Effects of an increasing the work force on an assembly line for an original equipment manufacturer

Abstract

An original equipment manufacturer has forecasted for demand for their product to expand rapidly over the coming years. Once main factor explored in keeping up with demand is the increase in assembly work force. Research data was collected on the time taken to complete each task in the assembly process. These times were then turned into flow rates and put through a simulation to obtain processing times and costing for differing numbers of assembly workers. The cost of manufacturing each adaptor was also found to only change slightly when increasing the work force. These findings dictate that the key driver for decisions on scaling supply to meet demand in the business should be processing time for each adaptor It was found that there is an exponentially decreasing relationship between processing time and increasing work numbers. For low demand this means there is a high benefit from increasing the work force and for high demand there is little benefit in increasing the work force to reduce processing time. Exploring different queuing models and improving employee feedback systems have been considered as the next steps of the practical application of these findings into the business.

ENGN2226 Research Portfolio Coversheet

Submission and assessment is anonymous where appropriate and possible.
Please do not write your name on this coversheet.

Student ID: U5673761

Portfolio Topic or Research Question:

Effects of an increasing the work force on an assembly line of an original equipment manufacturer

Analysis Tools
Place an 'x' next to each of the eight research methods and system perspectives you have engaged with:

	Research methods		System perspectives
X	R01: Research question	X	S01: Social & cultural
	R02: Surveys and interviews	X	S02: Safety & risk
	R03: Quantitative & qualitative	X	S03: Anthropometrics
X	R04: Data organisation	X	S04: Planning approaches
	R05: Research ethics	X	S05: Queue theory
	R06: Coding research data		S06: Process control
X	R07: Error types		S07: Control theory
X	R08: Descriptive statistics		S08: Material impact
	R09: Hypothesis testing - populations		S09: Energy-mass balance
X	R10: Hypothesis testing - categories		S10: Energy efficiency
X	R11: Simple linear regression	X	S11: Life-cycle cost
X	R12: Confidence intervals	X	S12: Payback period

Any comments to the reviewer

Contents

Motivation: Business Context

A business specialising in automated livestock medication and vaccination devices is currently working on expanding their manufacturing capabilities due to recent expansion into the American Market. Current Australian customer base has required the assembly of roughly 20 adaptors per month, where recent customer base in America has required in excess of 100 adapters within a few weeks (Edwards D., personal communication, 2016). If the current success in the US market is anything to go off, the business is looking to increase manufacture to keep up with demand (Edwards D., personal communication, 2016). The business needs to consider what improvements need to be made to current practices and the most economical way to make them.

Currently there is one employee working part time dedicated to the assembly of adaptors which currently takes around 35 minutes to assembly one adaptor. At the current pay rate of $25/hr this equates to $14.50 per assembly of each adaptor (Edwards D., personal communication, 2016). Although reducing this number is not a clear cut task. Given constraints such as; restrictions in workshop floor space, dependencies in assembly procedures, cost of labour and further complexities around business growth. Exploring the relationships between these factors will allow the business to understand the best actions to take for a particular stage of growth. From this a research question has been crafted to act as the framework for the portfolio;

"How does increasing the work force of the assembly team effect cost of production?"

Taking the theme of business growth, the topic of increasing supply was identified as a main concern. The focus of increasing workforce while maintaining cost effectiveness of assembly provided the greatest opportunity for improvement.

Device Mechanics

Currently their main product is made up of a hand held device that drives a plunger through an expendable attachment. This attachment is referred to as the medical adapter, as is attached to medication though a non-return valve. The device drives the plunger down the adaptor body to perform the injection action then as it retracts, medication refills the chamber ready for the next injection (automed, 2016).

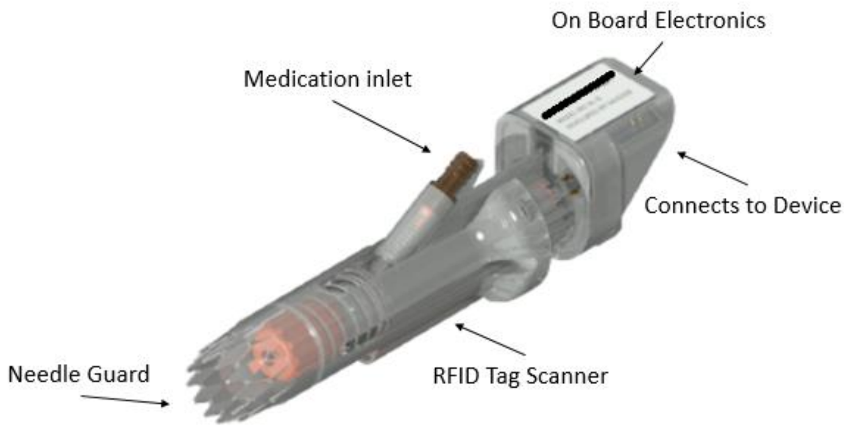

Figure 1: Livestock Medical Adapter.

Device Assembly and Manufacture

This device is assembled in two parts, the main body and the device connector. The main body which contains the medication chamber and on-board electronics that interface with the RFID antenna and the reed switch. The connector is the second part, which contains the PCB that connects with the main device which enables data collected from the adaptor to be sent to the device. The two parts are then glued together then a range of quality assurance testing is performed. Once the adaptor passes all quality assurance tests, the adaptor is packaged and ready to be shipped to the customer (Edwards D., personal communication, 2016).

Approach

The problem at hand contains a wide range of factors that are continuously changing in line with forecasted business growth. As Adaptors sales are expected to increase, labour dedicated to device manufacture must also increase. The amount of time dedicated to assembly is also an important factor as the businesses ability to reduce lead time of a product is important for overall retention and customer growth. Due to this predicted change in dynamics over time, a number of growth scenarios will be analysed regarding the number of adaptors required from business clients. For this analysis the number of adaptors will be as follows;

Table A: Growth Scenarios.

Growth Scenario	Adaptor Number
1 (current)	20
2	50
3	100
4	500
5	1000
6 (forecasted)	5000

Systems perspectives will be used to further define the system of assembly processes and constraints. Modelling will take place incorporating these constrains to understand the most advantageous worker number for a given growth scenario. Cost benefit analysis will be then being performed finding the relationship between adaptor build capacity, cost effectiveness and lead time. Recommendation's will then be made incorporating the results from the modelling and other relevant factors.

Data Collection

To properly model each assembly step, data was collected on the time taken for each assembly task twenty times. Each assembly process was completed by one casual employee and one part-time employee with experience in assembly. The interval of recording was taken from the moment a worker finished one task and started on the next one. This will eventually inform planning approaches and a dynamic model of the assembly procedures, although a number of considerations must be taken when handling this data to ensure overall accuracy and confidence in modelling. Data organisation standards were implemented to ensure records were traceable for reference and in case of error. Each entry was given an ID for the steps containing who recorded it and what record it was from. Each separate step was recorded in a different row depending on the step.

Errors

Time data collected consisted of two workers with varying skills and experience within the given tasks, which in turn could over-estimate the amount of time taken to perform certain steps. This is consideration falls under the theoretical concept of a learning curve, where the time taken to perform a task is decrease as a function of the repetitions of that task (Staats et al., 2011). This potential error can be illustrated in the figure below;

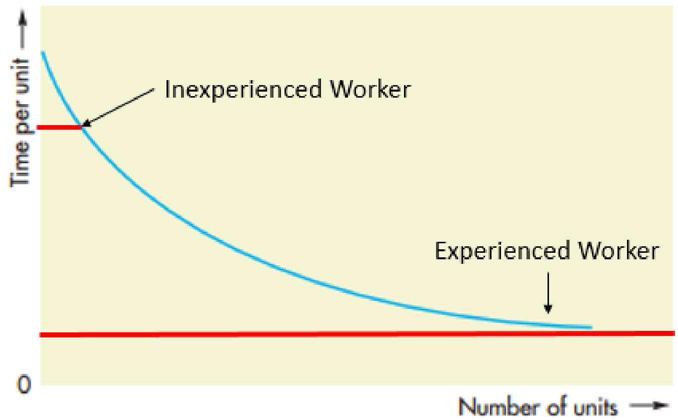

Figure 2: Learning Curve: Comparative between experienced and inexperienced workers.

In the context of the data collected and the observed variance in the data, this would only equate to a between 30 to 60 seconds over the course of the assembly. Accounting for the assembly of 1000 adaptors with up to 8 workers, an over estimate of time taken for a step could result in an error by;

$$Error = workers * estimated\ error\ in\ step * number\ of\ devices * pay\ rate\ (\$/s)$$

$$Error = 8 * 60 * 1000 * \frac{25}{3600} = \$3333.33 \quad (1)$$

This error was handled by allocating simpler tasks such as soldering and screw assembly to the more inexperienced worker. More complicated and critical tasks were handled and timed by the more experience worker.

Non-sampling errors include the occurrences of added complexities to a given task. Some tasks, if not done correctly require back tracking and thus more sub-steps must be added within the task. The inclusion of these data points increases the average time taken for a task, which again would have an accumulated effect of over estimating the cost of assembly. A common way of eliminating this type of error is via the collection of more data points (Hilborn, 2012), although due to data collection constraints, confidence intervals of two standard deviations will be used to adjust average times.

Table B: Adjusted mean by taking into account confidence intervals.

Step	Description	Mean (s)	Adjusted Mean (s)	Difference (s)
1	Place pins in the connector holes	301.7	291.2	10.5
2	Solder pins to PCB	73.9	67.7	6.2
3	Glue RFID antenna to adaptor body	85.4	79.4	6.0
4	Solder Reed switch to auxiliary PCB	101.9	101.9	0.0
5	Solder RFID antenna to auxiliary PCB	141.3	136.6	4.7
6	Solder Header pins into auxiliary PCB	86.4	79.4	7.0
7	Glue adaptor Body and adaptor connector together	272.8	271.6	1.2
8	Solder Header pins to connector PCB	111.9	106.6	5.3
9	Glue tube barb to top adaptor chamber	169.8	169.8	0.0
10	Attach magnet to needle guard	105.3	92.4	12.9
11	Assemble injection nipple and screw lock	29.9	30.2	-0.4
12	Program Adaptor PCB	13.9	12.1	1.8
13	QA testing	240.5	238.1	2.4
14	Glue PCB cover to adaptor connector	58.0	53.5	4.5

15	Packaging	34.9	34.9	0.0
	Overall time (s)	**1827.3**	**1765.2**	**62.1**

Taking into account values within the confidence intervals has provided little change in individual steps, although the accumulated decrease in overall processing time is substantial when calculating a time value for the large expansion scenario, also demonstrated in equation (1).

Modelling time variance: Stochastic and Non-Stochastic process

The set of times captured for each step has an associated variance around a calculate mean. This mean and distribution have significant consequences regarding how each step is modelled as a flow rate during the queuing simulation. Data sets demonstrating signs of fitting to a distribution are more appropriately modelled as a non-stochastic process (Knill, 2009) (one that has a constant rate with no randomness), as the mean of the distribution will accurately represent all results over a large period of time. For a data set that does not show any signs of fitting to a distribution, there is no evidence that the mean of the set will most accurately reflect the times captured and should therefore be modelled as a stochastic process (Knill, 2009) (one that has a constant rate with no randomness). In order to test if each data set fits inside a particular distribution, hypothesis testing will be performed on the likelihood of each set fitting a distribution. Traditionally hypothesis testing is formed around the assumptions that set data will fit a normal distribution (Massey, 1951), although these same set of assumptions will not be adequate for the collected data. Visual inspection of some data sets indicates that distributions might be skewed towards the left or right. Skewness calculated for all data sets also indicates that a p-test for a normal distribution will produce errors in the results (Massey,1951).

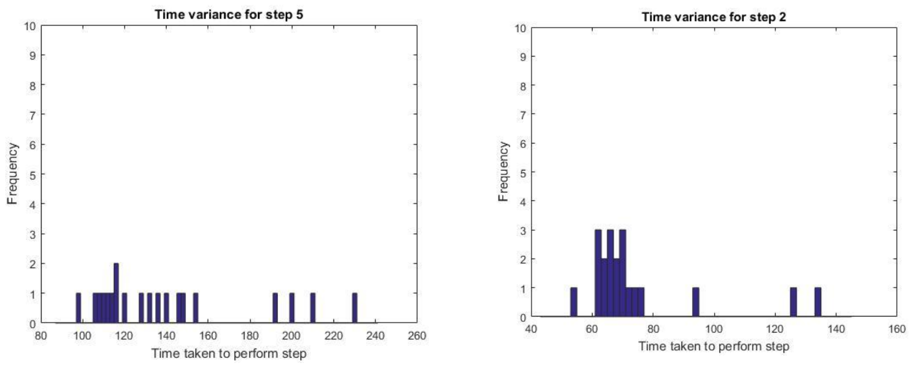

Figure 3: Visual representation of skewness in data sets for step 2 and 5.

The Kolmogorov-Smirnov test is a non-parametric probability test that compares a two given data sets and calculates the probability the two given samples follow the same distribution (Massey, 1951). The suitability of this test to the application is that is does not rely on the data to follow a normal distribution as with the p-test (Massey, 1951; Knill 2009). The recorded data set for each step will be compared against an artificial distribution found using descriptive statistical calculations for the sets. The mean, standard deviation and skewness were all calculated to create a distribution to compare each set with.

H_o: The data does not fit the distribution within a 5% significance level.

H_a: The data does fit the distribution within a 5% significance level.

Results

Table C: Hypothesis testing results for the Kolmogorov-Smirnov test.

Step Number	1 - Rejects null hypothesis 0- Accepts null hypothesis	P Value
1	0	0.137997
2	0	0.067494
3	0	0.414687
4	0	0.137997
5	0	0.252748
6	0	0.137997
7	1	0.011607
8	0	0.137997
9	0	0.252748
10	1	0.029572
11	0	0.252748
12	1	0.029572
13	0	0.252748
14	0	0.067494
15	0	0.137997

Analysis shown in table C shows that steps 7,10 and 12 all fit a given skewed distribution within a 5% confidence level. This aligns with the established complexity of these steps and the potential for each task to be extended. The steps that have accepted the null hypothesis will be modelled as a Poisson process flow rate within the MATLAB environment. Steps rejecting the null hypothesis will have their flow rate modelled as a constant as $steps\ completed/hr$.

The Model: Problem Constraints

The current workshop consists of a work bench 8.5mx1m for adaptors to be assembled thus limiting the number of people working at one time. Anthropometric measurements must be considered as the ergonomics of a workstation is critical to worker health and productivity (Deros et al.,2011; Safe Work Australia, 2009). In a study undertaken at a large automotive manufacture, recommended working distance for the arms at a stand up distance to be able to extent and rotate the forearm laterally from the should from a resting position (Deros et al.,2011). As the business currently does not have dedicated assembly workers employed, data was taken from the 95th percentile from American male populations. As male measurements are typically larger than female, this allowed the avoidance of under estimating the amount of room needed. Anthropometric data is also significantly lacking for Australian populations, although studies suggest that they are comparable with American populations (Ward, 2011).

Table D: Anthropometric data for worker capacity in workshop (Sourced from: The Anthropometric Survey of U.S, 1988).

	Forearm–Hand length (cm)	Space needed for worker (width) (cm)	Length of workbench (cm)	Number of workers	
Male (95th)	52.42	~ 105	850	8.0952	8

Values noted in table B have been used to inform capacity of the workshop. 8 workers are at the maximum capacity of the workshop. This number will be used as a maximum worker number in further analysis with queue optimisation.

Worker Safety: Risk Analysis

As a business in Australia, OH&S standards must be adhered to for a healthy and productive workforce. This is particularly relevant to manufacturing and assembly work as a study released from the Safe Work Australian shown that work related injuries in the manufacturing industry were found to be 26% higher than the average injury rate on Australians (Safe Work Australia, 2009). A risk assessment has been performed regarding potential hazards of adapter assembly.

Table E: Health and Safety risk assessment.

Risk	Hazard	Likelihood	Control
Standing for long periods	**Short term:** Muscular strain, **Long term:** Inflammation of veins, chronic joint pain in knees and hips, damage to tendons and ligaments.	High	**Substitution:** Purchase workstation seats. **PPE:** Purchase Anti-Fatigue mats
Exposure to Solder fumes	**Short term:** Irritation to nose, throat and respiratory organs. **Long term:** Occupational Asthma, injury related leave and compensation.	High	**Elimination:** Purchasing of a spot suction ventilation system. **Engineering Control:** Place soldering station next to the garage door, keep garage door open whilst soldering. **PPE:** Ventilation masks, safety glasses.
Exposure to high temperatures, Heat gun, glue gun and soldering iron.	Lack of a visible flame can create a false sense of security or false impression of safety, filament may lead to fire and/or explosion, Burns	Medium	**Isolation:** Heat gun station to have flammable materials removed. **Engineering Controls:** Fire Extinguisher installation in the workshop. **PPE:** Heat protection gloves, safety glasses.
Poor posture at assembly station	Muscle strain, lower back pain	High	**Admin Control:** Provide awareness training, Encourage short breaks every two hours.
Exposure to Chemicals from scotch-weld glue	Acute Toxicity (oral), Eye irritation/damage, respiratory damage, skin damage	Medium	**Engineering Controls:** Design Change to eliminate the use of glue **PPE:** Heat protection gloves, safety glasses.
Fatigue	**Short term:** Decreased ability to perform critical tasks, reducing quality, **Long term:** Mental Health issues, high blood pressure and other health related issues.	Medium	**Admin Control:** Encourage short breaks every two hours, ensure workers are taking entitled breaks during a shift.

Through the risk assessment demonstrated in table E, a number of re-occurring practices have been mentioned for the business to consider for the protection and elimination of these risks. Providing Personal Protection equipment including; gloves safety glasses and face masks have all been noted as necessary to lower the risk of exposure to chemical and high temperature operation equipment. Nonfatigue mats and seating would also reduce the risk of injury due to standing up and sitting down, in fact in a study undertaken by Safe Work Australia, it mentions that a combination of standing and sitting tasks during a work day reduces the risk of injury from either of the actions (Deros et al., 2011; Straker,2016). Risks that can be eliminated by more than one action such as the purchase of a spot ventilation system for the soldering station or placing near a well ventilated area will be analysed due to their costings. As the number of assembly workers increase, there is an associated cost for PPE equipment and other safety gear. How this cost effects the bottom line of the business will be explored further in lifecycle analysis.

Breaks during a working shift have also been identified as an important factor in reducing injury and fatigue. Set working hours for assembly workers in the business have not been decided yet (Edwards D. personal communication, 2016), although the National Union of Workers (NUW) suggests some additional complexities when managing employees during irregular working hours (NWU,2000). Working outside the normal working hours adds heightened risks to fatigue and injury and thus would need to be managed with particular caution (Cully, 2015; Safe Work Australia, 2013). Thus for the purpose of this model, a standard working day will be considered between the hours of 9am - 5pm with one hour dedicated to breaks. Thus 7 hours of productive work within an 8-hour day.

Modelling Dependencies: Planning Approaches

To accurately model the queuing process of the sequence of each step, dependencies must first be studied within the assembly procedure. Is modelling will eventually accommodate for up to 7 workers in the process, it is important to understand where they will fit into the assembly line. A PERT chart was created to understand dependencies.

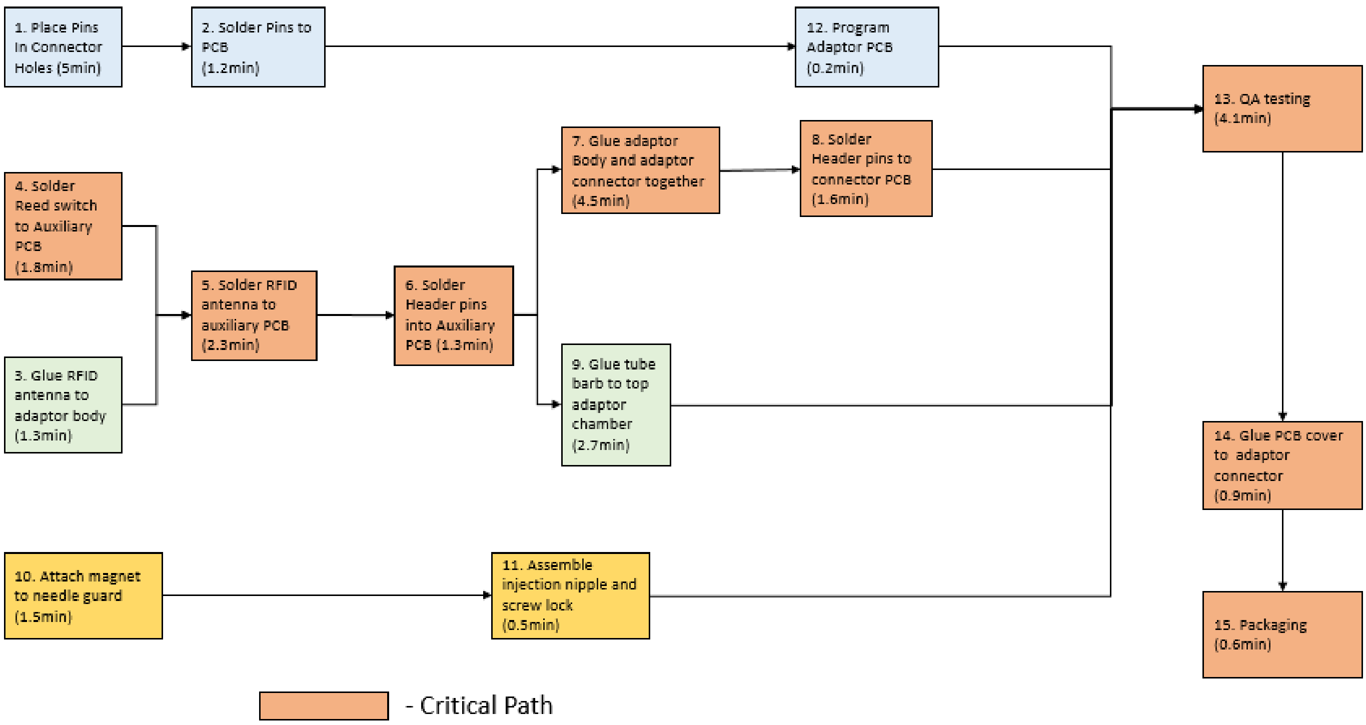

Figure 4: PERT chart of adaptor assembly process. TO DO: Change to identify critical path

The PERT chart shown in figure 4, illustrates the dependencies in the assembly process. Steps 1,4,3 and 10 can all be started immediately, whilst all other steps are dependent on the previous step noted by the arrow. The four independent steps listed above suggest that consideration must be taken to harness the maximum possible capacity of workers. Initially in the process 4 workers will be utilised leaving at worst case another 4 worker underutilised. This is a situation increases overall cost of assembly while not improving productivity by the increase in workers. To handle this dynamic in the problem, underutilised workers will be paired to complete the same tasks in parallel. Extra workers will be prioritised to work parallel on step 1 as it is the step that required the most amount of time. The critical path of the assembly process rides from steps 4,5,6,7,8,13,14,15 sequentially. This results in a minimum time of ~ 17 minutes to complete for one person. If two people are utilised on this path this time could be cut in half, assuming the linear relationship between worker number and processing time. As steps 13-15 are dependent on all other steps being completed for assembly, thus all workers in the assembly line can potentially be utilised to complete steps 13 and onwards. These insights have been summarized below.

Table F: Workforce Utilisation

Worker Number	Utilisation and Allocation to Assembly steps.
1	Worker will perform steps 1-15 sequentially.
2	Workers will be allocated to steps 1,3,4, then the next available step once the current task is completed.
3	Workers will be allocated to steps 1,3,4 then allocated to the next available step once complete.
4	Workers will be allocated to steps 1,3,4 and 10 then allocated to the next available step once complete.
5	Workers will be allocated to steps 1,3,4 and 4 then allocated to the next available step once complete.
6	Workers will be allocated to steps 1,3,4 and 4. The 5th and 6th workers will be allocated to steps 3 and 4. Then allocated to the next available step once complete.
7	Workers will be allocated to steps 1,3,4 and 4. The 5th and 6th workers will be allocated to steps 1, 3 and 4. Then allocated to the next available step once complete.

Simulation outcomes: Queuing Perspectives

Parameters of the queuing process have been identified through planning approaches, risk analysis and anthropometric analysis. These constraints have been implemented to simulate the completion time of each step and as a consequence the number of adaptors to be assembled within an 8-hour shift within the MATLAB environment. The time taken for each step to be completed has either been modelled as a stochastic or non-stochastic process based on Table D. This has been done using the `poissrnd` function in MATLAB to model stochastic steps and `mod()` function to model non-stochastic steps (MathWorks, 2016). Table E has been used to allocate each worker to the respective step for completion.

Methodology: Implementing Queuing theory.

Dependencies and worker assignment were modelled within the MATLAB environment. As steps initially as independent steps workers were assigned to them based of availability within the worker pool. Workers would be assigned to a given step until a predefined number of these steps were completed. This number is the defined number of adaptors to be made within the given simulation time.

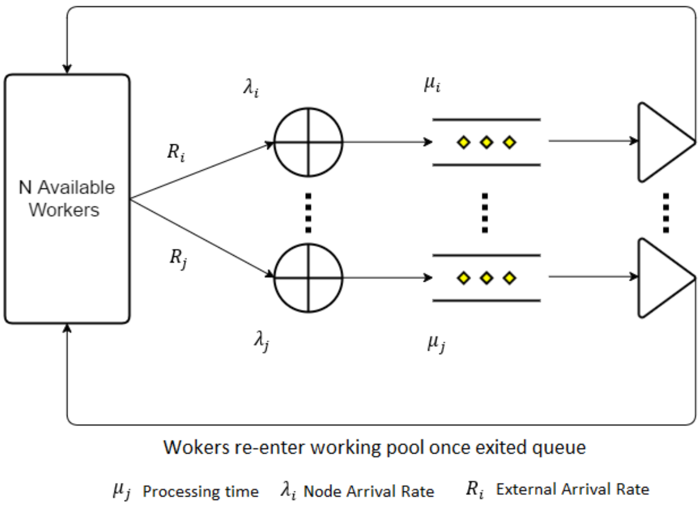

Figure 5: Queuing process for Assembly in the simulation.

The queuing dynamics can be explained through the diagram in figure 5, where λ is the node arrival rate, which is the processing rate of each step. The External arrival rate R is based upon the workers available and node arrival rate that comes up first. Processing time μ can be expressed as $\mu = \lambda\,(length\ of\ queue)$. This model of queuing is an extension of the first in first out method where traffic in the queue is assigned to the next available processing station (in this case assembly step) (Gross, 2008).

Limitations of the Model

For this simulation different queuing methods other than the one illustrated in figure 5 have not been explored. Methods such as custom and priority queuing are designed to deal with systems known to have multiple channels where some have longer processing times than others (Gross, 2008). similarities could be drawn to potentially prioritising all workers to the critical path (figure 4) to reduce the minimum assembly time for one adaptor or allocating a step a priority based on the amount of time taken to perform the task (more workers assigned to steps with longer processing times). There is potential to explore further improvement by changing queuing methodology, although the current configuration implemented through the MATLAB model provides an adequate comparative against each worker configuration and growth scenario.

Results of the Model

Figures below illustrate the comparative behaviour of each work force size and the duration to assemble for each growth scenario.

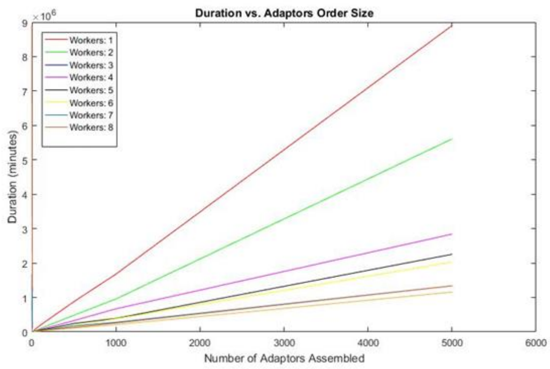

Figure 6: Worker assembly capability.

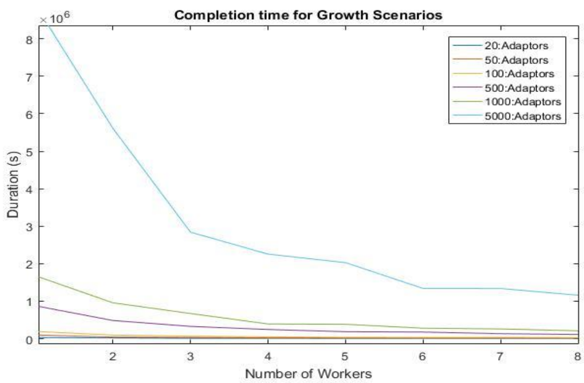

Figure 7: Completion times between Workers.

Table G: Residuals for duration of worker number and growth scenario.

Worker Number	Growth Scenario					
	20	**50**	**100**	**500**	**1000**	**5000**
1	0.0	0.0	0.0	0.0	0.0	0.0
2	50.3	52.9	48.9	52.4	51.7	48.1
3	30.4	25.3	33.9	33.7	33.4	33.9
4	22.2	29.4	23.4	21.1	25.5	25.1
5	12.1	9.9	17.9	19.8	19.9	20.0
6	10.8	18.3	19.5	17.1	16.5	9.3
7	11.1	22.5	10.6	13.9	9.8	19.5
8	4.1	-2.9	6.5	10.6	17.3	16.3

Figure 6 illustrates a linear relationship between the number of adaptors assembled and overall duration for each worker configuration. Although Figure 7 suggests that high leverage advantage can be taken from increasing the number of workers. The residuals in table G shows that the duration of adaptor assembly is cut in half when going from 1 to 2 workers. This cut in duration steadily decreases as the worker number increases suggesting that a there is potentially a lower limit to the how much the duration of adaptor assembly can be cut down. This is reflective of the critical path of assembly demonstrated in figure 4. There is very little benefit of increasing workers within the 6-8 region for reducing the overall duration of assembly, where the greatest advantage can be seen within the range of increasing workers between 1-4.

Cost Analysis: Life Cycle

The data gathered in the modelling process is to be weighed against the practical considerations of employee management. Risk analysis of the assembly process has given a number of actionable items for the business to purchase in order to maintain OH&S standards within the workplace. Training has also been identified as an important part of maintaining a safe work place and particularly important within the manufacturing industry which is reported to consistently more on safety training on their employees (Cully,2015; Safe Work Australia, 2015). As the business is currently operated locally, materials in the Acquisition section will be sourced from local hardware suppliers. Costings in the production section are already pre-defined from previous purchases and are thus taken from current suppliers.

Life cycle costings in the Acquisition and Production phases have only been considered in the analysis. Although the business does provide a considerable amount of in field support for users of the product, the responsibility within a different department of the business. The aim of this analysis will be to draw costings and figures associated with each number of assembly workers such that a comparative can be made between each worker configuration and growth scenario.

Table H: Cost Break down within the Acquisition and Operation phases of the product.

		Cost	Source
Acquisition			
	Anti- Fatigue Mats (per person) (90cmx120cm)	$105	Clark Rubber
	Ergonomic Chairs (per person)	$119	Bunnings
	PPE: heat resistant gloves (pk of 12)	$51.98	SETON
	PPE: Safety glasses	$7.50 ea.	SETON

	PPE: Respirators	$4.98 ea.	Bunnings
	Employee Training (person/ year)	$1000 ea.	Department of Industry, Innovation and Science (Cully,2015)
	Materials for adaptor build per adaptor (Disclosed information)	$ 23.13	Automed data base
Production			
	Employee wages ($/hr)	$25/hr	Automed Assembly Employee Contract.
	Glue gun sticks (1 stick per 20 adaptors)	4.98 10 pk.	Bunnings
	Scotch weld glue (1 cartridge per 20 adaptors)	$52.41 ea.	Blackwood's

Costings represented in Table G have been sourced from local and current suppliers of the business. Acquisition prices will be built into the pay pack period model as initial up front costings and will vary depending on the number of workers. Safe work Australia recommends business to actively maintain stock levels of PPE for workers (Safe Work Australia, 2015; Barton, 2013). Although there is no suggested number value for this, at least 2 extra sets PPE equipment will be kept for all worker configurations and built into the payback period model. Costings for the materials for adaptor build are likely to change significantly over time as the design is refined and cost is reduced. Although in consultation with the business, is has been established that there is no accurate way to account for the reduction in cost and associated R&D expenditure and will therefore be kept as a constant rate. Current inflation rate in Australia has been averaged to between 1-2% per annum over the last year (RBA, 2016). Although this rate dynamically changes year to year, it will be assumed that inflation will be set to 2%, the Royal Australian Banks current targeted rate (RBA, 2016). Inflation will be added per annum within the payback period model.

Cost Analysis: Pay Back Period

Costing identified in Life-cycle analysis and income will be modelled as the following;

$$Cost = Aquisition + [(materials + production\ cost) * prodctuion\ rate + wage * worker\ numer\ ] * time$$

$$Income = Profit\ from\ Adaptor\ Sale * Adaptor\ processing\ rate * time$$

Choosing an Adaptor processing rate.

Within each worker configuration data collected from the simulation results indicates a range of processing rates for each growth scenario, found by; $processing\ rate = \frac{Duration}{growth\ scenario}$. Figure 5 suggests a linear relationship between growth scenario and duration and therefore a constant processing rate for each worker configuration although calculated processing rates indicate a range of up to 320 seconds. This is a prime example of a heuristics problem experienced when performing simulation with random processes (Trumf,2016). Ten iterations of the simulation have been performed so that average processing times can be calculated and used for further analysis.

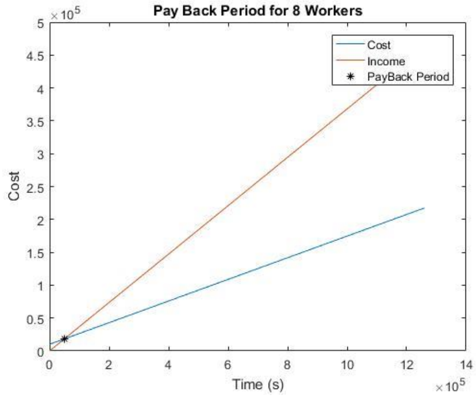

Figure 8: Pay Back Period for 8 workers.

Results

Table I: Pay Back Period for Worker Configuration

Worker Configuration	Pay Back Period (Hours)
1	12.07
2	11.50
3	11.9
4	12.0
5	12.7
6	13.0
7	12.9
8	13.7

Payback period for all the worker configurations are considered to be highly comparable taking into account costings within the acquisition and operation stages of the product. The range between the pay back periods Table H is between two hours, which is little difference between the workers. Therefore, there is no observable advantage between the worker configurations from taking into account costings within the acquisition and operation phases of the product life cycle.

Further Costings

Payback period calculations shown in table H contain some major limitations due to sections of the typical product lifecycle being left out of the costings. Costings in use, design and disposal are all considered to be major contributors to the cost break down structure and thus would extend the payback period for all worker configurations. Testing and further quality assurance are also seen to be large contributors to the cost analysis (Fabrycky et al.,1991). As a new product goes to market, measures are usually put in place to take into account new iterations of design that comes with user feedback (Kanh, 2013). In some cases, this can affect overall cost of materials, change assembly steps and production rate and also add additional cost for design. Although there is no evidence to suggest that the aforementioned costs have direct relationship with the number of workers in the assembly line other than extending the payback period. These factors are to be taken into account for future cost analysis.

Relationship between Lead Time, Assembly Cost and Workforce: Regression Analysis

The relationship between Processing Time, Worker Configuration and Assembly Cost and worker configuration have been explored through the use of regression analysis. Regression modelling with multiple polynomials have been explored in order to find the best fit for the data. By fitting the data through regression modelling there is a trade-off between expressing relationships with simplicity and expressing them with accuracy. The higher order polynomials will fit the data more accurately though express the relationship in a more complex manner. It is a general standard that if a polynomial fits the data with a 95% confidence, it is considered a good fit to the data (Mcdonald,2015; Trumf, 2016). This rule will be used to visually inspect these relationships and select the best fitting polynomial. Regressing modelling has been performed using the $fit(\,)$ function within the MATLAB environment (MathWorks, 2016).

Regression Modelling

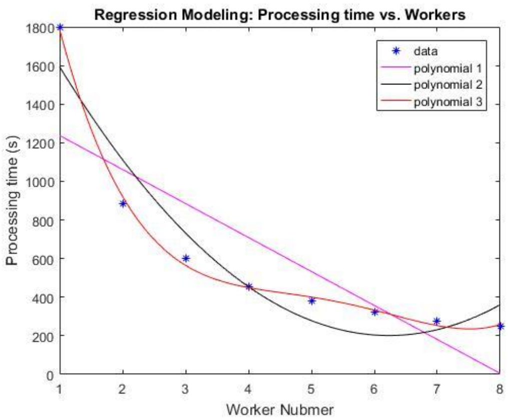

Figure 8: Processing time.

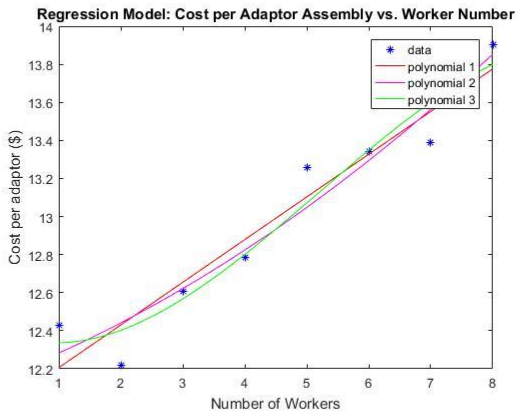

Figure 9: Cost of Assembly per Adaptor.

$$Processing\ time(Adaptor/seconds) = 3.79W^4 - 82.37W^3 + 653.5W^2 - 2306W + 3518$$

$Cost\ per\ Adaptor = 0.2243W + 11.98$ W: Number of Workers

Further Considerations: Social Perspectives

The relationships that have been formed from regression modelling can be extrapolated for future use and forecasting within the business to ensure that the amount of assembly workers are correct to meet current demands. Although it is important to consider the role of the employee within this dynamic and provide channels for workers to give voice on whether the results shown in the analysis are in fact reflective of the actual working environment. Management relations with employees has been widely acknowledged to have large impacts on morale and performance of the workforce (Behm 2009; Ahmad, 2001). As channels are opened for employee feedback and suggestions are welcomed, there is even evidence that OH&S performance is improved in the workplace (Behm, 2009). Workplaces even incorporating employee wellbeing into their OH&S policy are regarded to reduce sick leave and workplace injury (Safe Work Australia, 2015; Behm, 2009). Incorporating these factors into the relationship between employee and manager is vital to using the analysis in a useful manner.

In this case a majority perspective can be seen as operations and management, which is mainly where this analysis is of interest. The regression models potentially assist operations managers forecast, budget and keep track of production which is delegated out to assembly workers. The minority perspective can be seen as the assembly worker, where the quotas given to them by operations might underestimate the given time for assembly and therefore creating stress to reach unrealistic deadlines. Given this potential dynamic the analysis in this report can either be a useful or harmful tool in equipping the business to handle supply and demand into the future. This gives even greater reason for enabling channels through for operations staff and assembly employees.

Recommendation's

Throughout the following analysis data from the assembly line has been taken and processed to produce a model that has produced data regarding the processing times of varying worker force sizes and growth scenarios stated in table A. Cost analysis was then performed to analyse the behaviour between work force size and cost of assembly per adaptor. Results have been captured and presented throughout the report on the differing behaviour of the assembly system. Actions that the business takes are thus dependant on the stage of growth, sales and what is valued at a particular time based on management decisions. Recommendations have thus been made based on the best configurations for a given situation.

Recommendation 1: Worker Configuration for the lowest cost.

Cost analysis of the assembly system has shown no clear advantage for the cost benefit for different worker configurations. Regression modelling has shown a linearly increasing relationship between work force size and cost per adaptor (figure 9). Though as the gradient of the line is considered quite small ($0.2/worker) this relationship might be less significant for lower production needs. The relationship will become more relevant as production of adaptors approaches the forecasted rate of 5000 were $0.2/worker will become a significant cost over the assembly process. It is recommended that the business used this relationship as a deciding factor when deciding on work force size if processing time is a priority.

Recommendation 2: Worker Configuration for the shortest processing time.

A worker size of 8 has resulted in the lowest average processing time of 4.2 minutes per adaptor. There is little advantage in increasing the worker size between 7-8 workers where the processing time for a work force of 7 is 4.1 minutes per adaptor. The business is also to consider the growth scenario that current demand is most suited to. For lower growth rates there is a clear advantage of having 2 assembly workers as appose to 1 and again a significant reduction in processing time by increasing the worker force to 3. For higher growth scenarios there is less of a clear advantage for the reduction in processing time by increasing the work force.

Recommendation 3: Managing the relationship between employee and management.

In light of the results of simulation and modelling in this report it is recommended to the business that assembly employees are consulted on the use of the modelling to forecast assembly times. Feedback measures are also to be put in place for employees to comment regarding the accuracy and feasibility of the models presented in this report.

Next Steps

A number areas of further work have been established throughout the analysis to further validate results in this report and also to again more accurate numbers from the assembly system. Different queuing models are of interest to explore in relation to how they might decrease processing time of assembly. Priority queuing is of particular interest in its potential ability to decrease time taken to complete the critical path of the assembly process. More data is also to be gathered on the time taken to complete each step. Data processing in this report allowed for the characterisation of each process, though collecting more samples would help substantiate these claims or come to more accurate conclusions about step times. Costing analysis in this report failed to include key areas of the use and design phases in the product life cycle. Costings from these areas are to be incorporated into the current model to give a more useful and accurate figures to be used in budgeting. Regression models that derived from the simulation is also validated through the current real time forecasting of budgets and assembly employee feedback.

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