could also be explored to optimize labor allocation in a systematic way. Apart from the two allocations presented in this report, the author does not rule out the possibility for allocations that could achieve similar objectives in a better way. As such, it could be worthwhile to investigate the use of linear programming or similar methods to find the optimal allocation. Outlined below are preliminary thoughts that describe a linear programming problem that could be solved to find the optimal labor allocation.

The objective function in this case would be to minimize total costs. Costs to be considered for new allocations include labor costs. Labor costs are to be tagged to the number and level of skills required in each job scope.

The problem constraints would be:

- Number of task grouping types (i.e. job scopes) $\geq 1$
- Number of resources for each task group $\geq 1$

- Each resource utilization $\leq 95\%$
- All tasks are fulfilled by the resources

However, a number of considerations listed below have to be incorporated into the problem above:

- Similar priority tasks are to be grouped together so as to reduce interruptions.
- Job scopes will need to show an incremental skill hierarchy.
- Work sharing is to be limited within each task group to promote equal sharing.
- Resource traveling time is to be reduced.

Furthermore, production outputs will need to be determined from a separate computer simulation of the production floor.

## REFERENCES

1. Secord, H., 2003, "Implementing Best Practices in Human Resources Management," CCH Canadian Limited.

2. Silva S.D., 1998, "Performance-Related and Skill-Based Pay: An Introduction," International Labour Office, Geneva.

3. Schultz, K. L., McClain, J. O., and Thomas, L. J., 2003, "Overcoming the dark side of worker flexibility," Journal of Operations Management, **21**, pp. 81-92.

4. Sennott, L. I., Van Oyen. M. P., and Iravani, S. M. R., 2006, "Optimal dynamic assignment of a flexible worker on an open production line with specialists," European Journal of Operational Research, **170**, pp. 541-566.

5. Hopp, W. J., Tekin, E., Van Oyen, M. P., 2004, "Benefits of Skill Chaining in Serial Production with Cross-Trained Workers," Management Science, **50**(1), pp. 83-98.

6. Jordan, W. J., Graves, S. C., 1995, "Principles on the benefits of manufacturing process flexibility," Management Science, **41**(4), pp. 577-594.

7. Jackson, J. M., Harkins, S. G., 1985, "Equity in effort: and explanation of the social loafing effect," Journal of Personality and Social Psychology, **49**(5), pp. 1199-1206.

8. Ng, G.Y., 2008, "Optimization of Labor Allocation at a Syringe Production Facility: Work Study," Master Thesis, Massachusetts Institute of Technology, Cambridge, MA.

9. Liaw, S.S., 2008, "Optimization of Labor Allocation at a Syringe Production Facility Using Computer Simulation," Master Thesis, Massachusetts Institute of Technology, Cambridge, MA.

## APPENDIX A: Duration of tasks

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

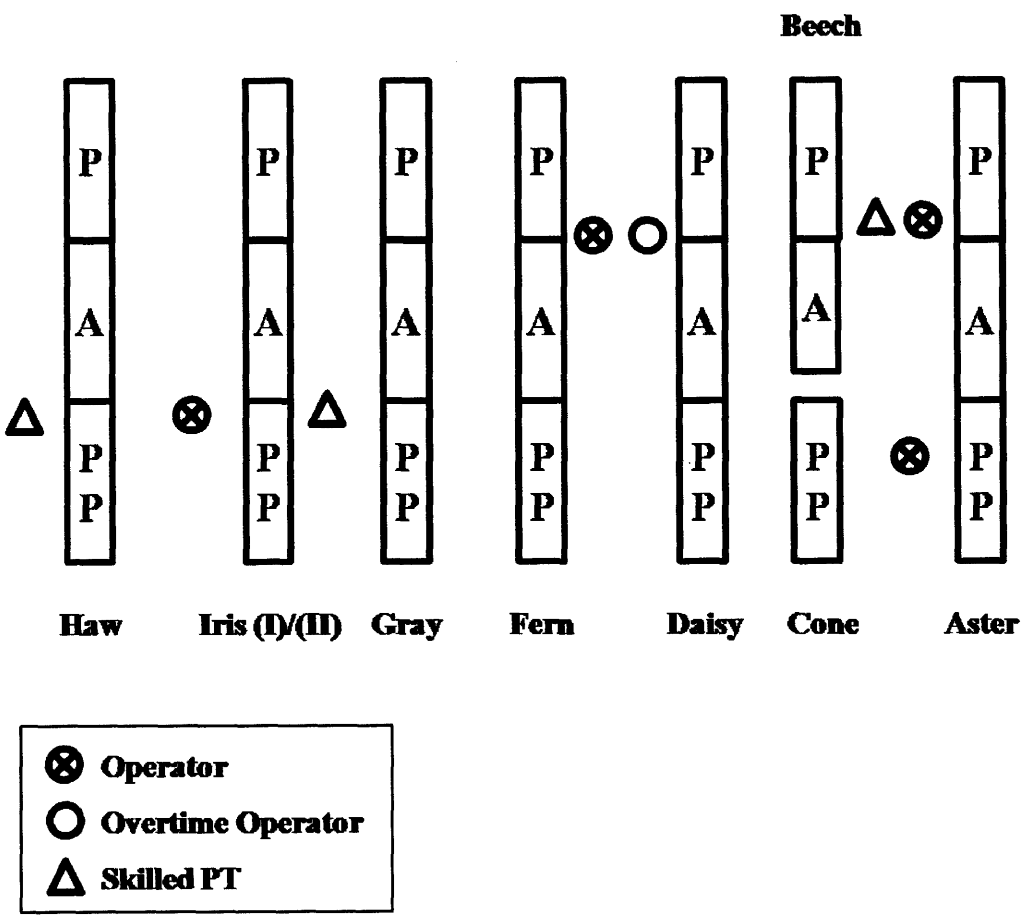
## APPENDIX B: Frequency of tasks

| Task No. | Stochastic Tasks | Number of occurrences per 8 hour shift | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average for one line | Aster | Beech | Cone | Daisy | Fern | Gray | Haw | Iris(I) | Iris(II) |
| 1 | Machine P stoppages | 7.20 | - | - | - | - | - | - | - | - | - |
| 2 | Machine P minor troubleshoot | 1.70 | - | - | - | - | - | - | - | - | - |
| 3 | Machine P major troubleshoot diagnosis | - | 0.61 | 0.43 | - | 0.39 | 0.49 | 0.77 | 0.45 | 0.54 | 0.54 |
| 4 | Machine A stoppages | 43.35 | - | - | - | - | - | - | - | - | - |
| 5 | Machine A minor troubleshoot | 3.94 | - | - | - | - | - | - | - | - | - |
| 6 | Machine A major troubleshoot diagnosis | - | 0.64 | 0.64 | 0.28 | 0.27 | 0.35 | 0.73 | 0.49 | 0.40 | 0.40 |
| 7 | Machine PP stoppages | 58.30 | - | - | - | - | - | - | - | - | - |
| 8 | Machine PP minor troubleshoot | 3.90 | - | - | - | - | - | - | - | - | - |
| 9 | Machine PP major troubleshoot diagnosis | - | 0.67 | 0.62 | 0.67 | - | 0.26 | 0.48 | 0.51 | 0.65 | 0.65 |

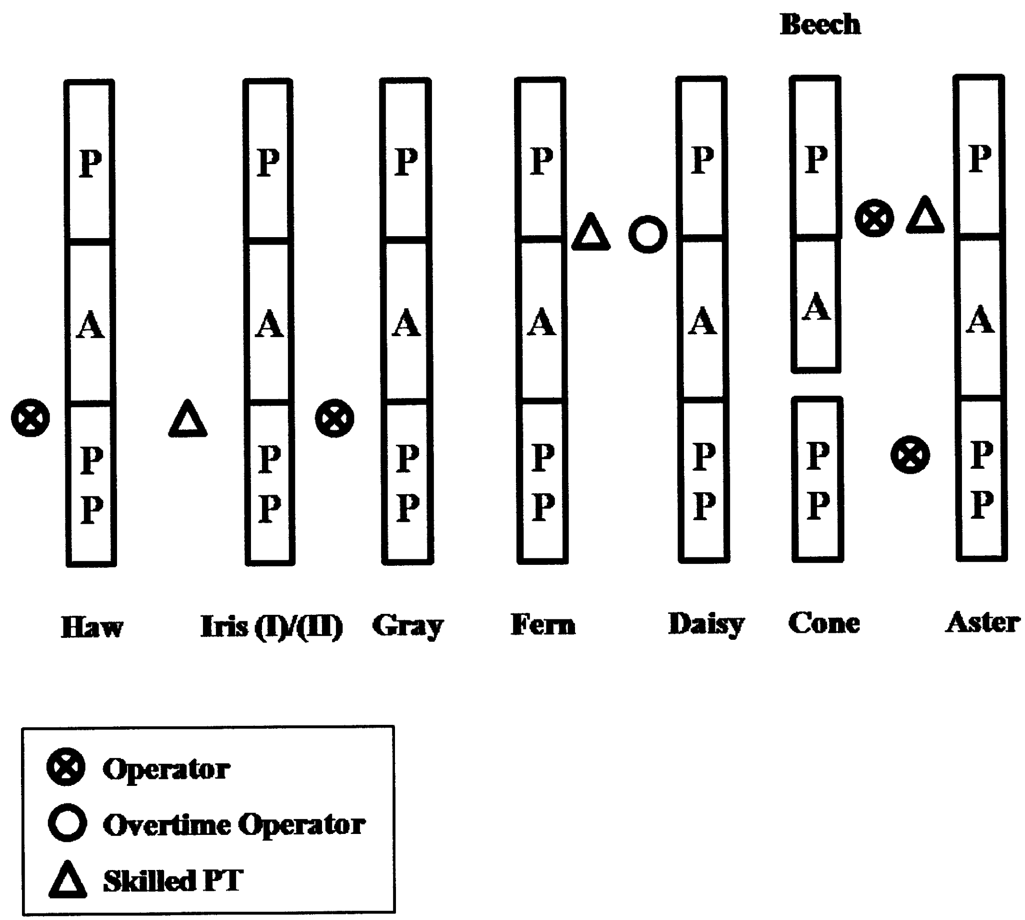
| Task No. | Deterministic Tasks | Number of occurrences per 8 hour shift | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average for one line | Aster | Beech | Cone | Daisy | Fern | Gray | Haw | Iris(I) | Iris(II) |
| 13 | Parameter checking for a machine | 8.0 | - | - | - | - | - | - | - | - | - |
| 14 | Printing hourly visual in-process inspection | 8.0 | - | - | - | - | - | - | - | - | - |
| 15 | Assembly hourly visual in-process inspection | 8.0 | - | - | - | - | - | - | - | - | - |
| 16 | Primary packaging hourly visual in-process inspection | 8.0 | - | - | - | - | - | - | - | - | - |
| 17 | Manual packing (Molded parts) | - | 6.8 | 6.8 | - | 8.2 | 8.2 | 3.6 | 5.8 | 2.9 | 2.9 |
| 18 | Manual pouring (Molded parts, assembled Cone) | - | 6.8 | 6.8 | - | 8.2 | 8.2 | 3.6 | 5.8 | 2.9 | 2.9 |
| 19 | Manual packing (Bulk, assembled Cone) | - | 23.3 | 25.0 | 30.8 | 19.5 | 47.7 | 56.7 | 61.2 | - | 72.0 |
| 20 | Manual packing (Scrap) | - | 1.9 | 1.9 | - | 1.6 | 1.6 | 0.9 | 1.8 | 0.8 | 1.2 |
| 21 | Material replenishment (Top web) | - | 2.0 | 1.3 | - | 0.3 | 1.8 | 1.7 | 1.6 | 0.4 | 0.7 |
| 22 | Material replenishment (Bottom web) | - | 1.3 | 0.7 | - | 0.3 | 0.3 | 2.5 | 1.1 | 0.9 | 0.5 |
| 23 | Material replenishment (Cone syringes) | - | - | - | 51.3 | - | - | - | - | - | - |
| 24 | Material replenishment (Cone clips) | - | - | - | 76.9 | - | - | - | - | - | - |
| 25 | Material replenishment (Stopper) | - | 0.8 | 0.7 | - | 1.6 | 3.4 | 5.0 | 9.9 | 6.4 | 4.4 |
| 26 | Material replenishment (Needle) | - | 4.5 | 2.3 | - | 0.0 | 7.0 | 6.8 | 5.1 | 0.0 | 0.0 |

| Task No. | Deterministic Tasks | Number of occurrences per PT per 8 hour shift |
|---|---|---|
| 10 | Machine startup | 1 |
| 11 | Housekeeping | 1 |
| 12 | Administrative work | 1 |

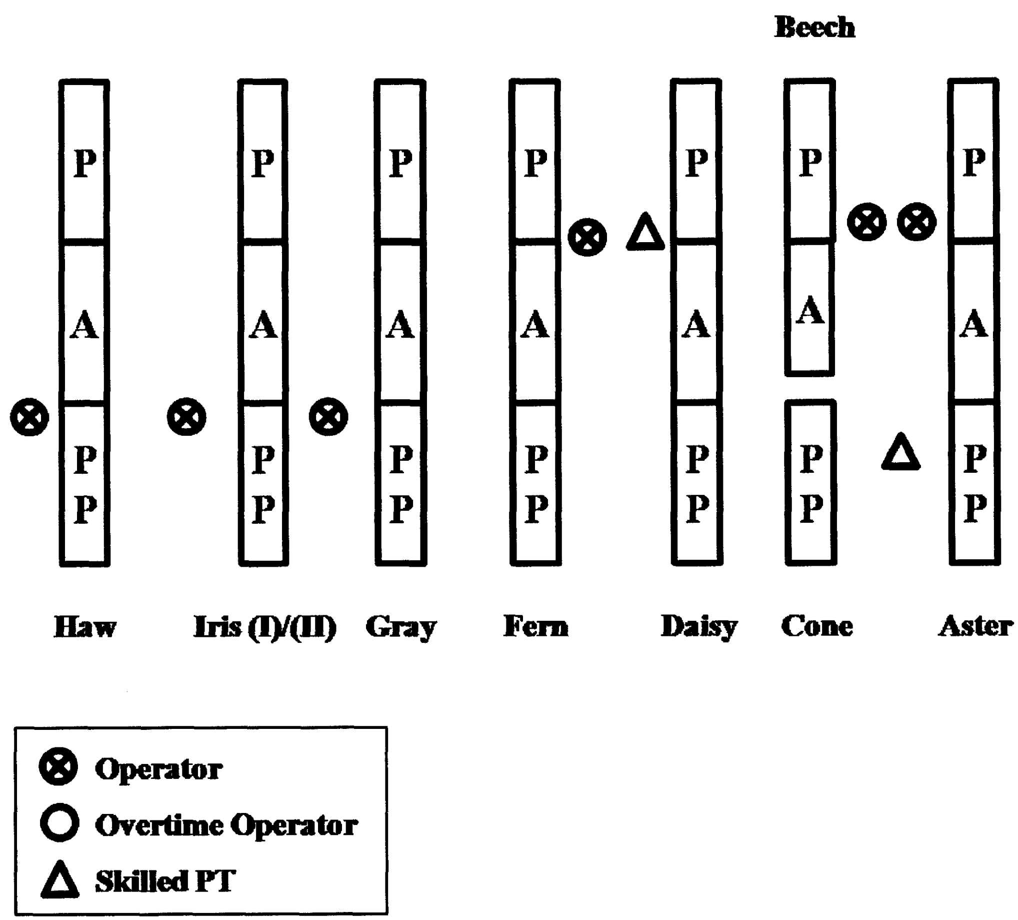
APPENDIX C: Production floor manning arrangement for Proposal 2 during 1st break period



APPENDIX D: Production floor manning arrangement for Proposal 2 during 2nd break period



APPENDIX E: Production floor manning arrangement for Proposal 2 during 3rd break period



APPENDIX F: Production floor manning arrangement for Proposal 2 during 4th/5th break period