Optimization of Labor Allocation at a Syringe Production Facility: Work Study

by

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Abstract

At MD Company (Singapore), the syringe value stream faces escalating labor cost and high labor turnover. Two labor allocations were proposed previously to optimize current labor resources, with the aim of controlling the labor cost effectively without affecting the production. Proposal Two, which had demonstrated significant increase in productivity and reduced labor cost through computer simulations, entailed an addition of two workers each in the new dedicated inspector and material handler job designations. The associated new job scopes combine tasks which are currently assigned broadly to production technicians working on the syringe production floor. A work study approach was undertaken with the broad aim of reducing waste from the new job scopes, as well as to verify headcount used in the simulation of Proposal 2. Dedicating tasks to individuals presented opportunities to reduce repetition and to achieve collective savings via changes in methods. Within the work study, a method study provided a theoretical basis of how best to carry out the new job scopes, while a time study established time needed to perform a given set of tasks. Results found were consistent with that from simulation of Proposal 2. Further improvements were made in reducing inspection cycle time through streamlining of inspections. Identification and separation of tasks which are not performed constantly paved the way for one of the two material handlers to be hired on an overtime basis. Future iterative identification of waste and its removal could help current work converge to an optimal work standard.

Keywords: Labor allocation, work study, optimization

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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.

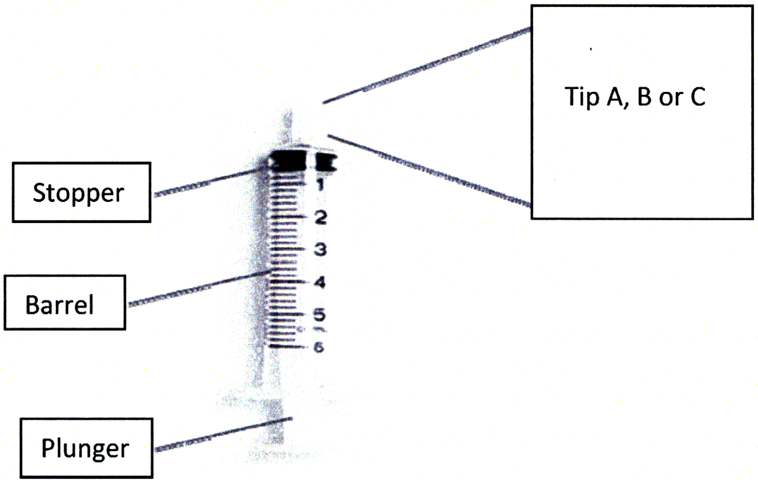

Figure 1: Different parts of a medical syringe

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.

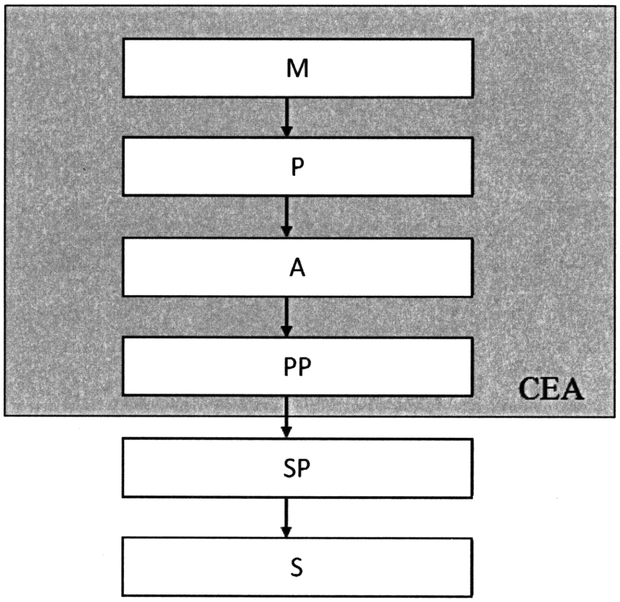

Figure 2: Process flow of syringe production

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 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 PP. 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

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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 Iris(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.

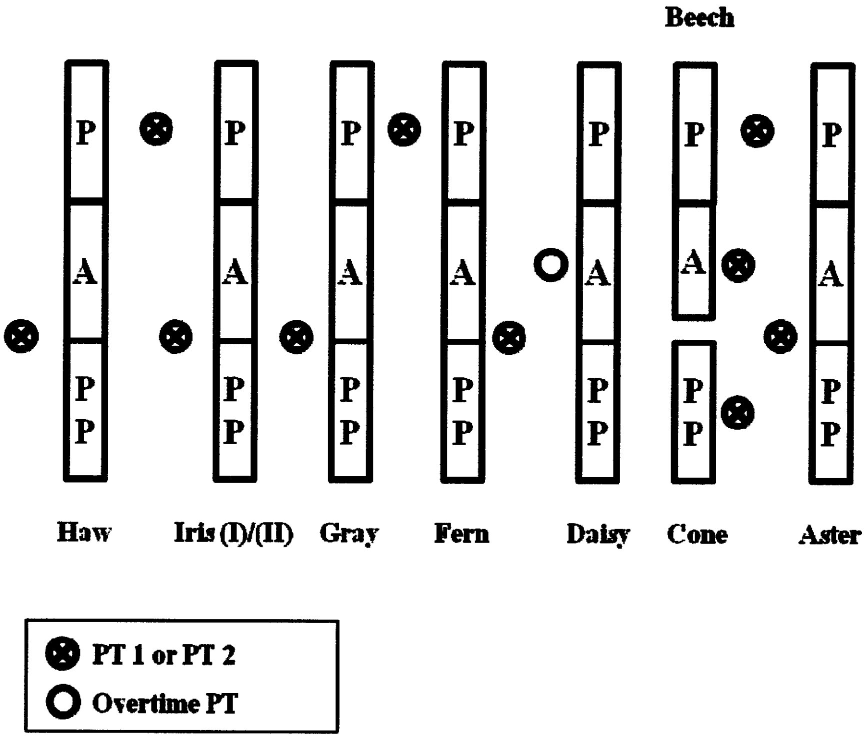


Figure 4: Production floorplan with current manpower allocation

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.

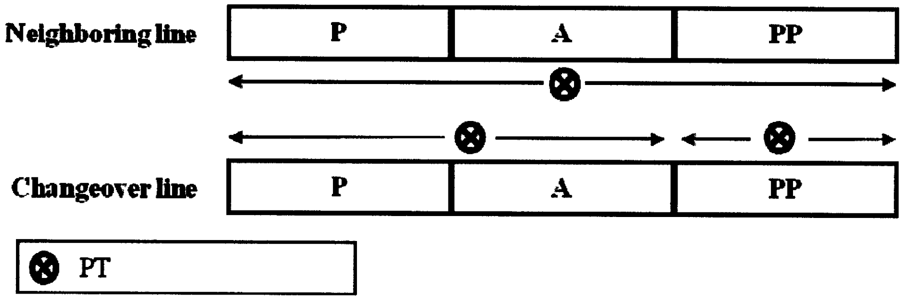


Figure 5: Labor arrangement during changeover

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).

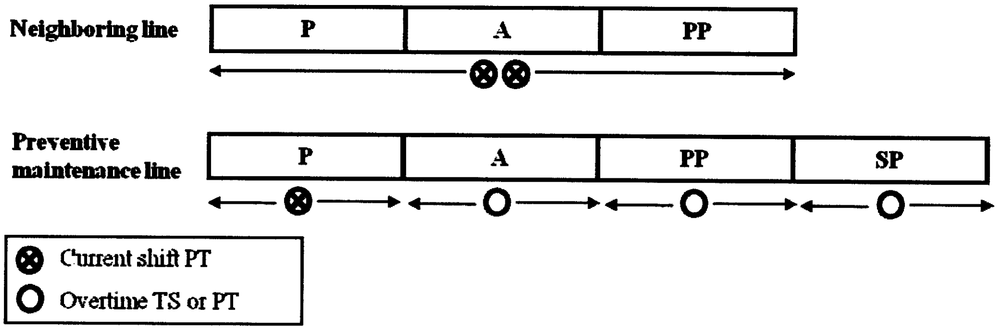


Figure 6: Labor arrangement during preventive maintenance

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:

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

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 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

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. 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

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 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	
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 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.

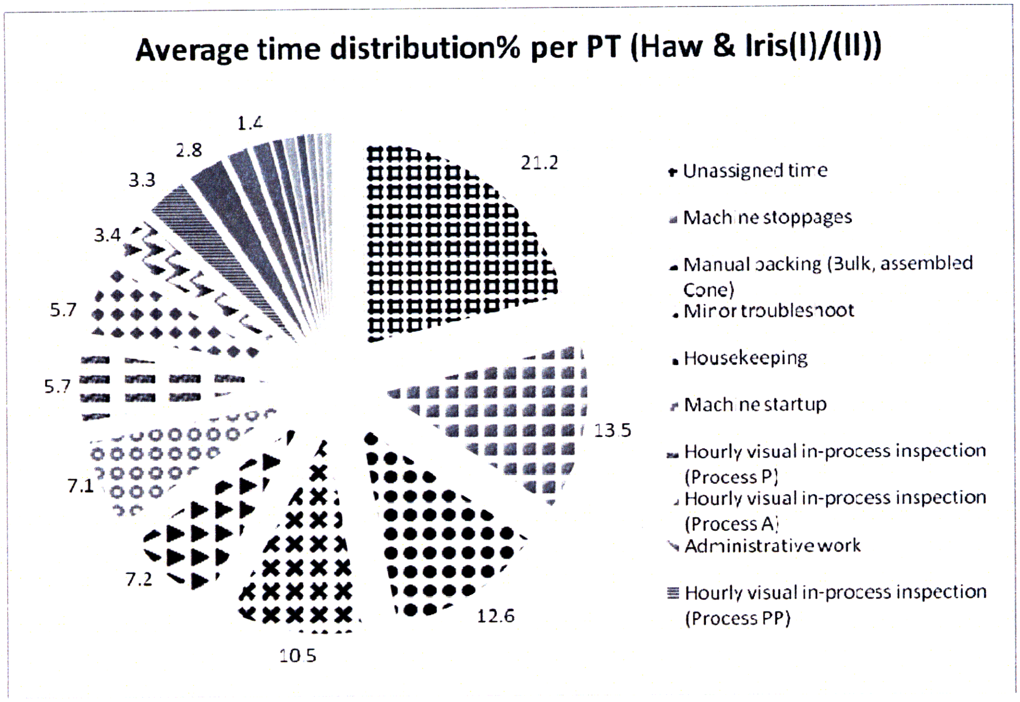


Figure 7: Pie chart of average time distribution of tasks per PT

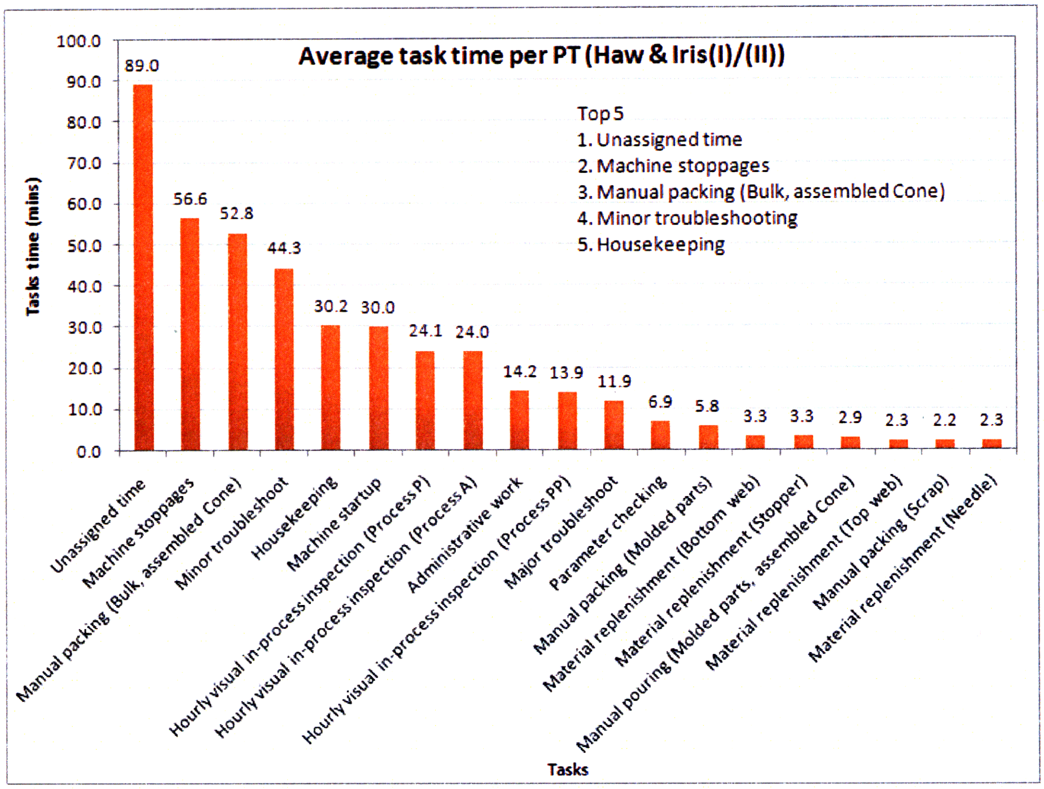


Figure 8: Pareto chart of tasks time per PT per shift

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 third portion of the project.

Chapter 3 Literature Review

Work study has been widely used by industrial engineers and some consultants as a tool for achieving continuous improvement in productivity. Known also as scientific management, it is a detailed observation and study of activities performed by workers with the aim of identifying waste, eliminating it, and ultimately improving productivity from "the bottom up".

The advantages of work study has been detailed by [3] from a lean standpoint. The first part to it, motion study, determines the best way of completing a repetitive task by reducing both macro and micro movements that are considered waste. The second part, time study, determines how long an average worker takes to perform each step within an operation at a typical pace. When combined, they quantify value-adding and non-value adding steps which can be analyzed to uncover opportunities to make the operation leaner and cheaper.

The established way of conducting work study is incomplete in more than one aspect. Using a single worker in timing, it does not factor in variability in speed of individuals. In addition, the one or several settings in which work study is conducted might not be representative of all possible states of the work environment. In [4], time study took on a mathematical model form through the incorporation of uncontrollable factors that could hinder or prolong task completion, such as facility problem, irregularity in electricity supply, and workers' absence. Time required for an operation can thus be calculated instead of timed. Similarly, in addressing the issue of over-simplification of task completion time in simulation, [5] highlighted various sources of human performance variation. Workers are modeled as passive entities whose performance is a function of external and internal factors. Nonetheless, the paper recognizes that in reality workers are proactive and not completely controlled by the environment.

Besides being deterministic, work study has also been labeled "Taylorism" with a negative connotation. [6] defended work study by establishing it as an ideal tool to be used in conjunction to total quality management (TQM). The paper viewed work study as a combined effort between employee and workers to bring about best practices, contrary to the popular belief that it wages war between both parties. The success of several companies, in cost reduction and subsequent competitiveness, are also attributed in part to work study.

In MD's Job Redesign (PPS) blitz at T&C Value Stream, work study was used as the primary method of waste identification, job rebalancing, and waste reduction. It has been established in MD as having a track record of success, which makes work study one of its preferred methods to conduct job redesign. It also serves the purpose of quantifying improvements and proving that a redesigned job scope is achievable by a PT under normal circumstances. Despite having limitations as discussed above, results from work study are effective in communication with the management. Tasks having a more deterministic nature are best suited for work study. Considerations shall be given under the method section to show that those job designations under investigation satisfy certain conditions to justify the use of work study in this work.

Chapter 4 Method

4.1 Work Study

An adaptation of work study, comprising both method study and time study, was used to investigate the feasibility of having two dedicated visual inspectors and two material handlers to cover relevant tasks across the production floor. Their specific job scopes are as described in Proposal 2 [7].

4.1.1 Dedicated inspector

Motion study

Data was collected for Process P, A and PP visual inspections to understand the current process of conducting such inspections. Time taken for each process was broken down and assigned to sub-activities, such as movements and recording of inspection results, to quantify the amount of value-adding and non-value adding activities. Processes were then checked for any possibility of being eliminated or simplified. The ideal case would be to leave pure operational activities behind by excluding walking, waiting or other manual actions that do not directly contribute to the production of a part. While it is not apparent what the current PT's are actually looking for during inspection, the quality plan provides a reliable breakdown of defects to be detected for quality compliance. The quality plan was hence an important reference for identifying opportunities to streamline the inspections.

A dedicated inspector is expected to go to every process stations on all lines to perform the three kinds of in-process inspections, for Process P, A and PP. Considering that the lines are supposed to be running on one-piece-flow and do not build WIP, there is opportunity for streamlining in-process inspections at fewer inspection points by consolidating some of the existing inspections. This is known as streamlined inspection and it is expected to cut waste in repetitive movements and repeated tasks.

A new inspection job scope was conceptualized and assigned to a dedicated inspector. A work sequence was then designed with respect to physical layout of the production floor; walking was timed and combined with the estimated time for streamlined inspection. This gave a fair basis of comparing cycle times (taken to complete one round of inspection for the entire floor) under the dedicated, streamlined or non-streamlined inspection options. The traveling routes that give the minimal possible walking times were drawn and presented in Section 5.1.1.

Time study

The inspection processes for all options were put through trial runs of 4 inspection cycles. It was supervised and recorded to ensure that steps taken to do the inspections were consistent. Average statistics from the study were used as a standard time for an average inspector to complete the tasks. A total of 12 man-hours were used for the study with 4 man-hours allocated each to a non-streamlined option and 2 streamlined options.

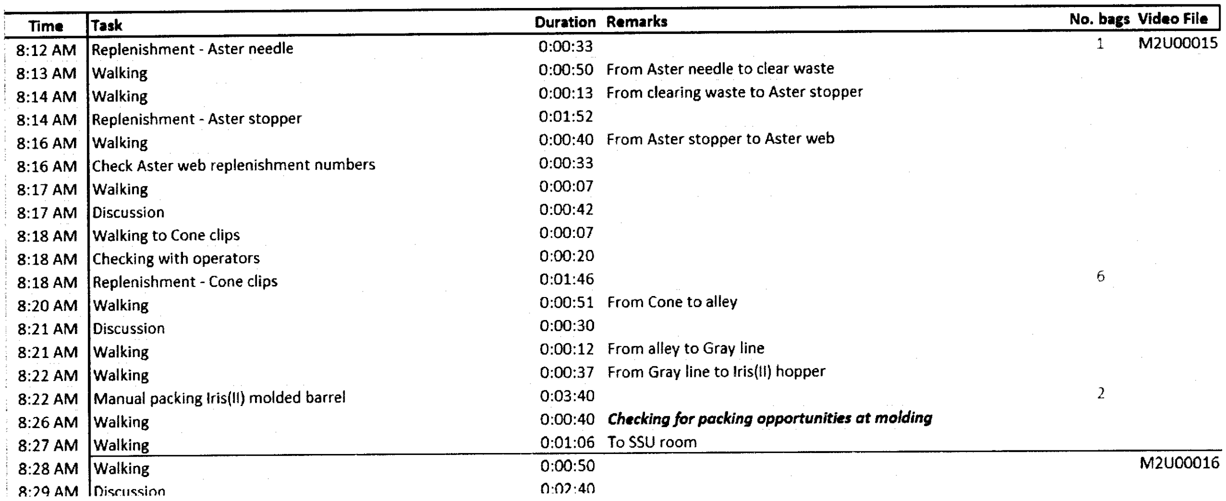
4.1.2 Material Handler

Motion Study

Since the need for replenishment is driven by rate of material consumptions, by calculating the number of hours which a full hopper bin is able to last production on the current machine speed, the time between replenishments was estimated. This served as a guide for the material handler to predict when to make a round of replenishments. Further coordination between replenishments of different types of material was done to develop a plan for the material handler to finish standard replenishment tasks with minimum traveling time and greater certainty. In between such replenishments, simple guidelines, which help the material handler predict his next task, were designed to help him to complete his job independently without having to travel extra to look for jobs on the lines.

Time study

Similar to the time study done for dedicated inspector, a trial run of 8 hours was conducted with a material handler. Before the trial, the production schedule was checked against production lots of the day so as to be sure of the exact parts to replenish. The production schedule was also used to choose the right date for the trial run so that there would be a big and small syringe bulk order production. This was a crucial part of the trial design that was meant to put the material handler to the test with more actions expected of him. Timing was done via stopwatch and video recording. Results were split into time segments of clearly defined steps; an example of detailed recording of activities captured on video is provided in Figure 9.



Time	Task	Duration	Remarks	No. bags	Video File
8:12 AM	Replenishment - Aster needle	0:00:33		1	M2U00015
8:13 AM	Walking	0:00:50	From Aster needle to clear waste		
8:14 AM	Walking	0:00:13	From clearing waste to Aster stopper		
8:14 AM	Replenishment - Aster stopper	0:01:52			
8:16 AM	Walking	0:00:40	From Aster stopper to Aster web		
8:16 AM	Check Aster web replenishment numbers	0:00:33			
8:17 AM	Walking	0:00:07			
8:17 AM	Discussion	0:00:42			
8:18 AM	Walking to Cone clips	0:00:07			
8:18 AM	Checking with operators	0:00:20			
8:18 AM	Replenishment - Cone clips	0:01:46		6	
8:20 AM	Walking	0:00:51	From Cone to alley		
8:21 AM	Discussion	0:00:30			
8:21 AM	Walking	0:00:12	From alley to Gray line		
8:22 AM	Walking	0:00:37	From Gray line to Iris(II) hopper		
8:22 AM	Manual packing Iris(II) molded barrel	0:03:40		2	
8:26 AM	Walking	0:00:40	***Checking for packing opportunities at molding***		
8:27 AM	Walking	0:01:06	To SSU room		
8:28 AM	Walking	0:00:50			M2U00016
8:29 AM	Discussion	0:02:40			

Figure 9: Activity log of material handler as captured on video

From the time study results of both dedicated inspector and material handler, both repetitive movements and actions that did not serve a purpose were identified. An example of repetitive movement for the dedicated inspector could be extra walking to collect the same set of items, needed for inspection, each time he or she reaches an inspection point. Uncertainty in real-time events on lines beyond the material handler's sight would have prompted him to check unnecessarily for demand in material handling; an example is bolded in Figure 9.

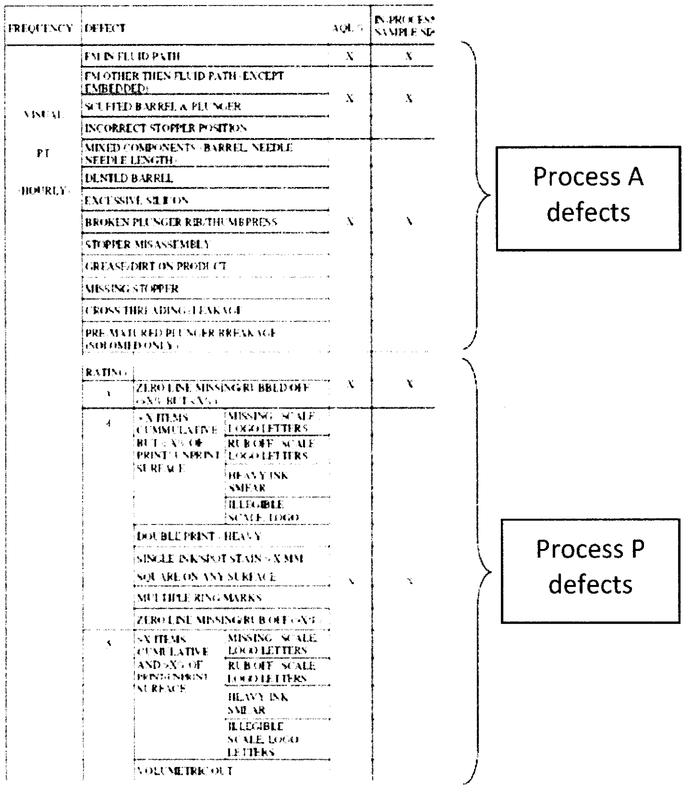
The main aim was to confirm that both new jobs scopes allowed all designated tasks to be finished within a cycle; 60 min for inspectors and 1 shift for material handlers. Time margin to allow for fatigue, break and unexpected circumstances were also considered. Where tasks were found to be above the allowable duration, projections of their new durations were made based on the assumption that waste could be further eliminated. Thus, improvement targets were set on how to keep the operations within the stipulated cycle time. The list of optimized operations and its corresponding time breakdown could be referenced by MD associates in creating a work standard for closer replication of results in the future.

Chapter 5 Results and Discussion

5.1 Dedicated Inspector

5.1.1 Motion Study

The quality plan of MD syringe production [8] was used to determine specific visual inspection items for which the dedicated inspector had to check. The original intention of conducting an hourly visual inspection at each station is to contain exposure time of parts to within an hour should there be defects. From the in-process quality plan of Process A, it was found that the Process P inspection items are being repeated in the Process A inspection list (Figure 10)[8]. The reason given by an MD quality engineer for such repetition is that Process A could potentially inflict damages, in the form of Process P defects, on previously defect-less parts. However, given that the WIP between Station P and A is minimal, it seems that the need to perform the same inspection twice was not justified. An inspection done after Process A would sufficient in covering both sources of Process P defects.



FREQUENCY	DEFECT			AQL %	IN-PROCESS SAMPLE SIZE
VISUAL PT (HOURLY)	FM IN FLUID PATH			X	X
	FM OTHER THEN FLUID PATH (EXCEPT EMBEDDED)			X	X
	SCUFFED BARREL & PLUNGER				
	INCORRECT STOPPER POSITION				
	MIXED COMPONENTS (BARREL, NEEDLE, NEEDLE LENGTH)			X	X
	DENTED BARREL				
	EXCESSIVE SILICON				
	BROKEN PLUNGER RIB/THUMBPRESS				
	STOPPER MISASSEMBLY				
	GREASE/DIRT ON PRODUCT				
	MISSING STOPPER				
	CROSS THREADING (LEAKAGE)				
	PRE-MATURED PLUNGER BREAKAGE (SOLOMED ONLY)				
	RATING				
	1	ZERO LINE MISSING/RUBBED OFF (>X% BUT <X%)		X	X
	4	>X ITEMS CUMMULATIVE BUT <X% OF PRINT/UNPRINT SURFACE	MISSING SCALE/LOGO LETTERS	X	X
			RUB OFF SCALE/LOGO LETTERS		
			HEAVY INK SMEAR		
			ILLEGIBLE SCALE/LOGO		
		DOUBLE PRINT (HEAVY)			
		SINGLE INK/SPOT STAIN > X MM SQUARE ON ANY SURFACE			
		MULTIPLE RING MARKS			
		ZERO LINE MISSING/RUB OFF (<X%)			
	5	>X ITEMS CUMULATIVE AND >X% OF PRINT/UNPRINT SURFACE	MISSING SCALE LOGO LETTERS		
			RUB OFF SCALE LOGO LETTERS		
			HEAVY INK SMEAR		
			ILLEGIBLE SCALE LOGO LETTERS		
		VOLUMETRIC OUT			

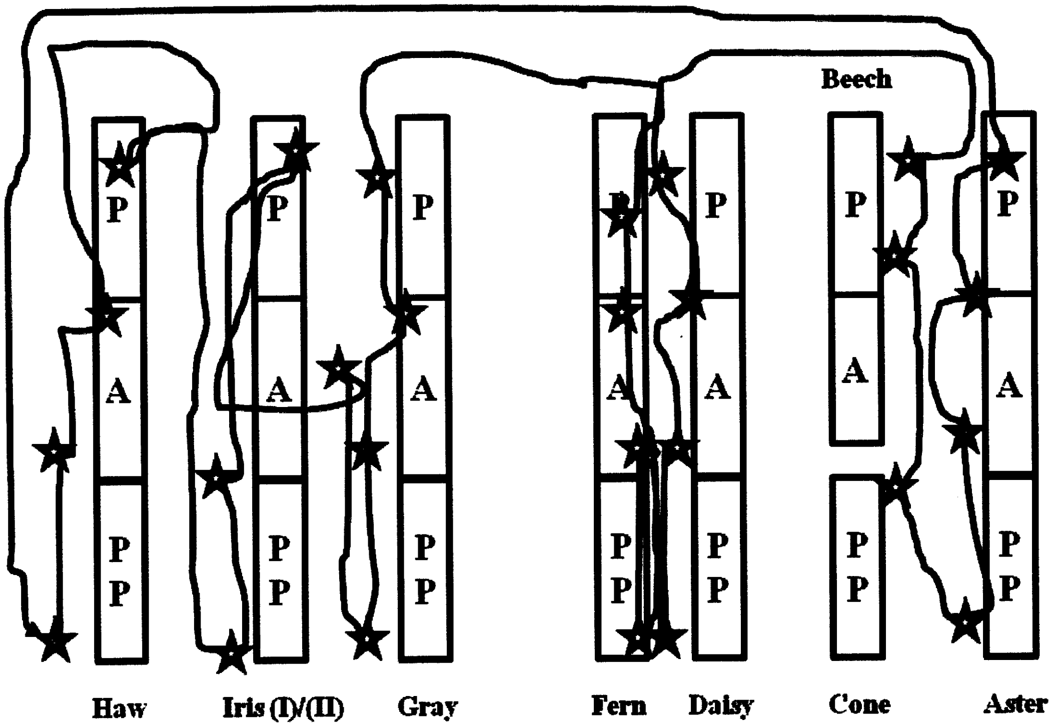
Figure 10: Excerpt of In-process quality plan of Process A

Based on locations of station and inspection items specified in the quality plan, two streamlined options (Streamlined Plan A and Streamlined Plan B) were designed. Both comply with the quality plan [8], whereby sample size must not fall below that stipulated for a given inspection. In Streamlined Plan A, both Process P and A inspections are to be done at Station A, with a sample size of 65 out of which the first 36 samples are subjected to both types of inspections while the remaining samples are only checked for Process P defects. Process PP inspection is retained at Station PP with the original sample size of 40. In Streamlined Plan B, all inspections are performed together at Station SP which is located out of the CEA. Due to the high cost of packaging blisters, only 40 samples could be used so that the amount of scrapped material do not exceed that of the current level. Such a drop from 65 samples to 40 samples for Process P inspection requires the approval of the MD quality department. The features of the As-Is and Streamlined plans are summarized in Table 4.

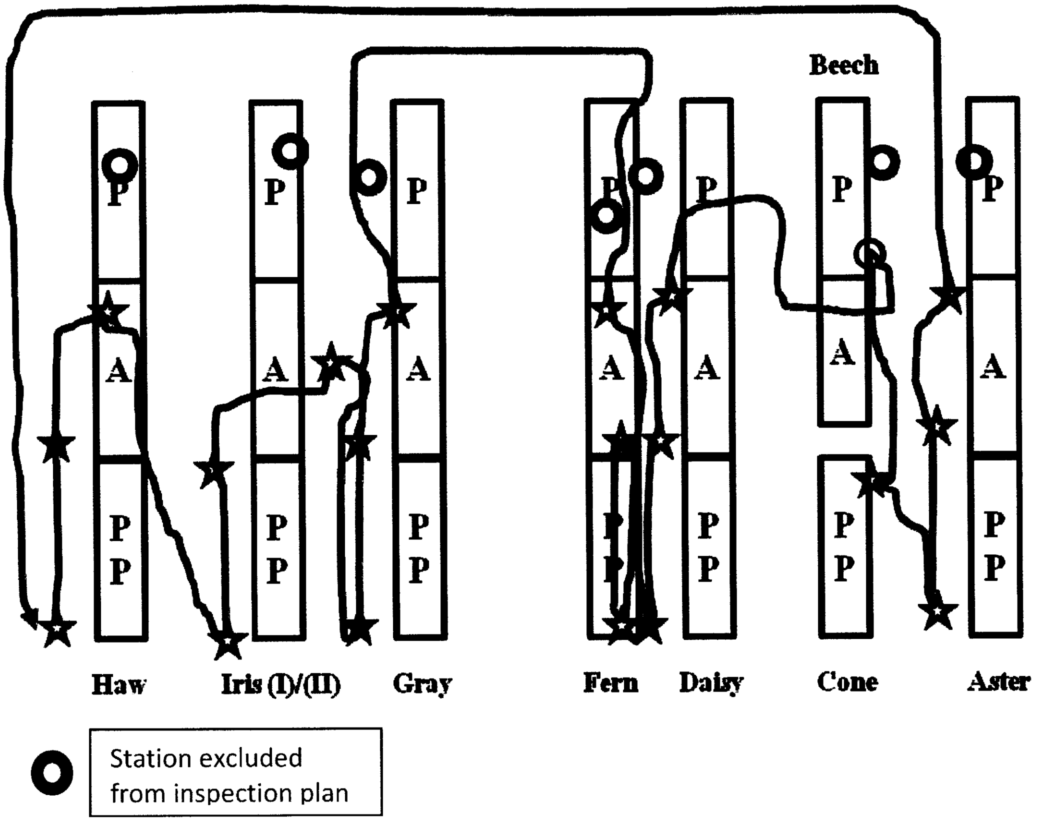
Table 4: Characteristics of inspection plans

	AS-IS (Non-streamlined)			**Streamlined Plan A**		**Streamlined Plan B**
Location	**Machine P, A & PP**			**Machine A & PP**		**Machine SP**
	Machine P	Machine A	Machine PP	Machine A	Machine PP	
Inspection Scope	P defects	A defects	PP defects	P, A defects	PP defects	P, A and PP defects
Sample Size	65	36	40	65	40	40
Additional Material Waste	0			0		0

The overall inspection time is expected to decrease from having a reduced inspection load for both options as compared to non-streamlined (As-Is) case, less walking, less sample collection and less recording sheets to be filled out, as well as a smaller sample size for Streamlined Plan B. The optimum traveling routes that can minimize walking times of the dedicated inspector are shown in Figure 11(a), (b) and (c) for As-Is, Streamlined Plan A and Streamlined Plan B respectively.


Beech
P
A
P P
Haw
Iris (I)/(II)
Gray
Fern
Daisy
Cone
Aster

a


Beech
P
A
P P
Haw
Iris (I)/(II)
Gray
Fern
Daisy
Cone
Aster
○ Station excluded from inspection plan

b

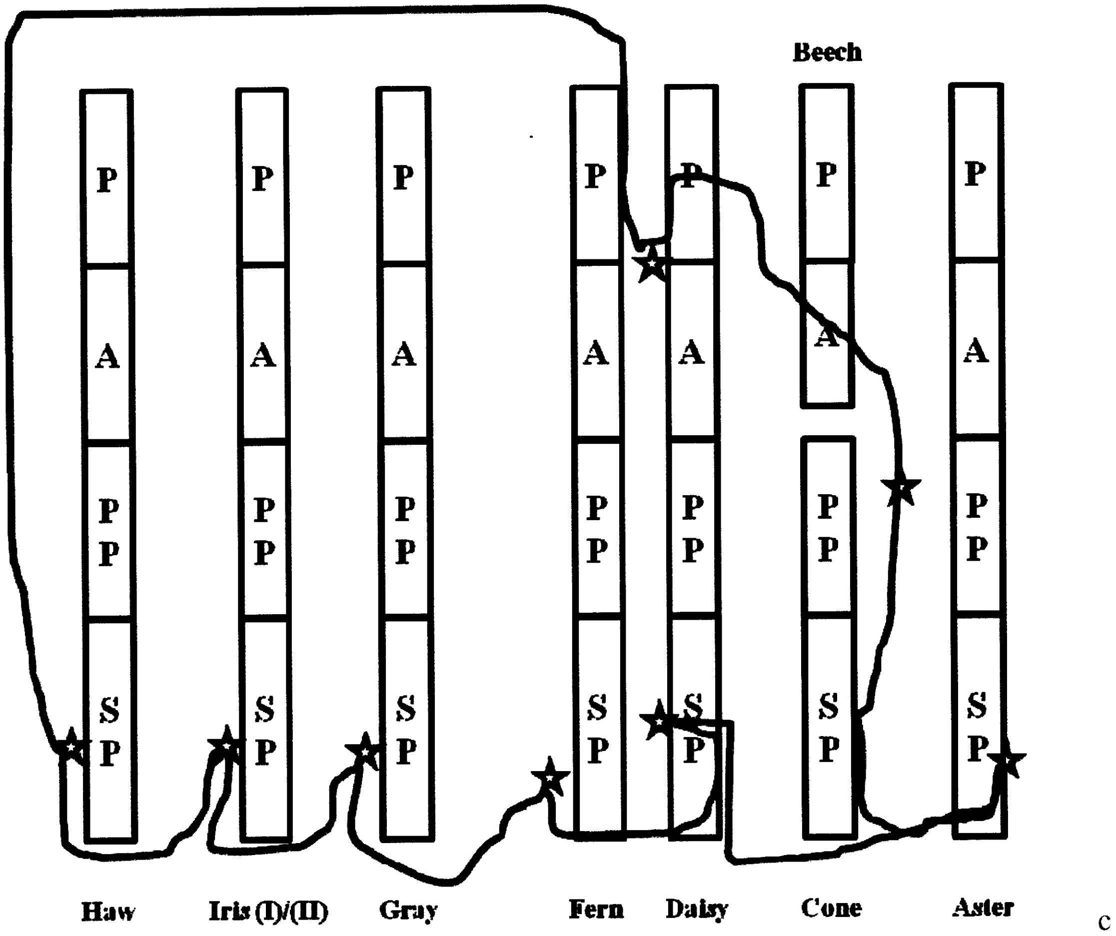


Figure 11: Traveling route of dedicated inspector in As-Is (a), Streamlined Plan A (b) and Streamlined Plan B (c)

5.1.2 Time Study

Results from two As-Is, four Streamlined Plan A and four Streamlined Plan B trial runs conducted with two PT's were compiled and presented in Figure 12. These trial runs were carried out on the same day with all lines running except for Daisy and Gray lines, and hence results are conservative for production scenarios up to 6 running production lines.

From Figure 12, total visual inspection cycle time is the highest for As-Is, followed by and Streamlined Plan B. Within each inspection type, timing is further broken down into activities that could be recognized as sub-categories of their own, such as sample collection, recording, clearing waste, walking, waiting and the actual inspection. Gloving/degloving applies only to As-Is and Streamlined Plan A to protect Process P and A samples from contamination, while changing and repacking applies only to Streamlined Plan B due to the need to de-gown and to replace scrapped samples taken from carton boxes respectively.

As-Is and Streamlined Plan A had similar proportion of time consumed by each activity in decreasing order of inspection, walking, sample collection, recording, clearing waste, gloving/degloving and lastly waiting. Inspection alone constituted at least 67% of total time for both inspection types, and therefore percentage time saved in inspection would be more significant towards the overall time reduction than other activities. There is a reduction of 5.4% in this activity in Streamlined Plan A compared to As-Is, and this could be attributed to the streamlining of inspection at Station A assuming that time taken for Process PP inspection was constant for both plans. There was also a decrease in time taken for sample collection (2 minutes) and recording (1 min) for Streamlined Plan A.

With timing for most activities comparable to that of As-Is and Streamlined Plan A, the overall reduction in time for Streamlined Plan B stemmed from a 23% time saved in inspection from As-Is, as well as a 63% time saved in walking. Given that streamlining of Process P and A inspection items brought about only a 5.4% decrease in the time taken in Streamlined Plan A, the use of a smaller sample size in Streamlined Plan B could be the main reason for this 23% time saving. Streamlined Plan B required less walking time since the inspector performed inspection only at one location at the end of each line and could move promptly between these locations.

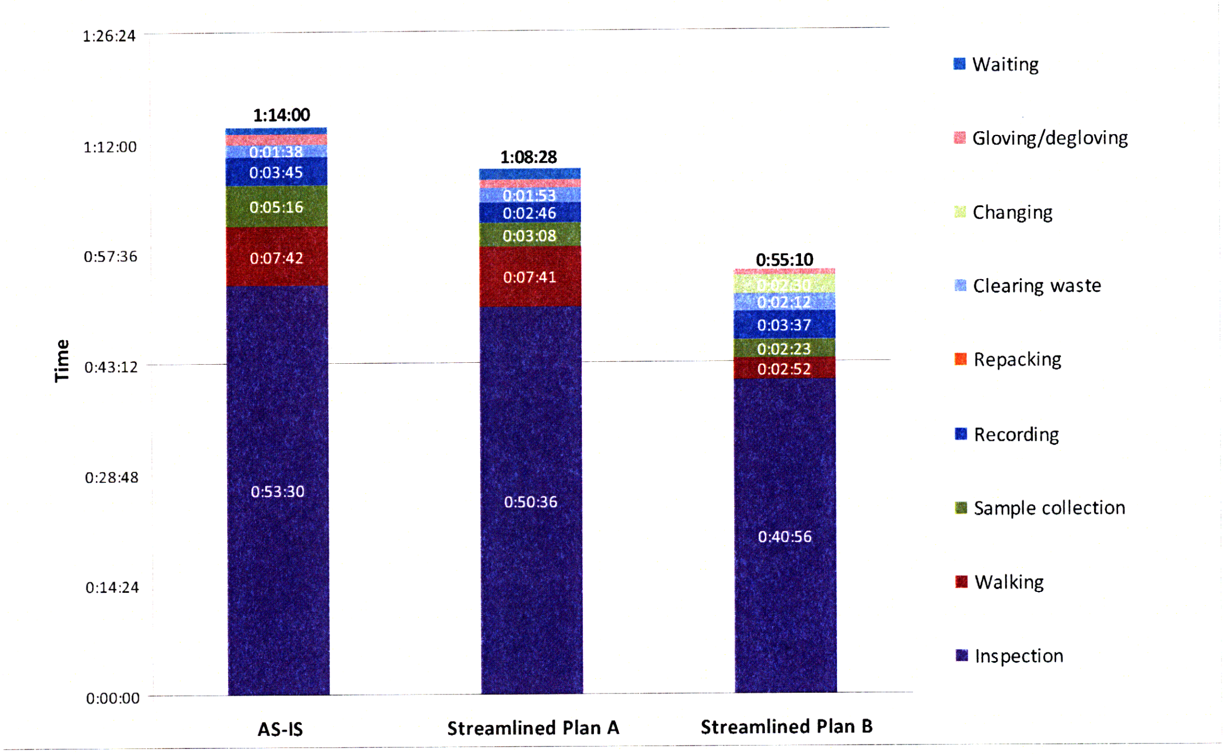


Figure 12: Trial run cycle time for As-Is, Streamlined Plan A and Streamlined Plan B quality inspection plan before removal of waste

Observations of the PT's' movements during trials revealed several opportunities for additional time saving. Some waste movements were found to be incurred by PT walking back and forth within each line to collect gloves and sample trays, in addition to walking to the end of the line to request for samples from the Station SP area. Subsequently the PT had to make an additional trip to receive the samples once they were ready. Improvements could be implemented by having the PT carry gloves with them and using designated trays placed at every station. Request for Process PP samples could be made more convenient by installing a call button at the head of a line. In addition, minor time savings could be achieved by placing a pen, used in recording, in the pen holder on the jumpsuit instead of the PT's' pocket. Long rulers typically used for crossing out fields with zero defects in the recording sheet should also be made available at every station. Time savings from these improvements were estimated from time logs of the trial runs, and deducted from the trial results to give optimized cycle times for each inspection types as shown in Figure 13.

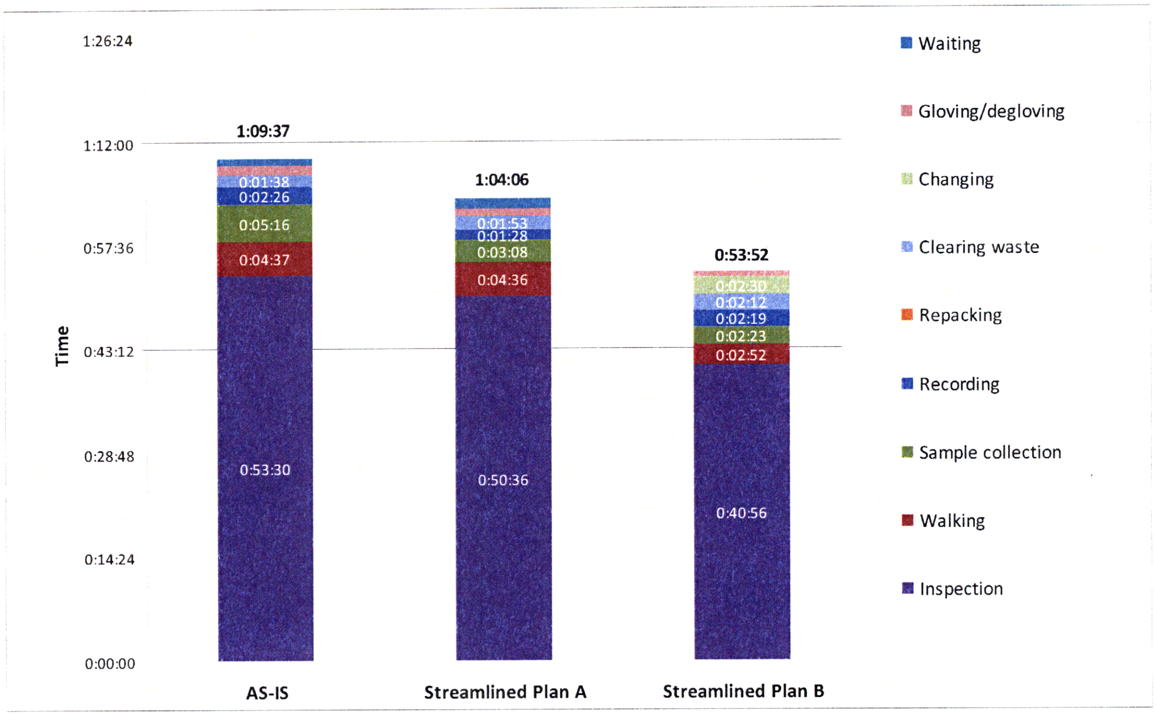


Figure 13: Trial run cycle time for As-Is, Streamlined Plan A and Streamlined Plan B quality inspection plan after removal of waste

From Figure 13, it is observed that the cycle times for As-Is and Streamlined Plan A benefited predominantly from an enhanced walking time. The improvement was 5.5% for As-Is and 6.4% for Streamlined Plan A. Since the walking time of Streamlined Plan B was already optimized in the trial runs, there was less room for further improvements and its cycle time decreased by 2.4% only. For the trial run scenario, the optimized cycle time of As-Is and Streamlined Plan A exceeded 60 minute while that of Streamlined Plan B falls within 55 minute. Since a dedicated inspector must finish the inspection cycle within an hour, only Streamlined Plan B could satisfy this requirement for the trial run scenario (six lines in operation).

Considering that cycle time is sensitive to the number of machines running, which is in turn governed by the production scenario, the MD management required all eight lines to be considered. Despite it being rare for all eight lines to be running concurrently, Streamlined Plan B cycle time was nonetheless extrapolated to estimate the effect of having all lines running (Figure 14). Due to limitation in time and availability of PT's for trial run, on top of the difficulty in arranging an "all lines running" scenario, extrapolation is an appropriate way to obtain the worst case cycle time.

The cycle times of all inspection types exceed the 60 min limit for 1 dedicated inspector; they range from 74.5 minutes to 96.5 minutes going from Streamlined Plan B to As-Is. The headcount requirement would thus be 2 inspectors with either one or both of them being under-utilized even if all machines were running. Expanding the scope beyond the in-line processes, inspection for molding machines are currently done separately by an inspector who is not utilized fully. Molding inspection time was added uniformly across the three inspection types as a rough-cut investigation on the feasibility of combining molding and line inspections. The resulting cycle times are shown for the worst case scenario of all molding machines and all line machines running in Figure 14. A line representing the 1 headcount limit was drawn above which inspection time exceeds the one-hour cycle time limit. Adding molding inspection cycle time to line inspection and averaging the total time over two inspectors achieved cycle time per inspector of 49 minutes for Streamlined Plan B, 57 minutes for Streamlined Plan A, and 1 hour for As-Is.

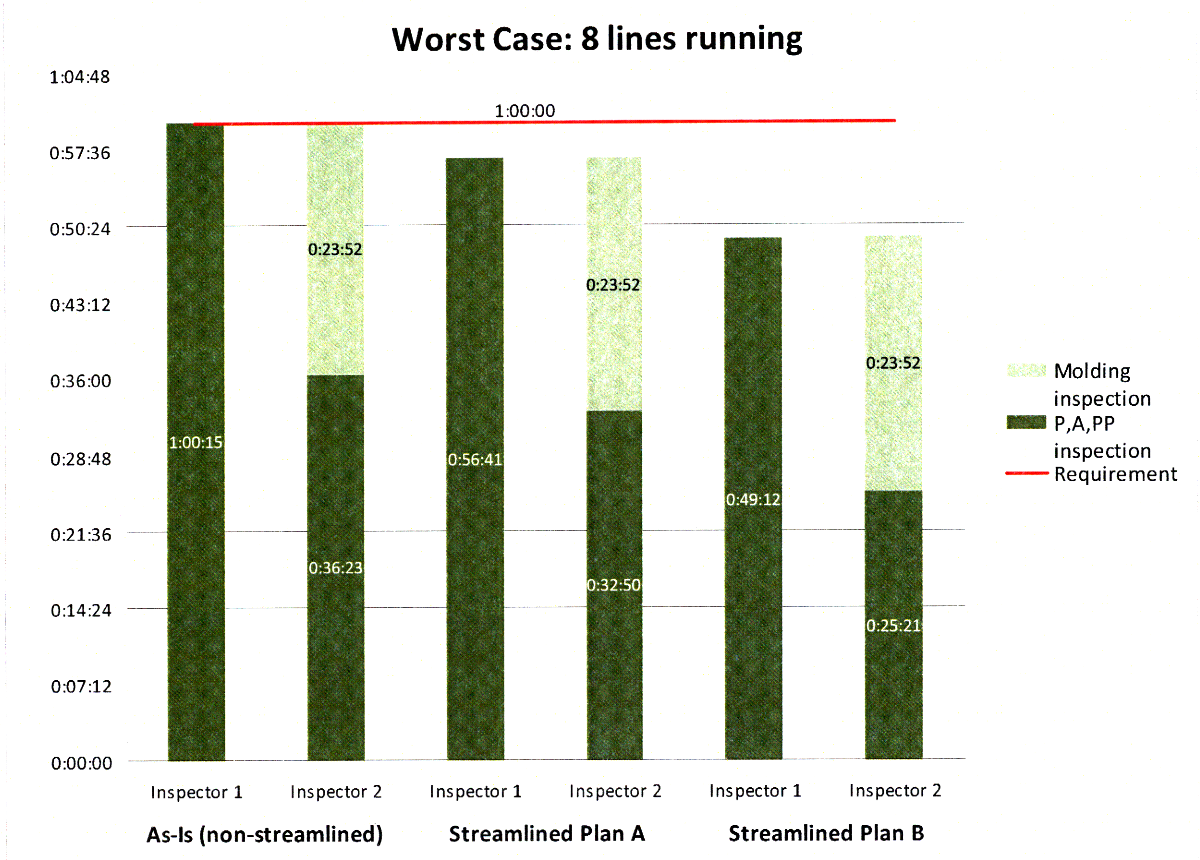


Figure 14: Cycle time for combined molding and line inspections by 2 inspectors for non-streamlined and streamlined inspection plans.

Based on cycle time of worst case scenario, both streamlined plans have significant reduction from the As-Is plan and therefore making their quality inspectors more efficient. For the same number of inspectors, in this case 2, some free time is available for breaks and fatigue. Despite being just slightly over 1 hour in cycle time, the non-streamlined option is not realistic since the inspector could not be utilized without any rest. To remain viable without further addition of headcount, the non-streamlined option should be restricted to only line inspections, which is in accordance to the manning arrangement in Proposal 2 [7]. However with streamlining, the same headcount could be deployed more efficiently and robustly to conduct additional molding inspection. Even though molding operations and manpower needs are not considered within this project scope, these results demonstrate the fact that production lines are not independent of other processes on the production floor, and some high-level savings could be attained through sharing of labor across both production areas. While savings at molding processes were not considered directly in assessing the value of a proposed allocation in the work of S.S.Liaw[9]. Streamlined Plan B is found to be most suitable way of conducting quality inspection for the job scope of dedicated quality inspector in Proposal 2.

Due to the inherent constrains of a short-term time study, not all possible production scenarios could be tested on with the various inspection types. The results gathered from a particular trial run are valid for scenarios that are comparable in terms of workload to that of the trial run period. Bearing in mind that both the trial run conditions and timings collected are single observations of random variables, the validity of time study approach in this case has to be supported by results that are conservative. This has already been achieved via the scaling up of timings in previous analysis.

5.2 Material Handler

5.2.1 Motion Study

The job scope of a material handler, as described in Proposal 2 [7], is summarized in Table 5. This job consists of manual packing, manual pouring, movements and replenishments of production parts for lines that are running on any given production day.

Table 5: Summary of material handling job scope

Job scope of material handler	Production parts involved
Manual Packing	Assembled syringes for bulk orders, molded parts, scrap
Manual Pouring	Molded parts
Material movements	New and used packaging material (top web/bottom web), stoppers from holding area
Material replenishment	Cone syringes, Cone clips, stopper, needle

Based on the specific production orders allocated to the eight syringe lines on the trial run day, inter-arrival times for the handling of materials were estimated and grouped. The general equation used in estimating inter-arrival times is given as Equation 2,

$$\text{Inter}-\text{arrival time of material replenishment task} = \frac{\text{Part capacity of hopper bin} - \text{base level of hopper bin}}{\text{speed of line in parts per minute}} \qquad (2)$$

The approach used in making these estimations differed from earlier estimations (see Equation 1) made in Section 1.5.3 in that the latter averages replenishment numbers over 6 months to take into account the occurrences of machine breakdown and other unexpected downtime, while the former was pegged to the line running speed. Given that replenishment, manual packing and pouring occur most frequently when the lines are running, a set of conservative inter-arrival times for material handling tasks could be calculated. Some of these results are presented on a relative scale in Figure 15.

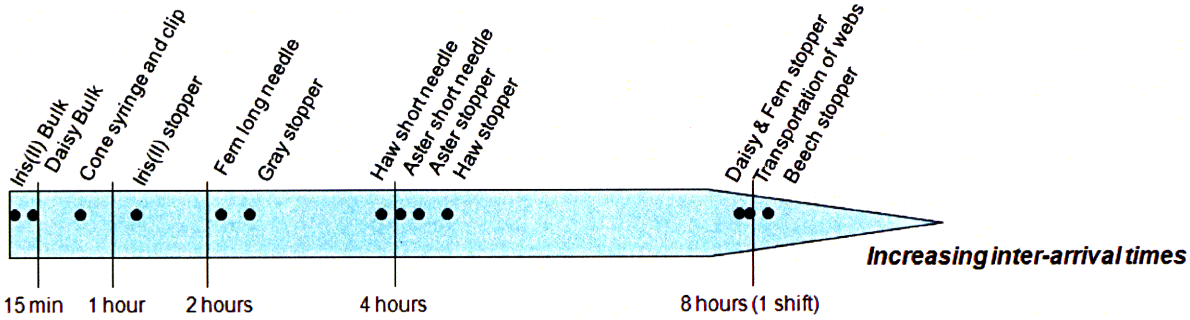


Figure 15: Selected inter-arrival times arranged on relative scale

In general, bulk packing has the smallest inter-arrival time or the highest frequency, followed by Cone syringe and clip replenishments, needle replenishment, stopper replenishment, and transportation of packaging webs, which is done once per shift only. Big syringe lines also tend to incur more material handling since big syringes and their components are larger; fewer of them fit into a hopper bin than small syringes for a similar hopper bin size. However, the knowledge of inter-arrival times itself does not allow scheduling of tasks for material handlers due to variability in the shift start time, and the amount of machine downtimes of the production lines. Variability in shift start time determines when manual packing and pouring of molded parts and bulk packing should start, while variability in machine downtime creates variation in the actual inter-arrival of tasks by delaying the depletion of material and creation of finished parts.

A simple rule-of-thumb was developed as a routine for material handlers to follow in the face of variation and uncertainty. At the start of a shift, the material handlers check for the production orders running at each line and assess what parts need to be replenished or packed. Bags of stoppers are to be brought into the CEA and distributed to the various holding areas within the lines. Top web and bottom web rolls are also pulled from the web holding area to lines with packaged orders. Once the less frequent replenishments have been completed, the material handlers have to remain at bulk packaging areas (Daisy, Iris(II) and less commonly, Haw lines). The material handlers leave the bulk packaging areas only when the next round of replenishment is due. Such instances occur more frequently for molded and Cone parts, and less frequently for needles and stoppers. Since hopper bins at bulk packaging area have finite storage capacity, emptying these bins before leaving the area gives material handlers more time to tend to other tasks without allowing the bins to overflow.

Besides reducing the need for constant checking of hopper bin states, and consequently, walking time, such an arrangement is robust against variability in consumption and production of parts by individual lines. As much as early replenishments do not impact production rate, slight lateness would not cause production downtime unless the safety stock in hopper bins is exhausted. At the same time, hopper bins at bulk packaging act as a buffer to contain the assembled bulk order parts until the material handlers return.

5.2.2 Time Study

A trial run was planned for a shift with one big syringe bulk order and one small syringe bulk order. However, only six out of eight lines were running; the big syringe bulk order was for Haw instead of Iris(II) line as was the case in simulation of Proposal 2 [9]. Constraints in resources also did not allow for a rescheduling and only one PT was utilized for trial run. Results were thus scaled to represent the worse case scenario of eight lines running.

Both the actual (6 lines) and the scaled results (8 lines) of tasks within the eight-hour trial run are presented in Figure 16. Manual packing and pouring formed the largest category of tasks constituting about 28.6% utilization of the material handler. Walking is the next highest time consuming activity with 20.4% utilization followed by manual packing of bulk order with 14% utilization, and other activities which have about 10% utilization or below each(material replenishment, 10.5%; material movements, 7.6%; shift start checks 6.4% and manual packing of scrap, 5.4%). These activities add to 95.2% total utilization.

Since material handling tasks are more predictable than random machine problems, a 95.2% utilization for a material handler would not affect productivity as much as it would for a line operator. Variations in the material handling tasks' occurrence, as highlighted previously, could be mitigated with some familiarity of the production. Moreover, trial run observations show that having one material handler was manageable for the production scenario of six lines in operation. This is true despite the limitation that Haw and Daisy lines started production about three and five hours into the shift respectively; at steady state the material handler successively completed replenishments of stopper and Cone parts, and manual packing and pouring of molded barrels, while doing bulk packing for the Haw and Daisy lines concurrently.

The results were scaled up by a factor of 1.33 in all categories except shift start checks and manual packing (bulk) to account for an additional two lines (0.33% increase) in the worst case scenario. Manual packing (bulk) was scaled by a factor of 2.33, since Haw and Daisy lines started production later than shift start time and bulk packing is more frequent in Iris(II) line than in Haw line. The total utilization for worst case scenario is therefore estimated to be 138.44%.

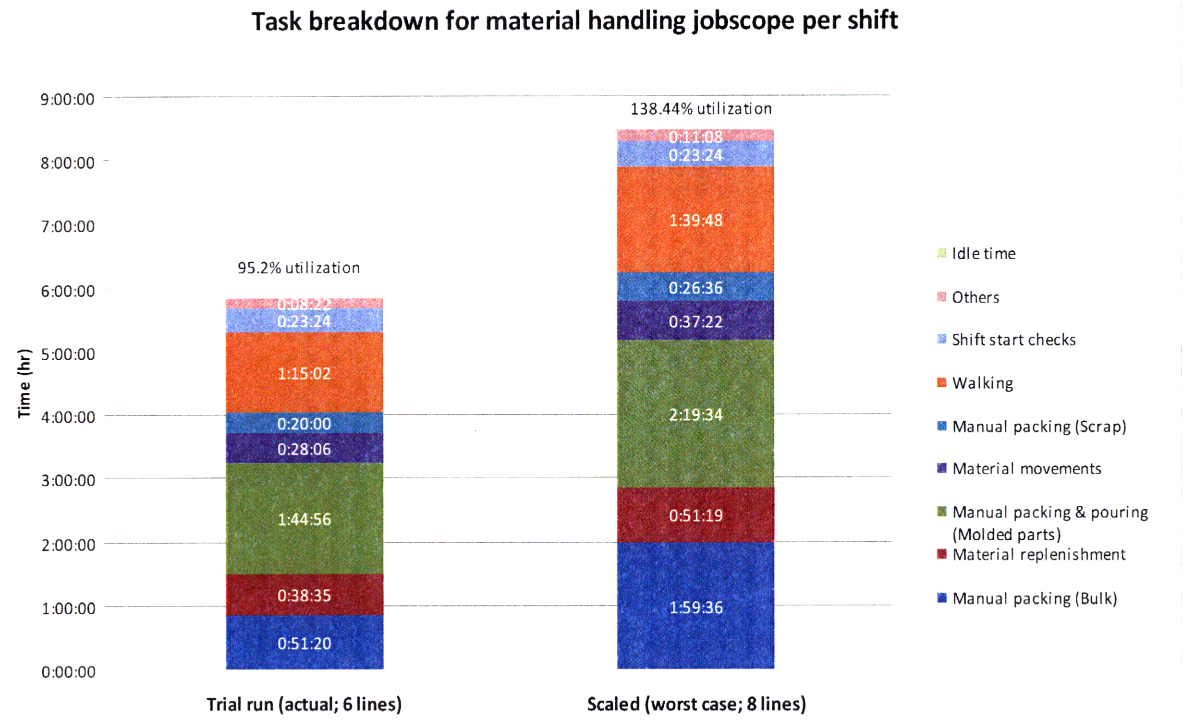


Figure 16: Trial run and scaled results for task breakdown of material handling

Having exceeded 100% utilization, the worse case scenario utilization points to a need for two material handlers if all lines are running. Such headcount need is consistent with simulation of Proposal 2 in [9] in which each of the two material handlers has an average utilization of 70.2%. Another similarity between trial run and simulation of Proposal 2 is that their total material handler utilizations are 138.44% and 140.4% respectively; the difference is less than 1.5%. Though scaling could introduce variation, such high resemblance in overall utilization between trial run and simulation helped to increase our confidence in the results of both approaches.

In view of an interest in optimizing labor in the company, the biggest components of utilization were examined for further opportunities. It is possible to separate manual packing and pouring, and manual packing (bulk) into two broad categories. One occurs regularly, while the other accompanies bulk order on either Daisy or Iris(II) line, or both. Differentiation of material handling tasks is rational since manual packing and pouring of molded parts and bulk orders tend to be more frequent than replenishments; alternating between latter tasks would be exhausting and distracting for a material handler. Moreover, having a clearly defined and reduced task variety allows the handler to coordinate tasks more efficiently. By assigning Daisy tasks and Iris(II) bulk packing to an OT material handler, who works only when there are relevant orders, and all other tasks to a regular material handler, local optimization of resource could be achieved. Based on this definition, utilization of an OT material handler and regular material handler would be 57.2% and 81.2% respectively. This ensures a consistently high utilization of the regular handler.

In the simulation of Proposal 2 [9], the material handler was modeled as a pool of two resources in which either resource would be mobilized if it were available; there was flexible sharing of work between handlers. Pre-assigning jobs scope to an OT handler and a regular handler inevitably gave rise to imbalanced utilization figures which have an unknown effect on productivity; a higher utilization means more work has been done, while a lower utilization gives a worker quicker response to urgent tasks. Productivity could suffer if the regular material handler could not fulfill replenishment and manual pouring (of molded parts) tasks in addition to the manual packing of molded part tasks. This impact on productivity, if any, could not be estimated fairly without taking into account the self-adjusting ability of the handler to plan ahead dynamically for replenishments before the latter are due.

The number of shifts which had neither Daisy nor Iris(II) bulk order was counted from the production schedule for each month from Nov 2007 to Mar 2008 and summarized in Table 6. It was found that the mean number of shifts not handling bulk order, μ, has an average of 40.8 within a 95% confidence interval of $20 \leq \mu \leq 61.6$ (calculation is shown in Appendix D). In light of the company's intent to optimize manpower usage and the uncertainties involved in the performance of the system, more rigorous studies in the form of additional time studies could be done to test the performance of a single material handler when there is no bulk order. For this arrangement to be feasible, changes in production throughput, expressed in monetary value, should balance the savings from reduced labor cost without incurring additional cost to the system.

Table 6: Number of shifts handling orders other than Daisy or Iris(II) bulk

	November ('07)	December ('07)	January ('08)	February ('08)	March ('08)
Number of shifts	43.5	15	39	61.5	45

Additional opportunities to optimize the system are possible since the company is already making efforts to balance the speed of molding and line machines. Balancing upstream molding and downstream line machines' speeds reduces the need to build molded part WIP in advance and to store them in bags, only to be used later on. The reduction in workload would be substantial since the trial run utilization from manual packing and pouring of molded parts was 33% for worst case scenario. However, the company has to ensure that there would be sufficient WIP to maintain productivity.

Chapter 6 Conclusion

In this work, a work study approach was applied to assess the feasibility of specific job scopes that were created as part of a manpower reallocation proposal. The job scopes of a dedicated quality inspector and material handler, proposed by a flexible manpower reallocation arrangement, were investigated. This called for a job redesign exercise to determine the optimal condition and best timing possible in performing a group of tasks. Information provided by work study is important in defining the new job scopes that were previously not done by someone.

The two-step work study was comprised of a motion study which broke up steps within a task to identify waste from high level, and a time study which documented time required to perform sub-tasks within a process.

Through waste elimination, an optimal timing was obtained for the dedicated quality inspector cycle time which in turn defined the headcount needed for this job scope. Given this link between timings and headcount, an attempt was made to reduce headcount below the number indicated in Proposal 2 [9]. Due to the allowance made for the worst case scenario, total headcount for inspection did not decrease. However, streamlining of inspections was able to reduce cycle time of the inspector to allow for an additional molding inspection and with sufficient break allowance. A non-streamlined inspection was found to be less efficient in this aspect. This opportunity for optimization also came about from a more flexible sharing of manpower to maximize capacity of inspectors. Hence, Streamlined Plan B was found to be most feasible in the context of Proposal 2 even though benefits arising from the former were not directly recognized under the scope of this project.

A simple strategy based on relative inter-arrival time of material handling tasks was designed to govern the movements of material handlers in the event that they do not have full information on the state of production on all lines. A trial run demonstrated that one material handler could satisfy material needs on a day with six lines in operation using such a strategy, while extrapolation of trial run results verified the need for two material handlers as stated in Proposal 2. With the discovery that a significant portion of tasks accompany only bulk orders, the potential use of one material handler on an OT basis becomes attractive.

Chapter 7 Recommendations and Future work

7.1 Recommendations

The second part [9] of this project had demonstrated that Proposal 2 could produce a significant monetary gain and its implementation was recommended by the author. In future implementation of Proposal 2, the two dedicated inspectors and two material handlers could be utilized more efficiently through (i) streamlining of in-process inspection according to Streamlined Plan B, (ii) addition of molding inspections to the inspection job scope, and iii) differentiation of material handling tasks into the categories of regular tasks and bulk-order tasks. Suggestion (iii) allows one of the material handlers to be engaged on an overtime basis to reduce cost.

Considering that a proper execution of the inspector and material handler job scopes require familiarity and consistency on the part of the workers, Suggestion (ii) and Suggestion (ii) should be implemented at a later stage. This gives the workers an opportunity to improve their competencies in those core tasks that were originally outlined in the first part [7] of this project. Once the production throughput stabilizes and the workers consistently complete their tasks within time limits, incorporation of Suggestion (ii) and Suggestion (ii) is expected to be smooth.

In the event that an inspector or a material handler is absent, a replacement must be found from two other teams working on other days of the week. This means that at any point of time a pool of four inspectors and four material handlers is available. Cross-training inspectors and material handlers could improve the flexibility of the system and allows a replacement to be found more easily. The risk of productivity loss from a lack of manpower is thus reduced.

7.2 Future Work

The work study approach in optimizing labor could be extended to other deterministic job scopes in future allocation proposals. A statistically significant length and number of observation would be preferable to better capture the random distribution of tasks with large variation in inter-arrival times.

The use of dedicated quality inspectors calls for an efficient yet effective method to check for defects to ensure the quality of all syringe products. There have been cases of critical defects found in an entire batch of syringes, a defect which the current line PT's performing inspections should have detected if quality checks were performed as intended. Moreover, current inspection records have shown that defects were seldom found in the hourly inspections. These pointed towards either a small defect count in syringe products, or an inability to detect defects. An assessment of the quality of checks by PT's would hence be beneficial. More importantly, the best inspection method should be established and executed faithfully. Experiments could be designed to test the sensitivity of various methods to critical defects by artificially inserting products with such defects.

Before the company embarks on balancing molding and line machines' speeds to remove molded part WIP, the optimal buffer sizes that could support the current level of productivity (from a machine downtime perspective) should be determined. Since molded part WIP allow molding machines to undergo changeover in advance for the next product lot, new strategies have to be devised to reduce changeover time or to schedule production differently.

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. Demir,S., Kikic,K., and Aslan,S., "Motion and time study for lean manufacturing," www20.uludag.edu.tr/~orbak/Grup20.ppt, accessed July 2,2008.

4. Oke, S.A., 2006, "A Case Study Application of Time Study Model in an Aluminum Company," *The Pacific Journal of Science and Technology*, 7(2), pp. 153-162.

5. Siebers, P.O., 2006, "Worker performance modeling in manufacturing system simulation: Proposal for an Agent-Based Approach," Handbook of Research on Nature Inspired Computing for Economy and Management, J.P. Rennard, ed., Pennsylvania: Idea Group Publishing, Pennsylvania, pp. 661-678.

6. Brown, S., 1994, "TQM and work study: Partners in excellence," *Production and Inventory Management Journal*, 35(3), pp34.

7. Su, X., 2008, "Optimization of Labor Allocation at a Syringe Production Facility: Design Proposals," S.M. Thesis, Massachusetts Institute of Technology, Cambridge, MA

8. MD, In process quality inspection-Syringe department, MXX-XXX, 2008, Singapore.

9. Liaw, S.S., 2008, " Optimization of Labor Allocation at the Syringe Production Floor Using Computer Simulation," S.M. 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	Process P hourly visual in-process inspection	8.0	-	-	-	-	-	-	-	-	-
15	Process A hourly visual in-process inspection	8.0	-	-	-	-	-	-	-	-	-
16	Process PP 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: 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: Calculation of confidence interval for μ

Sample mean, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{43.5 + 15 + 39 + 61.5 + 45}{5} = 40.8$

Sample variance,

$$s_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 = \frac{(43.5-40.8)^2 + (15-40.8)^2 + (39-40.8)^2 + (61.5-40.8)^2 + (45-40.8)^2}{4} = 280.575$$

Since the true population variance is unknown, the (1-α)% confidence interval for μ is given by:

$$\bar{x} - t_{\alpha/2,n-1} \cdot \frac{s_x}{\sqrt{n}} \le \mu \le \bar{x} + t_{\alpha/2,n-1} \cdot \frac{s_x}{\sqrt{n}}$$

where $\alpha = 0.05, \quad t_{0.025,4} = 2.776$

$$40.8 - 2.776 \cdot \frac{16.75}{\sqrt{5}} \le \mu \le 40.8 + 2.776 \cdot \frac{16.75}{\sqrt{5}}$$

Hence, the 95% confidence interval for μ is:

$$20.005 \le \mu \le 61.595$$