Department of Engineering

2023-24

Business and Operations Management

Business and Manufacturing Operations Plan

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Abstract

The development of a new production line manufacturing high quality footballs to FIFA specifications in terms of weight, circumference, roundness, bounce, water absorption, loss of pressure and size retention requires the development of a sound business and manufacturing operational plan. The principles of lean manufacturing have guided the plan with the aim of delivering efficient and effective processes which maximise value to the business. Following extensive research into football manufacturing, process mapping has been used to develop an efficient, parallel manufacturing process showing estimated timings, sequential order and precedence relationships before being combined into the final product. Consideration has been given to the resources required to balance labour productivity with cost efficient use of machinery. Based on forecasted demand, the report identifies optimum shift patterns for the eight employees during the first eight weeks of operation. The development of production process parameters has been instrumental in calculating Key Performance Indicators (KPIs) and determining process capability. Takt time has been calculated to understand the available production time based on demand in the first week. Multifactor productivity has been used to assess the efficiency of production. A P chart has been developed to identify the proportion of nonconforming products compared to a predetermined acceptable level. The balancing of the production line has been demonstrated through the development of a precedence diagram, whilst critical path analysis is used to understand the longest sequence of production tasks that could impact on timely delivery. This has led to the development of a proposed grouping of work stages to support the delivery of efficient operations.

In order to meet the variable demand over the eight weeks of production, the plan recommends a parallel manufacturing process with a branch for bladder production and a branch for panel cutting / preparation before they combine to form the final product, with the critical path being the process for panel making. Analysis shows the best compromise between machines and labour is to run a single eight-hour shift pattern with 60 minutes lunch and 30 minutes break a day. In terms of machines, to ensure employees continue to work efficiently, four machines are the best trade off as the cost is lower and can be achieved with the proposed shift pattern, with overtime being used in week one to meet peak demand. The production line has an efficiency of over 85% which is deemed acceptable. The costs base shows fixed costs of £88k, with variable cost of £10.81 per unit produced were used along with market research to determine a sales price of £35. The production breaks even after 3648 units are produced which means profit is generated within the eight weeks of the project. The in-depth research into the manufacturing of footballs led to the decision to run parallel manufacturing processes which has contributed significantly to the efficiency and profitability of the production.

Business and Manufacturing Operations Plan

Business and Operations Management

Introduction

This coursework is being carried out by Will Thompson and Aditya Milind Naik where the basis for it is the establishment of a new production line dedicated to manufacturing footballs. The task involves developing a robust business and manufacturing operations plan to guide the initial eight weeks of operations. Utilising the ethos of Lean Manufacturing, the approach will forecast demand, optimise manufacturing processes, and ensure operational efficiency. From determining manufacturing process steps to fine-tuning production parameters and balancing the line, each facet requires meticulous attention to detail and strategic planning. The process methodologies include developing comprehensive process flow charts, analysing Key Performance Indicators (KPIs) and determining Process Capability. Furthermore, the plan will investigate production capacity estimation, employee scheduling, cost analysis, pricing strategies, and breakeven analysis to ensure a holistic approach to operations planning.

Forecasted Demand

The estimate forecasted demand for the product in the first 8-weeks has been given using the demand engine. The demand randomly generates forecasted demand for the footballs for five days a week over an eight-week period. Also, it randomly generates proportion of finished products in a day that comes out as defective after quality inspections. The results from demand engine are shown in figure 1. These show the demand over 8 weeks is 3680 units with a daily average of 92 units. The demand ranges from the lowest day in week four of 47 balls and the highest day in week one with 167 balls.

6E6Z0004: Business & Operations Management

Demand Engine

Step 1: **Enter your Team Members ID Number**
(must be 8 digits)

Student 1 ID	20030429
Student 2 ID	20025377

Step 2: **Select your Product option**
(between 1..6)

Product Option	5

Step 3: **Your individual Demand table(below) and Production Process Parameters(right) are shown**

Production Process Parameter	Units	Value
Downtime for scheduled maintenance per shift	*(in minutes)*	36
Materials cost per product	*(£ per unit produced)*	£2.72
Average energy and utility cost per product	*(£ per unit produced)*	£1.72
Average labour rate	*(£ per labour hour)*	£8.74

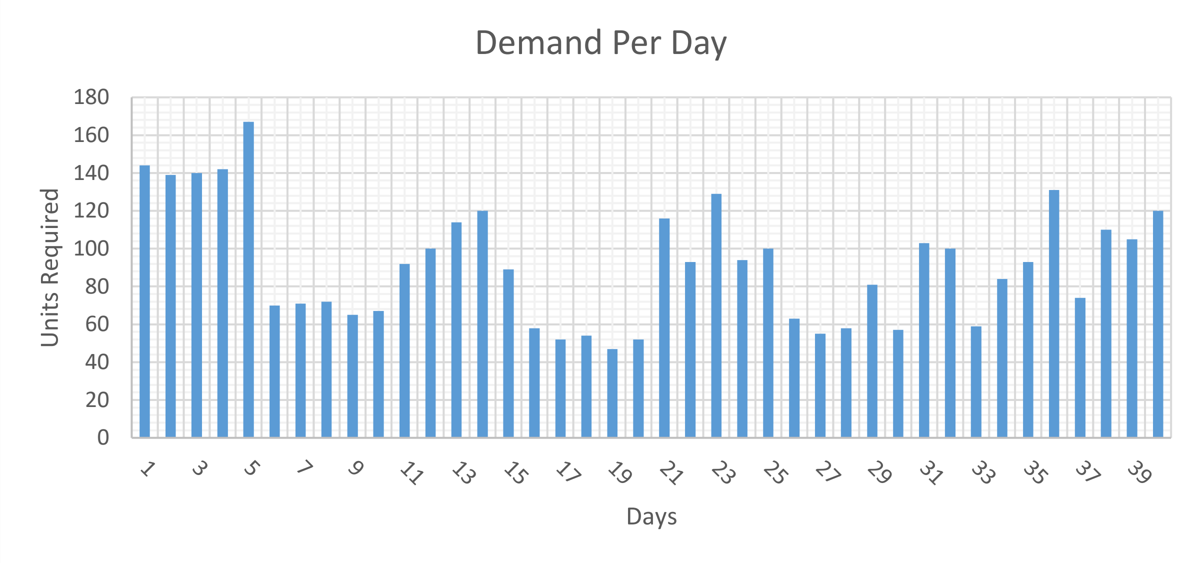
Individual Demand Table

	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		Week 7		Week 8	
	Demand	Defects	Demand	Defects	Demand	Defects	Demand	Defects	Demand	Defects	Demand	Defects	Demand	Defects	Demand	Defects
Day 1	144	0.037184	70	0.070046	92	0.008979	58	0.074081	116	0.086063	63	0.068365	103	0.086843	131	0.099329
Day 2	139	0.028660	71	0.070754	100	0.025294	52	0.051245	93	0.029533	55	0.028869	100	0.080195	74	0.002034
Day 3	140	0.029619	72	0.078358	114	0.067659	54	0.060432	129	0.097202	58	0.040451	59	0.000189	110	0.075303
Day 4	142	0.034194	65	0.035948	120	0.080645	47	0.033157	94	0.031308	81	0.099189	84	0.032383	105	0.058846
Day 5	167	0.081469	67	0.051704	89	0.005442	52	0.023285	100	0.047365	57	0.038760	93	0.062006	120	0.059292

Defects - proportion of defective finished products

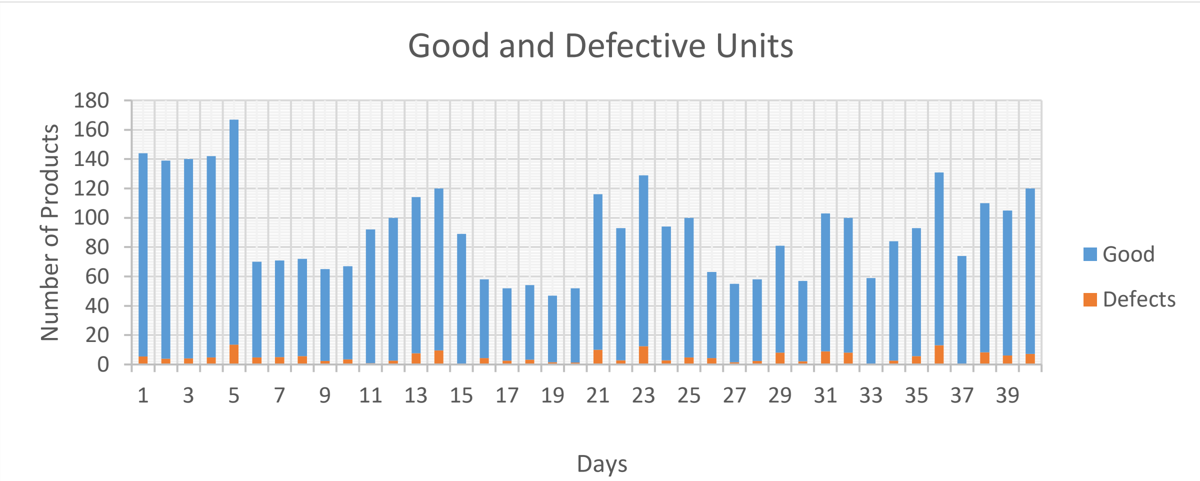
Figure 1 - Demand Engine Results

From the demand engine, a graph plotting the demand per day is created and shown in graph 1.



Graph 1 - Demand Per Day

The graph shows that demand in the first week is significantly greater than that of any other week, ranging from 25% - 65% higher than that of any of the other weeks. Graph 2 shows the portion of units per day that are defective.



Graph 2 - Total Units per Day

The master tables for the data of Graph 1 and Graph 2 are available in appendix 1.

Manufacturing Process

Manufacturing Process Steps

To determine the manufacturing process steps, in depth research was carried out. This consisted of various sources including a study of football production in Pakistan (Zaheer, 2019) which focused on process steps as well as videos which allowed determination to be made as to what types of machines were used. These videos include "How it's made: Inside the Mass Production of Football/Soccer Balls" (SatisFactory-Process, 2023) as well as a YouTube channel "Alex Wang" who is a machinery salesperson. The steps and timings in the table below have been derived from the research.

Step	Operation	Description	Mean cycle time	Labour	Tools / machines / equipment needed	Materials
A	Raw material from store.	The rubber bladders outsourced.	15 secs batch of 12	A	N/A	Bladder
B	Inflation of bladder.	The rubber bladder is inflated.	5 secs per bladder	A	Compressor	Bladder
C	Weight-checking of bladder.	The bladder is weighed to record volume of air.	5 secs per bladder	A	Scale	Bladder
D	Thread winding on bladder.	The rubber bladder is inflated.	30 secs grab 12,5 secs to set, 2 mins in machine per bladder	A	12 Slot Yarn Winding Machine	Bladder
E	Checking of bladder.	They are weighed to record volume of air.	5 secs per bladder	B	Scale	Bladder
F	Glue added on bladder.	A glue is attached to the bladder.	5 sec for hook, 5 secs glue batch of 6	B	N/A	Bladder
G	Glue Drying.	Put on heat conveyor where each bladder to 3-4 minutes to cure glue.	20 sec to place ball. Heat for 6 mins	B	Heat conveyor	Bladder
H	Inflation of bladder.	The glued rubber bladder is inflated.	5 Secs per bladder	B	Compressor	Bladder
I	Quality check.	The circumference of the bladder is measured.	10 secs per bladder	F	Circumference gauge	Bladder
J	Stamp synthetic leather sheet.	2 rolls are placed on top of each other and pulled through a stamp, panels are cut.	30 secs to collect 16 panels	C	Hydraulic cutter	Synthetic leather
K	Panels are screen printed.	Batches of 900 panels are arranged and screen printed.	Per panel 3 secs to lay 2 secs per print up to 5 times.	D	Screen print	Panels

			20 mins to dry 1 sec to collect = 900 Secs			
L	Panels are trimmed.	Using a stamp, the panels are trimmed to size and a hole put in one for valve.	10 Sec per 2 panels	E	Hydraulic press	Panels
M	Panels have glue applied.	Panels are covered in a heat activated adhesive.	Glue 2 sec, heat 1 min, collect 2 secs	E	Glue coating machine	Panel
N	Panels are arranged in hemispherical mould.	Pannels are arranged in a mechanised thermo-bonded football machine and removed after bonding.	30 secs to layout panels and balder, 6 min heat cycle	F	Mechanised thermo-bonded football machine	Bladder and Panels
O	Valve is attached.	Rubber valve is pushed through pre-cut hole.	5 secs per ball	F	Valve punch	Football + Valve
P	Ball finishing treatment.	Ball is placed in a ball shaping machine.	10 secs to place ball, 6 min heat cycle – 3 slots.	G	Ball laminating machine	Football
Q	Valve is trimmed and visually inspected.	The valve is trimmed away and then the ball is visually inspected.	10 secs to place ball, 6 min heat cycle – 3 slots	G	Snips	Football
R	Ball is packaged.	Balls are packaged.	5 secs per	G	Packaging material	Football
S	FIFA Quality Test.	Random units are taken for FIFA Testing.	Doesn't affect production time	H	Testing machines	Football

Table 1 - Football Manufacturing Process Steps

There are 3 different types of FIFA certifications that a football can gain. The three levels are FIFA Basic, FIFA Quality and FIFA Pro (IFAB, n.d.) and with the increase in quality, the balls can be sold for a higher price. For Step S, FIFA sets out a list of tests in order to gain a FIFA quality certificate which are as follows, Weight, Circumference, Roundness, Bounce, Water Absorption, Loss of Pressure and Size Retention. Each test has an upper and lower limit that a football must fall between in-order to gain certification with the more quality certifications having tighter limits (SportsBallShop, 2020). A table with these limits is shown in appendix 2.

Manufacturing Process Flowchart

Figure 2 is the process flowchart. This shows the steps' sequential order and precedence relationships. It also indicates that two different processes can happen simultaneously, bladder production and panel cutting/preparation before being combined into the final product.

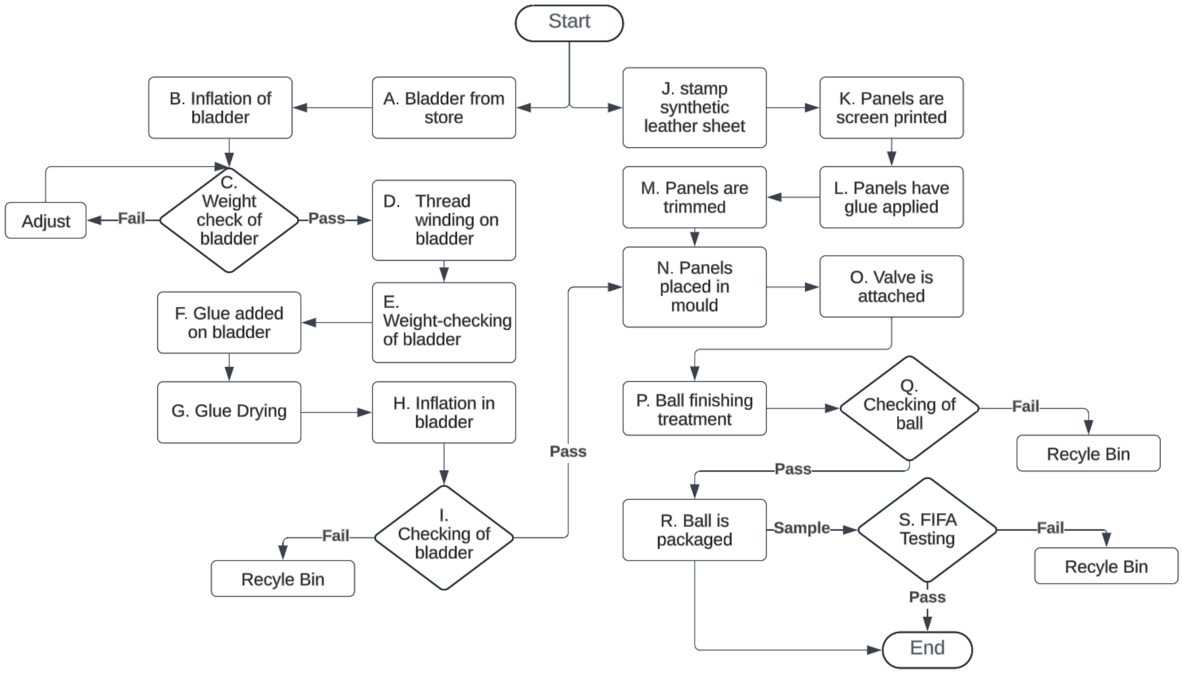


Figure 2 - Process Flowchart

Process Timing Estimates

Steps G and M use machines that have long cycle times but can be ran continuously as they use conveyer belts. That means that the cycle times of these machines can be ignored, as once parts start moving through them, the limiting speed then becomes the operator placing them on the line.

Steps D, N and P use machines that can't ran continuously and are causes of any bottlenecks due to operators being idle. Under this case, the process would be able to make 6 units per hour which is calculated by adding up the seconds per unit for the critical path. Having enough machines such that their operators aren't idle increases output to 27 units per hour. Both cases are shown in Table 2.

Steps Data			One Machine		Twelve Machines	
Step	Work Time	No. of Units per	No. of Machine	Secs Per Unit	No. of Machine	Secs Per Unit
A	15	12	1	1.25	1	1.25
B	5	1	1	5	1	5
C	3	1	1	3	1	3
D	20	12	1	1.66667	1	1.66667
E	3	1	1	3	1	3
F	10	6	1	1.66667	1	1.66667
G	20	1	1	20	1	20
H	5	1	1	5	1	5
I	10	1	1	10	1	10
J	30	2	1	15	1	15
K	900	160	1	5.625	1	5.625
L	40	1	1	40	1	40
M	4	1	1	4	1	4
N	360	1	1	360	12	30
O	5	1	1	5	1	5
P	120	1	1	120	12	10
Q	30	1	1	30	1	30
R	5	1	1	5	1	5
S	n/a	n/a	1		1	
			secs per unit	570.583		130.583
			mins per unit	9.510		2.176
			units per hr	6.309		27.569
Units required per hour to meet demand				106.984		24.484

Table 2 - Minimum and Maximum Machines for Steps N & P

Whilst adding more machines may seem to be the best options, this can incur high capital costs. However, when only using 1 machine, the amount of overtime to cover any shortfalls may not be viable. To find the best compromise between Number of Machines and Overtime, a graph plotting the incurred cost can be made. Table 2 and Graph 3 shows how number of machines affects hours required to meet demand in week one (excluding breaks) and cost to run the first week. Any overtime hours costs are factored in at time and a half. Cost per machine is in Appendix 3

A table was made that mapped the total units per hour required each day whilst factoring in break patterns and the number of shifts. There are six different permutations of shift patterns given the option in the coursework brief. Appendix 3 shows this table, and it indicates that there is little change in the units per hour required based on a 30-minute lunch and 20-minute break vs a 60-minute lunch and a 30-minute break. Therefore, it has been decided that a 60-minute lunch and a 30-minute break would improve work moral whilst not significantly affecting the production. The costs for the machines are broken down in appendix 4.

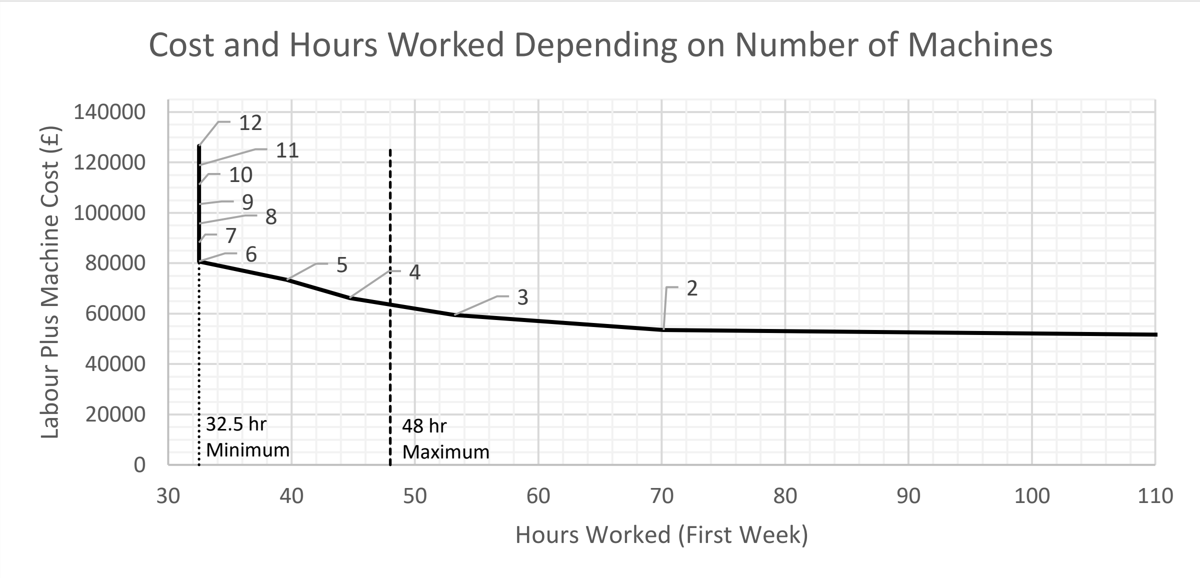
	Number of Mahcines											
	1	2	3	4	5	6	7	8	9	10	11	12
Percentage of shift time requiered to meet demand	329%	191%	145%	121%	108%	98%	92%	87%	83%	80%	77%	75%
Overtime hours	74.425	29.575	14.625	6.825	2.6	0	0	0	0	0	0	0
Overtime per day	14.885	5.915	2.925	1.365	0.52	0	0	0	0	0	0	0
Labour cost (£)	25,984.89	21,281.03	19,713.07	18,895.01	18,451.89	18,179.20	18,179.20	18,179.20	18,179.20	18,179.20	18,179.20	18,179.20
Machine cost (£)	27,000.00	36,000.00	45,000.00	54,000.00	63,000.00	72,000.00	81,000.00	90,000.00	99,000.00	108,000.00	117,000.00	126,000.00
Total cost (£)	**52,984.89**	**57,281.03**	**64,713.07**	**72,895.01**	**81,451.89**	**90,179.20**	**99,179.20**	**108,179.20**	**117,179.20**	**126,179.20**	**135,179.20**	**144,179.20**

Table 3 – Overtime Hours and Costs Based on the Number of Machines

Legally in the UK, according to the Working time directive legislation, 48 hours per week is the most an employer can make employees work. Employees can be asked to work longer and if they agree can sign an agreement but there are no repercussions if they don't agree (Citizens Advice, 2019). However, 48 hours is taken as a 17-week average, so it is possible to go over 48 hours for one week if needed.

Using graph 3 to determine how many machines would be required, to ensure employees continue to work efficiently, a 48-hour cut for hours worked in the week is used which eliminates having only 1, 2 and 3 machines. As the shift patterns are 8-hour shifts and have a 60-minute lunch break and a 30-minute break only 6.5 hours can be utilised which equates to 32.5 hours a week and is the lower cut-off. The 32.5-hour lower cut-off eliminates 12 to 7 machines as there is no time gained for increased costs.

Graph 3 further helps with making the decision that 4 machines is the best trade off as the cost is the lowest whilst when including breaks only requires 47.5 hours at work. Furthermore, due to utilising lean manufacturing process, if overtime is dropped to 2 hours, days 1 – 4 can be covered and day 5 would be 23 balls short. This option helps keep staff morale high as it allows the employees to maintain their long lunch and breaks.



Graph 3 - Number of machines vs Cost.

Table 4 shows how using two hours overtime for the first week will allow the production line to mostly fulfil the demand except for the last day. Due to the fact that lean manufacturing principles are being utilised, any shortfalls in those days production are accepted.

		Total Units	Staffing	Core working	Overtime	Total	Units made per shift
Week 1	Day 1	144	8.47	6.5	2.00	8.50	144
	Day 2	139	8.18	6.5	2.00	8.50	139
	Day 3	140	8.24	6.5	2.00	8.50	140
	Day 4	142	8.35	6.5	2.00	8.50	142
	Day 5	167	9.82	6.5	2.00	8.50	144

Table 4 - Week one Overtime Production

Production Process Parameters and KPIs

Product Process Parameters

Due to staffing limitations of only having eight employees and the production plan utilises all eight, only one 8-hour shift a day can be used.

For choosing break patterns, it is important to look at how changing the patterns will affect the demand. A full table is shown in appendix 2 however, the only point of significant concern is week one where overtime has been used to meet requirements. There is no significant difference in requirements between only having 30-minutes lunch with 20-minute break compared to 1 hour lunch and 30-minute break. This means that the employees can be given a 30-minute break and 60-minute lunch. The production process parameter is shown in table 4.

Production Process Parameter	Value
Number of 8-hour shifts in a day	1
Lunch/Dinner time per shift (in minutes)	60 min
Comfort break time per shift (in minutes)	30 min
Downtime for scheduled maintenance per shift (in minutes)	36 min
Average materials cost per product (£ per unit produced)	£2.72
Average energy and utility cost per product (£ per unit produced)	£1.72
Total labour hours over 8-weeks of production	((10 hours x 5 days) + (8hr x 5 days x 7 weeks)) x 8 workers = 2640
Average labour rate (£ per labour hour)	£8.74
Manufacturing overhead costs over 8-weeks of production	£5,000

Table 5 - Production Process Parameter

Takt Time

Takt time is a way to represent the available production time divided by the quantity of goods demanded by the customer during that time. For this project, we are interested in the average takt time over week one. The equation used to calculate average takt time is:

$$\textbf{\textit{Takt Time}} = \frac{\textbf{\textit{Available production time in week one}}}{\textbf{\textit{Customer demand in week one}}}$$

$$Number\ of\ products\ = 144 + 139 + 140 + 142 + 167\ = 732\ units$$

$$Available\ time\ per\ shift\ = (8hrs + 2hrs\ OT) \times 60 = 600\ mins$$

$$Stoppage\ per\ shift = 60\ min\ lunch + 30\ min\ break + 36\ min\ schedule\ stop = \ 126\ mins$$

$$Net\ production\ time\ per\ shift = Available\ time - Stoppage\ time = 600 - 126 = 474\ mins$$

Due to only having one shift a day, Net production time per day = Net production time per shift

$$Number\ of\ days\ in\ week\ one\ = \ 5\ days$$
$$Net\ production\ time\ in\ first\ week\ = 474 \times 5\ = \ 2{,}370\ mins$$
$$Average\ TAKT\ time\ required\ in\ first\ week\ = \frac{2{,}370}{732} = 3.237\ mins$$

Multifactor Productivity

Multifactor productivity (MFP) is a measure used to assess the efficiency of production by comparing the output of goods and services to the inputs used in the production process. It uses the equation:

$$\boldsymbol{MFP = \frac{Output}{Labor\ cost + Material\ cost + Energy\ cost + Manufacturing\ overheads}}$$

$$Total\ Labour\ cost = Labour\ Rate\ (Demand\ Engine) \times Labour\ Hours \times No.of\ employees$$

$$= \ £8.74 \times ((8\ hrs \times 5\ days \times 8\ weeks) + (1.5 \times 2\ hrs \times 5\ days)) \times 8$$

$$= \ £8.74 \times 335 \times 8\ = \ £23{,}423.20$$

$$Total\ materials\ cost\ = \ Material\ cost\ per\ unit\ (Demand\ Engine) \times Total\ Number\ of\ Units$$

$$= \ £2.72 \times 3{,}680\ = \ £10{,}009.60$$

$$Total\ energy\ cost = \ Energy\ cost\ per\ unit\ (Demand\ Engine) \times Total\ Number\ of\ Units$$

$$= \ £1.72 \times 3{,}680\ = \ £6{,}329.60$$

$$Manufacturing\ overheads\ = \frac{£23{,}423.20}{20\%} = £4{,}684.64 \approx £5{,}000$$

$$MFP\ = \frac{3680}{£23{,}423.20\ +\ £10{,}009.60\ +\ £6{,}329.60\ + £5{,}000} = 0.08221\ product\ per\ £$$

P-Chart

The purpose of a P chart is to help maintain the stability of a process by identifying when the proportion of nonconforming units deviates from a predetermined acceptable level. The P-chart is particularly useful in situations where the data being monitored consists of attributes or proportions, rather than measurements. It is commonly used in quality control to monitor processes where the output can be classified as either conforming or nonconforming.

To locate non-conformance, upper and lower process control limits are required. The Upper Control Limit (UCL) is the highest allowable value for a statistic on a control chart whereas Lower Control Limit (LCL) is the lowest allowable units. It is calculated using the following equations:

$$\boldsymbol{UCL: \bar{p} + z\sigma_p}$$

$$\boldsymbol{LCL: \bar{p} - z\sigma_p}$$

$$\boldsymbol{\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}}$$

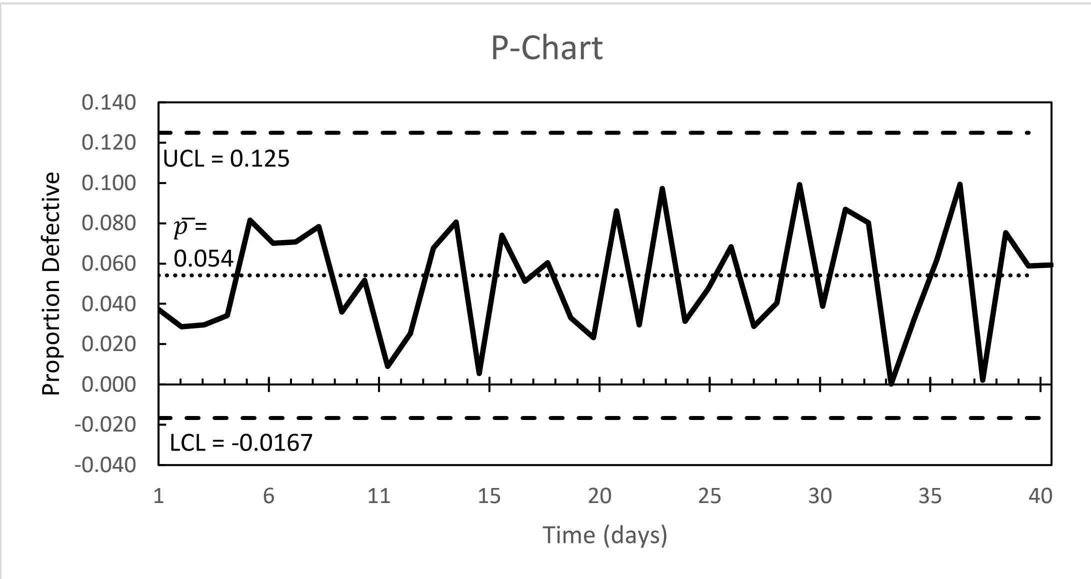
$$\boldsymbol{: z = \ 3\ \bar{p} = \frac{(total\ defects)}{(total\ sample\ observations)} = 0.051334\ n = \frac{3680}{40} = 92}$$

Appendix 1 show the number of defectives and portion of defects per day.

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{0.051334(1-0.051334)}{92}} = 0.0223589$$

$$UCL = \bar{p} + z\sigma_p = 0.051334 + (3 \times 0.022406383) = 0.12.4892$$

$$LCL = \bar{p} - z\sigma_p = 0.051334 - (3 \times 0.022406383) = -0.01664$$



Graph 4 - P-Chart

Balancing of the production line

A. Total number of products

Net production time for eight weeks of production is calculated as (((10 hours x 5 days) + (8hr x 5 days x 7 weeks)) - (1.5 x 5 x 8)) = 270 hrs = 16,200 Mins.
3680 units need to be produced in 16,200 Mins.

B. Precedence Diagram

There are two start points on the precedence diagram based two processes (bladder production and panel making) that can run in parallel. These are at steps A and J and they meet at step I which is shown is shown in figure 3.

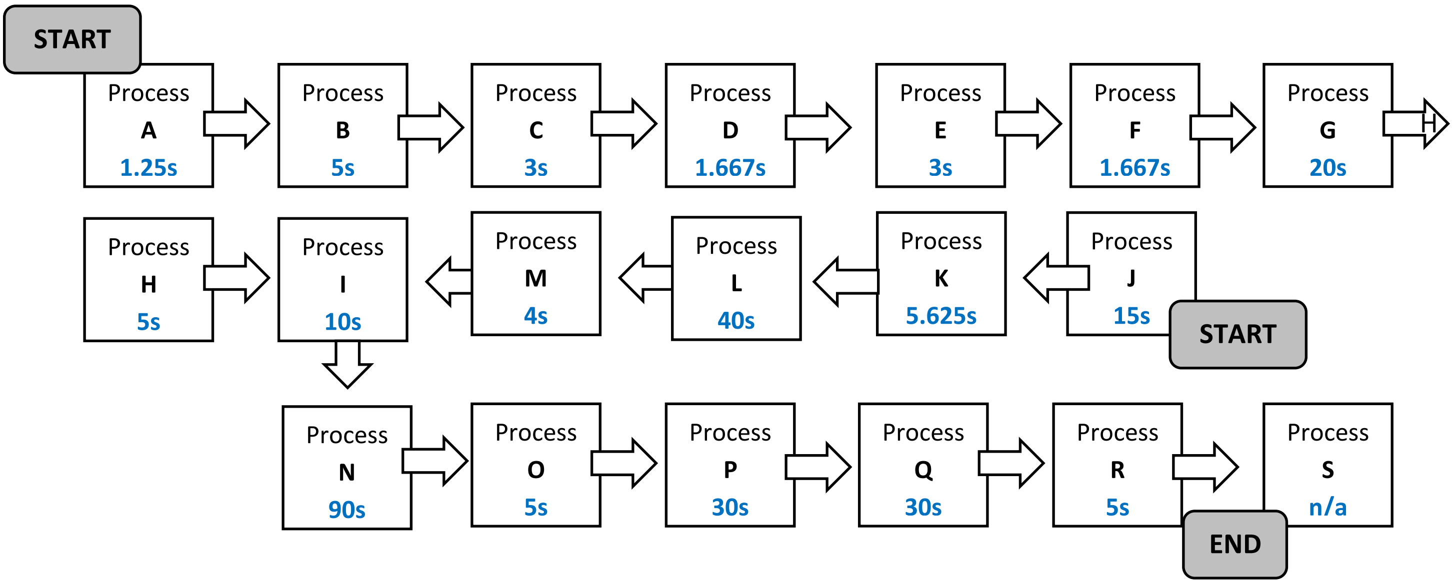
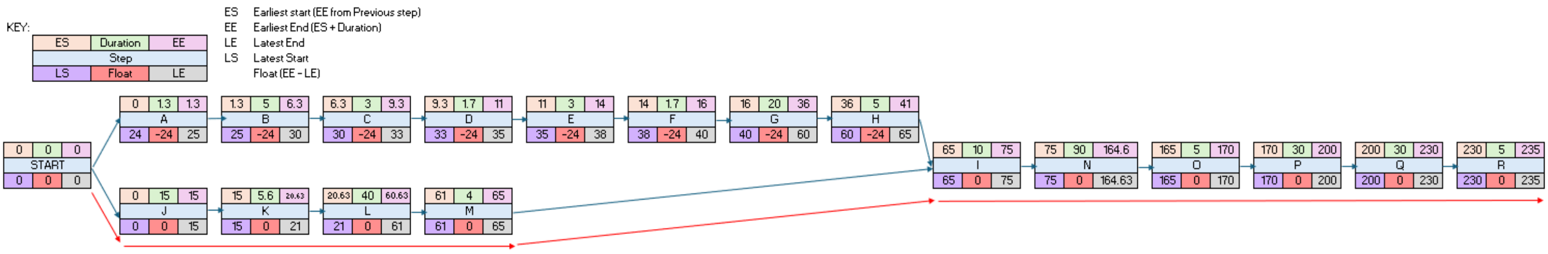


Figure 3 - Precedence Diagram

Below in figure 4 shows a critical path analysis to further demonstrate the process lines precedence. It also shows that the process for panel making, Steps J to M, is the longest process before both elements are combined in Step I.



The times for the duration take into account the accual time one ball would take to be made. It does not take into account processes where more than one can be made ata a time
Discription of how this works can be found on:
[What Is a Critical Path Method in Project Management? (project-management.com)]

Critical path is where there is no float allowed - ie. J, K, L, M, I, N, O, P , Q, R

Figure 4 - Critical Path Analysis

C. Desired cycle time

Based on the figure 2 precedence diagram, total completion time for all elements 275.208 secs = **4.58 mins**

Desired cycle time, $C_d = \frac{\text{Net production time available}}{\text{Desired units of output}}$,

Net production time = (((10 hours x 5 days) + (8hr x 5 days x 7 weeks)) - (1.5 x 5 x 8)) = 270 hrs = 16,200 Mins.

$C_d = \frac{16{,}200}{3680}$

= **4.40217**

D. Theoretical minimum number of workstations

Theoretical minimum number of stages $= \frac{\textit{Total completion time of all work elements}}{\textit{Desired cycle time}} = \frac{4.58}{4.40217}$

= 1.04 which can be rounded up to **2 stages**

E. Group work elements into workstations / stages

Figure 5 demonstrates how to group workstations together in a balanced production line. This shows group 1 duration is 1.92 minutes and group 2 duration are 2.67 minutes.

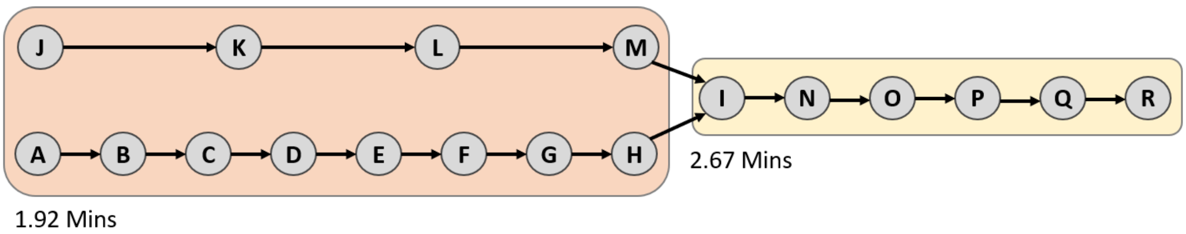


Figure 5 - Balanced Production Line

F. Calculate efficiency of the production line

Actual Cycle Time, C_a = maximum of (1.92, 2.67) mins = **2.67 mins**

Efficiency of the line, $E = \frac{\text{Total completion time of all work elements}}{\text{Actual number of stages x Actual cycle time}}$

$= \left(\frac{4.58}{2 \times 2.67}\right) \times 100$ = **85.77%**

Balance loss or balance delay = *(100 - E) %* = (100 – 85.77%) % = **14.23%**

The production line can be considered balanced as the theoretical minimum number of work Stages (2 Stages) is shown to be is acceptable as no single stage exceeds the actual cycle time. Furthermore, the production line has an efficiency of over 85% which is acceptable.

Value Stream Map

Overall Equipment Effectiveness

Overall Equipment Effectiveness (OEE) is a metric used to measure the efficiency and effectiveness of manufacturing equipment or processes. It provides insights into how well equipment is performing relative to its full potential. OEE is calculated based on three main factors: availability, performance, and quality.

$$\boldsymbol{OEE = Availability \times Performance\ Rate \times First\ Pass\ Yield}$$

Availability

Availability measures the proportion of scheduled production time during which equipment is available for operation. Performance measures the speed at which equipment operates compared to its maximum potential speed. It quantifies the efficiency of the equipment in producing goods or performing tasks.

$$\boldsymbol{Availability = \frac{Total\ Actual\ Production\ Time}{Total\ Potential\ Production\ Time}}$$

$$Potential\ production\ time = (8\ hrs \times 5\ days \times 7\ weeks) + (10 hrs \times 5\ days) = 330\ hours$$

$$Total\ downtime = (30\ min + 60\ min + 36\ min\ maintenance) \times 1\ shifts \times 5\ days \times 8\ weeks$$
$$= (0.5\ hrs + 1\ hr + 0.6\ hrs) \times 1\ shifts \times 5\ days \times 8\ weeks = 84\ hours$$

$$Total\ actual\ production\ time = 330\ hrs - 84\ hrs = 246\ hrs$$

$$Availability = \left(\frac{246}{320}\right) \times 100 = 74.54\%$$

Performance Rate

Performance rate measures the proportion of good-quality products or outputs produced by the equipment compared to the total output. It reflects the effectiveness of the equipment in producing products that meet the required quality standards.

$$\boldsymbol{Performance\ Rate = \frac{Total\ Actual\ Output}{Total\ Theoretical\ Output}}$$

$$Hourly\ Standard = 17\ units$$

$$Total\ Theoretical\ Output = Hourly\ Standard \times Total\ actual\ production\ time = 17 \times 246$$
$$= 4182$$

$$Total\ Actual\ Output\ (\ Demand) = 3680\ units$$

$$Performance\ Rate = \frac{Total\ Actual\ Output}{Total\ Theoretical\ Output} = \frac{3680}{4182} = 0.8799$$

First Pass Yield

First Pass Yield (FPY) measures the percentage of products or units that pass through a manufacturing process successfully without requiring any rework or repairs. It represents the proportion of good-quality products produced on the first attempt.

$$\boldsymbol{FPY = \frac{Total\ Number\ of\ Good\ Quality\ Products}{Total\ Actual\ Output}}$$

$$Output\ (Demand)\ =\ 3680$$

$$Total\ Good\ Quality\ Parts\ =\ Demand\ -\ Defects\ =\ 3680\ -\ 200\ =\ 3480$$

$$FPY\ = \frac{3480}{3680}\ =\ 0.9457$$

OEE

$$OEE = Availability \times Performance \times FPY\ = 0.7454 \times 0.8799 \times 0.9457 = 0.6202 =\ 62.02\%$$

VSM Map

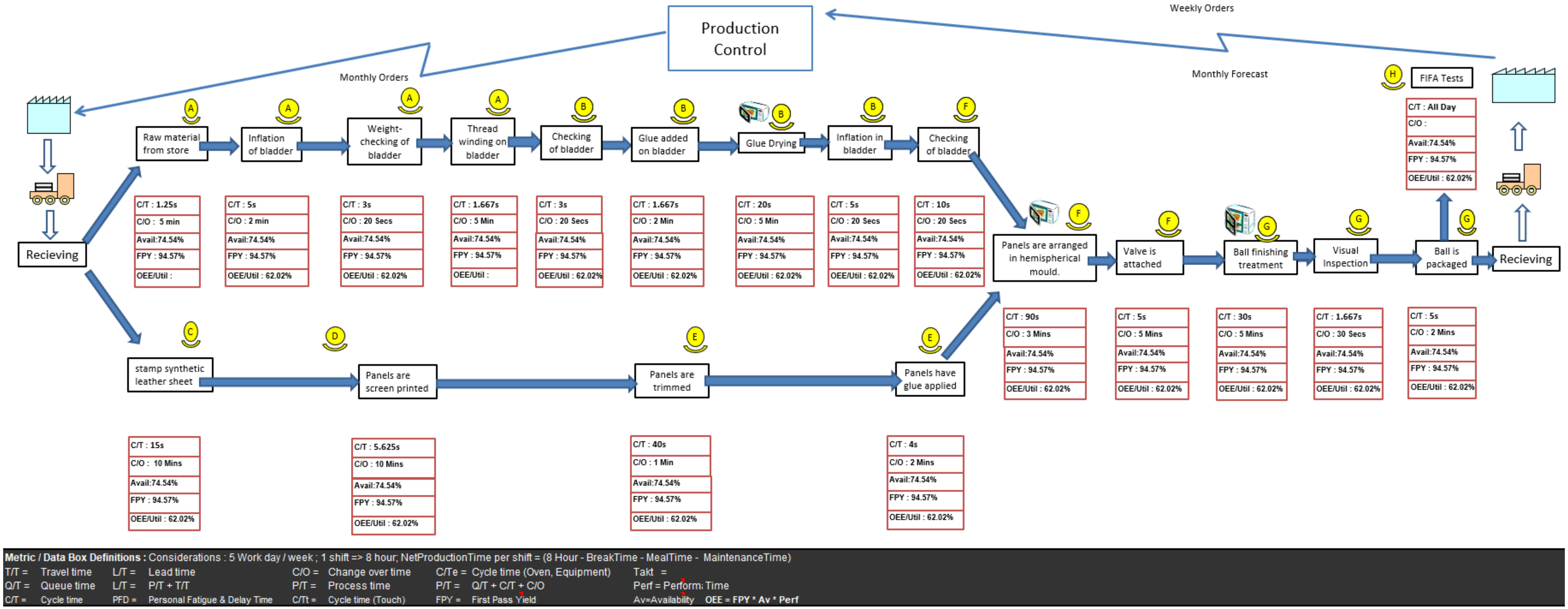


Figure 6 - Value Stream Map

Production Capacity

Effective Daily Capacity refers to the maximum amount of output or production that a manufacturing facility, machine, or process can achieve in a single day under normal operating conditions. It represents the practical limit of what can be produced within the constraints of available resources, such as equipment, labour, materials, and time.

$$\boldsymbol{Production\ Line\ Effective\ Daily\ Capacity} =$$

$$(\boldsymbol{Production\ lines}) \times (\boldsymbol{Hrs\ Per\ Shift}) \times (\boldsymbol{Shifts}) \times (\boldsymbol{Utilisation}) \times (\boldsymbol{Efficiency}):$$

$$Production\ line = 1$$

$$Hours\ per\ shift = 8.25^{*}\ hours$$

*Accounting for Week One 10hr a day overtime

$$No. of\ shifts = 1\ shift$$

$$Utilisation = Availability = 0.7454$$

$$Efficiency = Performance = 0.8799$$

$$Production\ Line\ Effective\ Daily\ Capacity = 1 \times 8.25 \times 1 \times 0.7454 \times 0.8799 = 5.41\ Hours\ per\ Day\ or\ 324.66\ Mins\ per\ Day$$

Employee Schedule

As previously discussed, it was determined that 2 hours of overtime a day for the first week was needed to make up for the extremely high demand in that week.

The production line could run with only 7 employees but only at a reduced rate. Therefore, the days off should be when production is at its least. The eight days with the least requirements are all of Week 4 and Tuesday to Thursday in week 6. This will allow all employees to have one day off. The employee schedule is shown in Table 6.

Week	Week 1					Week 2					Week 3					Week 4				
Day	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri
Shift	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Worker A	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h		8h	8h	8h	8h
Worker B	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h		8h	8h	8h
Worker C	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h		8h	8h
Worker D	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h		8h
Worker E	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	
Worker F	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker G	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker H	10h*	10h*	10h*	10h*	10h*	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h

*8 hr + 2 hr overtime at time and a half

Week	Week 5					Week 6					Week 7					Week 8				
Day	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri	Mon	Tue	Wed	Thur	Fri
Shift	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Worker A	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker B	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker C	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker D	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker E	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker F	8h	8h	8h	8h	8h	8h		8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker G	8h	8h	8h	8h	8h	8h	8h		8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h
Worker H	8h	8h	8h	8h	8h	8h	8h	8h		8h	8h	8h	8h	8h	8h	8h	8h	8h	8h	8h

Table 6 - Employee Schedule

Costs, Pricing and Breakeven Analysis

Breakdown of Cost

Table 7 is a breakdown of the various cost to run the production line and whether the costs are a fixed cost or a variable cost which will affect data on the breakeven analysis.

	Cost Area	Variable Cost (£ per unit produced)	Fixed Cost (£)
A	Average materials cost per product	2.72	
B	Average energy and utility cost per product	1.72	
C	Average labour cost per product	((8x8.74x5x8x8) +(2x1.5x8.74x8x5))/3680=6.37	
D	Manufacturing overhead expenses		5,000
E	Other fixed capital expenses		83,250
Total Cost		10.81	88,250

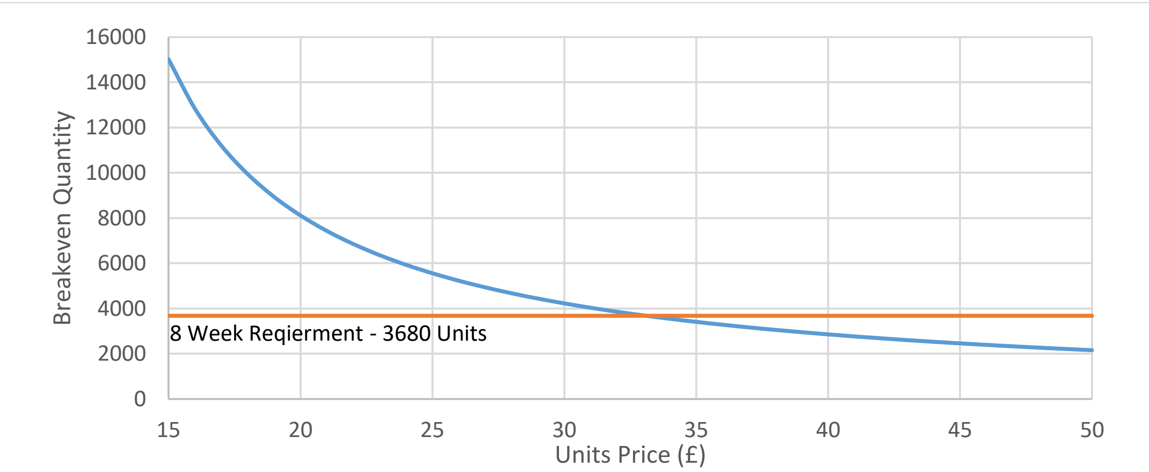
Table 7 - Cost Breakdown

Determining a sale price

The production has been designed on a higher quality football model with processes that allow it to achieve FIFA Certification which would allow it to be sold at a higher unit price. Based on the current market, higher quality balls can range in price from £15-£50. To determine the unit quantity to break even, the following equation is used:

$$Gross\ Revenue\ =\ sale\ price \times\ quantity$$
$$Total\ Variable\ Cost\ =\ variable\ cost \times\ quantity$$
$$At\ the\ breakeven\ point, Total\ Revenue\ =\ Total\ Fixed\ Cost\ +\ Total\ Variable\ Cost$$

Graph 5 shows the breakeven point at different unit sale prices in order to determine how many units would need to be sold to breakeven. The table with raw data is shown in appendix 5.



Graph 5 - Breakeven Point Per Unit Price

Due to the fact that the football production plan aims to make high quality footballs, a £35 price point is an appropriate price for the quality that will also allow the breakeven point to be met within the initial 8-weeks.

Using graph 5 to set the unit sale price, a break-even analysis graph can be created.

With a sale price set at £35

$$q = Breakeven\ quantity$$

$$Total\ Revenue\ = £35 \times q$$

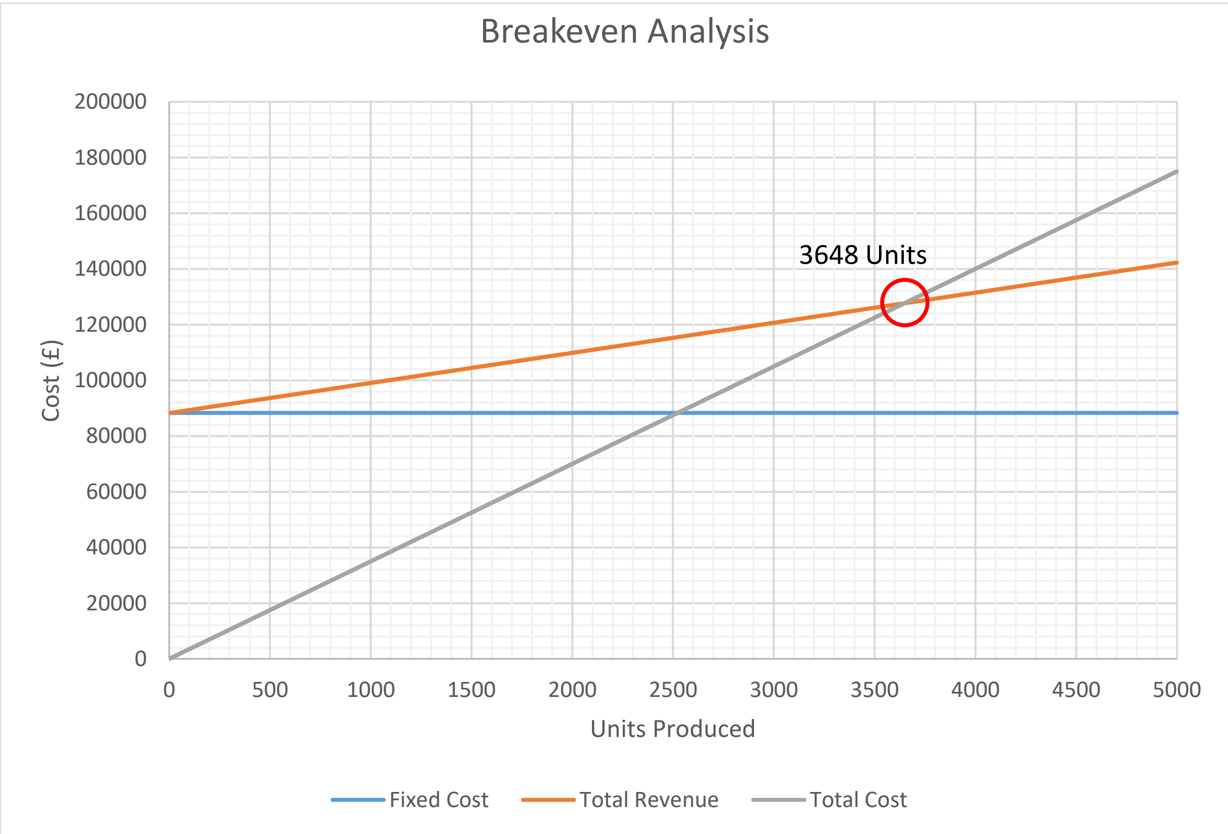
$$Total\ Variable\ Cost = £10.81 \times \mathrm{q}$$

At breakeven point: $Total\ Revenue\ = Total\ Fixed\ Cost\ +\ Total\ Variable\ Cost$

$$35q = 83{,}250 + 10.81q$$

$$35q - 10.81q = 88{,}250$$

$$q = \frac{88{,}250}{24.19} = 3{,}648.202 \approx 3648\ Units$$



Graph 6 - Breakeven Analysis

Conclusion

The proposed production line is mostly able to meet demand without issue on almost every day excluding week one. This is because in week one, there is a higher demand every day than any other week. Despite this, the production line does become profitable by the eighth week. Due to the fact that the project follows lean manufacturing principles very strictly, no shortfall mitigation practices could utilise, these include being able to optimise working time be utilising the production line to alleviate requirements on high demand days during low demand days which would eliminate most of the un-fulfilled orders.

Manchester Metropolitan University

Appendices

Appendix 1 - Demand and Defects Master Table

		Demand	Defect Proportion	Defects
Week 1	Day 1	144	0.037184	5.354
	Day 2	139	0.02866	3.984
	Day 3	140	0.029619	4.147
	Day 4	142	0.034194	4.856
	Day 5	167	0.081469	13.605
Week 2	Day 1	70	0.070046	4.903
	Day 2	71	0.070754	5.024
	Day 3	72	0.078358	5.642
	Day 4	65	0.035948	2.337
	Day 5	67	0.051704	3.464
Week 3	Day 1	92	0.008979	0.826
	Day 2	100	0.025294	2.529
	Day 3	114	0.067659	7.713
	Day 4	120	0.080645	9.677
	Day 5	89	0.005442	0.484
Week 4	Day 1	58	0.074081	4.297
	Day 2	52	0.051245	2.665
	Day 3	54	0.060432	3.263
	Day 4	47	0.033157	1.558
	Day 5	52	0.023285	1.211
Week 5	Day 1	116	0.086063	9.983
	Day 2	93	0.029533	2.747
	Day 3	129	0.097202	12.539
	Day 4	94	0.031308	2.943
	Day 5	100	0.047365	4.737
Week 6	Day 1	63	0.068365	4.307
	Day 2	55	0.028869	1.588
	Day 3	58	0.040451	2.346
	Day 4	81	0.099189	8.034
	Day 5	57	0.03876	2.209
Week 7	Day 1	103	0.086843	8.945
	Day 2	100	0.080195	8.020
	Day 3	59	0.000189	0.011
	Day 4	84	0.032383	2.720
	Day 5	93	0.062006	5.767
Week 8	Day 1	131	0.099329	13.012
	Day 2	74	0.002034	0.151
	Day 3	110	0.075303	8.283
	Day 4	105	0.058846	6.179
	Day 5	120	0.059292	7.115
	Total	3680		199.174

Appendix 2 – FIFA Certification Requirements

Circumference

	FIFA QUALITY PRO	FIFA QUALITY	IMS
Outdoor Football Size 5	68.5 - 69.5 cm	68 - 70 cm	68 - 70 cm
Outdoor Football Size 4	Not Available	63.5 - 66 cm	63.5 - 66 cm

The ball's radius is measured at 45,000 points and the circumference is calculated to ensure the ball is consistent and within the limits at every point.

Roundness

	FIFA QUALITY PRO	FIFA QUALITY	IMS
Outdoor Football Size 5	Max 1.5%	Max 1.8%	Max 1.8%
Outdoor Football Size 4	Not Available	Max 1.8%	Max 1.8%

The ball is measured at 45,000 points. The difference between each point is then calculated to ensure any errors on the ball are picked up.

Rebound

		FIFA QUALITY PRO	FIFA QUALITY	IMS
Outdoor Size 5	**@ 20°C**	135 - 155 cm	125 - 155 cm	125 - 155 cm
	@ 05°C	Min 125 cm	Min 115 cm	Min 115 cm
Outdoor Size 4	**@ 20°C**	Not Available	115 - 155 cm	115 - 155 cm
	@ 05°C	Not Available	Min 115 cm	Min 115 cm

In the test the balls are dropped 10 times onto a steel plate from a height of 2 metres. The conditions are temperature controlled and the ball must consistently rebound within a specified range of heights.

Water Absorption

During this test the ball is turned and squeezed 250 times in a tank of water. The ball should not absorb more than 10% of the water to achieve a pass.

Weight

	FIFA QUALITY PRO	FIFA QUALITY	IMS
Outdoor Size 5	420 - 445 g	410 - 450 g	410 - 440 g
Outdoor Size 4	Not Available	350 - 390 g	350 - 390 g

In this test balls are weighed 3 times in a sealed cabinet to ensure the test is not influenced by external factors. The weight must fall within the specified range as below.

Pressure Loss

	FIFA QUALITY PRO	FIFA QUALITY	IMS
Outdoor Size 5	Max loss 20%	Max loss 25%	Max loss 25%
Outdoor Size 4	Not Available	Max loss 25%	Max loss 25%

In the test the ball is inflated to the industry standard of 0.8 bar. After 72 hours it must not have lost more than a specified percentage of its air to meet the badge standard, as below.

Shape and Size Retention

Outdoor Size 5	FIFA QUALITY PRO	FIFA QUALITY
Increase in circumference	Max 1.5 cm	Max 1.5 cm
Deviation on sphericity	Max 1.5%	Max 1.8%
Change of pressure	Max 0.1 bar	Max 0.1 bar

The ball is tested by firing it against a steel plate at 50kph over 2000 times. The valve and seams must remain intact and undamaged.

Appendix 3 – How Shift Patterns Affect Requirements

		Total Units	30 lunch 20 Break Units/hr each shift			45 lunch 20 Break Units/hr each shift			060 lunch 20 Break Units/hr each shift			30 lunch 30 Break Units/hr each shift			45 lunch 30 Break Units/hr each shift			60 lunch 30 Break Units/hr each shift		
			1 Shift	2 Shifts	3 Shifts	1 Shift	2 Shifts	3 Shifts	1 Shift	2 Shifts	3 Shifts	1 Shift	2 Shifts	3 Shifts	1 Shift	2 Shifts	3 Shifts	1 Shift	2 Shifts	3 Shifts
Week 1	Day 1	144	21	11	7	21	11	7	22	11	8	21	11	7	22	11	8	23	12	8
	Day 2	139	20	10	7	21	11	7	21	11	7	20	10	7	21	11	7	22	11	8
	Day 3	140	20	10	7	21	11	7	21	11	7	20	10	7	21	11	7	22	11	8
	Day 4	142	20	10	7	21	11	7	22	11	8	21	11	7	22	11	8	22	11	8
	Day 5	167	24	12	8	25	13	9	26	13	9	24	12	8	25	13	9	26	13	9
Week 2	Day 1	70	10	5	4	11	6	4	11	6	4	10	5	4	11	6	4	11	6	4
	Day 2	71	10	5	4	11	6	4	11	6	4	11	6	4	11	6	4	11	6	4
	Day 3	72	11	6	4	11	6	4	11	6	4	11	6	4	11	6	4	12	6	4
	Day 4	65	10	5	4	10	5	4	10	5	4	10	5	4	10	5	4	10	5	4
	Day 5	67	10	5	4	10	5	4	11	6	4	10	5	4	10	5	4	11	6	4
Week 3	Day 1	92	13	7	5	14	7	5	14	7	5	14	7	5	14	7	5	15	8	5
	Day 2	100	14	7	5	15	8	5	15	8	5	15	8	5	15	8	5	16	8	6
	Day 3	114	16	8	6	17	9	6	18	9	6	17	9	6	17	9	6	18	9	6
	Day 4	120	17	9	6	18	9	6	18	9	6	18	9	6	18	9	6	19	10	7
	Day 5	89	13	7	5	13	7	5	14	7	5	13	7	5	14	7	5	14	7	5
Week 4	Day 1	58	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3
	Day 2	52	8	4	3	8	4	3	8	4	3	8	4	3	8	4	3	8	4	3
	Day 3	54	8	4	3	8	4	3	9	5	3	8	4	3	8	4	3	9	5	3
	Day 4	47	7	4	3	7	4	3	8	4	3	7	4	3	7	4	3	8	4	3
	Day 5	52	8	4	3	8	4	3	8	4	3	8	4	3	8	4	3	8	4	3
Week 5	Day 1	116	17	9	6	17	9	6	18	9	6	17	9	6	18	9	6	18	9	6
	Day 2	93	13	7	5	14	7	5	14	7	5	14	7	5	14	7	5	15	8	5
	Day 3	129	18	9	6	19	10	7	20	10	7	19	10	7	20	10	7	20	10	7
	Day 4	94	14	7	5	14	7	5	15	8	5	14	7	5	14	7	5	15	8	5
	Day 5	100	14	7	5	15	8	5	15	8	5	15	8	5	15	8	5	16	8	6
Week 6	Day 1	63	9	5	3	10	5	4	10	5	4	9	5	3	10	5	4	10	5	4
	Day 2	55	8	4	3	8	4	3	9	5	3	8	4	3	9	5	3	9	5	3
	Day 3	58	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3
	Day 4	81	12	6	4	12	6	4	13	7	5	12	6	4	12	6	4	13	7	5
	Day 5	57	8	4	3	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3
Week 7	Day 1	103	15	8	5	15	8	5	16	8	6	15	8	5	16	8	6	16	8	6
	Day 2	100	14	7	5	15	8	5	15	8	5	15	8	5	15	8	5	16	8	6
	Day 3	59	9	5	3	9	5	3	9	5	3	9	5	3	9	5	3	10	5	4
	Day 4	84	12	6	4	13	7	5	13	7	5	12	6	4	13	7	5	13	7	5
	Day 5	93	13	7	5	14	7	5	14	7	5	14	7	5	14	7	5	15	8	5
Week 8	Day 1	131	19	10	7	19	10	7	20	10	7	19	10	7	20	10	7	21	11	7
	Day 2	74	11	6	4	11	6	4	12	6	4	11	6	4	11	6	4	12	6	4
	Day 3	110	16	8	6	16	8	6	17	9	6	16	8	6	17	9	6	17	9	6
	Day 4	105	15	8	5	16	8	6	16	8	6	15	8	5	16	8	6	17	9	6
	Day 5	120	17	9	6	18	9	6	18	9	6	18	9	6	18	9	6	19	10	7

Appendix 4 – Machine Costs

Machine	Price	Supplier
Winding	£6300	Rubber Bladder Winding Thread Use 12 Positions Thread Winding Machine - China Thread Widing Machine and 12 Position Thread Winding Machine (made-in-china.com)
Glue Dry	£4500	Hot Melt Glue Systems | Hot Melt Dispensing Systems - Adhesive Laundry
hydraulic stamp	£3200	Servo Four-Column Hydraulic Press Iron Powder Forming Machine Metal Stamping and Drawing Hydraulic Press - AliExpress
glue machine	£2000	https://www.aliexpress.com/item/1005006041938979.html
heat mould	£4000	Mechanized Thermo Bonded Football Machine - China Football Laminated Machine and Mechanized Thermo Football Machine (made-in-china.com)
ball treatment	£3700	Servo Four-Column Hydraulic Press Iron Powder Forming Machine Metal Stamping and Drawing Hydraulic Press - AliExpress

Appendix 5 – Breakeven Point Per Unit Price

Total Units	Sale Price	Breakeven Quantity
3680	15	15023
3680	16	12838
3680	17	11207
3680	18	9945
3680	19	8938
3680	20	8116
3680	21	7432
3680	22	6855
3680	23	6361
3680	24	5933
3680	25	5560
3680	26	5230
3680	27	4938
3680	28	4676
3680	29	4441
3680	30	4228
3680	31	4035
3680	32	3858
3680	33	3697
3680	34	3548
3680	35	3411
3680	36	3284
3680	37	3166
3680	38	3057
3680	39	2955
3680	40	2858.333
3680	41	2768.659
3680	42	2684.44
3680	43	2605.194
3680	44	2530.492
3680	45	2459.955
3680	46	2393.244
3680	47	2330.055
3680	48	2270.118
3680	49	2213.186
3680	50	2159.04