ROBOTICS PROCESS AUTOMATION THROUGH LEAN ENGINEERING

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Introduction

Most countries have a need to receive, store, and distribute blood for safe and adequate use in hospitals or simply to ensure that the blood bank is responsive to emergencies. Indeed, securing the nation's blood supply by ensuring a safe and adequate blood supply and providing specialist transfusion medicine services is a national blood service undertaken mostly at the public sector level. In Singapore, the Blood Services Group (BSG) is no exception.

The BSG is responsible for collecting, processing, and distributing blood and the blood components to all public and private hospitals in Singapore. The blood components of plasma, Red Blood Cells (RBC), white cells, and platelets, used in different healthcare settings, are typically processed in the Components Processing Inventory (CPI) lab of the BSG. The CPI lab processes the entire blood collected in the form of blood bags into the component products, and the patients may be treated with the whole blood (A, B, O, AB, Rh), or the specific blood components required for the various medical conditions.

The handling process in the CPI lab involves blood collection (either done on site or from the various blood donation sites located all over the island), blood processing, blood testing, and blood inventory. The whole blood is collected daily from the central blood bank and another three satellite blood banks located strategically at blood donation points (BloodBanks) sited in the CBD, shopping mall in the West, and a civic centre in the north of the island. The whole blood collected will be inspected and further processed after arriving in CPI lab within 24 hours. The component products will be stocked as inventory before distribution centrally to the demand points, which are usually the 26 hospitals and specialty centres. In this paper on robotic process automation using lean engineering, the focus will be on the processing and inventory of blood components.

The intent of this study will be divided into two stages. The first stage is to map the current handling process of blood in the CPI. It starts with collecting the process information, mapping the current state ("as-is") including the entire material and information flows, followed by analysing both the value-adding and non-value-adding activities, and eventually identifying the hidden waste and sources of waste. In this stage, the detailed value stream workflow of the blood handling process and inventory in the CPI lab will be described. The information on each activity such as labour, location, time, objective, target output, and procedures will be meticulously captured. The successor-precedence relationships between the different activities also need to be understood. After developing the current state map with the information collected, a thorough process analysis is performed to find opportunities for removing the non-value added activities. Considering the large amount of manual labour involved in the current workflow, the opportunities for process automation so as to reduce labour costs will be identified using a discounted cash flow cost-benefit analysis. Upon completing the current handling process map, the second stage is on the future process improvement. In short, the study will show how through lean engineering, robotic process automation can be deployed operationally and meaningfully using design thinking. The goal is to improve the overall efficiency of the BSG workflow in the CPI lab.

This paper is structured as follows. Section 1 has introduced the background and context of the problem. Section 2 provides the necessary literature review under the various streams of work. Section 3 details the research method. Section 4 shows the effort at the current state VSM, in particular the blood processing steps. Section 5 presents the future state map. Section 6 highlights the results of the cost-benefit analysis. Section 7 concludes with some suggestions for future research.

Literature review

Lean Manufacturing

The modem concept of lean manufacturing dates back to the early 1900's, Henry Ford implemented the continuous assembly line and flow in the Model T automobile manufacturing at the Ford Motor Company. From the 1940's through the 1970's, the Japanese automotive industry had been inspired by this concept and the revolution first occurred with the Toyoda family who formulated the Toyota Production System (TPS). The TPS, focused on reducing the cycle time, cost, defects, and waste. It aims to achieve the same output with less input, such as less time, less space, less human effort, less machinery, less material, and less cost. The TPS system enabled Toyota to survive and even remain profitable during the oil crisis in 1974 (Womack et al. 2007).

The TPS has defined seven forms of wastes ("muda") in the manufacturing process. The first form of waste is overproduction, which means producing more, sooner, faster than necessary or required by the customer. The second waste is defect which can lead to a waste of money, production time as well as the effort spent for rework or correction. The third waste is inventory which brings inventory carrying cost including storage cost and operating cost, and for perishable goods there is also risk of depreciation. The fourth waste is transportation; the excessive movement is non-value adding. The fifth waste is waiting, which also leads to a waste of money and time. The sixth waste is over-processing, which is excessive processing work than needed, using more resources than required. The seventh waste is unnecessary motion, or the extra movement of people which slows down the production flow (Rampersad & El-Homsi, 2007). Lean manufacturing is usually applied to identify and minimize all these wastes, creating a more efficient work flow.

In the mid-1990's, the lean manufacturing concept was introduced to the American industries, and over time, it was applied not only in the production environment but also the entire supply chain even including the office administrative processes. Lean manufacturers have now turned into lean enterprises, involving all parties and roles in the value chain, focusing on obtaining the best possible value from the collective efforts of all the stakeholders (Keyte & Locher 2016). Today, lean thinking is a popular mantra.

Value Stream Mapping (VSM)

The most commonly used lean tools today include the 5S workplace organization and standardization, overall equipment effectiveness, mistake proofing, Kanban, and VSM (Voehl et al. 2013). VSM is a powerful visual management and communication tool. It is a lean-management method for analyzing the current state and designing a future state for a series of events that takes a product or service from its beginning through to the customer (Rother & Shook 2003). It is useful for identifying waste, reducing processing cycle times, and implementing process improvement. As it is applied visually, VSM helps to see the big picture and improve the entire flow. To do this, VSM uses a system of symbols to describe the activities and information flows, and the items are mapped as either adding value or not from a customer's perspective. The core of VSM is to seek out waste in any process and produce the most value in the most efficient way.

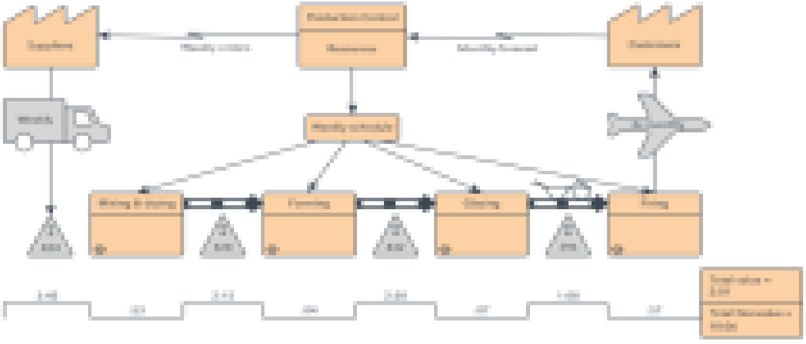

Figure 3: VSM example

Generally, a VSM tool contains a current state map and one or more future state maps that represent improvement to the current state. Generically, the steps to conducting a value stream analysis are set as follows:

1. Define the product family - Define and scope problem, Pick product family, Determine VSM objective and benefits, and Create VSM charter.
2. Document current state - Map current state value stream, Document each significant step in process, Collect process data and quantify current state value stream performance in terms of inventory type and size, cycle time, process time, number of workers, available working hours, Add process data to data boxes in VSM, Create a timeline to map process time and lead times through process steps, and Analyze and identify improvement opportunities.
3. Design future state - Develop future state VSM, use "kaizen burst" symbol on current state VSM to clearly communicate new improvements, and Prioritize improvement projects.
4. Create implementation plan - Develop implementation plan, Seek management approval, and Implement plan and monitor progress.

There are many software tools available for VSM; some allow the user to draw current state/future state with process variables such as material, employee, cycle time, and lead time. More complex tools allow for model building and simulation.

Lean management practices in healthcare industry

Lean management principles is also successfully applied to the healthcare sector. There are examples of healthcare organizations successfully using lean thinking to streamline their processes, reduce cost, and improve the quality of their products and services. The interested reader can refer to Nelson-Peterson and Leppa (2007) who reported on how a mid-sized medical centre adopted lean management principles since 2002. By working to eliminate waste, the centre created more capacity in the existing programs and practices to save significant capital expenses: $1 million for an additional hyperbaric chamber that was no longer needed; $1 to $3 million for endoscopy suites that no longer needed to be relocated; $6 million for new surgery suites that were no longer necessary. Using lean principles, the staff, providers, and patients have continuously improved or redesigned processes to eliminate waste, requiring fewer staff and less rework, and resulting in better quality. In another case study, Barnas (2011) reports on a health delivery system involving three hospitals, 27 physician clinics, and a 300,000-member health plan, based in a state in the US. The initiative for them to think lean in 2004 is that the leaders recognized that waste is the result of time the staff spent in "putting out fires,". As a result, they believe that designing processes that work better will reduce waste and enable staff to better meet the needs of patients. The emphasis is this case is on reducing waste and the non value-added work. Through this focus, they managed to save $3.3 million in 2004, $154,000 in the catheterization lab supply procurement processes, reduced the accounts receivable from 56 to 44 days equivalent to $12 million. Both these studies highlight the financial and operational impacts of lean thinking on reducing waste in healthcare.

Research method

The methods used on the case study include drafting the general workflow after understanding the physical process, filling in the detailed process description, data collection, VSM current state analysis, and future state development. A mix of quantitative and qualitative methods was used for data collection and analysis (Williamson,2002).

The qualitative methods such as interviews and discussion with the officers and operators in the CPI lab, were adopted to create the general workflow of the blood handling process. It is regarded as the start point of the project, providing a structure to make further measurements. Based on the general workflow drafted, we then went on to improve the process descriptions for each activity.

The quantitative methods include time, labour, dimension, cost measurements are conducted for filling the data in value stream maps. The data was collected during visits to the CPI lab over four months. Much of the data collection involved the measurement of time. Each step of the process was observed and the cycle time was manually clocked. The cycle time is defined as the duration from the time one component starts to be processed until the next component is placed. The cycle time is divided into two parts: machine time and labour time. Machine time refers to the time that a component is handled by an equipment. Labour time refers to the time the operator uses to prepare or wrap up an activity, i.e. bring materials to station, packing, cleaning the tools, moving the finished components from the equipment, etc. The reason to measure machine/labour time separately is to compute the machine/labour cost later in our study. While recording the cycle time, we also recorded other observations such as the number of staff involved in the activities. All the measurements collected were put onto an Excel file to be further analysed in the VSM analysis. A path map by product was then drawn with the VSM tool, eVSM to better visualize the movement of the components.

The workflow, detailed process descriptions, and the data collection serve as the foundation for creating the VSM current state. The map drawn with eVSM aids in understanding the processing activities and the various component flows. From the current state VSM, process inefficiencies are identified visually. Next, the future state VSM is created and measures of capacity, time, labor efficiency are tabulated. A discounted cash flow, cost-benefit analysis done on Excel is used to evaluate the feasibility of improvement.

Current state

To understand the entire process of CPI lab, we need to outline the blood collection and processing stages.

Generally, blood is processed after collection to yield the different products for specific treatments, and the handling process includes blood collection, blood processing, blood testing, and blood inventory. Blood collection is the start of the entire flow and carried in the four blood banks. The whole blood collected at the satellite blood banks is sent to the CPI lab twice daily at 3 pm and 9 pm respectively. Each bag of blood has a barcode and a record of the time of donation. The whole blood bag is then sent for processing. A random sample of blood is taken at the incoming inspection to scan the temperature, ensuring the blood components are in the active range of 20 to 24°C. Next, the whole blood is centrifuged. The centrifuge can handle 6 x 2 units of blood bags each time, spinning for 15 minutes and then decelerating to rest within 30 minutes. The blood is now put into a semi-automated extractor for 3-5 minutes. For some special products required by blood and marrow transplant (BMT) patients, the white cells are removed, and the blood undergoes filtration. The filtered blood can now be handled for component pooling to get the specific components of blood, of which 60% is the supply of platelets. The next step is blood testing. Six test tubes are prepared for the six different types of mandatory tests. The turnover time for each test varies from ½ to 6 hours, and all the test results of the samples are released by noon of the next day. The test results are recorded in the IT system, and only blood bags which passed will be labelled to produce the final product. The blood test runs simultaneously while the samples are being processed. During the testing process, when the blood samples are centrifuged, the top layer is pipetted to test for HIV, hepatitis, Zika, malaria, antibodies, and syphilis. Finally, the handled blood is stocked for inventory. The labelled RBC's which are ready for distribution as well as the quarantined products that await labelling by noon of the next day are kept in a cold room.

Having an overview of the blood processing helps to identify and locate each individual procedure, especially for the component processing (including separation and pooling) and inventory. By adopting the 5W1H (Who, What, When, Where, Why, and How) approach, we were able to investigate what happens at each stage and gather the information needed for the VSM. The data/information is collected from the standard operation procedures, actual process observation, and interviews with the lab manager and senior lab officer.

Time usage was recorded using a stopwatch in terms of the machine time, labour time as well as the waiting time. The average time data is taken based on at least 2 sets of raw data. For example, for the procedure of whole blood centrifugation, we recorded the time for the breakdown of the activities, e.g. preparation work such as arranging samples, weighing and balancing the samples, travelling from the preparation work station to the centrifugation work station, as well as centrifugation by the machine. Batch size is also recorded in order to understand the efficiency per batch or per bag (see Table 1).

Table 1: Sample table of time motion study

Final product	Procedure	Activity breakdown	Avg time	Batch size
RBC+(BC)+Plasma	Centrifugation	Arrange samples	3 min	12 bags
		Weigh and balance samples	1 min	12 bags
		Travel	45 sec	12 bags
		Centrifugation	30 min	12 bags

Another key consideration is the human footprint in the process. We obtained the floor layout of the CPI lab, followed by identifying the functional areas of the lab. The major functional areas are: Incoming Receipt & Inspections, Separation, Component Pooling, Labelling Station, Storage rooms (pending and final product storage for RBC, plasma and pooled platelet), and Inventory & Distribution. To analyse the footprint, we observed during our visits to the CPI lab how the operators travelled between these functional areas. The data on the travel distance point to much human movement in the lab between the different stages of the process, as shown in Table 2.

Table 2: Current human footprint in RBC process line

From	To	Distance (m)
Door entrance	Receipt of satellite samples	2.55
Receipt of satellite samples	Incoming inspection station	6.84
Incoming inspection station	Centrifuge	3.52
Centrifuge	Extractor	1.93
Extractor	RBC filtration rack	2.43
RBC filtration rack	Inventorising station	9.07
Inventorising station	RBC pending cold room	15.47
RBC pending cold room	Labelling station	2.60
Labelling station	RBC FG cold room	26.13
RBC FG cold room	Temp storage for RBC dispatch	25.03
Temp storage for RBC dispatch	Dispatch window	3.20

Based on the process information collected, the current state VSM is obtained through the Standard Work Wizard in eVSM. Three major products, namely, RBC, plasma, and pooled platelets are included in the VSM, and the procedures are described as activity centres with the machine, labour, and waiting times indicated.

Muda identification

Over-production waste: Due to the nature of the blood component services, all fresh whole blood have to be processed (at least to the RBC and plasma level), regardless how much the actual demand is. Thus, over-production waste is not a concern.

Processing waste: The production procedures cannot be changed as any change would potentially affect the quality of the product. Thus, no steps are identified to contribute to the excess quality which customer (hospital in this case) does not require.

Transport waste: During the site visits, it is observed that there are unnecessary movements of people and materials from one location to another. This suggests that the design of the layout can be improved with some automation of transport within the processing lab. The current layout of the CPI lab is rectangular with its length 3.2 times its width. Figure 2 shows that the sample receipt entrance point (Point A) and the finished goods distribution window (Point B) are very close to each other. The temporary and finished goods storage room/area are dispersed in the layout (yellow shaded area).

Figure 2: Storage area in current layout

Such a design results in inefficient travel routes in the processing activities. For example, from Figure 3, when the labelling of the RBC's is complete, the RBC bags are transferred from the labelling station to RBC (finished goods) cold room for storage (Red route below). The distance of the route from the labelling station to the RBC (finished goods) cold room is almost half of the length of the lab. When the RBC is needed for distribution, it has to be transferred from the cold room to the dispatch storage area which is nearer to the distribution window, as shown in the green route.

Figure 3 Example of travel routes in RBC processing

If we "straighten" the red and green travel routes and sum them, it transverses the entire length of the lab. In addition, the travel in the lab is currently done manually, which means the staff has to push a trolley with samples from one station to another; the travel speed is now slower than normal walking speed. Clearly, visual observation suggests a potential for automating the transport system.

Waiting Time Waste: During line visit, it is observed that the unexpected down-time of blood component extractor occurs at a noticeable frequency. The extractor machine pauses when such machine errors occur; the staff has to manually adjust the blood bag and tubing. This requires the staff to pay extra attention and monitors the machine running status and immediately adjusts to avoid process delays. Hence, waiting time is incurred.

Inventory Waste and Defects: Again, due to the nature of the blood component services, over-production is allowed, and hence inventory is maintained at a more-than-sufficient level. Defect is not the focus of the process optimisation as well.

Future state VSM

The future CPI lab can be re-designed for better flow and less interruptions, and robotic process automation can be introduced to reduce the need for manpower, lift productivity, and ensure consistency of work speed. We now look at each aspect.

The design of the future floor layout assumes that the floor area of the future CPI lab is unchanged. This provides for a better comparison between the current and future travel distances. The functional areas are rearranged in the sequence of component processing steps which allow materials to move in a "U-shape" path from the receipt entrance to the finished goods distribution window (exit). Figure 4 shows an example of the future movement path in RBC processing. The functional activities which are shared across components, such as incoming inspection, centrifuge, and extraction, are located next to the receipt entrance. Those functional areas which process specific components are moved to the back of the lab. The storage rooms for the pending and released products are moved to the side facing the distribution window; there are two purpose of such a design. First, it reduces the travel distance from the storage to dispatch stations and avoids any path intersection of the components. Second, the cold room placed next to the distribution window blocks any outside views, lending privacy to the internal operations. In general, such a design reduces the redundant travel distance to the greatest extent by ensuring that the component does not move back and minimizes route intersections. A reduced travel distance indicates time savings.

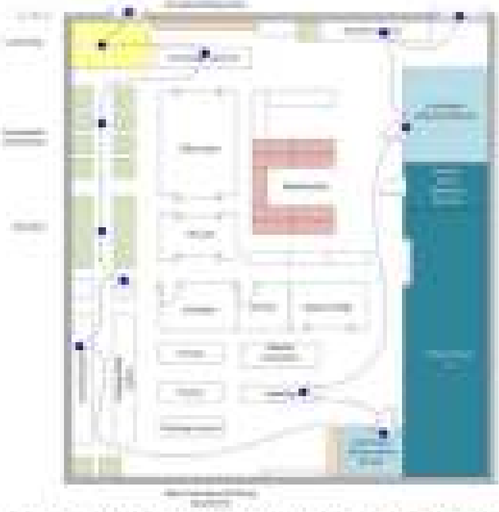

Figure 4: Example of future travel path in RBC processing

The paths of the three components, RBC, plasma and pooled platelets are plotted with eVSM and the distance between the functional areas are measured. Figure 5 shows the distance savings for each functional activity. Based on the data collected, by finding the total travel distance of each component, the new floor layout would yield a 37% distance savings for the RBC, and 45% for the plasma. The travel distance in the pooled platelets is found to be comparable with the current design. Again, time can be saved.

Figure 5: Example of RBC travel distance by functional area comparison

Currently, in the lab, the materials, e.g. blood bags are transferred manually or by trolleys. Automating the transport system will free the lab officers from the manual task of transferring the samples and assigning them to more value-added tasks. Implementing a simple to use conveyor system which can be customized with a maximum width of 60 cm, maximum load of 91 kg can help to achieve robotic process automation and is sufficient for the transfer of the lab samples. In fact, robotic process automation in blood handling not only helps to enhance the efficiency, but also enables the process to proceed in a safer environment. In the blood components processing, automated devices can reduce the amount of manual operations such as centrifugation, component separation, and so on. Semiautomatic equipment is also available for the separation of plasma, RBC, platelets, which greatly enhances the efficiency of processing the leuko reduced products (Pasqualetti et al. 2004). Automation eliminates manual errors, reduces manpower, and provides uniform performance (Gupte 2015), which also plays an important role in testing.

In a possible future layout with process automation introduced, the storage area can be grouped and arranged in sequence along one side of the lab. The conveyor system can be installed along the wall of the storage rooms as demonstrated in Figure 6 in the orange patterned area. It will offer minimum disruption to the lab officer's normal workflow.

Figure 6: Conveyor in proposed future layout

A lift gate for the conveyor will be installed in front of the entrance of each storage room so that it can be easily lifted for access through the conveyor line. The conveyor system is designed with an automatic stop/start control. When the gate is lifted, the conveyor will stop automatically. When gate is returned to its original position, the conveyor will resume.

The labelling (inventorisation) station can also be automated. Inventorisation is a key step used to record the newly processed/extracted blood components into the IT system. Upon inventorisation, the qualified products will be labelled with a printed label. This currently requires a PC, a handheld barcode scanner and a labelling machine. The staff picks up a component bag, scans the barcode on the existing bag label to enter the bag ID into the IT system, and apply a new label generated by the labelling machine onto the bag.

This work process can be automated by using a barcode scanner robotic arm, a small conveyor, and a labelling placement robot. Figure 7 shows a simple demonstration of an existing laboratory application by Microscan. The barcode scanner is installed on the robotic arm, with a slight modification of the robotic hand so that the soft gripper can pick up the blood bags instead of the test tubes. The scan speed of such a scanner is 1000 scans/second. Installing this equipment can reduce the work time at the scanning station.

Figure 7: Barcode scanner robotic arm.
Source: files.microscan.com/case-studies/cs_lab-auto_ms-3.pdf

Ideally, the blood bags are to be placed on the small-scale conveyor which can be integrated into the inventorisation work station. When the barcode scanning is complete, the blood bags are transferred by conveyor to the next step for labelling placement. As the distance between these two steps is short, the small conveyor is optional. Staff who is assigned at the component pooling workstation can help in this transferring process.

Next, we consider using a robotic precision labelling applicator for the labeling placement (Figure 8). As the robotic arm lifts each sample to the labelling machine, apply the label on the sample, and return the sample back to the tray.

Figure 8: Label placement robot
Source: http://www.inventekengineering.com/services/robotic-precision-label-applicator/

The advantages of the automated storage and retrieval system (ASRS) for storing the blood bags can help to eliminate human errors, increase safety during dispensing and better use of the storage area. Automating the storage removes the need for static shelving. Instead there will be a robotic replacement for the vertical carousel. The lab officer will no longer need to locate, pick, and verify the blood bags in a very low temperature environment. The lab officers only needs to key in the required retrieval instructions on a PC, and the ASRS will retrieve the items accordingly.

Figure 9: Swisslog storage and retrieval system
Source:http://www.swisslog.com/en/Products/HCS/Medication-Management-Systems/BoxPicker-Automated-Pharmacy-Storage-System

We now propose, through design thinking and applying lean engineering principles, two options for the future state VSM. The first option is without automation while the second option incorporates robotic process automation where possible.

VSM for future layout without automation

Based on the proposed future layout, we developed the future state VSM. As the RBC processes cannot be modified, the focus of the future state will be on the optimisation of the movements between the production processes, e.g. travel time. For instance, the original movement from the labelling station to RBC finished goods cold room takes a minute. In the proposed future layout, the distance is shortened, allowing for a 30 second transit instead, assuming the walking speed of the staff remains constant (see Figure 10).

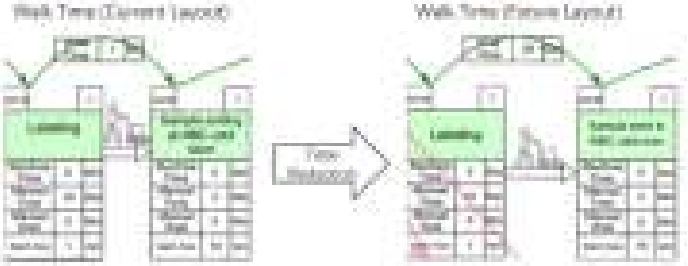

Figure 10: Walk time reduction of future layout vs. current layout (w/o automation)

VSM for future layout with automation

Automation will further enhance productivity by reducing the walk time, storage, and retrieval times as well as the time spent on inventorisation/labelling. For example, the lab officer will no longer need to push the trolley to transfer the samples manually. Instead, samples will be delivered on conveyor belt so that manual walking time is significantly reduced. By adopting an automated system of labelling, storage, and retrieval, physical walking and waiting is reduced. Figure 11 shows that the walk time by a staff is now 0.

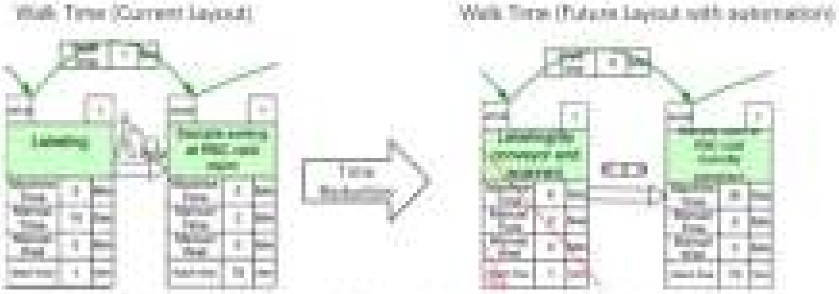

Figure 11: Walk time reduction of future layout vs. current layout (with automation)

Cost Benefit Analysis

To decide which of the two future VMS states to adopt, we now need to undertake a cost-benefits analysis to determine the impact of the capital cost of purchasing, installing and maintaining the automation equipment. The costs of the automation equipment were collected from suppliers or from Alibaba based on the current throughput and floor space data. The cost calculation includes the set-up cost, operating cost, and a straight line depreciation. The set-up cost for the ASRS, for example, includes the cost for the grid structure, the work stations, robots, necessary control software, and equipment installation. Suppose the automation equipment depreciates to a half of its original price within 5 years, and the annual operating costs are estimated to be 10% of the original cost, there would be an additional cost of $141,146.50 each year under robotic process automation, as shown in Table 3.

Table 3: Cost-benefit analysis

Cost Benefit Analysis for Automation					
Costs					
Category	**Item**	**Qty**	**Cost (S$)**	**Depreciation period**	**Cost**
Transport system	Conveyor belt	15	$ 350.00	5 years	$ 5,250.00
	Conveyor lift gate	4	$ 200.00	5 years	$ 800.00
Inventorisation automation	Barcode scanner robotic arm	3	$ 3,200.00	5 years	$ 9,600.00
	Label placement robot	3	$ 7,000.00	5 years	$ 21,000.00
ASRS	ASRS system	1	$ 80,000.00	5 years	$ 80,000.00
Operating cost					$ 11,665.00
				Total Cost	$ 141,146.50
Benefits(estimated per annum)					
Increase in productivity per FTE					16%
Reduction in labour cost	$				(122,592.00)
Non-monetary benefits					
Reduction of human error					
Improvement in employee safety					
Optimized space utilization					

The main benefits brought about by process automation is the increase in productivity and reduction in labour cost. Before automation, the daily productivity of a full time staff is 101.57 blood bags; with automation, this value increases to 117.99. Hence, with automation, labour productivity increases by 16%. This effectively reduces the number of staff from 3.45 to 2.97 for each weekday and from 5.51 to 4.75 for each weekend, respectively. Assume 261 weekdays and 104 weekends in a year, and an average labour cost of $40/hour, the saving in manpower cost is found to be $122,592.

Besides the annual cost increase of $18,554.50, there are also other non-monetary benefits. In the current manual process, human error in the picking and labelling is inevitable, using robotic process automation would increase the operation accuracy significantly. Further, automation also offers a higher level of employee safety. For example, using the ASRS, staff would not have to enter the plasma storage cold room of under -30°C. It reduces the probability that an operator could experience physical harm. Deploying an ASRS will also optimize the space utilization by allowing for more products to be stored in the same space.

Our future layout design was predicated on a constrained floor space. This limits the choice of the automation system. In reality, with more floor space available, a more elaborate transport system other than a conveyor belt could be considered (i.e., AIV robot).

Conclusion

In this study, the current state of the blood handling process and inventory in the CPI lab was documented. All the waste and non-value-added activities were identified, as well as the opportunities for floor layout improvement and automation, using simple principles of lean engineering. The new floor layout design aims at re-allocating the functional activities and areas to optimize space utilization and minimize the transport time. Later, through design thinking, automation was proposed in the transport, inventorisation and labeling, as well as the storage and retrieval of the blood components. A future VSM was developed in two scenarios under a redesigned floor layout with/without the adoption of automation. Under automation, labour productivity improved by 16%. A cost-benefit analysis was also conducted to evaluate the economic feasibility of automation. Last but not least, this study can help other time sensitive and perishable service firms to consider using the traditional VSM redesign as part of the design thinking and lean engineering to improve their workflow, reduce waste in travel and waiting, and lift the productivity of existing operations.

References

Due to the constraint in space, the references are available from the authors on request.