

OPTIMISING PLANT LAYOUT FOR
COST-EFFECTIVE OUTPUT
EFFICENCY: A CASE STUDY OF
ATHERTON BIKES NEW FACTORY
USING SYSTEMATIC LAYOUT
PLANNING.

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1 ABSTRACT

The project's objective was to optimise the layout of AB's new plant to reduce material handling costs and distance between resources, aiming to achieve cost-effective output efficiency. The project achieved its objectives from a theoretical viewpoint, but its success will only be fully achieved after implementing the layout. The project scope was to obtain maximum capacity output efficiencies, which will not be seen until at least 2025. The AM-specific processes were not considered, as the project priority was to optimise the AL product line. Systematic Layout Planning (SLP) was adopted for collecting and analysing data related to PL. The decision-making selection, however, lacked real structure. The next phase of the layout planning would be to conduct a more in-depth analysis on a local level of the time, relationships, routing, and space to optimise AB's facility further.

Additionally, a bottleneck analysis should be conducted to ensure buffers are identified, and space is allocated for WIP between processes. A simulation would prove to be a powerful tool to validate the layout's effectiveness and would aid in decision-making. Finally, production studies should be conducted to ensure that the plant's output efficiency is sustainable.

2 ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere appreciation to Atherton Bikes for providing the opportunity and support to complete this project. The freedom to work on a blank canvas has been an invaluable learning experience that will undoubtedly shape my career. Thank you for entrusting me with this project and for being a key contributor to my academic and professional development.

Secondly, I would like to thank the University of Wales Trinity Saint David for their unwavering support and dedication in ensuring that the Lean & Agile Operations program could continue despite the challenges posed by the COVID-19 pandemic.

Last but not least, my deepest gratitude goes to my dissertation lecturer, Andrew Thorn, for his invaluable guidance, support, and expertise throughout this journey. His exceptional knowledge and wisdom have been instrumental in shaping my project and enabling me to achieve my academic goals. Thank you for being an inspiring mentor and a true champion of education.

3 AUTHORS DECLARATION

I declare that the work in this dissertation was carried out in accordance with the regulations of UWTSD. The work is original except where indicated by special references in the text, and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the UWTSD.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

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Signed: William May-White

Date: 23/04/2023

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7 DEFINITION TABLE:

AM – Additive Manufacturing

CF – Carbon Fibre

Ti6 – Titanium alloy

Al – Aluminium alloy

Frame kit – Kit consisting of lugs and tubes.

Post Processing – The processing of Ti6 lugs from AM build plate to the final finish stage.

Production kit – A set of lugs and tubes needed to bond a bike frame

PL – Plant layout

MFA – Material flow analysis

MFD – Material flow diagram

SLP – Systematic layout planning

VSM – Value stream mapping

PM – Process mapping

HT - Heat treatment

GIO – Goods in and out

QCK – QC and Kitting

ANO – Anodising

PK – Production Kit

PP – Post-processing

QC – Quality Check

BA – Bike Assembly

MBOQ – Minimum Batch Order Quantity

FPC – Flow Process Chart

8 RESOURCES

Autodesk Fusion 360

Microsoft Excel

Systematic Layout Planning

9 INTRODUCTION

This project will explore methodologies of plant layout planning to understand if there is a suitable methodology to aid Atherton Bikes in obtaining effective and efficient operations.

Plant layout is far more than just arranging equipment in a given space. It understands the relationship and effect of equipment, manning, material flow, data flow, and production capabilities. For a plant layout to succeed, the planner must have a good working knowledge of all processes and accurate data to understand how operations will work with the new layout. In the ideal world, the processes will be designed to maximise operational capability; however, this is rarely the case and often needs to be adapted to fit within a given building criteria.

New plant selection is a complicated and arduous process and must align with the organisational strategy for the future. It is balancing the operational needs of today, tomorrow and the future. It would not be cost-effective for a business to pay for space which is not needed, and naturally, space will always be filled as quickly as possible.

A well-planned plant is critical to the operations of a business. It will reduce material handling, give a safe working environment, improve workflow, allow for growth, and reduce bottlenecks, ultimately giving higher output levels at a lower cost.

In manufacturing plant layout, the objective is to maximise the transformation of inputs to outputs of the business. This will increase productivity and reduce waste with an optimised plant layout.

The waste that needs to be reduced is transportation which is the moving materials that add no value to the product and increase the likelihood of damage and quality deterioration. Motion is the waste of movement of people within the business to perform a process. Waiting is the waste of idle time within the company, which can be in the form of people or equipment. Eliminating these wastes through an optimised factory layout will give employees more time to carry out value-adding processes.

9.1 COMPANY OVERVIEW

Atherton Bikes (AB) currently offers one product line, AM, a low-volume, high-variation product. The business will provide a second product line, a medium volume, medium variation. With introducing the second product line, AB requires a larger manufacturing facility, thus needing

an optimised factory layout. AB's new manufacturing facility is a leased building; therefore, there can be no influence on size or structural design.

The second product line will most likely be the flagship product of AB. However, the business and factory must be agile enough to adapt to an increase in output and a shift of resources if the current AM product line increases sales and becomes the flagship product.

10 LITERATURE REVIEW

10.1 PURPOSE:

This literature review aims to identify the current knowledge of plant layouts as a whole and specific to manufacturing. Further, it will identify key fundamentals of plant layout methodologies that have resulted in success for a business.

10.2 SCOPE

The literature review will be divided into three main topics. The first is understanding different types of plant layouts and what kind of manufacturing can be used to utilise them effectively. This base knowledge gained will be the foundation of the research and will be evaluated and applied to AB.

The second will be best practices for designing plant layouts with the research of different methodologies and frameworks which can be used to identify, evaluate, and implement the plant layouts. It will better understand the tools available to aid the plant's design. Ideally, this will be in the form of real-life case studies; however, this may be challenging as companies do not often formally release this information.

Thirdly, the challenges in plant layout design will be identified and considered, where the balance of conflicting organisational objectives will be identified and considered.

The scope of the literature review will be biased toward manufacturing; however, aspects of service and retail layout will be covered to gain further understanding due to layouts directly affecting consumers.

To understand the success of plant layout methodologies, it is essential to factor in that the plant layout studied may have been successful based on other companies' metrics. However, no business wants to show its failings and may not give an accurate representation of the results.

10.3 BACKGROUND

The concept of plant layout has been used for centuries, but no exact date can be determined. Researchers have seen it dating back to 2600 BCE when Mohenjo-Daro, now Pakistan and

North India, was designed with complex underwater supply and drainage, suggesting a planned layout (Smith, 2007).

In modern-day manufacturing, it is said to be Frederick Winslow Taylor, who first formally defined plant layout in his book "Scientific Management" which states the benefit of locating equipment and workers to increase productivity and reduce manufacturing wastes (Winslow Taylor, 1911). He had a scientific approach to manufacturing and understood the importance of time and motion to optimise production flow and reduce movement.

Another pioneer was Henry Ford, who made the first moving production line in 1913 (Ford Motor Company, 2023). Henry Ford gained much success by creating a flow production line and optimising workstations to have the required resources. This did not only benefit Ford but also the consumer by making automobiles affordable. It was said an automobile at the time took 12 hours to make, which Ford optimised to 93 minutes (Detroit Historical Society, 2023).

Since these early pioneers, some influential companies have used plant layouts to gain a sizeable advantage over their competitors. Toyota, specifically Taiichi Ohno, said to be the father of lean manufacturing, used plant layout to optimise the workflow and reduce manufacturing wastes of transport and motion (Toyota Global, 2023).

Amazon is another company not in the manufacturing industry that has invested heavily in plant layout and sub-systems to maximise operation speed and efficiency. It has gained a sizeable competitive advantage by reducing order processing time, and now Amazon is the world's largest online retailer (Amazon, 2023).

Another plant layout which deserves mentioning is Ikea, whose one-way shopping layout encouraged shoppers to explore all that Ikea had to offer and enticed buyers to buy more products. Again, Ikea used the layout to gain a competitive advantage and increase revenue (BBC, 2018).

From the pioneers of plant layout to the now world-leading retailers all using plant layout to gain competitive advantage, an optimised plant layout is fundamental to the success of a business.

All these successful companies have a common theme, reducing the waste of transportation and motion and increasing the available time to add value to a product or service.

10.4 METHODOLOGY

The methodology of the research will be a systematic and critical review. The systematic review will give criteria for research, and the relevancy will be determined. The critical review will allow the research evaluation the literature's strengths and weaknesses. The output from this will be a robust methodology for AB to optimise its plant layout.

10.5 SYSTEMATIC CRITERIA

Keywords:

TABLE 1 RESEARCH KEYWORDS

Plant layout	Manufacturing layout	Material flow
Workflow	Facility layout	Process layout
Lean manufacturing layout	Kanban system	Manual handling
Time and motion	Transportation waste	Motion waste
Workstation layout	Ergonomic layout	Space utilisation
Flexible manufacturing layout	Assembly line	Flow efficiency
Layout effectiveness	Cellular layout	Productivity layout
Just-in-time manufacturing	Operational efficiency	Agile manufacturing

The criteria for which research will be carried out is that all researched case studies, books, and journals will be peer-reviewed with the industrial application of which it has been used. The database of research will be industry-recognised books from the University of Wales Trinity Saint David Library and reputable academic resources.

10.6 FINDINGS

10.6.1 MANUFACTURING LAYOUTS

From research on manufacturing layouts, four were dominant and presented several different sources: (Slack, et al., 2016) (Tompkins, et al., 2010) (Teicholz, 2001) (Hodges & Sekula, 2013).

Each layout has advantages and disadvantages; the choice depends on the product, volume, and feasibility.

Fixed position layout – The product does not move, but transforming processes are carried out on the product in the fixed location. According to Slack et al., this is commonly used where it is not feasible to move due to the size, capital expenditure or sensitivity (Slack et al., 2016). This is commonly used in aircraft assembly when moving the aircraft to the transforming resources is not feasible.

Functional / Process-Oriented Layout: This layout groups similar processes for convenience of material handling, shared services and working environments, technical support required and localised workflow efficiencies (Slack et al., 2016). A functional layout can be seen in many supermarkets where products are grouped for convenience; for example, frozen food shares the same environment and are stored together. A study by Tarigan et al. showed that applying a process-oriented layout with systematic layout planning reduced material handling by 19% by grouping high-frequency processes (Tarigan et al., 2021).

Cell Layout: This layout group processes together to move parts from one process to the next with the least material handling. Commonly all processes required to transform raw material into finished goods will be within the cell and are in sequence (Slack et al., 2016). A cell layout can be seen in automotive engine manufacturing, where the sequential process is coupled next to each other to reduce the time and distance between processes. Studies from (Khorasgani & Ghaffari, 2018) and (Chang et al., 2013) show the importance of understanding the cost of cell layout and considering cell formation, layout, tool changing and sequence.

Line layout: Line layout linearly locate the transforming processes. Each product is passed through a predetermined route where the process is in sequence and commonly all required to take the raw material to the finished product (Slack et al., 2016). A line layout is a common form of a production line where workstations are arranged linearly and have high levels of efficiency, primarily used in high-volume manufacturing. A Study by Fan et al. used complex material modelling for line layout for mass customisation production, which is not commonly associated with production line layouts. The results found a practical use for a production line (Fan et al., 2017).

Mixed / Hybrid Layout: This approach can combine elements of each type of layout for the system or have sub-layouts within the process to maximise the effectiveness of the process. This approach creates customised layouts, which give far more versatility (Slack et al., 2016).

The selection of these layouts is essential to ensure maximum production efficiency and optimised use of resources. According to Muther and Hales (2014), The selection process should consider unit volume, manufacturing process and product type (Muther & Hales, 2014).

10.6.2 APPLIED METHODOLOGIES

The best practices of plant layout are not one-size-fits-all due to the variation of different factors. The research will be conducted to identify if a commonly used layout framework has the potential to be used in this project.

10.6.3 CASE STUDIES AND WORK CARRIED OUT BY RESEARCHERS.

TABLE 2 CASE STUDIES REVIEW

Name Author	Method	Findings
Design and Simulation Plant Layout Using Systematic Layout Planning, (Suhardini, et al., 2017)	Simulation of SLP	Used SLP for re-layout and simulated increased capacity and decreased MH costs. Partwise exchange method to be used for further improvement.
A Classification of Different Types of Facility Layout Design, (Taha & Tahriri, 2008)	Literature review	Review of the objectives of facility layout, material flow and manual handling.
Multiple objective facility layout: a heuristic to generate efficient alternatives (Malakooti, 1989)	Use of heuristic method for plant layout	The methodology used may not have given the most efficient layout. Layout decision-makers significantly affected the outcome and proposed a new technique for layout choice.
A simulation-based approach for plant layout	A framework for simulation-based plant layout with	Understands the lack of a proper framework for

design and production planning (Zhang et al., 2019)	integration of heuristics and algorithms.	simulation-based plant layout and propose such. However, it states that simulation is costly and hard to master to give reliable results.
A genetic algorithm with the heuristic procedure to solve the multi-line layout problem. (Sadrzadeh, 2012)	Used a genetic algorithm to solve studied plant layout problems.	A genetic algorithm and heuristic procedure can generate a cost-effective alternate layout based on an example study.
SLP-based Technical Plant Layout Planning and Simulation Analysis, (Xu, 2020)	Use of SLP method verified with simulation	Concluded SLP made sizable efficiencies verified by simulation software. However, limitations of resources failed to implement a realistic model from simulation.
A multi-factor plant layout methodology (Harmonosky & Tothero, 1992)	A method of layout design using qualitative and quantitative factors.	Combined with the pairwise exchange can give realistic layouts for large layout designs.
Selection of multi-criteria plant layout design by combining AHP and DEA methodologies (Arunyanart & Pruekthaisong, 2018)	Using analytic hierarchy (AHP) process and data envelopment analysis (DEA) for layout selection for SLP	Offers a systematic layout decision-making approach using AHP and DEA applied to SLP.

Research literature has shown several different methods of PL; however, one methodology is used frequently and effectively. Systematic layout planning by Murther and Hales has shown its industrial application, such as Kumar and Malleswari (2022), which used SLP on the largest

Rail stations in India. The coach maintenance works an improvement of 30% in utilisation and 20% in material flow rate (Kumar & Malleswari, 2022). Patil and Kuber (2014) used SLP in an auto-ancillary company. They had results of reduced MH cost, time and labour, and the company now has a clear justification for space utilisation (Patil & Kuber, 2014). Hossain and Talapatra (2014) applied SLP in the jute industry and reduced the distance and cost of material handling (Hossain & Talapatra, 2014). Further studies of SLP have all shown the same results (Yang et al., 2000), (Wiyaratn & Watanapa, 2010),

SLP is not a golden egg of PL; it is a methodical, procedure-based approach that offers numerous tools to identify and capture data on business operations and apply it to PL. The fundamental steps of SLP can be seen in several different resources such as (Pemberton, 1974), (Moran, 2015), (Teicholz, 2001), (Salvendy, 2001), (Wu, 1994)

All of which had the same fundamental elements:

1. Objectives: Create operational objectives for the layout
2. Product: Understand the product being made concerning volume, cost, quality, and priority.
3. Manufacturing: Collect data on required resources, processing time, the relationship between resources, constraints of resources, safety, material flow, manning flow, and process sequence.
4. Design: Develop different layouts, analyse against objectives, and iterate designs.
5. Evaluate: Evaluate different layouts to find the best solution to objectives.
6. Implement: Install new design and maintain.

Through this process, data must be collected on which layouts will be based. To ensure that the data is relevant and valuable, manufacturing tools to aid in capturing data are critical.

Value stream mapping (VSM) – A lean tool to map out all value-adding and non-value-adding processes. Lasa et al. (2008) concluded from the study that VSM is a valuable tool in redeveloping production systems and gives a visual representation of the whole system. (Lasa, et al., 2008).

Process mapping – A map of all processes required with a timeline. According to Antonacci (2021), when PM is deployed correctly, it supports a better understanding of complex systems and is a vital improvement tool (Antonacci et al., 2021).

Material flow analysis – A flow analysis of materials within the manufacturing process. Research from Hameri (2011) stated that MFA is a well-established method of identifying common routes and thus forming natural resource cells to complete tasks (Hameri, 2011).

Process relationship analysis – The analysis of the relationship between processes. Murther and Hales (2014) see the process relationship analysis as a critical fundamental of SLP. It gives an understanding of the relationships of processes and encourages discussion of the criteria of the relationship (Muther & Hales, 2014).

CAD / Simulation – To design and simulate operations of different layouts. According to Zhang et al., using CAD and simulation is now an effective way of visualising operations and allowing data-driven decisions (Zhang et al., 2019).

10.6.4 CHALLENGES OF PLANT LAYOUT

While efficient PL will give several benefits to a company, there will always be challenges that must be overcome. As with all operational decisions, it always comes down to understanding the benefits against the costs.

Space constraints are a regular occurrence in PL; according to Pemberton (1974), the building should be a shell to house the optimised layout. However, that is rarely not the case, so the ideal PL should be designed and then adapted to the constraints of the building (Pemberton, 1974).

Safety Concerns will always be a challenging issue in PL. A study by Shikdar and Al-Araimi (2001) and Shin and Park (2017) only seen a 66% rate of compliance with safety regulations of safe working space in small manufacturers (Shin & Park, 2017), (Shikdar & Al-Araimi, 2001).

Equipment placement and maintenance are critical in PL. Studies from Achouch et al. (2022) and Arinez and Cochran (2000) explained without correct thought of equipment placement concerning maintenance often results in significant losses in downtime due to the increased time of repair (Arinez & Cochran, 2000) (Achouch et al., 2022).

Change of needs and growth must be considered when designing a PL. The ideal layout today may not be the perfect layout tomorrow. Managers will need to strike a balance between optimising the design for today and having the flexibility and adapting the company's objectives in the future. A study by Briano et al. (2010) used simulations for what-if situations. It concluded that simulation software could be used for feasibility analysis before investing significantly in PL or new equipment (Briano, et al., 2010). Further to the importance of adaptability is the introduction of Industry 4.0; Pei, et al, expect companies will need to adopt technologies of

intelligent manufacturing and data acquisition to maintain a competitive advantage in their industry (Pei, et al., 2017).

Cost and budget constraints are present in all PLs. Managers must decide to have the most optimised PL on the company's budget. According to Kainian, et al (2019), there is a lack of comprehensive tools for cost and sustainability-based decisions of investing in new technologies and or PL (Kianian, et al., 2019).

10.6.5 REVIEW

Despite the benefits of optimisation of PL, several challenges exist to overcome. The biggest is balancing the conflicting objectives of having the most cost-effective, optimised PL for today and the future. From the research, the management decision-making process lacked a process or framework as it is a heuristically based decision. Models have been proposed by (Malakooti, 1989) (Arunyanart & Pruekthaisong, 2018) (Sadrzadeh, 2012) to aid in the decision; however, these need an extensive investment of resources in the acquisition of qualitative and quantitative data and knowledge in the field of algorithms and simulation.

The most significant decision to be made from a management perspective is optimising the layout for the future; the company could be paying for capacity or space that currently is not being used in the hope of future growth (Salvendy, 2001). It is essential to have scalability in the PL and be considered in the initial PL design if extra capacity is needed. Simulation can answer some of the unknowns of the scaling capacity; however, as Xu, (2020) concluded, the initial cost, knowledge and time required of the simulation are often not cost-effective for smaller companies (Xu, 2020).

From the literature reviewed, it was clear that the SLP is a robust and effective methodology of PL. The simple step-by-step method of understanding the product, collecting data, forming a relationship, and planning implementation. Furthermore, SLP is an open educational resource, making it ideal for AB.

10.6.6 FURTHER RESEARCH

Further research must be conducted to identify suitable simulation software and frameworks. While a simulation will not be conducted in this project, it will be used to validate layouts once all information is acquired.

Additionally, research into decision-making tools would be advantageous to this project; however, being conscious of the workload of this project, this will be conducted at a later date.

11 MAIN BODY

11.1 OBJECTIVE

To gain cost-effective output efficiency from Atherton Bikes' new plant by optimising the layout to reduce material handling and distance between resources for AL products as a priority.

The units per year on which this report will be based are:

TABLE 3 FORECASTED SALES

Product	2023	2024	2025
AM	300	600	600
AL	500	1500	2500

All analysis in this report will be based on AM and AL at maximum output in 2025, ensuring that AB designs for the future and maximising the efficiency at the highest output.

11.2 SCOPE

The scope of this report will be to carry out SLP at a plant level of common resources used to transform the AL and AM product lines. Efficiencies will be made with the AL product line's priority due to the forecasted larger volume.

11.3 Method

The SLP framework will be used as the method of data collection, design layout, and evaluation.

SLP has five phases, as seen in Figure 1. Phase one is the identify phase, where data is captured in the P-Q study; this will naturally give the layout types required, which will be explained in further detail later in this report.

Phase two is forming the relationships through R-S-T analysis using relationship diagrams and material flow analysis.

Phase three will give an understanding of the space required and available space, providing space relationship diagrams.

Phase four will output several block layouts that will be adapted to the limitations of the available space.

Phase five will evaluate and approve the layouts based on cost and effectiveness to the objectives.

Phase loop, once this is complete from a plant level, the phases start again but at a more local level, for instance, at the work centre level, and then at a room level.

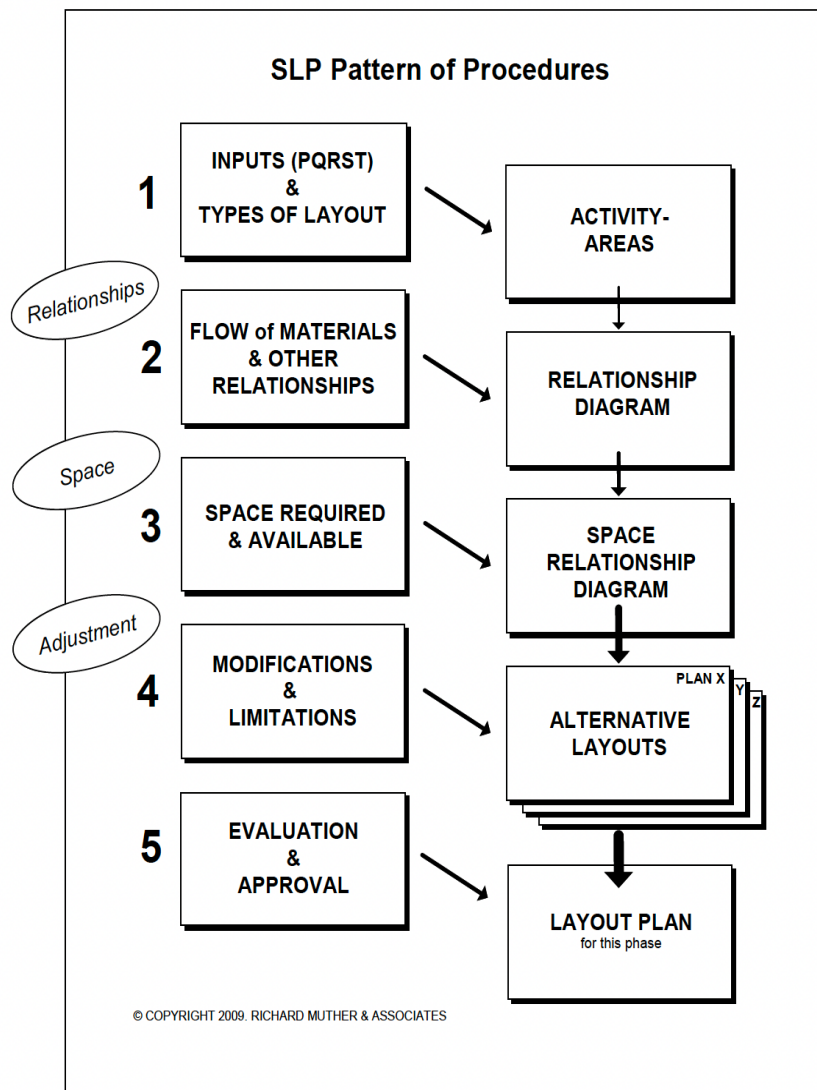


FIGURE 1 SYSTEMATIC LAYOUT PLANNING PATTERN OF PROCEDURES

11.4 TOOLS

- PM – Process mapping
- MFA – Material flow analysis
- RD – Relationship diagrams
- SD – Space diagrams
- PED – Product evaluation document
- FPC – Flow process chart
- OMD – Operator motion diagram

11.5 DELIVERABLES AND KEY PERFORMANCE INDICATORS

The deliverable of the report is to give a detailed factory layout for AB of their two product lines, AM & AL. The layout must work for current volumes and have the potential to grow with the business when it understands the market and as the products mature.

To determine the success of the factory layout, key performance indicators (KPI) must be defined to give measurements of the improvements. The KPIs will be:

- Output
- Labour cost per unit
- Value work time availability (employees)
- Output per meter squared.

11.6 PROJECT MILESTONES

TABLE 4 PROJECT MILESTONES

Pattern of Procedures Section Number	Key Documents:	Other Documents	Form of Output
1 Activities	P-Q Analysis	- P-Q Data Sheet - Checklist of splitting or combining factors	List of activity-Areas
2 Relationships	Relationship Chart	- Operation process chart - Multi-product process chart - From-to chart - Relationship survey	Activity relationship or flow diagram
3 Space	Activity Areas and Features	- Survey of current space assigned - Machinery, Equipment area, Feature sheets - Office layout requirement data - Space requirements, converting form	Space relationship diagram
4 Adjustment	Block layout drawings	- Scaled and grid-lined templates of activity-areas	Alternative layouts
5 Evaluation	Evaluation of alternatives	- Cost estimates and comparisons	Selected overall layout

11.7 PHASE 1: PQRST & LAYOUTS

11.7.1 P-Q ANALYSIS

Evaluate the product lines to be manufactured to understand quantity, manufacturing complexity, priority, and cost.

11.7.2 LIST OF ACTIVITIES

The list of activities identifies functions and briefly describes all the activities within the business. This gives the foundation on which all other analysis takes place.

TABLE 5 LIST OF ACTIVITIES

Identification & Name / Definition	
1. Main Entrance	Entrance for employees and public
2. Lobby	The main lobby, a meeting point for the public and a showroom
3. Offices	Employee office space
4. Rest Area	Area with food cooking facilities with seating
5. WC Facilities	Toilets, showers and wash stations for employees and visitors
6. AM Room	All additive activities
7. Post Process	Processing of AM lugs
8. Tube Process	Processing of all tubes
9. QC & Kitting	Quality inspection of all parts and storage for WIP
10. Pre-Bond Process	The sorting and cleaning of parts for the bond process with wash facilities
11. Bond Process	All bonding activities
12. Post-Bond Process	All activities post bonding
13. Assembly	Frame and bike assembly, including packing for shipping

14. Goods in/out	For all incoming materials and outgoing products
15. Component Stores	The store for all components

11.7.3 PRODUCT - QUANTITY DATASHEETS

Product - Quantity datasheets give a method of organising information on products and quantity. It provides details of production description, materials/components required, product details, and quantity. These data sheets are the starting point of SLP and serve as a good foundation for further analysis to be carried out in areas such as inventory policies, scheduling strategy, and process technologies.

Figure 2 and Figure 3 show the product quantity data sheets for the AM and AL products. The key points taken from the PQ datasheets are:

AM

1. Lugs are produced in-house.
2. CF tubes are bought and cut to length from the supplier.
3. It is manufactured to order.
4. Maximum forecasted units 600 per year.
5. 15 components are needed to produce a frameset.

AL

1. Lugs are outsourced.
2. AL tubes are bought in 2-meter lengths and cut to size.
3. It is manufactured to stock on production introduction.
4. Maximum forecasted units 2500 per year
5. 10 components are needed to produce a frameset.

11.7.4 PRODUCTION STRATEGY

The AM product line production strategy is built to order; this utilises the strengths of additive manufacturing, as variation does not come at an increased cost. This allows AB to offer many sized bikes compared to competitors and is industry-leading in available sizes. The current AM lugs that AB currently produces are made in-house; the decision to bring this manufacturing method in-house was based on the limited outsourcing availability. Additive manufacturing at

the time was heavily adopted in medical engineering, formula one and aerospace; this meant that outsourcing prices were inflated and were not feasible for AB to use these services. At the time capacity of additive manufacturing could only be scaled by adding further machines as the current additive machine is running at a maximum capacity of 1 bike per build. However, since the adoption of additive manufacturing in more industries, outsourcing is becoming readily available and is now an option for AB to gain more capacity. Therefore, AB will outsource additional capacity until the new machine is onboarded.

The CF tube manufacturing is outsourced due to the significant capital required to manufacture in-house; furthermore, the production rate of this process would not balance with the additive process and thus would not be utilised to its potential without scaling AM further.

The AL product line production strategy is built to stock but will mature to make-to-order. The AL product is comprised of CNC 7075 aluminium lugs and aluminium tubes. Aluminium CNC machining is outsourced and widely available across the globe. The availability of this made commercial sense to outsource the production of lugs. This allowed the production to be scaled when needed with minimal risk and capital. This production strategy results in AB not offering a wide range of sizes due to the cost associated with variation and the risk of holding unwanted stock.

As for quantity produced, AL's highest capacity will be four times more than AM; therefore, a greater emphasis on prioritising optimisation will align with AB's objectives. The AL lugs will be produced and shipped in batches, with the tubes coming in long lengths, which will be cut to size and batched to anodises.

The overview of the products indicates that the AL has been designed for manufacturing at a higher volume. By outsourcing the manufacturing of the lugs, AB can achieve the forecasted unit target by optimising the in-house processes to be able to achieve.

Product - Quantity Data Sheet

Product Description				
Product Name:	AM			
Description:	Additive Bike			
Part Number:	AM.XXX.0002			
Unit of Measure:	Frame			
Starting Material(s):	Ti-6Al-4V Powder			
	Carbon Fibre Tube			

Material(s)/Components Required				
	Decription	Part Number	Quantity	Weight
1	Heat Tube	XXX.1001	1	
2	Bottom Bracket	XXX.1002	1	
3	Seat Tube Lug	XXX.1003	1	
4	Bend Lug	XXX.1004	1	
5	Yoke	XXX.1005	1	
6	Brace	XXX.1006	1	
7	Dropout LH	XXX.1007	1	
8	Dropout RH	XXX.1008	1	
9	Chainstay Lug LH	001.1001	1	
10	Chainstay Lug RH	001.1001	1	
11	Downtube	003.1001	1	
12	Top Tube	003.1002	1	
13	Seat Tube Lug	003.1003	1	
14	Trail Stay	003.1004	1	
15	Gravity Stay	003.1005	1	

Product Details			
Details:	In-house manufacturing		
Production Strategy	Built to order		

	Raw Material	Origin	Supply Qty / Rate
Material Source:	Ti-6Al-4V	Canada	100kg monthly supply
	CF Tube	New Zealand	Outut based monthly supply

Quantity			
	Per year	Per month	Per Day
Quantity Produced 2023	300	25	1.2
Quantity Produced 2024	600	50	2.4
Quantity Produced 2025	600	50	2.4

Trends:	Size
Seasonal:	Yes
Operating hours	8
Supplier	AB
MOQ	N/A
Lead time:	N/A
Notes:	

FIGURE 2 PRODUCT - QUANTITY DATA SHEET AM

Product - Quantity Data Sheet

Product Description				
Product Name:	AL			
Description:	Aluminium Bike			
Part Number:	AL.XXX.0002			
Unit of Measure:	Frame			
Starting Material(s):	7075 Aluminium			
	7075 Aluminium Tube			

Material(s)/Components Required				
	Decription	Part Number	Quantity	Weight (g)
1	Heat Tube	XXX.1001	1	390
2	Bottom Bracket	XXX.1002	1	398
3	Seat Tube Lug	XXX.1003	1	146
4	Bend Lug	XXX.1007	1	182
5	LH Rear Tri	XXX.1004	1	591
6	RH Rear Tri	XXX.1005	1	626
7	Brace	XXX.1008	1	111
8	Down Tube	003.1007	1	
9	Top Tube	003.1008	1	
10	Seat Tube	003.1009	1	

Product Details			
Details:	In-house assembling		
Production Strategy	Hybrid of built to stock/order		

	Raw Material	Origin	Supply Qty / Rate
Material Source:	7075 Al Lugs	China	Monthly supply
	7075 Al Tube	China	Monthly supply

Quantity			
	Per year	Per month	Per Day
Quantity Produced 2023	500	41.7	2.0
Quantity Produced 2024	1500	125.0	6.0
Quantity Produced 2025	2500	208.3	9.9

Trends:	Size
Seasonal:	Yes
Operating hours	8
Supplier	Star Rapid & Alumina
MOQ	20 Bikes
Lead time:	8 weeks
Notes:	Plan to onshore manufacturing of lugs

FIGURE 3 PRODUCT - QUANTITY DATA SHEET AL

11.8 SUPPORTING SERVICES

Supporting services are generally non-value-adding processes, functions, and equipment that must be present to allow the value-adding processes to function correctly. In PL, it is vital to consider these services at an early stage, and often these services occupy more floor space than the value-adding work centres (Muther & Hales, 2014). Basic supporting services are a legal requirement under the welfare at work regulation (HSE, 2007) and give provisions for facilities for the welfare of workers. AB's new facility will have basic supporting services such as restrooms, wash facilities, an elevator, a staff rest area, and a bike shed that adheres to the regulation.

- Further support services for production:
- Goods in and out – This will be the process of sending and receiving materials.
- Stores – The storage of components and packaging for the assembly and shipping of bikes.
- Consumable stores - The storage of consumables used in the manufacturing process.
- Quality Checks – The work centre of which all quality checks are carried out once received from suppliers and outsourcing.
- Kitting – The work centre where all sorting of parts is carried out.

11.9 PROCESS & ROUTING

The next stage of product analysis is understanding what is required to transform materials into products. The AM and AL products are of different materials but share the same construction architecture (lug and tube). This common architecture allows both products to share manufacturing processes.

11.9.1 PROCESS MAPPING

To depict this, an operational and process map can be seen in Figure 5 and Figure 5 respectively, showing each product's transforming processes. The operational map details the whole process, which includes outsourcing, whereas the process map gives detail of the in-house processing that AB carries out. Due to the capital expenditure and knowledge required, it is unlikely that AB will bring any of the outsourcing in-house.

Figure 5 is a level 1 process map; each numbered process has a further level process map which can be seen in the appendix. The level 2 process map gives further detail about each process step.

The data from the process map can be seen below:

TABLE 6 PROCESS MAP FINDINGS

Product line	Number of transforming processes	Time is taken to process (h)	Number of outsourced functions
AM	25	50.7	3
AL	16	25.4	1

Once the layouts have been designed, due to the complexity of the process, a flow process chart will be made. This will give detail of each process sequence, processing time, transportation, motion, delay, storage, and distance travelled. This level of detail is required so that calculations of distance and material delays can be used for each layout. This will also identify where space needs to be allocated to store materials if minimum batch quantities are required.

Operational Map

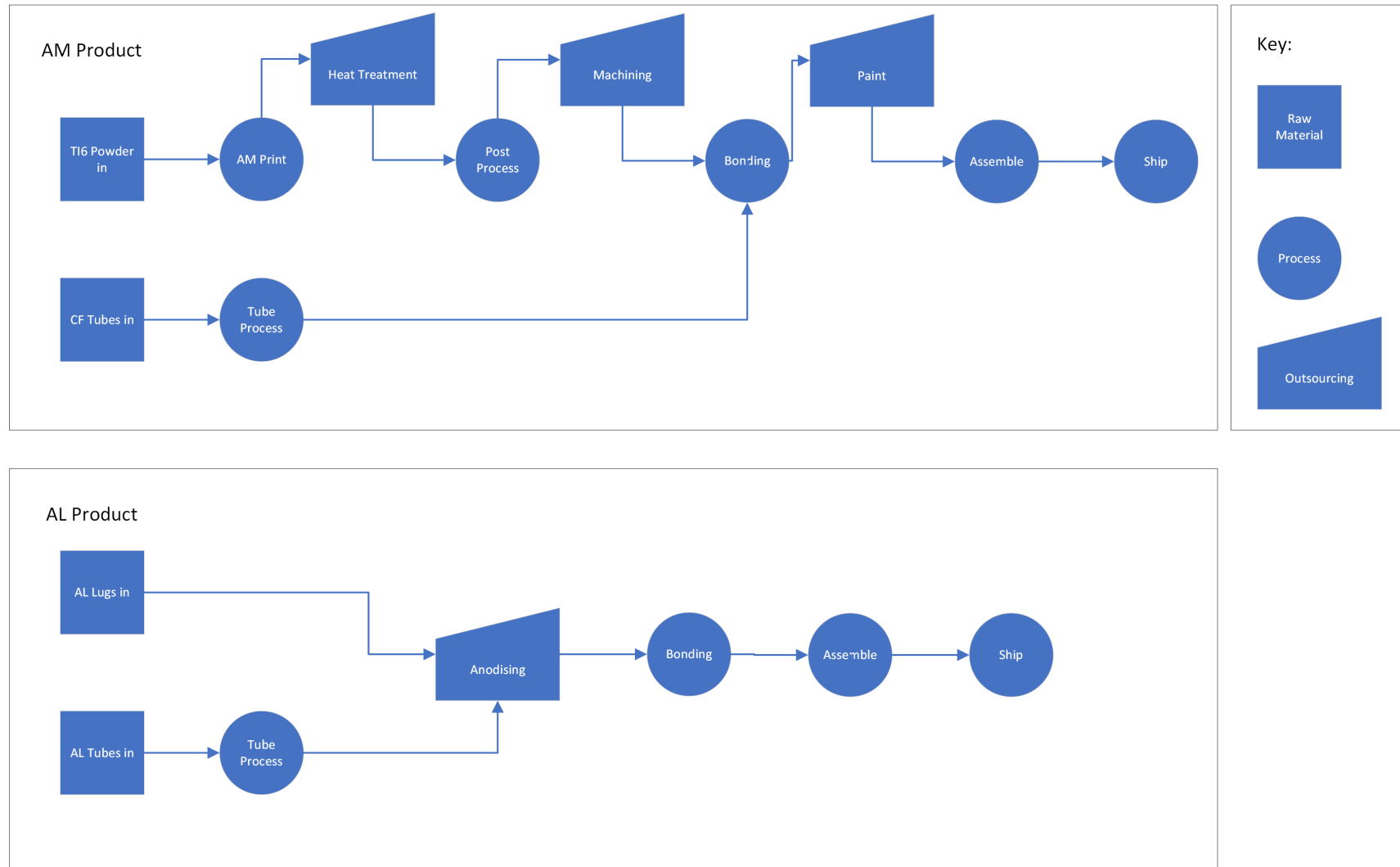


FIGURE 4 OPERATIONAL MAP

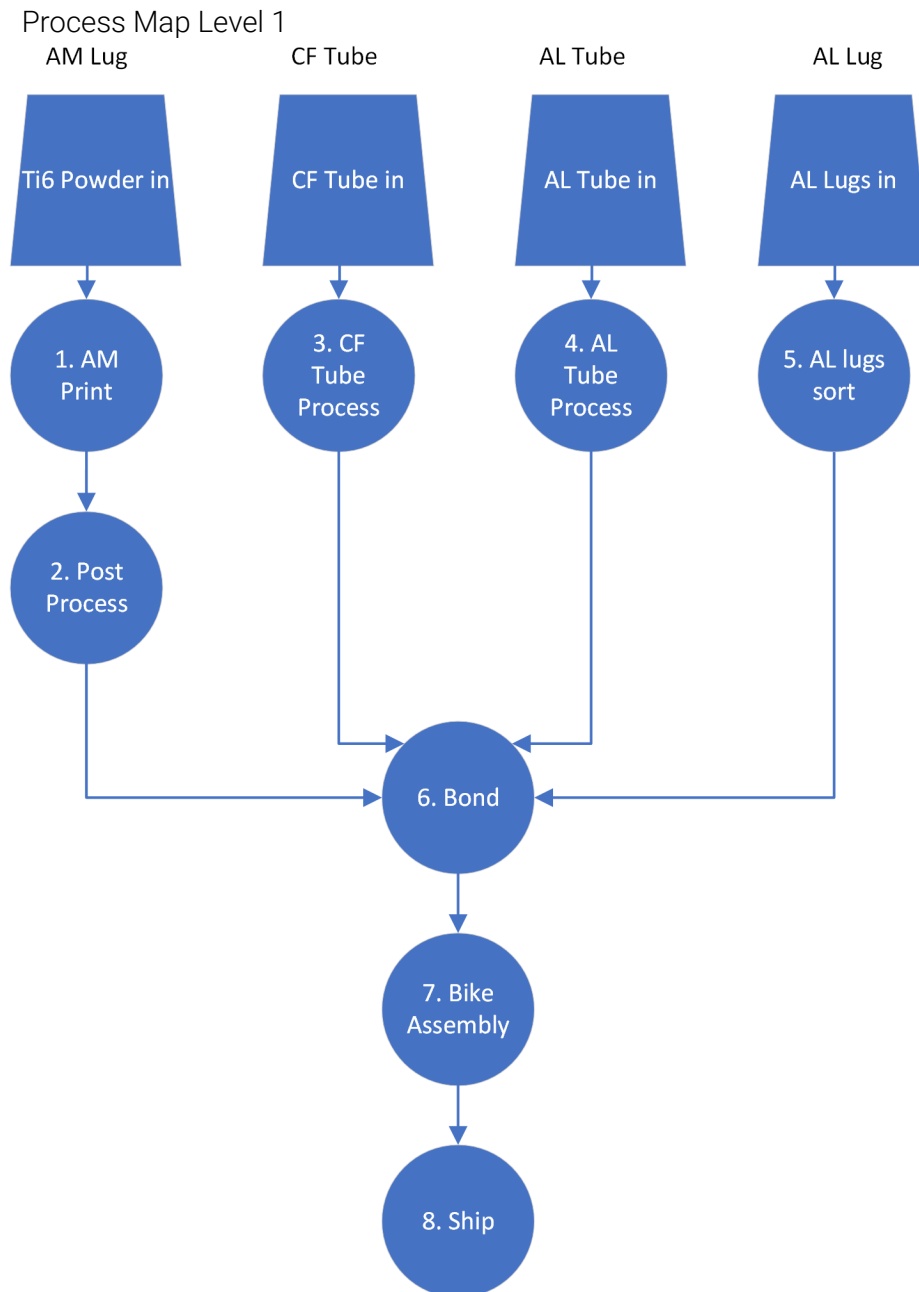


FIGURE 5 PROCESS MAP L1 AM & AL

11.9.2 MATERIAL FLOW

The process map's next step is carrying out a material flow analysis. At AB, there are currently eight work centres for the AM product which are given below; these have been carried forward into the new AL product due to many common processes. These work centres will be the basis of the AL product, but changes will be made if commercially viable.

1. AM print
2. Post process
3. Tube process
4. QC
5. Kitting
6. Bond
7. Bike assembly
8. Goods in / out

To ensure that data in the material flow diagram (MFD) is captured, a From-To chart for each material was used to indicate how material flows from one work centre to another and at what volume. The From-To charts are shown in the appendix.

The MFD depicted in Figure 6 shows the interaction of each work centre at level 1. However, the two product lines have been split into separate products, showing the shared processes. From the MFD, the AM process is far more complex than the AL, with high-frequency interactions with goods in and out. While the AL product having far fewer processes allows for a more streamlined process, however having high-frequency interactions in kitting, bonding, and assembly.

Figure 7 is a further analysis of material flow but with product lines integrated into one MFD, with the line weighting representing the volume of material flowing. By analysing the diagram based on the level of interaction, volume and frequency, there is heavy interaction and volume between four work centres, kitting, bond, assembly, and goods in and out. There is an opportunity to reduce the material distance between these work centres and thus reduce the material handling cost.

While AM has the most significant number of interactions per bike with goods in and out due to outsourced functions, the rate of material is lower than AL. While still obtaining the objectives of the projects, it would make commercial sense to reduce the distance of the interaction of AL with goods in and out rather than AM.

11.9.2.1 FURTHER CONSIDERATIONS

The MFD is a powerful tool for mapping how material flows through the system; however, some considerations have not been captured. The material does not always flow at a linear rate through the system. As with many outsourced functions, it is a balance of manufacturing flow and cost-effective minimum batch order quantity (MBOQ). At AB, the outsourced function requires an MBOQ, so while the material flows through each work centre, it may not be daily. Commonly batches are made and transported as one entity to outsourced functions. While the volume could potentially be high, the movement is singular. This MBOQ must be captured to ensure efficiencies are not made in the wrong locations.

Further considerations are the size of the WIP between work centres. At the start of the process, WIP is small and can be easily carried, such as lugs which will be transported in small boxes. However, later in the process, such as post assembly, the lugs, tubes, components, and box become a finished bike and thus much larger. This must be transported as a single piece and will be over 1.4m long. The size of the WIP will need to be considered in the layout to ensure efficient movement of the WIP.

Material Flow Diagram Level 1

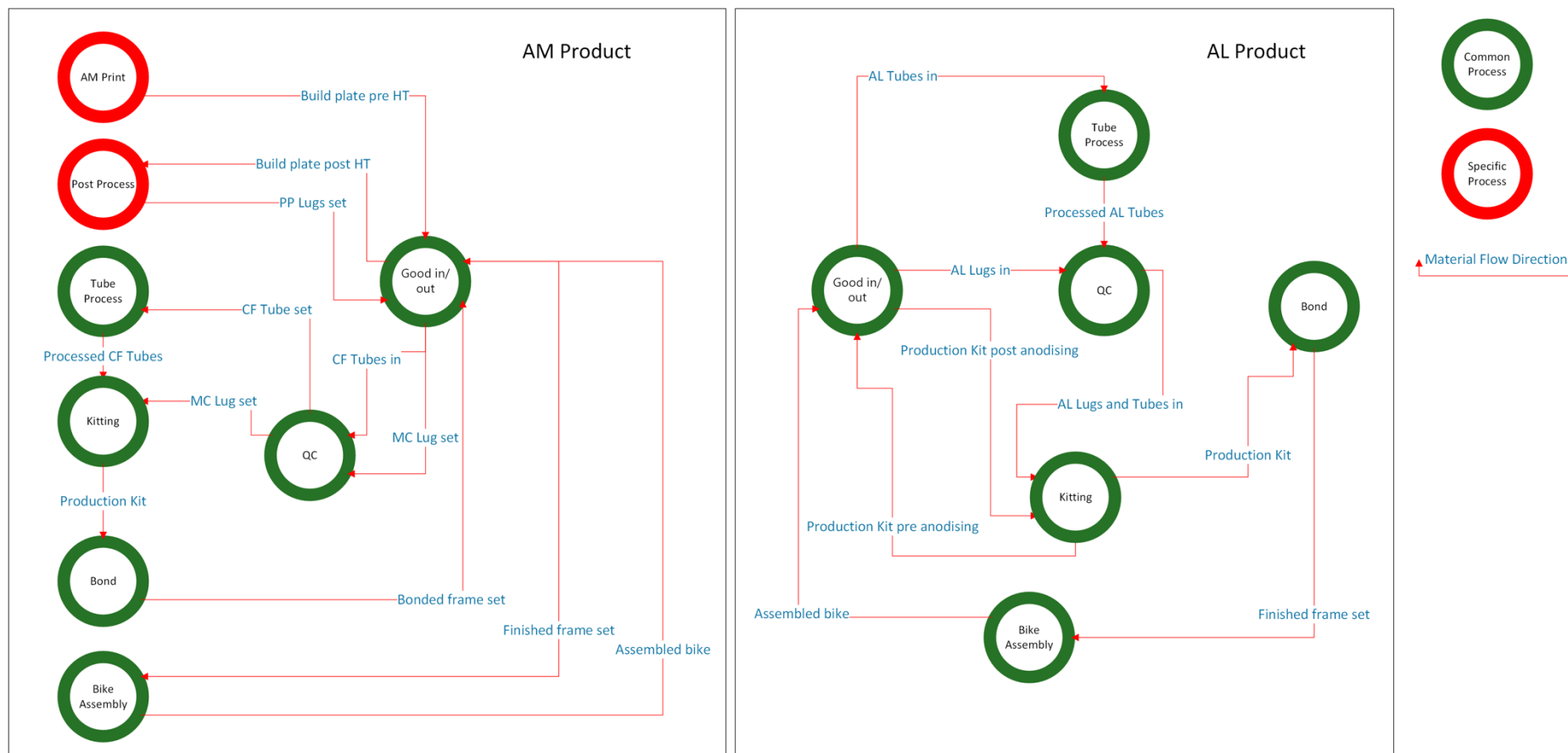


FIGURE 6 MATERIAL FLOW DIAGRAM AM & AL LEVEL 1



11.9.3 TIME

The next step is understanding the time required to process each product line. The current AM product has a production flow rate of 7 bikes per week. This is based on the AM machine's maximum capacity of 1 bike per day, 7 days a week. The rest of the AM process has a capacity of 7 bikes per 5 days. On average, customer demand is greater than the production rate; thus, the lead time increases with every order. AM production is a 35-hour, 5-day working week, with AM print on a 7-day work pattern split between two operators.

The AL product will maintain the 35-hour, 5-day working week at a capacity of 2500 per year. This equates to 50 bikes per week and 10 bikes per day. To ensure the objective capacity has been met, an understanding of the cycle time of the process must be present to allow for an adequate number of employees and workstations to fulfil the objective.

11.9.3.1 VALIDITY AND ASSUMPTIONS

As the AM product is in production, accurate cycle and process times can be given at each work centre. However, this is in the current AB facility, where the layout is not optimised, and process time will vary in the new facility.

A cycle time study as part of a bottleneck analysis has been carried out on several AL processes, such as a bond, tube process, kitting, and QC, which will reasonably represent actual results.

However, there has been no study on the GIO of AL parts. This is a significant process function, so assumptions have been made by timing scenarios with AM parts to allow for reasonably accurate times. Further considerations are that many of the tasks within GIO are processing batches from suppliers and outsourcing. While this processing will be at one time, an average time will be taken per bike for a process and cost analysis.

To calculate the time taken for the movement of materials, a time has been given as 1 second per 1 meter; this will allow the carrier not to be rushed and have a level of care for the material. This unit of measurement was based on an average time taken from the process time study.

11.9.3.2 PROCESS AND CYCLE TIMES

To ensure the correct number of workstations and employees are available to meet the objective, the times must be first defined.

Cycle time – Time taken to carry out the specific activity.

Process time – Time taken to complete the specific activity.

The cycle time of the process will dictate the number of employees required, while process time will influence the number of workstations and equipment, thus, space required. Accurate process timings are crucial in any manufacturing company; they allow for accurate planning and scheduling, resource allocation, and cost control. Further benefits of considering process timing in PL is the allocation of space for buffers and batches within the layout. Without these buffers, processes could become blocked or starved.

The formula for workstation/employee calculation:

$$\begin{aligned} & (\text{cycle time} / \text{available work hours}) \times \text{required output} \\ & = \text{number of workstations/employees} \end{aligned}$$

Cycle & Process Time Data

AM

Work Centre	Cycle Time (h)	Process Time (h)	Requirements
AM Print	2.0	22.5	0.6
AM Post Process	5.3	5.3	1.5
AM Tube Process	1.0	1.0	0.3
AM Pre Bond	0.4	0.4	0.1
AM Bond	3.4	15.4	1.0
AM Post Bond	0.8	0.8	0.2
AM Goods in & out	0.3	0.3	0.1
AM Kitting	0.2	0.2	0.1
AM QC	0.5	0.5	0.1
Total:	13.9	46.4	
Assembly	4.2	4.2	1.19
Package	0.2	0.2	
Total Time	18.2	50.7	5.2

AL

Work Centre	Cycle Time (h)	Process Time (h)	Requirements
AL Tube Process	1.3	1.3	1.88
AL Pre Bond	0.4	0.4	0.52
AL Bond	2.8	14.8	4.00
AL Post Bond	0.4	0.4	0.60
AL Kitting	1.8	1.8	2.60
AL Goods in & out	1.7	1.7	2.44
AL QC	1.4	1.4	2.02
Total:	9.8	21.8	
Assembly	3.3	3.3	4.76
Package	0.2	0.2	
Total Time	13.4	25.4	18.8

FIGURE 8 CYCLE & PROCESS TIME DATA

Figure 8 has been calculated from the assumptions made for AL cycle time from similar process from AM. The key takeaways from calculations regarding workstations are bond and assembly. Based on the times required, bond as a combined process will need 5 workstations (1 AM, 4 AL) based on the cycle time but with 12 jigs when process time is considered. The space required to store the jigs will need to be considered in the layout of the bonding space.

Assembly will require 5 workstations in total to meet the output combined total. It is important to note that the assembly process is based on assembling one bike in a fixed location. There is an opportunity to layout assembly into an assembly line format to gain increased output in less space. Furthermore, the assembly time of a frame was not considered; therefore, there is potential for extra capacity from assembly.

11.9.3.3 FURTHER CONSIDERATIONS

The cycle and process time of the AB process will need further analysis. A bottleneck analysis will need to be carried out to validate if the increased number of workstations will add capacity to the system once a layout has been installed. Furthermore, efficiencies in time can be made with optimised workstations, adopting lean principles such as 5's and conducting time and motion studies to understand the time between motions.

11.10 RELATIONSHIPS

The next step is to create and understand relationships between work centres. First, a criterion must be set so the relationships can be formed. This project aims to maximise manufacturing output by reducing material handling and distance travelled. Therefore, the criterion will be driven by company objectives which are stated below:

TABLE 7 RELATIONSHIP CRITERION

Reason for importance:	Closeness Importance:
1. Material flow 2. Ease of supervision 3. Common personnel 4. Necessary contact 5. Environmental 6. Similar equipment 7. Shared services	A -Absolutely necessary E – Especially important I – Important O – Ordinary Closeness U – Unimportant X – Not Desirable

The criterion is for a relationship chart in Figure 9 where each work centre is given a reason for the relationship and the required closeness.

The findings in the MFA and PM have been the basis of the relationship diagram and have formed key relationships that must be considered in the layout design.

RELATIONSHIP CHART

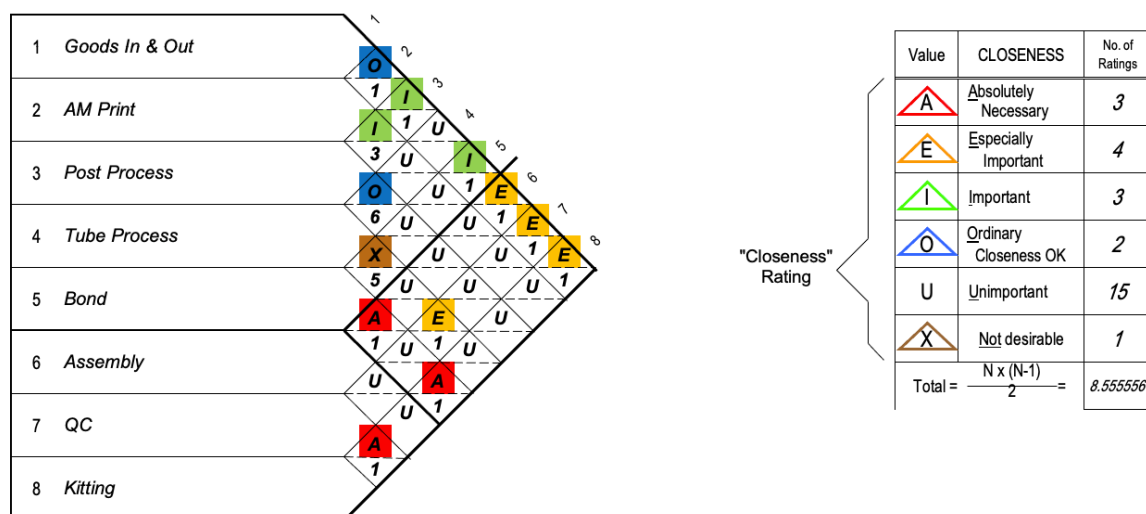


FIGURE 9 RELATIONSHIP CHART

The key relationships that must be considered are all absolutely necessary and especially important.

8. Kitting to 5. Bond – This route has the highest throughput of parts of any work centre on any given day. All lugs and tubes will need to be moved from kitting to bond and transported on a trolley per bike which will also become the stand for the bond station. The frequency of this movement is a factor of output and potentially will need to be carried out 12 times per day.

5. Bond to 6. Assembly - As all AL bikes will route from bonding straight to assembly. The material moved will be finished frame sets, often carried as a frame set by a person. With the output of AL being at a rate of 10 per day, the distance of this movement will accumulate and could be a substantial cost. Furthermore, the risk and probability of damage in the movement are high, and the consequence of that could result in a damaged frame.

7. QC to 8. Kitting – With all parts routing through QC and then to kitting, these work centres must be in proximity of each other concerning material flow. Another consideration is that QC and kitting will share the same personnel; reducing the distance between these work centres will increase the available value adding time for the employee.

1. GIO to 7. QC – as seen in MFA, all incoming parts are quality inspected before processing. The QC department routes all lugs and tubes through; therefore, GIO and QC must be close based on material flow. The material flowing from GIO to QC will often be in batches, and considerations must be made on the size of batched material; for example, AL tubes in the raw material form will come in lengths over 2 meters.

8. Kitting to 1. GIO – Due to all AL lugs and tubes being assorted into a production kit for anodising, the volume of parts which route through these work centres is high, and thus the reasoning is material flow. Furthermore, the production kits to fulfil the batch requirement will not be able to be carried and will most likely be transported with handling equipment. The production kits will be batched to anodising and will not have a daily flow rate.

9. Assembly to 1. GIO – This relationship is based on the size of the material moved. The assembly output is a boxed bike; it would be unlikely that multiple units will be moved at one time, thus the need for reducing the distance as the output will dictate the number of movements required in a day.

4. Tube process to 5. Bond – This relationship is based on the environments that each requires. The bond work centre is required to be a clean area where minimising contamination is a priority. Due to the processed materials, the tube process will create contamination in dust and

swarf. Therefore, it would be ideal to have the most distance between these work centres as possible.

Several outputs from the relationship chart will form the foundation of the layout design. There is evident importance of grouping work centres such as QC, kitting, and bond due to the frequency of interactions and volume of throughput. Furthermore, assembly to GIO will also be a high priority due to the size of the material needed to be moved. Based on the findings of the relationship chart, combining QC and kitting into one work centre would ensure the material flows with the least distance, allowing maximum utilisation of personnel.

From the relationship chart, the defined relationships are depicted in a relationship diagram seen in Figure 10. While in its current form may not look useful, when the layouts are designed, the work centres are moved to their desired locations, and it will verify if the lengths of the lines between work centres have achieved the closeness.

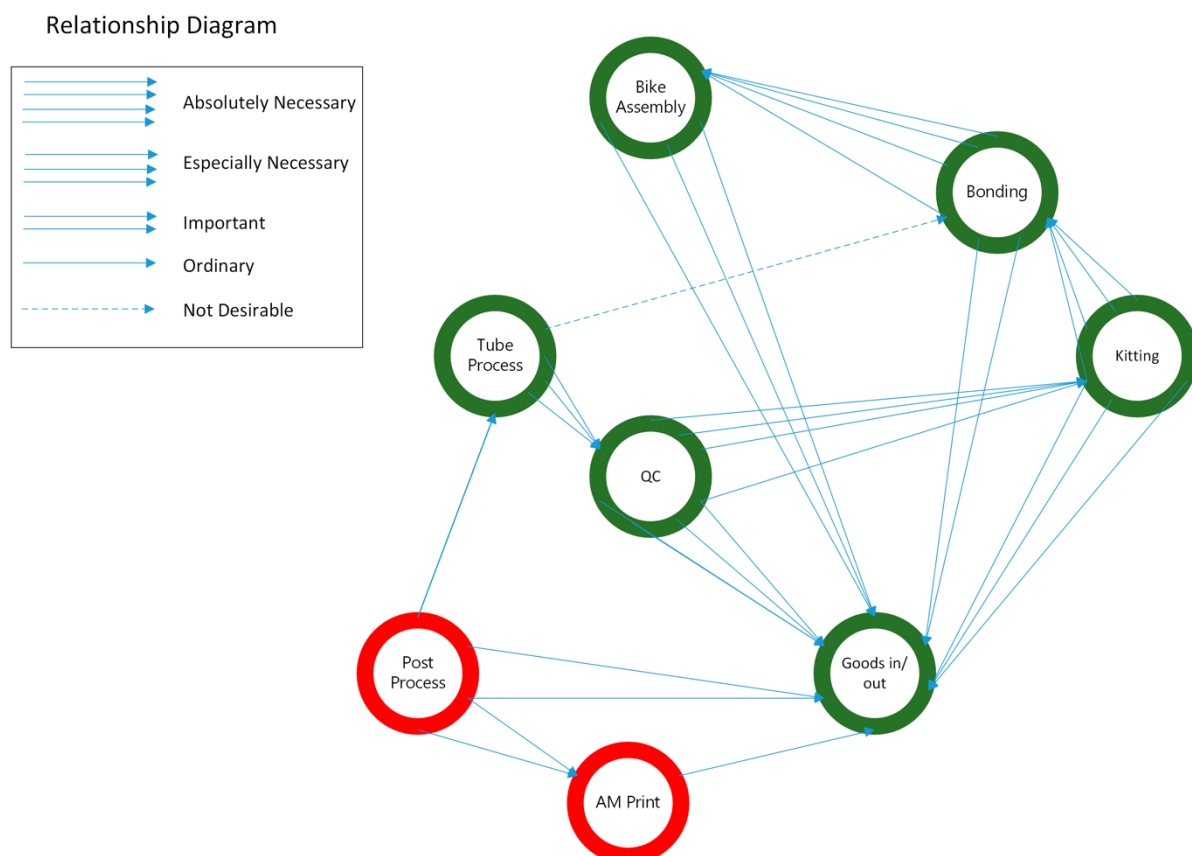


FIGURE 10 RELATIONSHIP DIAGRAM

11.11 SPACE

The purpose of the space step is to create a visual picture of all the data collected in the previous steps by adding the required space of each work centre. The first step is to understand the space available. Figure 11 is AB's new facility, which has 375m² of available factory space to house all transforming processes and adhere to health and safety regulations. With the adherence to health and safety regulations, the available space will be reduced. The space available is fixed, and there is no opportunity for extension in the future.

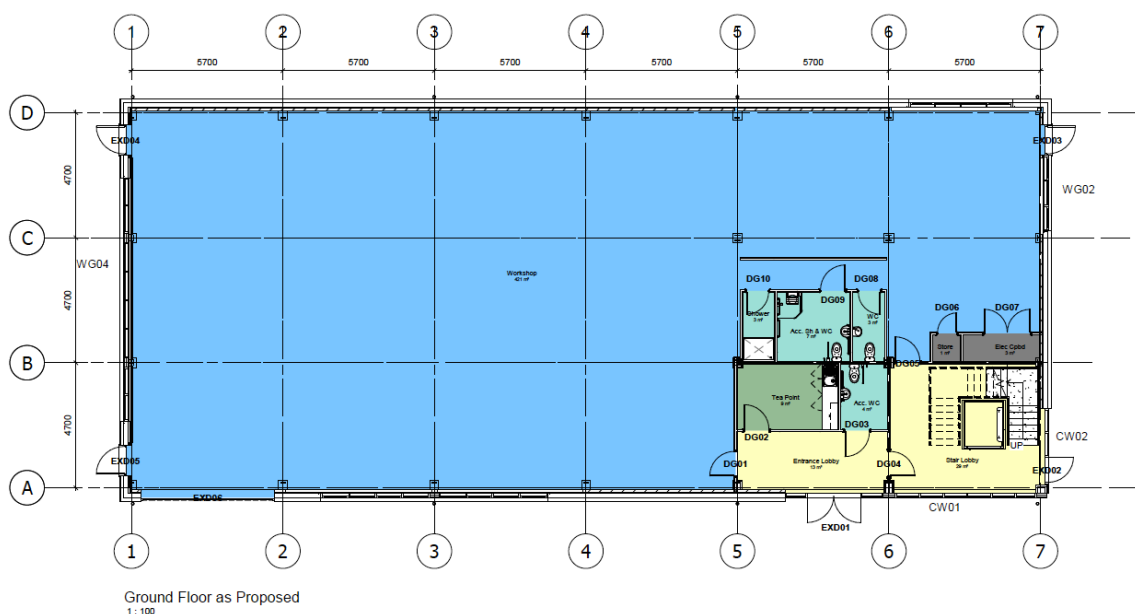


FIGURE 11 ATHERTON BIKES NEW FACILITY PLAN DRAWING

11.11.1 FACILITY CONSTRAINTS.

As with all buildings, some constraints must be factored into the design at the earliest possible phase to reduce iterations and time. The constraints of AB's new facility follow:

- Height restrictions A-D and 5-7 are covered by a mezzanine floor with a maximum height of 3300mm.
- Internal water supply and drainage are available between 4-5 and B-C.
- Fire exits are at each corner.
- Double height roller shutter at A, 1-2.
- The maximum wall hole diameter is 300mm.

11.11.2 WORK CENTRE DATA SHEET

The second step is to create work centre data sheets which detail all aspects of the work centre, such as services, power, floor space, maintenance, safety, resources, and manufacturing sequence. This information will be the basis of space diagrams and can dictate the location of the processes. As mentioned in 0, QC and kitting will be combined into one work centre. The work centre data sheets are detailed below.

TABLE 8 WORK CENTRE OVERVIEW

Work Centres	AM	Post Process	Bond
Processes	• Print • Powder Recovery • Filter Passivation	• Post Processing • CF Tube Processing	• Pre bond • Bond • Post bond
	QC Kitting	Tube Process	Goods in and out
	• Quality Inspection • Kitting	• Tube Processing	• Packaging • Send and Receive • Stores
	Assembly		
	• Frame Assembly • Bike Assembly		

TABLE 9 WORK CENTRE DATA SHEETS

Work Centre:	Additive Manufacturing Process
Services:	Three-phase power supply Argon Ventilation Water supply HVAC
Safety Systems:	Oxygen sensors ESD floor ATEX-rated electrical equipment. Argon ventilation with HEPA filter Fire detection system
Type of layout:	Functional layout – All AM-based functions are to be carried out due to the environment.

Process:	AM Print
Description:	Printing of titanium additive lugs.
Location:	AM Room
Equipment:	Additive manufacturing machine: Renishaw 500Q 1.236 x 2.165m System chiller: 0.97 x 0.38m Emulsion vacuum cleaner: Ruwac – 0.6 x 0.6 COSHH Storage - 0.7 x 1.8m Argon supply: 16m ² bottle with a regulator – 0.5 x 0.5m

	Workbench: 0.6 x 1.2 x 0.8m Build plate storage shelving 0.6 x 1.2 x 0.8m Air conditioning unit Bins
Working Envelope:	AM Machine: 4.236 x 4.165 x 3m Chiller: 1.980 x 1.77 x 1.2m
Safety Concerns / Requirements:	Flammable material particles Inert gas release Secondary earthing Gas bottle fixing ESD Flooring
Environment:	Sealed room, clean, forced ventilation, AC
Further considerations:	Machine install movement. Floor load rating Vibration damping Power supply for emulsion vacuum Airflow management for chiller and machine cooling
Maintenance requirements:	AM machine has a minimum maintenance working area of 1.5m front and rear, 1m on each side, minimum room height of 3m

Process:	Powder Recovery System
Description:	Recovering powder from cyclone from AM machine
Location:	AM Room

Equipment:	Mechanical Sieve – 0.85 x 0.45m Argon supply – 16m ² bottle with regulator Powder bottle storage shelving – 0.6 x 0.6 x 1.1m
Working Envelope:	1.45 x 1.5m
Safety Concerns / Requirements:	ATEX-rated sealed room Inert gas release Secondary earthing Gas bottle fixing ESD floor ATEX electrical lighting and fittings FD30 walls & door Negative pressure
Environment:	Sealed room within AM room, clean
Further Considerations:	N/A
Maintenance requirements:	N/A

Process:	Filter passivation
Description:	AM filter passivation station with waste disposal
Location:	Building Exterior
Equipment:	Filter wash station: 3 x 1.2m Emergency spill tray 3 x 1.2 x 0.2m Waste barrels

	Water supply
Working Envelope:	Filter station with waste disposal
Safety Requirements:	Emergency spill tray
Environment:	Outside build,
Further Considerations:	Route for waste disposal of barrels, the weight of 200kg per barrel
Maintenance requirements:	N/A

Work Centre:	Post Process
Services	Pneumatic HVAC
Safety Systems:	Fire detection system
Type of Layout:	Cell-line layout. Process-specific workstation, WIP moves through each station until completed.

Process:	Post Processing
Description:	Processing Ti6 lugs from plate to pre-machine state
Location:	Post Processing Room
Equipment:	Workstation(s) 3 x 0.65 x 1.1m Linisher 1.2 x 0.6 x 0.8m Abrasive blaster 1.2 x 1.8 x 1.9m Emulsion extraction 1.4 x 0.7 x 1.2m Tool cabinets 0.68 x 0.46 x 0.9m

	ERP station COSHH storage Bins
Working Envelope:	Workstation(s) 3.2 x 1.8m Linisher 2.4 x 0.6 x 0.8m Abrasive blaster 1.2 x 1.8 x 1.9m Emulsion extraction 1.4 x 1.2m
Safety Concerns / Requirements:	Machine Guarding Workstation height Dust extraction
Environment:	Sealed room, dirty
Further Considerations:	Safe, ergonomic working conditions Waste disposal Consider cell layout for workstations
Maintenance requirements:	Linisher and shot blast are moveable

Process:	Carbon Fibre Tube Processing
Description:	Processing CF tube – Drilling and slotting holes
Location:	Post Processing Room
Equipment:	Workstation – 1.2 x 0.65 x 1.1m Vice Fixtures

	Bins
Working Envelope:	1.2 x 1.8m
Safety Concerns / Requirements:	N/A
Environment:	Sealed room, dirty
Further Considerations:	Material Contamination
Maintenance requirements:	N/A

Work Centre:	Bonding Process
Services	Pneumatic HVAC
Safety Systems:	N/A
Type of Layout:	Fixed position. Parts move to fixed positioned jig; once the process is completed, the jig is left to cure.

Process:	Pre-Bond
Description:	Decontaminating Ti6 lugs post machining Decontaminating CF tube post-processing Preparing frame kit for the bond process Debugging Al lugs and tubes for the bond process
Location:	Pre-Bond Room
Equipment:	Ultrasonic wash 0.5 x 0.3 x 0.4m

	Drying rack Water disposal Water supply, Drainage Workstation – 4 x 1 x 1.1m Bins
Working Envelope:	2.5 x 5m
Safety Concerns / Requirements:	Ventilation Non-slip matt
Environment:	Sealed room, clean
Further Considerations:	Trolly storage
Maintenance requirements:	N/A

Process:	Bond
Description:	Bond process of lugs and tubes for AM and SM frames. Using two-part epoxy adhesive.
Location:	Bonding room
Equipment:	Front end jigs 1.2 x 1.2 x 1.5m Rear end jigs 0.7 x 0.3 x 0.2m Workstation 3 x 0.6 x 1.1m Jig plate storage 0.6 x 0.4 x 1.8m Adhesive dispenser 0.9 x 2m COSHH storage 1.2 x 0.7 x 1.8m

	Tool storage 0.6 x 0.4 x 0.9m ERP station Bins
Working Envelope:	11 x 5m
Safety Concerns / Requirements:	Extraction COSHH
Environment:	Sealed room, clean
Further Considerations:	Trolley storage Movement of jigs Consider line layout
Maintenance requirements:	The adhesive dispenser needs 0.5m on all sides

Process:	Post Bond
Description:	Processing bonded frame components pre-surface finish Alignment and visual quality inspection
Location:	Post Bond Room
Equipment:	Workstation Quality inspection equipment Consumable storage Bin ERP station
Working Envelope:	2 x 5m

Safety Concerns / Requirements:	Ventilation
Environment:	Sealed room, clean
Further Considerations:	Storage of frame WIP
Maintenance requirements:	N/A

Work Centre:	Quality Check and Kitting
Services	HVAC
Safety Systems:	N/A
Type of Layout:	Functional layout. All aspects of quality inspection of the process are to be carried out and then stored for production scheduling.

Process:	Quality Inspection
Description:	Quality inspection of titanium/aluminium lugs and aluminium/carbon tubes. Work in progress storage
Location:	QC and Kitting
Equipment:	Quality inspection equipment Workstation lighting Shelving for work-in-progress kitting boxes Production kit boxes Workstation

	ERP Station Bin
Working Envelope:	4 x 1.6
Safety Concerns / Requirements:	N/A
Environment:	Open to the factory, clean
Further Considerations:	N/A
Maintenance requirements:	N/A

Process:	Kitting
Description:	Packaging of Titanium lugs pre and post subcontracting Packaging of Aluminium lugs pre and post subcontracting Packaging of Carbon Fibre tubes Packaging of Aluminium tube
Location:	QC and Kitting
Equipment:	ERP station Shelving storage Bin Frame kit boxes Trolleys
Working Envelope:	8 x 4m

Safety Concerns / Requirements:	Manual handling
Environment:	Open to the factory, clean
Further Considerations:	Trolley storage space
Maintenance requirements:	N/A

Work Centre	Tube Process
Services	Pneumatic HVAC
Safety Systems:	N/A
Type of Layout	Cell layout. Material is processed at sequential specific workstations until the product is complete.

Process:	Tube Processing
Description:	Cutting, drilling and slotting tubes
Location:	Tube Process Room
Equipment:	Band saw Pillar drill Workstation Bin Swarf bin Storage

	Tool cabinet Vacuum cleaner
Working Envelope:	Band saw 2 x 4m Pillar drill 1 x 1.2m Workstation 2 x 0.6 x 1.1m Swarf bin Storage Tool cabinet 0.6 x 0.4 x 0.9m
Safety Concerns / Requirements:	Manual handling
Environment:	Sealed room, dirty
Further Considerations:	Easy clean area
Maintenance requirements:	N/A

Work Centre:	Goods In and Out
Services	N/A
Safety Systems:	N/A
Type of Layout	Functional layout – All aspects of send and receive are located in the area

Process:	Packaging
Description:	Packaging of Titanium lugs pre and post subcontracting Packaging of Aluminium lugs pre and post subcontracting Packaging of Carbon Fibre tubes Packaging of Aluminium tube
Location:	Goods in and out
Equipment:	Workstation Chair Bin
Working Envelope:	TBC
Safety Concerns / Requirements:	N/A
Environment:	Open to factory
Further Considerations:	N/A
Maintenance requirements:	N/A

Process:	Send & Receive
Description:	Sending completed products and receiving third-party components
Location:	Goods In and Out
Equipment:	ERP station Workstation

Working Envelope:	TBC
Safety Concerns / Requirements:	Manual handling of weighted goods
Environment:	Open to factory
Further Considerations:	Manual handling equipment
Maintenance requirements:	N/A

Process:	Stores
Description:	Storage of all components
Location:	Goods in and out
Equipment:	Racking ERP station Pallet truck
Working Envelope:	TBC
Safety Concerns / Requirements:	Manual handling
Environment:	Open to factory
Further Considerations:	Manual handling equipment
Maintenance requirements:	N/A

Work Centre	Frame and Bike Assembly
Services	Pneumatic HVAC
Safety Systems:	N/A
Type of Layout:	Fixed position layout. All bike assembly processes are to be in a fixed location with resources brought to stand

Process:	Frame and Bike Assembly
Description:	Assembling either frame or bike
Location:	Assembly
Equipment:	Workstation ERP station Tool Cab 0.6 x 0.4 x 0.9m Bike Stand Bearing Press
Working Envelope:	TBC
Safety Concerns / Requirements:	N/A
Environment:	Open to factory
Further Considerations:	Size of the finished box to be transported to goods out Movement of the flat-packed box to assembly
Maintenance requirements:	N/A

From the analysis carried out in routing and relationships, apparent efficiencies can be made by the location of crucial work centres. The following relationships will be used in the phase 1 layout design in order of priority.

1. QCK – Bond
2. Bond – Assembly
3. Assembly – GIO
4. GIO - QCK

As a starting point, the location of GIO will be at the shutter door, which makes the most sense due to its function. The bond is constrained by the need for water supply and drainage, which is fixed to the centre of the building.

Further considerations of space requirements are growth. While the work centre data sheets detail what is required to carry out the activity, it is essential to remember that space will be the biggest constraint on output in AB. A capacity analysis was carried out in AB, and it was found that the bond process had the most significant effect on capacity due to the following:

- Cure time – Once processed, WIP must remain on the jig until the adhesive is cured for a minimum of 12 hours.
- Process time – 3-4 hours to complete the process (product line depending)

To ensure AB is prepared for growth with its current process, the bond room will be the largest space within the factory.

Factors to consider when making a safe working environment are the fire risk and the fire strategy (HSE, 2023). This will consider aspects such as the risk of fire, routes to the fire exit, number of employees and detection systems.

11.12 LAYOUT

The layout can now be formed with an understanding of the process, flow, relationship, and space required. The first step will be to create block spaces for each work centre based on the calculations from the space requirements sheet in the appendix. This will be undertaken with Autodesk Fusion 360 CAD software.

Three layouts will be designed, and calculations will be made from material handling distance on a given day with the addition of batch material from suppliers. For this analysis, routes from post process and AM will not be considered; the analysis will be conducted on common work

centres only, which are QC, Kitting, Bond, Assembly and Goods in and out. The material handling distance will be calculated by creating material routes through the facility per layout. As this is an approximation, the material will flow to the centre of each work centre and then follow the walkways through the facility. The distance of the priority relationship will also be an output of the calculation to determine if the layouts conform to the requirements previously set out by the relationship diagram. The distances will then be calculated and compared. Further comparison will be if the layouts satisfy the space requirement sheet. This will be calculated by finding the area of space required and subtracting it from available space.

11.12.1 PHASE 1 LAYOUT EVALUATION

The layouts can be seen in Figure 13, Figure 14, and Figure 14 with the objective in mind of optimising AB layout to reduce material handling costs; the difference in layouts are common processes. The post process and AM work centres are in a fixed location due to the priority of optimisation and ease of installation. Considerations have been made of a fire strategy at this early stage; however, it will need to be verified by a fire assessor.

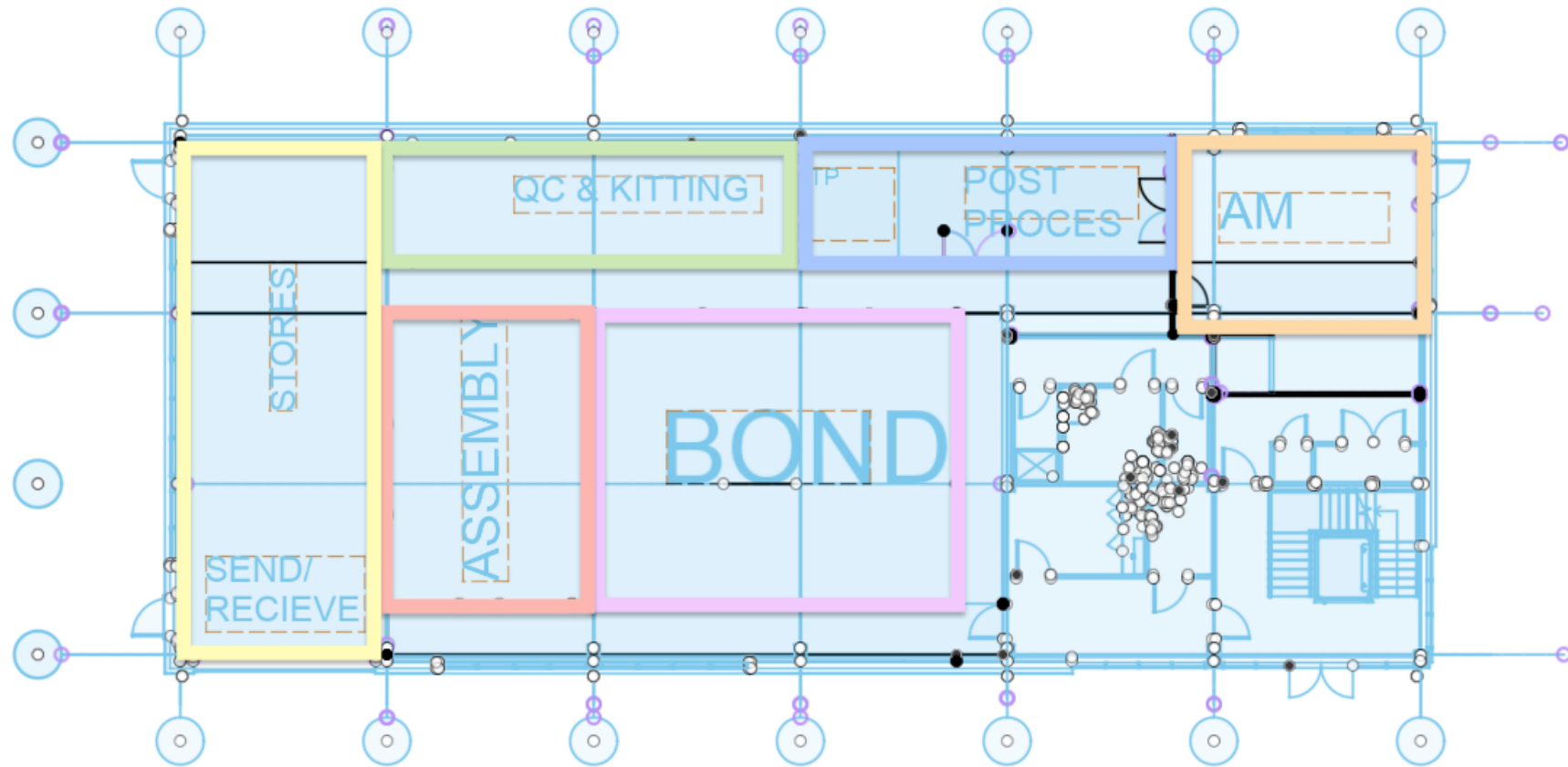


FIGURE 12 LAYOUT 1

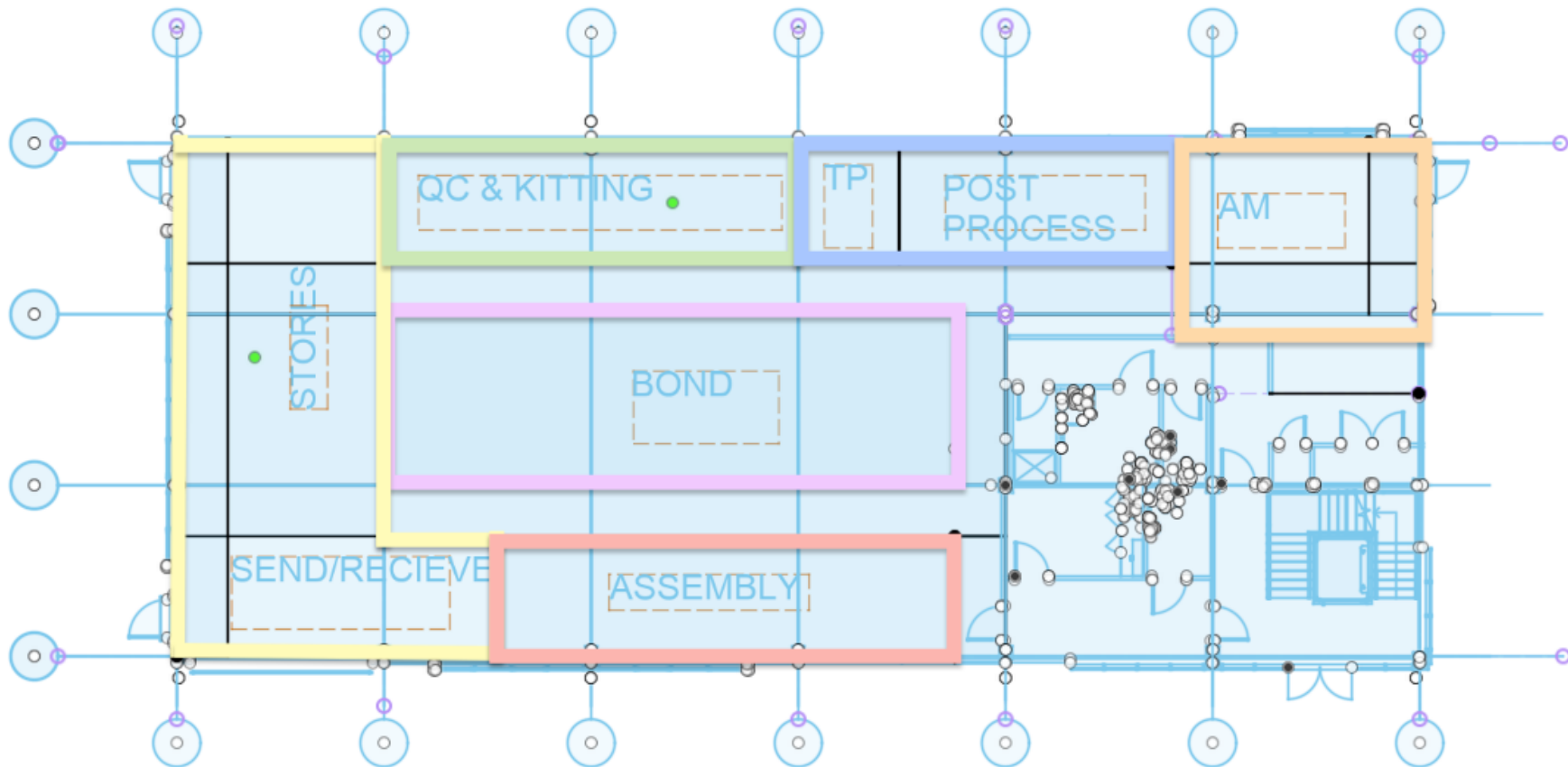


FIGURE 13 LAYOUT 2

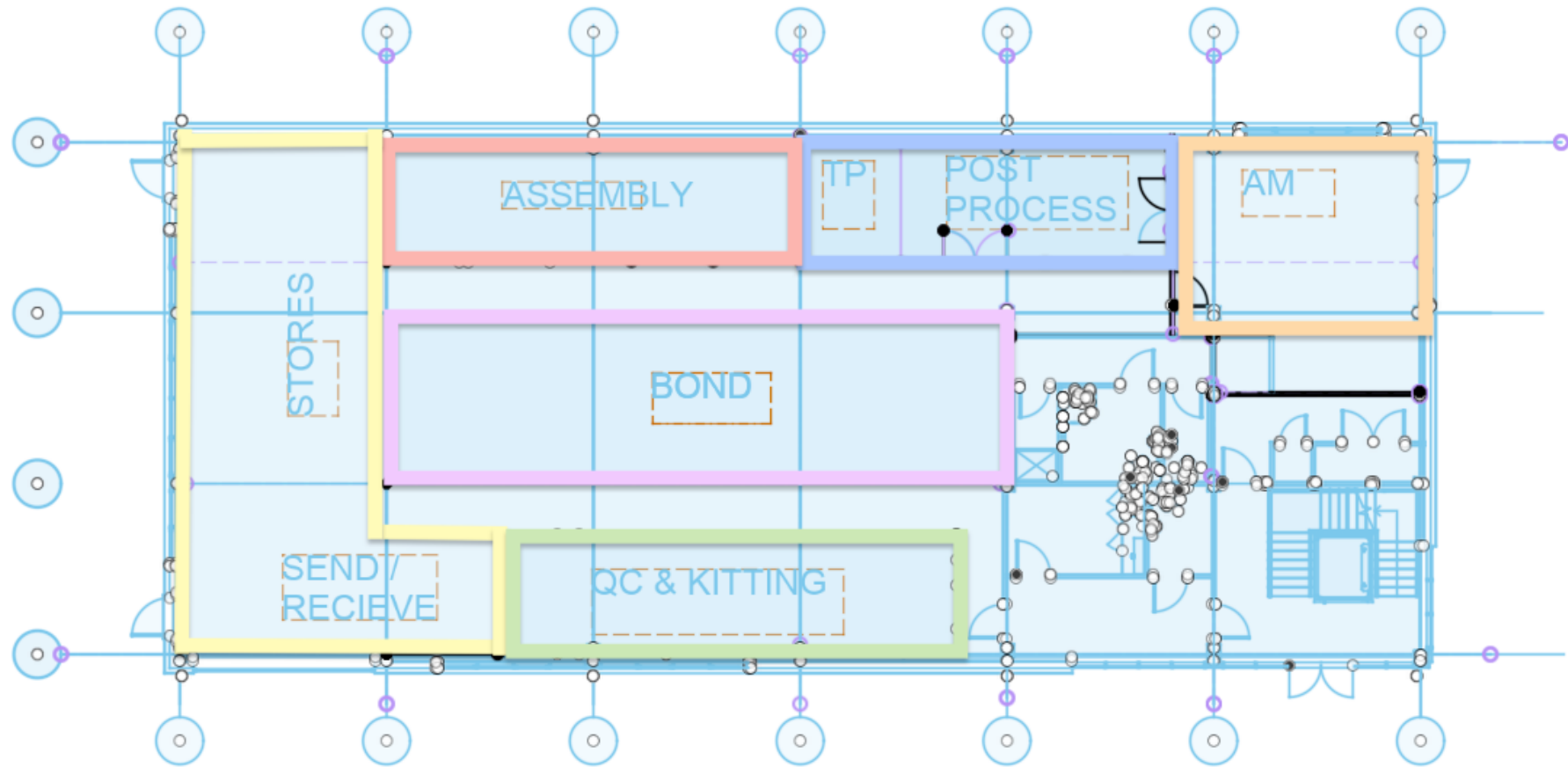


FIGURE 14 LAYOUT 3

Evaluation Calculations

Material Flow Distance							
KEY	LAYOUT 1		LAYOUT 2		LAYOUT 3		
Material In	12.5		12.7		2.2		
	11.7	24.2	12.5	25.2	16	18.2	
Lug & Tube	5		2.6		4.8		
	5.6		4.9		13	17.8	
Bonded Bike	4.5		3.3		2.9		
	11.7	26.8	13.1	23.9	4.5		
Complete Bike	4.9	4.9	2.7		2.5	9.9	
	4.5		7.5		8.2		
Processed Tubes	7.9	12.4	2.2	12.4	12.7	20.9	
	2.4		11.3		2.3		
Bike Components	6		1.7	13	3.6		
	2.4	10.8	2.6		8		
	4.5		4.8		2	28.6	
	5	9.5	2.6	10	5.6		
			5.2		8.2	13.8	
			11.7	16.9			
Daily Operations MF	77.8		91.4		80.6		
Daily with Tube	88.6		101.4		109.2		
Total Priority Distances	38.6		44.7		37.3		
Space Allocation							
Importance	LAYOUT 1		LAYOUT 2		LAYOUT 3		REQUIRED SPACE
1 QC KITTING	3.3 x 11.4	37.62	3.3 x 11.4	37.62	3.3 x 12.6	41.58	33.5
1 BOND	10 x 8	80	4.7 x 15.7	73.79	4.7 x 15.7	73.79	66.92
1 ASSEMBLY	5.7 x 8	45.6	3.3 x 12.6	41.58	3.3 x 11.4	37.62	40
2 GIO	14.1 x 5.7	80.37	14.1 x 5.7 + 3.3 x 3	90.27	14.1 x 5.7 + 3.3 x 3	90.27	89.3
2 TP & PP	3.3 x 10.2	33.6	3.3 x 10.2	33.6	3.3 x 10.2	33.6	33.53
3 AM	5.2 x 6.8 + 1.5 x 4	41.36	5.2 x 6.8 + 1.5 x 4	41.36	5.2 x 6.8 + 1.5 x 4	41.36	38.24
	318.55		318.22		318.22		

FIGURE 15 LAYOUT EVALUATION LEVEL 1

As previously discussed, the evaluation criteria are material flow distance and space allocation. Figure 15 shows the results of the evaluation. Starting with material flow, layout 1 had the least material flow distance, closely followed by layouts 3 and 2. With the inclusion of tube processing into the evaluation, the layouts were ranked 1,2 and 3. It is essential to mention that the distance travelled by completed bikes which is the most significant material by size to move, was lowest in layouts 1 and 2, and layout 3 was the highest. Layout 3 had the lowest distance in the priority relationships, which would be advantageous with the amount of outsourcing within the AB supply chain.

Concerning the output of the relationship chart, the highest priority was reducing the distance between QC - Kitting, Bond – Kitting, and Bond – Assembly. Based on the priority distance, the layouts ranked 3, 1, and 2. While the priority distance is of utmost importance, it would not be a deciding factor at this current estimation stage.

Space allocation was the next step to evaluate. Based on the space requirements document findings, the layouts were ranked on the capacity to meet the required space. The importance of the space requirements was based on the findings of the bottleneck analysis, which identified the constraining factors of the AB manufacturing process. Layouts 1 and 2 met all the space requirements of number 1 importance, while layout 3 only met 2 of 3. Noticeable differences are that layout 1 had far more space available in bonding which is seen as AB's biggest constraint of overall capacity; furthermore, layout 1 had larger space in assembly. Layout 1

shows good potential for future growth with the extra space available. As for GIO layout 1 did not meet the target of available space, which may be a cause for concern later in the project.

The next phase of the evaluation will be in the further depth of material flow, focusing on the material flow between processes. From the work centre data sheet and space requirement sheet, the process will be put in block form into the designs to calculate the distance of material flow. Based on the findings of phase 1 evaluation, layouts 1 and 2 will be used in the next phase. Layout 1 had the least material flow distance and the most significant amount of spare space in critical work centres for growth. While layout 2 was a reasonable all-rounder, it met all the space requirements; it has available space in the critical work centre, the second lowest material flow with tubes factored in. However, it has the highest distance travelled of critical work centres, which will be a high priority in the optimisation phase.

An essential consideration in this early design phase is having extra space in work centres that will not utilise the extra space to increase output. It may not be an issue at this phase, but it will be carefully considered when processes are allocated to work centres.

11.12.2 PHASE 2 LAYOUT EVALUATION.

This phase will add the workspace required to carry out tasks. All workstations and racking will have a 1.2m working envelope allocated to ensure safe working practices. The walkways will be 1.4m wide to conform to fire regulations. Withing GIO, send and receive will have an area of 4.7 x 5.7m open space. A fire strategy will be incorporated in this phase to ensure that all designs conform to fire regulations; this will ensure less wasted time in the later phases if the designs do not conform. The material flow point of contact with workstations will be at the centre of the workstation even if multiple processes are carried out. This will reduce the complexity of the calculations; however, this will be carried out on a local level once the final layout design has been selected. Furthermore, due to the similarities of positions of work centres in the layouts, calculations of tube processing, AM and post-processing will be withdrawn to reduce complexity further.

Figure 17 and Figure 17 are level 2 MFD of layouts 1 and 2 with processes added to the layout; the material flow has been mapped out using red lines. This will allow for calculations of material flow to be made. After mapping the diagrams, some efficiencies have been found to reduce the distance. Moving material from QCK to Bond uses an inefficient route. While this will make little difference in the calculations, as both have the same path, revisions will be made to reduce distance further in the final design.

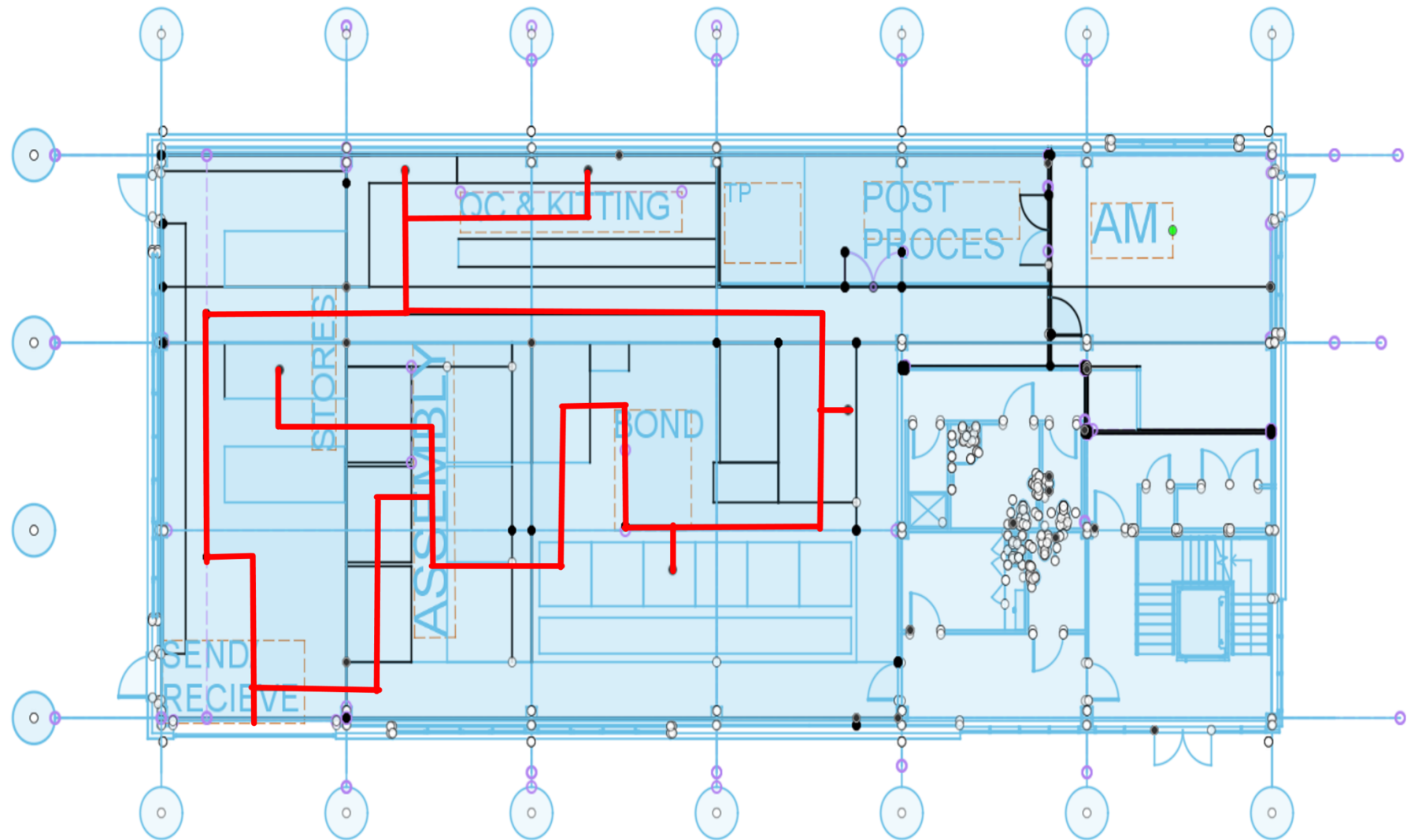


FIGURE 16 LAYOUT 1 MFD LEVEL 2

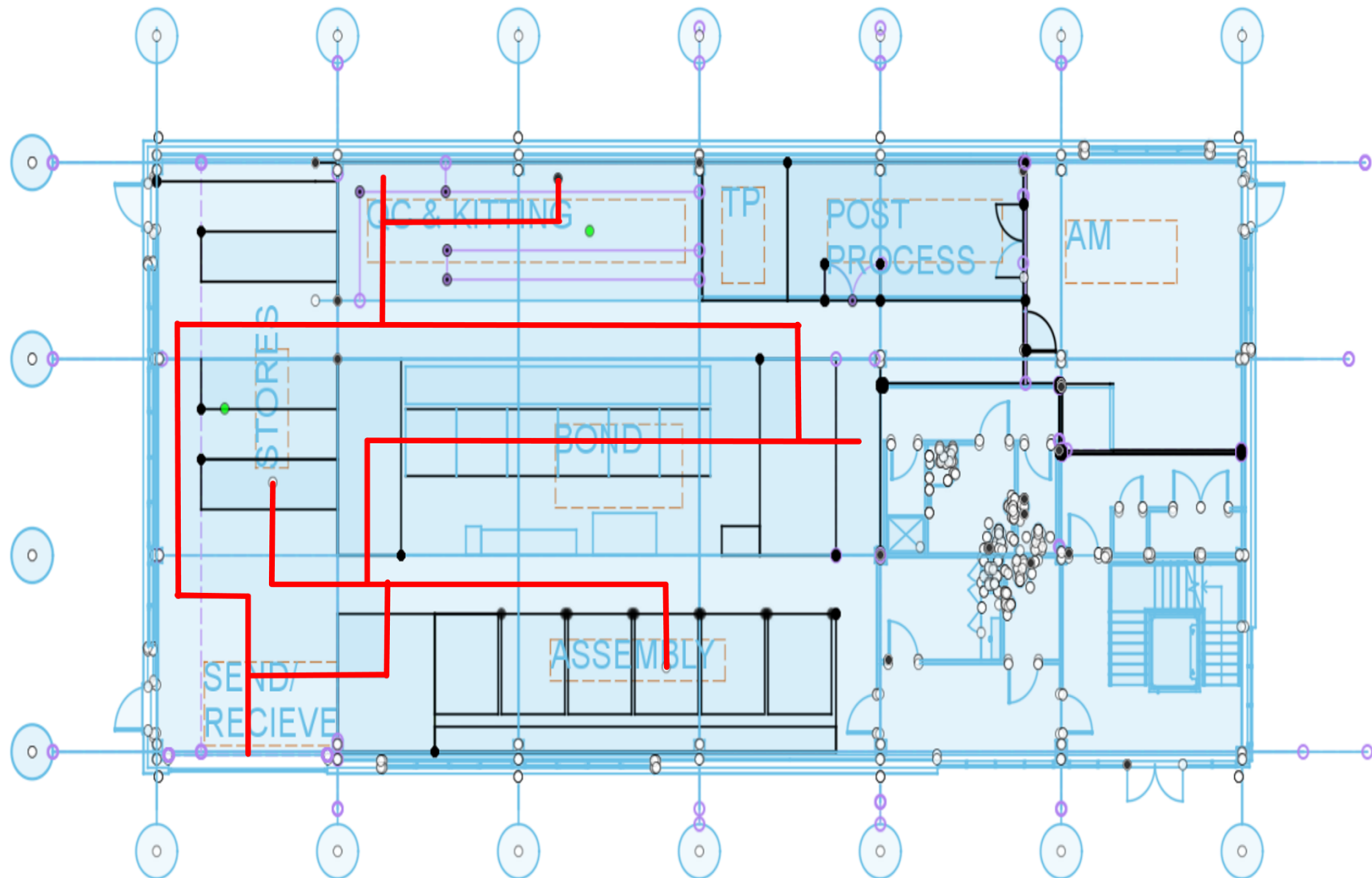


FIGURE 17 LAYOUT 2 MFD LEVEL 2

From the phase 2 evaluation, calculations are made, which can be seen in Figure 18. As expected, layout 1 still has the least amount of material flow distance travelled, with 83.7 meters per bike, compared to layout 2. It also has the least distance between priority work centres at 39.9 meters.

With respect to time per bike, every meter is assumed to be one second. With the output of AB forecasted to have a combined product line output of 3100 in 2025, there is a time saving of 23.93 hours annually between layouts.

Level 2 Material Flow

KEY	Layout 1	Layout 2
Material In	21.6	23.4
Lug & Tube	27.6	36.1
Bonded Bike	17.6	30.8
Complete Bike	9.2	6.5
Bike Components	7.7	14.7
Priority Relationship	83.7	111.5
	39.9	44.1

FIGURE 18 MATERIAL FLOW CALCULATIONS LEVEL 2

A layout evaluation matrix is a method of comparing the layouts. The criterion used to evaluate will be:

- Material flow distance – Distance of material travelled through the manufacturing process.
- Priority relationship distance – Distance of material travelled between priority relationships defined in the relationship diagram.
- Time per year of material handling – Time per year of material flow, assumption of 1 second per meter. $(\text{Distance} \times \text{output}) / 3600$
- Ease of installation – The amount of capital, resource, and availability to obtain the required layout.
- Compliance with space requirements – The compliance of the layout space to the space requirement sheet.
- Bond scalability – Availability of extra capacity if required in the bond work centre due to the length of process time.
- Adherence to health and safety regulations – If the layout conforms to health and safety regulations.
- Distance of movement of large WIP – The distance of transporting completed bikes in a box to goods in and out.

Figure 19 is the evaluation matrix of layouts 1 and 2. Each criterion is given a weighting based on AB objectives. From the matrix, layout 1 outscores layout 2 by 3 points, all in high-weighting criteria. With the objectives of reducing material handling and distance between priority work

centres, layout 1 is the layout which will be further evaluated to see what the actual material handling cost is. Regarding the compliance with space requirements in layout 1, once a more in-depth design is created, an accurate space calculation can be made, which may result in adequate space available.

Further considerations of the next phase of the layout design are to include doors and walkways through work centres. This will ensure consideration of fire strategy, location of equipment and material size.

Layout Matrix

Criterion	MF Distance	Priority Relationship Distance	Time per year of Material Handling (h)	Easy of Install	Compliance to Space Requirements	Bond Scalability	Adherence to H&S	Distance of Movement of Large WIP	Total
Weight	10	8	5	8	9	10	7		
Layout 1	83.7	39.9	72.08	Medium	83%	Yes	Yes	6.4	4
Layout 2	111.5	44.1	96.01	Medium	100%	Yes	Yes	11.6	1

FIGURE 19 LAYOUT EVALUATION MATRIX

From the level 2 material flow, there were optimisation opportunities found. The route from kitting to pre-bond doubled back on itself, thus increasing the distance travelled by 13 meters. The next MFA will remove this route by locating shelving in a different position, thus making a through route from kitting to bond.

11.12.3 PHASE 3 LAYOUT EVALUATION

The level 3 material flow analysis will map material at a process level. Mapping this will allow for accurate material handling calculations as the material does flow through processes without being moved. The space relationship diagram of layout 1 can be seen in the appendix, which validates the choice of the layout. The optimisation opportunity will be included in this phase, with space added to equipment to ensure no interference with routing and equipment. The layout with the added processes can be seen in Figure 20. Once the process is mapped out, the calculations will be made of the distance of each movement. This will be used in a flow process chart (FPC) which traces material movement through each process step. The purpose of the FPC is to give an overview of the process and include all collected information on process and material handling to track improvements made when there is a layout change. The FPC will give detail of the unit, process sequence; distance travelled, identify storage requirements, process delays, manual handling, transportation requirements, and frequency. The FPC considers the operational and process map seen in 11.9.1 and the material flow distance captured in this phase of the layout evaluation.

Layout Details

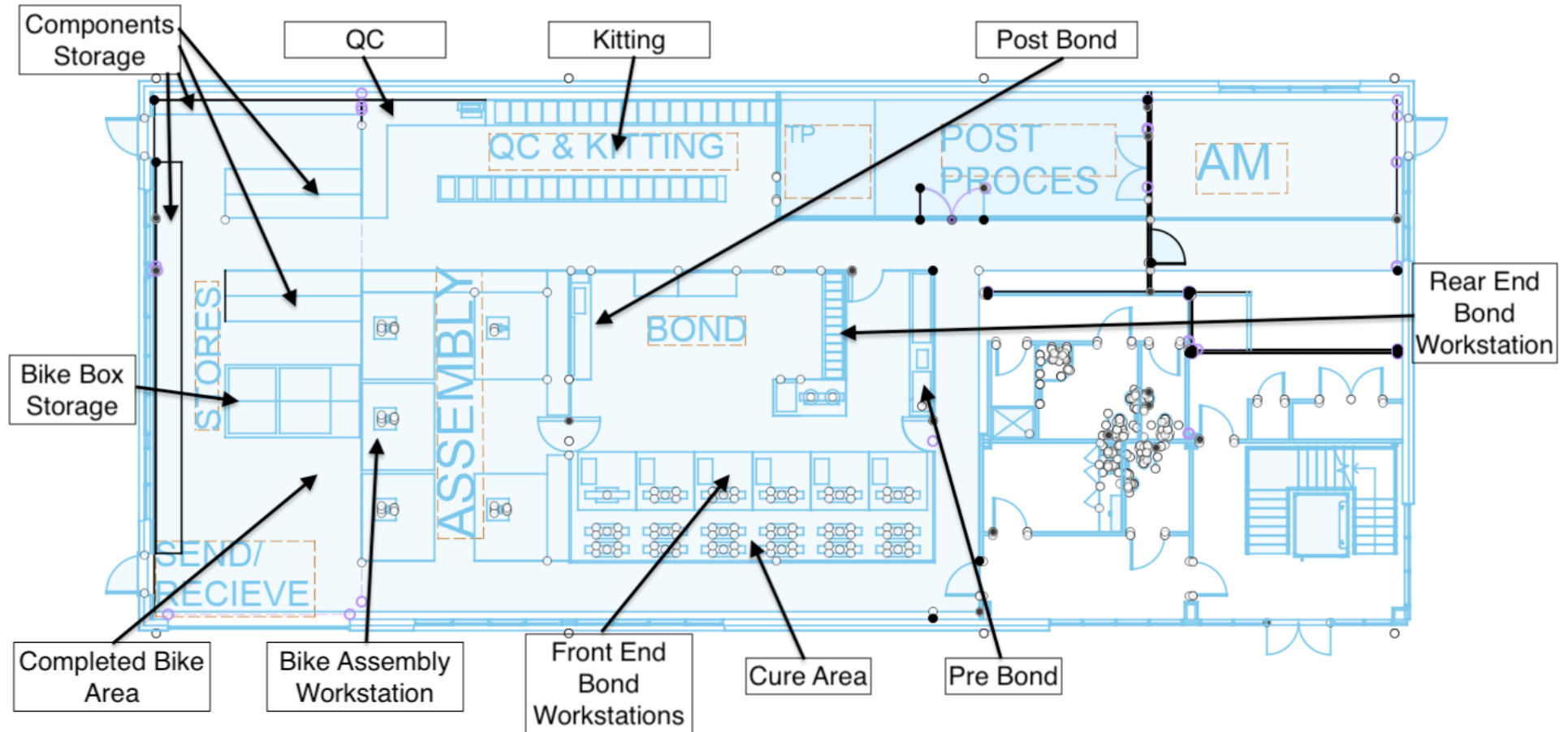


FIGURE 20 LAYOUT 1 DETAILS

From the phase 3 layout evaluation, the material distance was calculated to be 88.4 meters from when lugs and tubes enter the building from the outsourced anodises to a boxed bike shipped. This is an increase from level 2 MFA due to the inclusion of the added detail of processes. The priority relationship distance has been reduced from level 2 MFA to 26.7 meters, which is a reduction of 13.2 meters due to the optimisation of kitting to the bond route.

Level 3 Material Flow

KEY

Material In

Lug & Tube

Bonded Bike

Complete Bike

Shipping Box

Bike Components

Priority Relationship

GIO - QC	20.4
QC - Kitting	7.3
Kitting - Pre bond	13
Pre Bond - Bond	12
Bond - Post Bond	12.4
Post Bond - Assembly	6.4
Assembly - Ship	8.6
Stores - Assembly	5.4
Stores - Assembly	2.9
Total:	88.4

26.7

FIGURE 21 MATERIAL FLOW CALCULATIONS LEVEL 3

There are some critical distances of material from layout 1, which are detailed in Figure 21. Shipping box to assembly, bike components to assembly and completed bike to ship. Due to the size of the material moved, the distances are deemed adequate considering frequency. Furthermore, calculations have been made from layout 1 of raw material in and out to anodises, totalling 105.9 meters per batch, assuming the batch will be processed and transported in one movement.

Figure 22 is the level 3 MFD of layout 1 with the detailed processes included. Each coloured line represents the material handled, and corresponding colours are detailed in the key. The mapping of material in this diagram will aid in the choice of transportation method as it details the route through the facility and what possible issues may arise concerning space. Each route will need careful consideration of transporting material with attention to size, weight, sensitivity, and quantity requirements. The transportation method will be captured in the FPC once there is a level of understanding of frequency and quantity.

11.12.3.1 FLOW PROCESS CHART

The FPC of the production kit can be seen in Figure 23, the remaining FPC of AL lugs, AL tubes, bike boxes, and components are available in the appendix. The production kit to ship FPC is given in the report as the scope covers all high-frequency movements of the production system and shares the same routes as raw material to outsourced anodises.

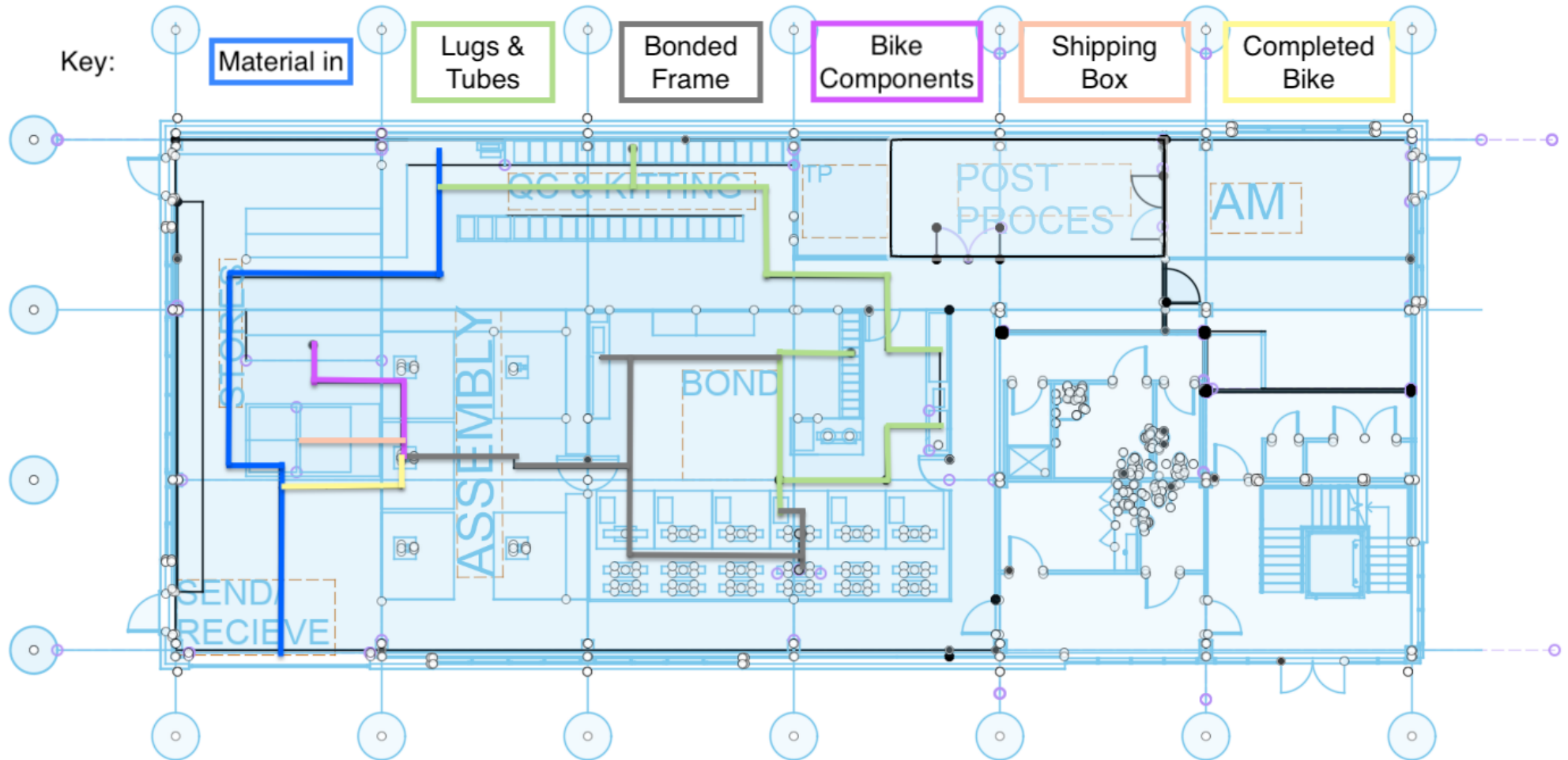


FIGURE 22 LAYOUT 1 MFD LEVEL 3

Flow Process Chart

Process line: Production kit

Charted Unit	Units per load	Action						Description of Action	Size	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Production kit	20	○	□	→	□	□	▽	Receive production kits from anodiser	0.7 x 0.6 x 0.4						
2 Production kit	20	○	□	→	□	□	▽	Move to Kitting	0.7 x 0.6 x 0.4	1	27.7	27.7			Transported on pallet truck due to size and weight
3 Production kit	1	○	□	→	□	□	▽	Place production kit on shelves	0.7 x 0.6 x 0.4						
4 Production Kit	1	○	□	→	□	□	▽	Stored from anodiser	0.7 x 0.6 x 0.4						Awaiting production schedule
5 Production Kit	5	○	□	→	□	□	▽	Move to Pre-bond	0.7 x 0.6 x 0.4	2	13	26			Transported by trolley to reduce frequency
6 Production Kit	1	○	□	→	□	□	▽	Clean parts	0.7 x 0.6 x 0.4						
7 Production Kit	1	○	□	→	□	□	▽	Let parts dry	0.7 x 0.6 x 0.4						Force dry
8 Production Kit	1	○	□	→	□	□	▽	Move to bond	0.7 x 0.6 x 0.4	10	6.6	66			Transported by trolley per bike will become work surface for bond station
9 Production Kit	1	○	□	→	□	□	▽	Visual check	0.7 x 0.6 x 0.4						Visual check at bond station
10 Bike Frame	1	○	□	→	□	□	▽	Bond bike	1.2 x 0.7 x 0.15						Fill adhesive, consider dispensing location
11 Bike Frame	1	○	□	→	□	□	▽	Cure for 12 hours	1.2 x 0.7 x 0.15						Jig will need to be moved to cure position (high sensitivity)
12 Bike Frame	1	○	□	→	□	□	▽	Remove from jig	1.2 x 0.7 x 0.15						
13 Bike Frame	1	○	□	→	□	□	▽	Move to post bond	1.2 x 0.7 x 0.15	10	10.5	105			Carried per bike by operator
14 Bike Frame	1	○	□	→	□	□	▽	QC	1.2 x 0.7 x 0.15						
15 Bike Frame	1	○	□	→	□	□	▽	Store for assembly	1.2 x 0.7 x 0.15						Storage space required for WIP awaiting processing
16 Bike Frame	1	○	□	→	□	□	▽	Move to assembly (AL)	1.2 x 0.7 x 0.15	10	6.4	64			Carried per bike by operator, clear route for movement, dual entry doors
17 Assembled Bike	1	○	□	→	□	□	▽	Assemble bike	2 x 1.4 x 0.3						All components brought on trolley pre-made
18 Assembled Bike	1	○	□	→	□	□	▽	QC	3 x 1.4 x 0.3						QC at workstation
19 Boxed Bike	1	○	□	→	□	□	▽	Pack for shipping	4 x 1.4 x 0.3						Done at workstation
20 Boxed Bike	1	○	□	→	□	□	▽	Store for batch to be transported	4 x 1.4 x 0.3						Batched in 5 on trolley
21 Boxed Bike	5	○	□	→	□	□	▽	Move to GIO	5 x 1.4 x 1.5	2	8.6	17.2			Transported by operator on trolley
22 Boxed Bike	1	○	□	→	□	□	▽	Ship	6 x 1.4 x 0.3						

Total: 305.9

FIGURE 23 FLOW PROCESS CHART - PRODUCTION KIT AL

The FPC in Figure 23 is the process of transforming a production kit of anodised lugs and tubes into shipped bikes. The captured information in this chart follows; the charted units are the input form in which an action takes place, units per load are the number of units being actioned, actions of what is taking place, size per charted unit, numbers of trips, distance per trip and per day, time and cost per trip, and notes of action.

From the initial FPC, there is a totalled covered distance of 478.7 meters based on each movement being done in a single unit. This would be an inefficient transport method, therefore an improvement of transport method needed to be found. Transporting production kits from kitting to pre-bond by trolley would save 104 meters per day; further improvement found was moving 5 boxed bikes on a trolley at one time. This not only saved 68.8 meters but also reduced the risk of injury to the operator due to the size of the unit. The resulting improvements are seen in Figure 23 which the total daily distance is 305.9 meters of an output of 10 AL bikes per day. These transportation method improvements must be considered so that access to routes can be factored in.

Another outcome of the FPC is the need for designated space to store WIP awaiting processing in bond to assembly and assembly to ship. This space must be considered in the localised MFA later, which may result in a further iteration of layout design.

Currently, the FPC does not have calculated time or cost. This will be calculated in the process-specific FPC with factors such as size, weight, and access to the movement that can be considered.

11.12.3.2 OPERATOR MOTION ANALYSIS

The following evaluation phase analyses the operator's motion within the process. While MFA is a valuable tool for calculating material flow distance, it does not always affect how the operator moves with the material. At AB, the material will be moved by operators, so ensuring the most efficient route is taken is vital. Analysing at this stage may identify efficiencies which may not have been as visible in early analysis.

The first step of the analysis is to put the motion in a diagram seen in Figure 24. The colour represents the work centre that the operator works at, and the line dashing is the method of transport.

From the diagram, it can be said that there is a wasted motion in the bond work centre. Once the operator completes the frame front-end bond process, the second process is to bond the

frame's rear end. There is a large space between the rear-end bond workstation and all other workstations in the work centre. The total distance of operator motion in the bond process is 30.5 meters, in line with the distance from the level 3 MFA. With the combination of these figures, an improvement should be made to reduce this distance.

Operator Motion Diagram

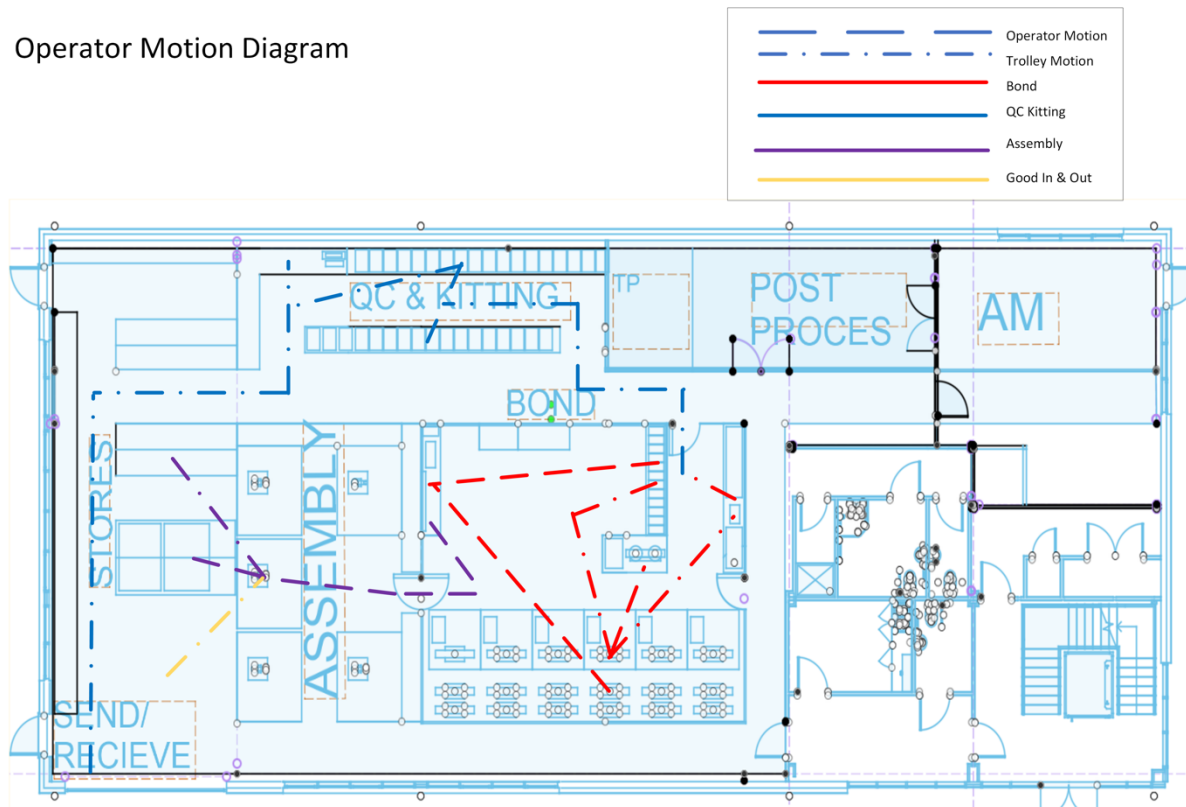


FIGURE 24 OPERATOR MOTION DIAGRAM

The revised layout of the bond work centre can be seen in Figure 25 the distance has been reduced by 3.4 meters, with an additional capacity of 3 bond workstations has been added if required in the future. However, with this revised layout, the transportation between post bond and assembly would have been increased. To ensure this will not be an issue, access from assembly will be added to allow WIP to be moved without entering the bond work centre.

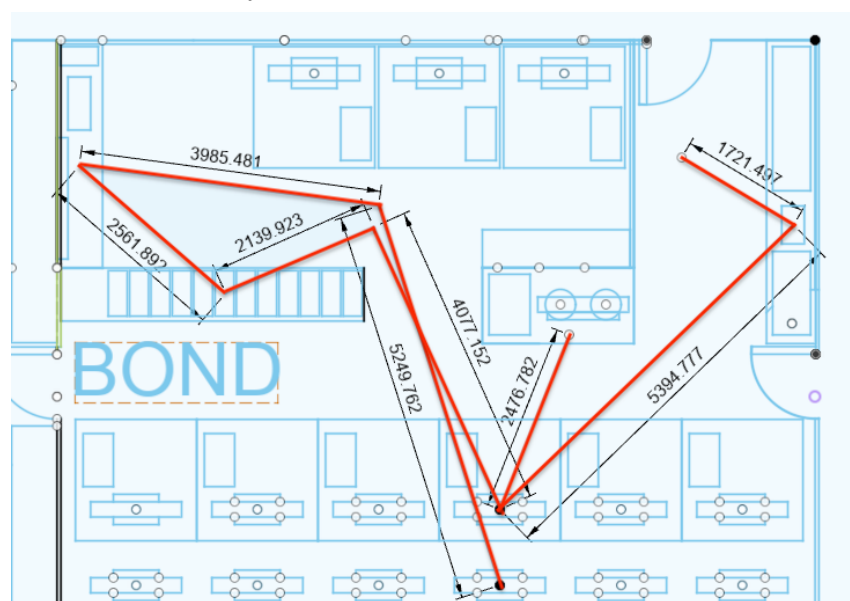


FIGURE 25 REVISED BOND WORK CENTRE

With the revised layout, the MFA calculations can be compared to the original to see if there is an improvement. Figure 26 shows that the difference in material flow was 0.6 meters.

While the saving in the distance is marginal, the additional capacity is still in line with the objective of this project of gaining cost-effective output.

With the additional output in the bond, extra capacity must be added to the system. As the lugs and tubes are outsourced, capacity can be added easily. The in-house processes can gain extra capacity by adding shift work to meet the bond output. The additional workstations added to the bond will increase the output by 1400 units annually.

Comparison of MFA

Pre Bond - Bond	12	11.6
Bond - Post Bond	12.4	12.3
Post Bond - Assembly	6.4	6.3
Total	30.8	30.2

FIGURE 26 MFA COMPARISON

11.12.4 FINAL DESIGN

From the analysis carried out, the outcome of the design can be seen in Figure 27. The layout has factored recommendations from FPC of QC and kitting and assembly, which can be found

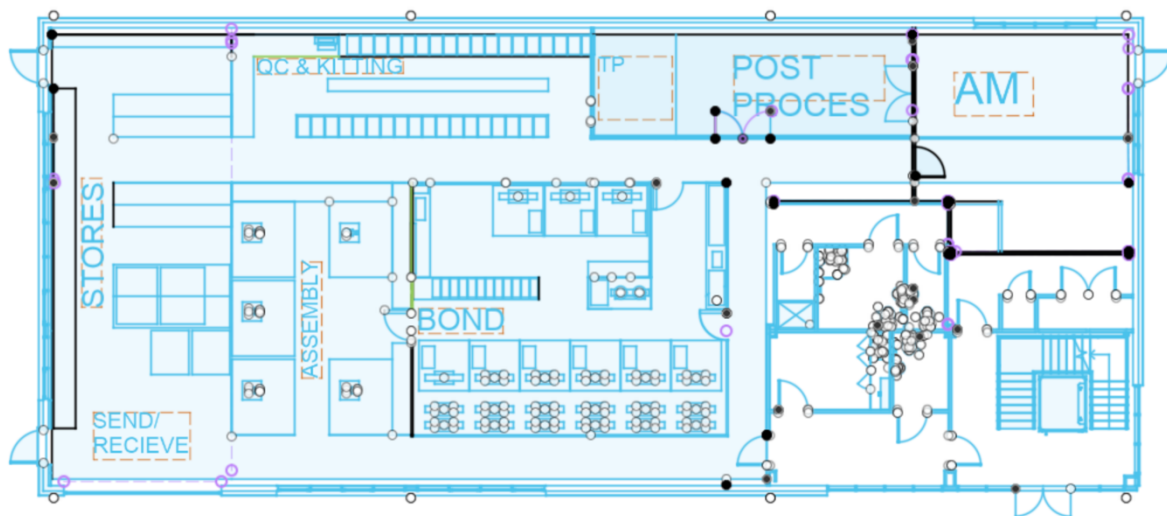


FIGURE 27 FINAL LAYOUT DESIGN

in the appendix. The recommendations are space for a trolley or roller racking in QC and kitting; this will reduce the number of repeated trips to store production kit boxes. At the assembly, additional access to bond has been added so WIP can be taken without entering the room. This access point will further reduce the likelihood of contamination within the room.

While this design is finalised for this report, factors must be considered before implementing this design. First of capital required to install this design, while this is optimised for output of

3100 units per year of all product lines, this may not be the best solution for the current output. For instance, the bond space is $80m^2$ with a capacity of 18 units per day. Constructing a room that size at such an early stage in the ramp-up would need increased capital, and the returns will not be seen for 2 years. Furthermore, the bond space is a temperature and humidity-controlled environment. Controlling the environment of this unused space comes at a cost, which would need to be divided by the current output, thus increasing the cost of lower output units.

The remaining work centres within the business can be scaled with output. Assembly can be scaled by adding more workstations and operators with the possibility of forming a production line layout. QC and kitting can add more storage space to meet the demands. Goods in and out will require additional storage to scale or can adopt a just-in-time inventory model.

With the capital expenditure of the installation and growth in mind, the design will need to be scaled with output. This can be achieved by creating a modular design of the bond work centre. This will reduce the initial cost of structure and HVAC equipment. Furthermore, it will reduce the running cost and thus cost per unit. The AM product line work centres will be installed at 600 per year as this product line is in high demand, and the output increase will be much shorter.

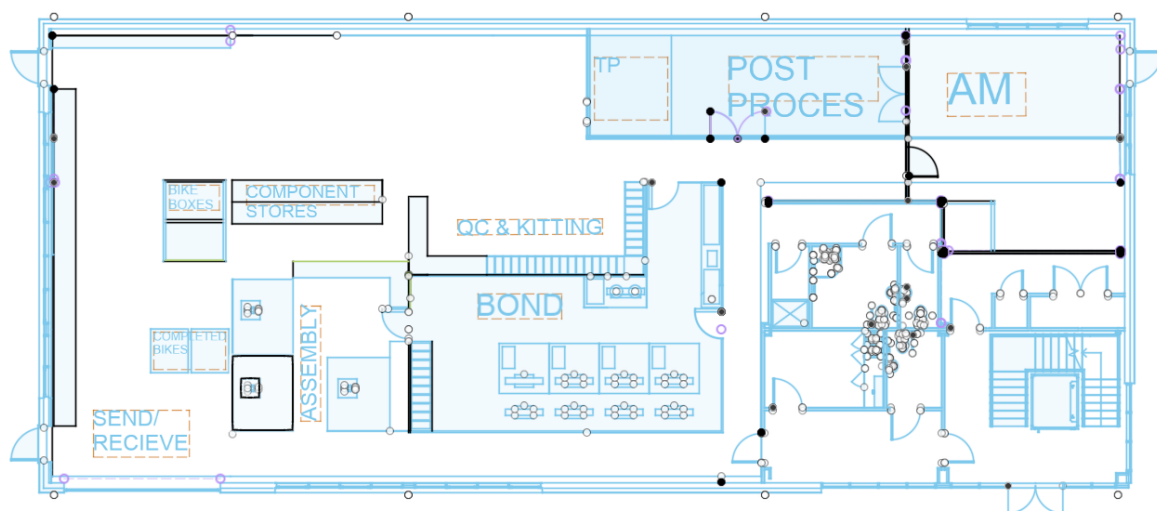


FIGURE 28 SCALEABLE REVISION

The proposed revision of the layout can be seen in Figure 28. The revised bond space is $57m^2$ with the potential to output 8 bikes per day. While the output is still substantially over the initial requirements, it will ensure AB is not modifying the room yearly. Furthermore, by reducing the space in the bond, QC and kitting can be moved closer to bond, which was a priority relationship, thus reducing the total material flow distance substantially. The material flow distance in the revised layout is 64.6 meters which are 19.1 meters less than the level 2 MFA.

Additional consideration of the current design is adhering to health and safety regulations. The fire regulation has been considered in the early design phase with clear fire exit routes through the facility. All rooms have additional fire detection systems; no fire exit route passes through a medium to high-risk area. All enclosed spaces, such as AM, post-process, and bond, will have adequate ventilation and lighting. An expert will validate the design before implementation to ensure that all the health and safety regulations are adhered to.

11.13 PROCESS CALCULATIONS

To keep with this project's objectives, KPIs need to be met. To measure the successfulness of the layout, design calculations must be made to ensure the layout meets AB's desired growth targets. The KPI calculations are as follows.

- Output –The maximum capacity of the manufacturing system.
- Labour cost per unit – The cost of producing the system's maximum capacity.
- Value work time availability (employees) – The available time that an employee has to add value to goods.
- Output per meter squared – The effectiveness of the output of the facility per square meter.

The initial objective of output was to produce 3100 units annually (2500 AL and 600 AM). With the understanding that the bond process is the bottleneck due to the high process time, the overall capacity is constrained. The layout design proposed in this project can produce a total of 4500 units annually, an increase of 45%.

Labour cost per unit formula:

$$\frac{\text{Total manufacturing labour costs}}{\text{Units}} = \text{Labour cost per unit}$$

Labour cost per unit can be calculated; however, several assumptions must be made to calculate this. Firstly, the processing time of many functions is from simulation and estimations of an actual value cannot be calculated until the facility is implemented. The second assumption is considering batch as a per unit time. For instance, unpackaging outsourced lugs is divided over an output, while in a real-world scenario, it will be carried out as a batch at one time. The third assumption is that workload is shared across work centre employees instead of having job-specific roles within the work centres. The available working hours of employees were assumed to be 420 minutes per day, which allows time for bathroom breaks, morning meetings and pre and post-break movements. The labour cost of AL at 2500 annually is £204.40, with AM

at 600 is £212.50, which assumes the assembly of complete bikes. With the increased output of 4500 units, therefore 3900 AL, the labour costs are £199.50. The calculations can be found in the appendix.

Value work time availability is the metric which is heavily influenced by the outcome of this project. While material handling is not the only contributing factor to this metric, it substantially influences it at AB. Material handling is seen as a non-value-adding process, and therefore, reducing this increases value work time availability. From the FPC found in the appendix, the material flow distance has been calculated for each common work centre. The assumption is that the receiving batch distance will be divided by the batch quantity to give per unit distance. The formula for calculating material handling time is:

$$\left(\frac{\text{Distance of travel of material per day}}{\text{Output per day}} = \text{Distance per unit} \right)$$

$$\text{Distance per unit} \times \text{time taken to travel 1 meter} = \text{Time per unit}$$

$$\text{Time per unit} \times \text{Cost of material handling} = \text{Total cost of material handling}$$

From the formulas given, calculations have been made for the material handling cost at AB. The results can be seen in Figure 29, the total distance travelled per day was 50.18 meters with the inclusion of batched raw material per bike is 58.98 meters per day. Annually this totalled 182,838 meters at an output of 3100 units. The average cost of employment of a production operator at AB is £14.45 per hour, and the total time taken handling material based on 1 second per meter is 50.79 hours per year; therefore, the total cost of material handling per year at 3100 units is £733.89.

As said, this is not the only factor in the metric of value-adding available time. However, further analysis of the manufacturing process at a more local level regarding layout can increase the available time. While it may not have such a significant

Flow Process Chart Results

Batch Material	Distance	
AL Lugs	121.1	
AL Tubes	54.9	
Total	176	
Total / Batch Quantity (20)		8.8

Processed Material	Distance	
Bond	325	
Assembly	96.2	
QC Kitting	80.6	
Total	501.8	
Total / output (10 per day)		50.18

Average distance travelled per bike:	58.98
Distance per year @ 3100 units:	182838

		Cost per year (£)
Average cost per hour of employment	14.45	
Time taken per bike (seconds)	58.98	
Hours per year @ 3100	50.79	733.89
Hours per year @ 4500	73.73	1065.33

FIGURE 29 FLOW PROCESS CHART RESULTS

effect on cost, it may have an increase in output. Optimised workstations are a potential use of layout analysis on a local level that can be conducted to increase the available time further.

Output per square meter is another metric used to track the effective use of space. With the layout at maximum capacity, the output per square meter is 0.025 units; this excludes walkways. While this metric as a single metric is not that useful, comparing different layout configurations can aid in decision-making. For instance, the scaling revision made in the bond work centre to reduce the capital and running costs can be calculated to see the most effective use of the space. The original layout has an output per square meter of 0.1, while the revised layout has 0.12, with the output set at 8 per day. Naturally, the higher the value, the more effective the use of space is. This also reflects material handling; if the space between processes can be reduced, the output per square meter and material handling distance is reduced.

12 CONCLUSION

To conclude, the objective of this project was to gain cost-effective output efficiency from AB's new plant by optimising the layout to reduce material handling costs and distance between resources. Based on the objectives, the project can be seen as a success from a theoretical view. However, until the implementation of the layout, success will not be fully achieved. The project scope was to obtain output efficiencies at the facility's maximum capacity, which will not be seen until at least 2025. AB forecasted output sales are 3100 in 2025, but this project has shown the plan's capacity is 4500, an increase of 45% based on the constraints of the bond process. This will need to be further verified by conducting a bottleneck analysis once production has commenced. As for material handling cost, the theoretical value is £733.89 annually; while there is no accurate comparison at AB, it could be said to be a reasonably low cost. It is important to mention that this cost is only for common manufacturing work centres, and the cost of handling goods in and out has not been factored in due to the number of assumptions required. Therefore, while the cost given in this project is low, it is likely to increase substantially when the whole system is considered. Furthermore, the AM-specific processes were not considered due to the priority of the project was to optimise the AL product line. Due to the AM sharing many common processes, it inherently has become more efficient and thus reducing cost further in the process.

Additionally, the optimisations made of material handling were at the highest volume and at lower volumes, the cost will further increase. Conversely, the layout can be scaled to reduce the material handling at lower volumes. This was proven in the layout revision in 11.12.4, where the reduction of bond space allowed for the movement of other work centres, thus reducing the material flow distance. These scaling opportunities should be implemented in the scaling phase of the business to keep unit costs low and increase value work time availability high.

Another essential part of this project was the use of Systematic layout planning. From the research conducted in this project, the reoccurring successful use of SLP in case studies was evident, which was a driving factor in adopting the method in this project. SLP is a methodical approach to collecting and analysing data related to PL. The step-by-step approach gives layout planners milestones to meet to ensure all relevant data is captured before moving on to the next step. This ensured that there were no oversights in the project and reduced iterations later in the project, which could potentially delay the project. However, in line with many researched case studies, the decision-making selection lacks real structure. Understandably there are many contributing factors in decision-making; what makes sense with regard to layout efficiencies

may not make sense commercially. The adoption of a decision-making model would be useful to SLP; however, this is not a one size fits all scenario. The decision-making model proposed by Arunyanart & Pruekthaisong, 2018 could prove to be a suitable addition to layout planning where the use of analytic hierarchy process and data envelopment analysis was used to weigh qualitative performance metrics and determine suitable layouts based on efficiencies (Arunyanart & Pruekthaisong, 2018). Simulation can be a powerful tool for decision-making to validate the layout's effectiveness. It will generate accurate measurements, which can aid in decision-making. Furthermore, simulation can identify buffers and efficient batching, which must be incorporated into the layout.

In this project, simulation was not used due to the resources available for this project and the expertise required to produce an accurate simulation. Conversely, with the vast amount of simulation outsourcing now available, the data collected in this project will be used for simulation at a later date. Furthermore, from research into a simulation, there is an agreement with Zhang, et al, 2019 that there is a lack of frameworks for simulation-based layout (Zhang, et al., 2019). The lack of framework would have proven challenging if the simulation had been adopted in this framework with little knowledge of the subject.

13 FURTHER DEVELOPMENT

The next phase of the layout planning would be to conduct an analysis on a local level. The information collected on product, quantity, and supporting services will remain the same, but the time, relationships, routing, and space analysis should be conducted at this level. Further inclusion of AM-specific work centres should be included to optimise the AB facility further.

Another consideration for further development is WIP storage. There was a minor consideration of WIP storage in work centres such as bond and kitting; however, it was not fully understood. The implication of not fully understanding the requirements of WIP can be substantial and could cause loss of capacity with increased costs associated with holding excessive inventory. Therefore, a bottleneck analysis should be conducted in the simulation to ensure buffers are identified and allocate space for WIP between processes. Once this information is obtained, it should be validated in a production environment, as inventory indicates an unbalanced production system.

Once further analysis is completed, the next phase is to install and implement the design into the new facility. This is an enormous undertaking, and careful consideration should be used in planning this. SLP offers recommendations for planning the installation; however, the

experience required to manage the installation is out of the scope of this project. Commonly, project managers would influence many factors of the plant layout to ensure ease of installation; however, due to the resources available, this project has had no influence on this. Nevertheless, a level of knowledge present in designing the layout and installation of equipment such as AM machines has been factored into the design.

Once production commences at the facility, further studies that should optimise the manufacturing process should be carried out. While these studies may not optimise the layout, they will aid in meeting the objective of cost-effective output efficiencies. The studies are stated below:

- Time and motion study to ensure workstations are optimised for efficiency.
- Workload study to understand employees' workload to allow balancing or workload within work centres.

Finally, PL plays a vital role in the efficiency and effectiveness of any manufacturing business. As processes evolve and change, so must the PL to ensure the utilisation of resources, workflows, and productivity. Changes in business needs and market demands necessitate the need for flexible and adaptable PL that can accommodate the future changes with minimum disruption. Companies must embrace continuous improvement and be willing to make changes to their PL to meet the changing needs of their business and the market. By doing so, they can position themselves for success in a dynamic and competitive environment.

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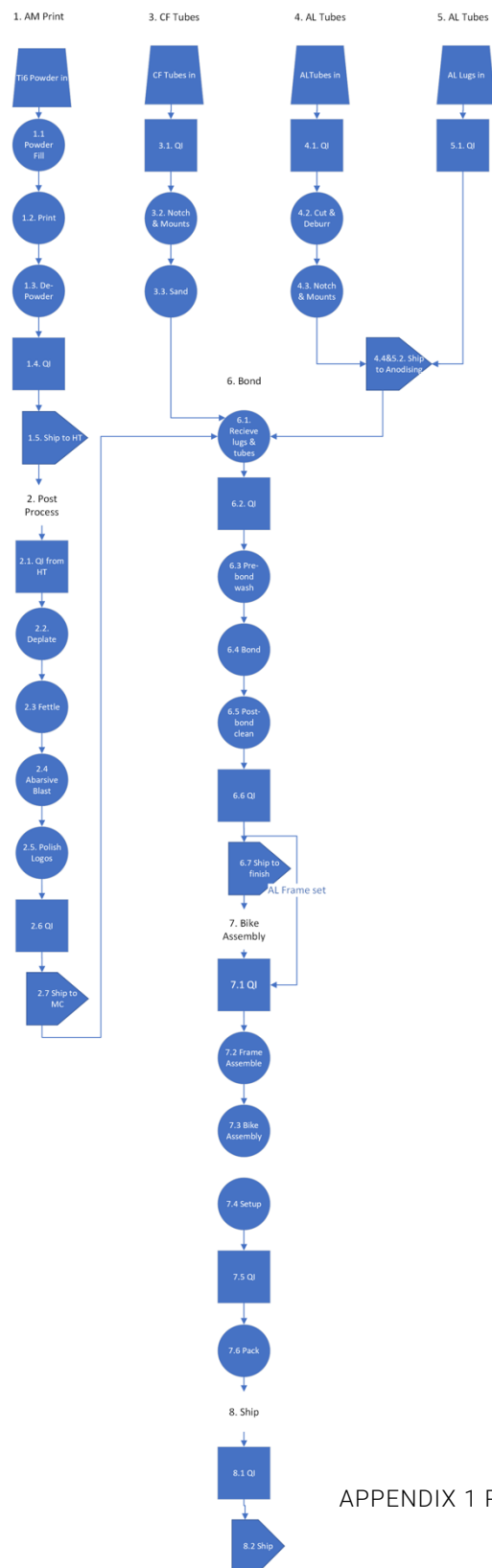
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15 APPENDIX

Process Map Level 2



APPENDIX 1 PROCESS MAP LEVEL 1

FROM-TO-CHART

Item(s) Charted:
AM & AL

Basis of Values:
Bike per day 2025

Activity or Operation FROM \ TO	Activity or Operation TO								TOTAL
	Goods In/out	AM	Post Process	QC	Tube Process	Kitting	Bond	Bike Assembly	
	1	2	3	4	5	6	8	10	
1 Goods in/out			Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10	Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10	Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10	Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10		AM Frame Set: 2	
2 AM	Lugs AM: 2								
3 Post Process	Lugs AM: 2								
4 QC	Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10				Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10	Lugs AM: 2 Lugs AL: 10 CF Tubes: 2 AL Tubes: 10			
5 Tube Process	Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10					Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10			
6 Kitting							Lugs AM: 2 Lugs AL: 10 Tubes CF: 2 Tubes AL: 10		
7 Bond	AM Frame Set: 2							AL Frame Set: 10	
8 Bike Assembly	Complete Bike: 12								
TOTALS									

APPENDIX 2 FROM-TO-CHART AM & AL

FROM-TO-CHART

Item(s) Charted:
AM Lugs

Basis of Values:
Lug per day

Activity or Operation FROM \ TO	Activity or Operation TO								TOTAL
	Goods In/out	AM	Post Process	QC	Tube Process	Kitting	Bond	Bike Assembly	
	1	2	3	4	5	6	8	10	
1 Goods in/out				2				2	6
2 AM	2								2
3 Post Process	2								2
4 QC						2			2
5 Tube Process									0
6 Kitting							2		2
7 Bond	2								2
8 Bike Assembly	2								2
TOTALS	8	0	0	2	0	2	2	2	

APPENDIX 4 FROM-TO-CHART AM LUGS

FROM-TO-CHART

Item(s) Charted:
AL Lugs

Basis of Values:
Lug per day

Activity or Operation FROM \ TO	Activity or Operation TO								TOTAL
	Goods In/out	AM	Post Process	QC	Tube Process	Kitting	Bond	Bike Assembly	
	1	2	3	4	5	6	8	10	
1 Goods in/out				10		10			20
2 AM									0
3 Post Process									0
4 QC	10								10
5 Tube Process									0
6 Kitting							10		10
7 Bond								10	10
8 Bike Assembly	10								10
TOTALS	20	0	0	10	0	10	10	10	

APPENDIX 3 FROM-TO-CHART AL LUGS

FROM-TO-CHART

Item(s) Charted:
CF Tubes

Basis of Values:
Tubes per day

Activity or Operation FROM \ TO	Basis of Values: <i>Tubes per day</i>								TOTAL
	1 Goods in/out	2 AM	3 Post Process	4 QC	5 Tube Process	6 Kitting	7 Bond	8 Bike Assembly	
1 Goods in/out				2				2	4
2 AM									
3 Post Process									
4 QC					2				2
5 Tube Process						2			2
6 Kitting							2		2
7 Bond	2								2
8 Bike Assembly	2								2
TOTALS	4	0	0	2	2	2	2	2	

APPENDIX 6 FROM-TO-CHART CF TUBES

FROM-TO-CHART

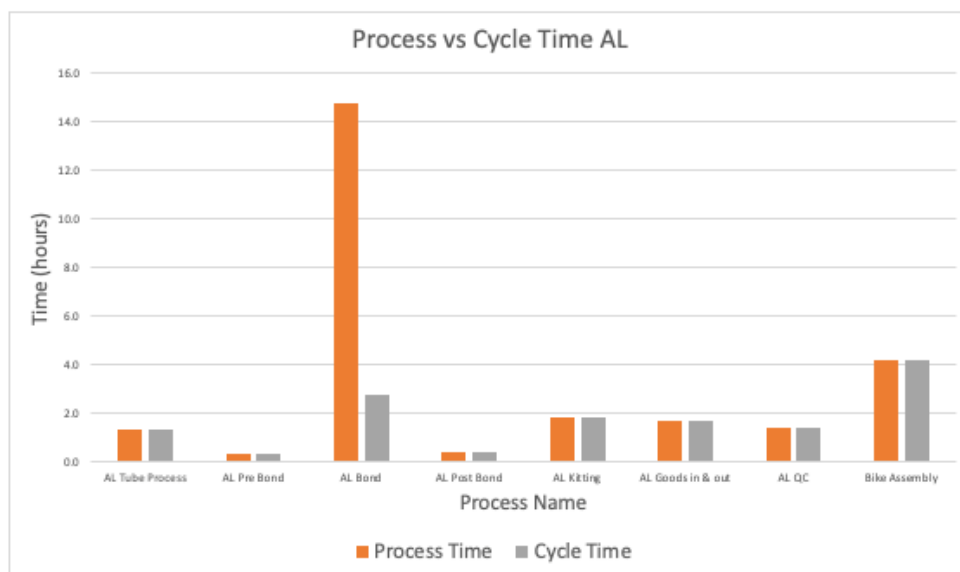
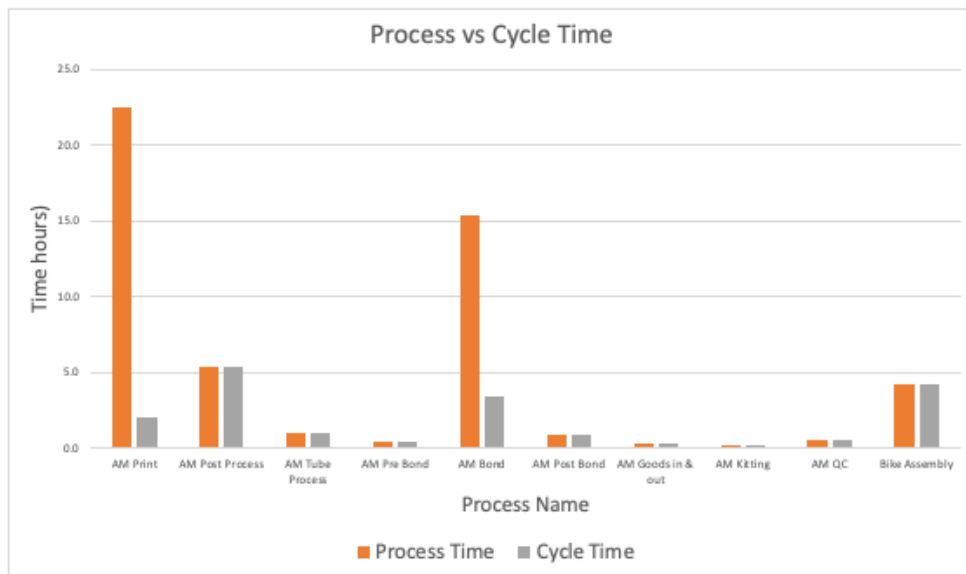
Item(s) Charted:
AL Tubes

Basis of Values:
Tubes per day

Activity or Operation FROM \ TO	Basis of Values: <i>Tubes per day</i>								TOTAL
	1 Goods in/out	2 AM	3 Post Process	4 QC	5 Tube Process	6 Kitting	7 Bond	8 Bike Assembly	
1 Goods in/out				10				10	20
2 AM									
3 Post Process									
4 QC	10				10				20
5 Tube Process	10					10			20
6 Kitting							10		10
7 Bond								10	10
8 Bike Assembly	10								10
TOTALS	30	0	0	10	10	10	10	20	

APPENDIX 5 FROM-TO-CHART AL TUBES

Bottleneck Analysis Results



APPENDIX 7 BOTTLENECK ANALYSIS RESULTS

Space Requirement Sheet

Work Centre	Equipment	Dimensions (m)	Working Envelope (m2)	Height requirements	Quantity	Sqr meter	Total	Space allocation
AM Print	AM Machine	1.236 x 2.165	4.236 x 3.165	3	2	13.41	26.8	
	System Chiller	0.97 x 0.38	1.98 x 1.77		2	3.50	7.01	
	Ruwac	0.6 x 0.6			1	0.36	0.36	
	Argon Bottle	0.4 x 0.4			1	0.16	0.16	
	Work Bench	0.6 x 1.2			1	0.72	0.72	
	COSHH	1.2 x 0.7			1	0.84	0.84	
	Bin				1		0.00	
							35.9	
						18.99	0	
Powder Recovery System	Mechanical Sieve	0.85 x 0.45	1.45 x 1.5	2.8	1	2.18	2.18	
	Argon Bottle	0.4 x 0.4			1	0.16	0.16	
							2.34	38.24
Filter Passivation	Filter wash station	3 x 1.2	3 x 1.8	Min 2.8m	1	5.40	5.40	
	Spill tray	3 x 1.2			1		0.00	
							5.40	
Post Process	Fettle booth	3 x 0.65	3 x 2.1		2	6.30	12.6	
	Linisher	1.2 x 0.6	2.6 x 0.6		1	1.56	0	
	Abrasive blaster	1.2 x 1.8	2.4 x 1.8		1	4.32	1.56	
							4.32	

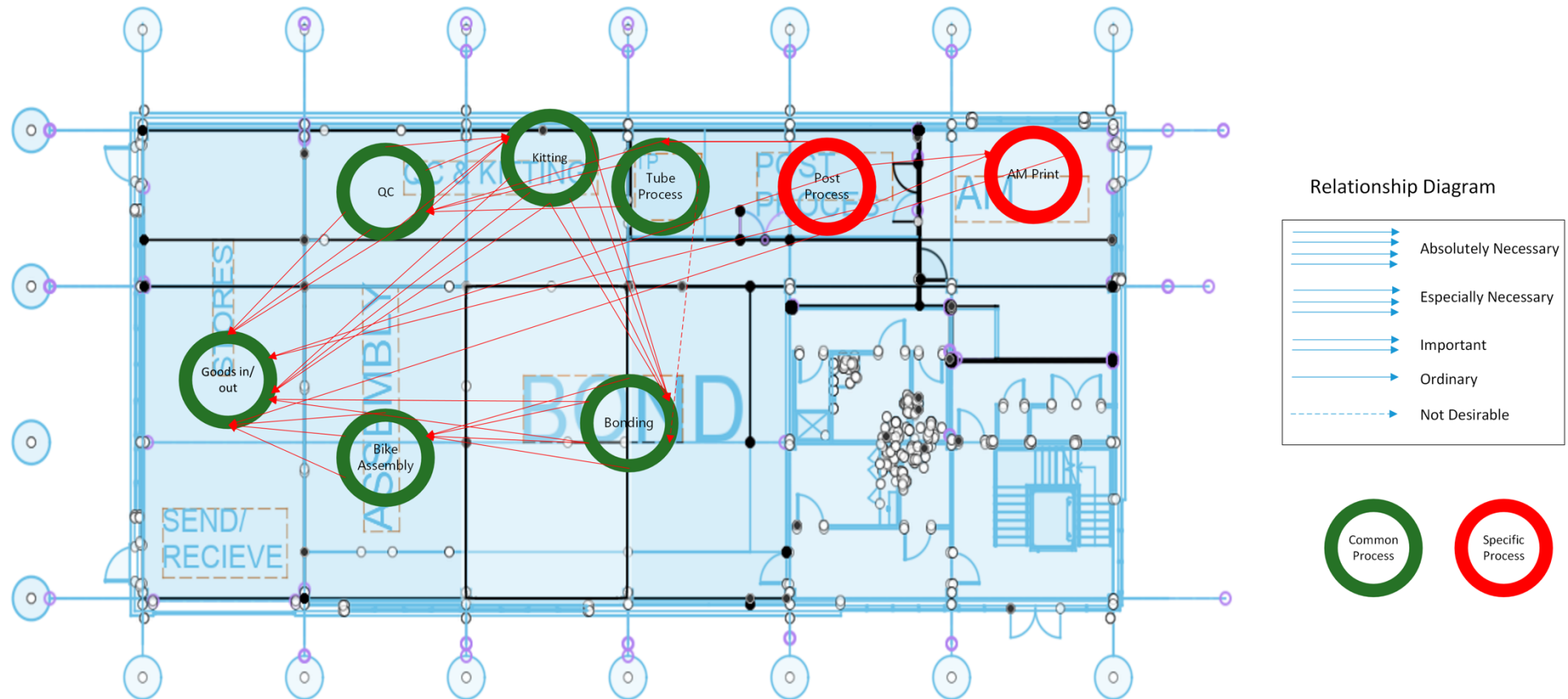
	Emulsion extractor	1.4 x 0.7		1	0.98	0.98
	Tools storage	0.68 x 0.46		1	0.31	0.31
	ERP station				0.00	0.00
						19.7
						7
Pre Bond	Ultrasonic wash	0.5 x 0.3		2	0.15	0.3
	Workstation	4 x 1	4 x 2.4	1	9.6	9.6
						9.9
Bond						13.4
	Front end jigs	1.2 x 1.2		4	3.36	4
	Rear end jig	0.7 x 0.3		4	0.21	0.84
	Workstation	3 x 0.6	3 x 1.8	1	5.4	5.4
	Adhesive dispenser	0.9 x 2		1	1.8	1.8
	COSHH	1.2 x 0.7		1	0.84	0.84
	Tool storage	0.68 x 0.46		1	0.31	0.31
	ERP station					22.6
						3
Post Bond	Workstation	3 x 0.6	3 x 1.8	1	5.4	5.4
	QI equipment	0.4 x 0.3		1	0.12	0.12
	Consumable storage	0.68 x 0.46		1	0.31	0.31

							5.83	38.36
Quality Inspection	Workstation ERP station	4 x 0.65	6 x 1.85		1	11.1	11.1	
							11.1	
Kitting	Shelving	8 x 0.7		2.8	2	5.6	11.2	
	Walkway	8 x 1.4	1.4		1	11.2	11.2	
							22.4	33.5
Tube Process	Band saw	2 x 1.2	2 x 4		1	8	8	
	Pillar drill	1 x 1.2	1 x 2.4		1	2.4	2.4	
	Workstation	2 x 0.6			1	1.2	1.2	
	Tube rack	2 x 0.8			1	1.6	1.6	
	Tools storage	0.68 x 0.46			1	0.31	0.31	
	Vacuum cleaner	0.5 x 0.5			1	0.25	0.25	
	Bin				1		0	
							13.7	
							6	33.53
Goods In & Out	Workstation	2 x 0.6	2 x 2		1	4	4	
	Bike box storage	2 x 4			2	8	16	
	Shelving	2 x 0.7	2 x 2.1		1	4.2	4.2	

							24.2	
Stores	Shelving	13 x 0.7	13 x 2.1		11	2.1	23.1	
		4 x 0.7	4 x 2.1		5	8.4	42	
							65.1	89.3
Assembly	Bike stand	0.6 x 0.6	2 x 2.4		5	4.8	24	
	Workstation	2 x 0.6	2 x 1.6		5	3.2	16	
							40	

APPENDIX 8 SPACE REQUIREMENT SHEET

Relationship Diagram Layout 1



APPENDIX 9 RELATIONSHIP DIAGRAM LAYOUT 1

Flow Process Chart

Process Name: Aluminium Lugs

Charted Unit	Units per load	Action						Description of Action	Size (m)	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Boxed lugs	20	○	□	→	□	□	□	Lugs from supplier	1.2 x 1 x 0.6						
2 Boxed lugs	20	○	□	→	□	□	□	Move to QC	1.2 x 1 x 0.6	1	20.4	20.4	20.4	0.102	Transported on pallet truck due to size and weight
3 Boxed lugs	20	○	□	→	□	□	□	Remove from box and place on QC work stations	1.2 x 1 x 0.6						
4 Lug	1	○	□	→	□	□	□	Quality inspection	0.1 x 0.1						
5 Lug	1	○	□	→	□	□	□	Assort to bike product line and size	0.1 x 0.1						
6 Lug	1	○	□	→	□	□	□	Place lugs in production kit box	0.1 x 0.1						
7 Production kit	1	○	□	→	□	□	□	Move to Kitting	0.7 x 0.6 x 0.4	10	7.3	73	73	0.365	Could be moved on roller racking to reduce repeated journeys
8 Production kit	1	○	□	→	□	□	□	Place production kit on shelves	0.7 x 0.6 x 0.4						
9 Production kit	1	○	□	→	□	□	□	Wait for batch	0.7 x 0.6 x 0.4						
10 Production kit	20	○	□	→	□	□	□	Store	0.7 x 0.6 x 0.4						
11 Production kit	20	○	□	→	□	□	□	Move to GIO and transport to anodiser	0.7 x 0.6 x 0.4	1	27.7	27.7	27.7	0.1385	Transported on pallet truck due to size and weight
											Total:	121.1		0.61	

APPENDIX 11 FLOW PROCESS CHART AL LUGS

Flow Process Chart

Process Name: Aluminium Tubes

Charted Unit	Units per load	Action						Description of Action	Size	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 2m lengths	100kg	○	□	→	□	□	□	Tubes from supplier	2m						
2 2m lengths	100kg	○	□	→	□	□	□	Move to tube process	2m	1	35.5	35.5	35.5	0.1775	Transported on pallet truck due to size and weight
3 2m lengths	1	○	□	→	□	□	□	Place tubes on rack	2m						
4 2m lengths	1	○	□	→	□	□	□	Store in racks until production scheduled	2m						
5 2m lengths	1	○	□	→	□	□	□	Cut to length	<0.65m						
6 Cut tube	1	○	□	→	□	□	□	Place on rack	<0.65m						
7 Cut tube	1	○	□	→	□	□	□	Deburr, notch and bottle mount	<0.65m						
8 Cut tube	1	○	□	→	□	□	□	QC checks	<0.65m						
9 Cut tube	1	○	□	→	□	□	□	Place tube in production kit box	<0.65m						
10 Production kit	1	○	□	→	□	□	□	Move to kitting	<0.65m	1	19.4	19.4	19.4	0.097	Consideration of reducing distance from TP to Kitting by linking work centres using a door, or using pallet truck
											Total:	54.9		0.27	

APPENDIX 10 FLOW PROCESS CHART AL TUBES

Flow Process Chart

Process line: Bond

Charted Unit	Units per load	Action						Description of Action	Size	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Production Kit	5	○	□	→	□	□	▽	Move to pre-bond	0.7 x 0.6 x 0.4						Transported by trolley - consider access door to pre bond
2 Production Kit	1	○	□	→	□	□	▽	Remove parts from box	0.7 x 0.6 x 0.4						Use cut out in boxes to reduce transportation damage
3 Production Kit	1	○	□	→	□	□	▽	Wash in clean solution	0.7 x 0.6 x 0.4						
4 Production Kit	1	○	□	→	□	□	▽	Place parts on dry rack	0.7 x 0.6 x 0.4						
5 Production Kit	1	○	□	→	□	□	▽	Wait for parts to dry	0.7 x 0.6 x 0.4						Consider force drying with clean warm air
6 Production Kit	1	○	□	→	□	□	▽	Place on bond trolley	0.7 x 0.6 x 0.4						
7 Production Kit	1	○	□	→	□	□	▽	Move trolley to bond station	0.7 x 0.6 x 0.4	10	5.3	53	53	0.265	Consider traffic when moving trolleys to stations
8 Production Kit	1	○	□	→	□	□	▽	Fill lug joints with adhesive	0.7 x 0.6 x 0.4	10	2.4	24	24	0.12	Adhesive dispenser on retracting ceiling mounted gun
9 Production Kit	1	○	□	→	□	□	▽	Place lugs on trolley	0.7 x 0.6 x 0.4						Use cut outs on trolley
10 Bike Frame	1	○	□	→	□	□	▽	Bond front end	0.7 x 0.6 x 0.4						
11 Bike Frame	1	○	□	→	□	□	▽	Move jig to cure location	0.7 x 0.6 x 0.4	10	0.9	9	9	0.045	Sensitive at early stage in bond
12 Bike Frame	1	○	□	→	□	□	▽	Cure for 12 hours	0.7 x 0.6 x 0.4						In cure position
13 Bike Frame	1	○	□	→	□	□	▽	Transport rear end parts to jig	0.7 x 0.6 x 0.4	10	6.1	61	61	0.305	
14 Bike Frame	1	○	□	→	□	□	▽	Bond rear end	0.7 x 0.6 x 0.4						
15 Bike Frame	1	○	□	→	□	□	▽	Cure for 12 hours	0.7 x 0.6 x 0.4						
16 Bike Frame	1	○	□	→	□	□	▽	Remove frame from jig	2 x 1.4 x 0.3						Operator to carry 1 frame per trip
17 Bike Frame	1	○	□	→	□	□	▽	Move to post-bond	2 x 1.4 x 0.3	10	11.5	115	115	0.575	
18 Bike Frame	1	○	□	→	□	□	▽	QC frame	2 x 1.4 x 0.3						
19 Bike Frame	1	○	□	→	□	□	▽	Store for assembly	2 x 1.4 x 0.3						
20 Bike Frame	1	○	□	→	□	□	▽	Move to Assembly	2 x 1.4 x 0.3	10	6.3	63	63	0.315	Consider dual access to WIP storage
										Total:	325			1.63	

APPENDIX 12 FLOW PROCESS CHART BOND

Flow Process Chart

Process line: QC Kitting

Charted Unit	Units per load	Action						Description of Action	Size	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Outsourced Production Kits	20	○	□	⇄	□	□	▽	Move to QC Kitting	1.2 x 1 x 0.6						Transported by pallet truck - consider route and corners
2 Production Kit	1	○	□	⇄	□	□	▽	Place lugs and tubes on inspection table	0.7 x 0.6 x 0.4						Positioning of box to stop unnatrual movements
3 Production Kit	1	○	□	⇄	□	□	▽	QC of parts	0.7 x 0.6 x 0.4						
4 Production Kit	1	○	□	⇄	□	□	▽	Place parts back in production kit box	0.7 x 0.6 x 0.4						Cut outs to reduce risk of damage
5 Production Kit	5	○	□	⇄	□	□	▽	Batch for transport	0.7 x 0.6 x 0.4						
6 Production Kit	1	○	□	⇄	□	□	▽	Move to kitting shelves	0.7 x 0.6 x 0.4	2	7.3	14.6	14.6	0.073	Transport in batch using trolley or roller racking
7 Production Kit	1	○	□	⇄	□	□	▽	Place production kit of shelves	0.7 x 0.6 x 0.4						Consider weight of kit and reach of opeator on high shelves potenital risk to H&S
8 Production Kit	1	○	□	⇄	□	□	▽	Stored until production is scheduled	0.7 x 0.6 x 0.4						Clear marking of model to ease of location
9 Production Kit	1	○	□	⇄	□	□	▽	Pick production kit for processing	0.7 x 0.6 x 0.4	10	4	40	40	0.2	Consider weight of kit and reach of opeator on high shelves potenital risk to H&S
10 Production Kit	1	○	□	⇄	□	□	▽	Batch for transport	0.7 x 0.6 x 0.4						Batch to be moved to bond to reduce distance travelled
11 Production Kit	5	○	□	⇄	□	□	▽	Move to pre bond	0.7 x 0.6 x 0.4	2	13	26	26	0.13	Consider access and route to ensure tight corners and doors
										Total:		80.6		0.40	

APPENDIX 13 FLOW PROCESS CHART QC & KITTING

Flow Process Chart

Process line: Assembly

Charted Unit	Units per load	Action						Description of Action	Size	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Bike Frame	1	○	□	→	□	□	▽	Move to assembly stand	0.7 x 0.6 x 0.4						
2 Bike Frame	1	○	□	→	□	□	▽	Fit frame to stand	0.7 x 0.6 x 0.4						
3 Bike Frame	1	○	□	→	□	□	▽	Assemble frame	0.7 x 0.6 x 0.4						All hardware and tools at stand
4 Bike Frame	1	○	□	→	□	□	▽	QC of frame	0.7 x 0.6 x 0.4						Check of alignment and movement of rear end
5 Bike Frame	1	○	□	→	□	□	▽	Receive bike components	0.7 x 0.6 x 0.4	10	5.4	54	54	0.27	All components on one trolley
6 Completed Bike	1	○	□	→	□	□	▽	Assemble bike	0.7 x 0.6 x 0.4						
7 Completed Bike	1	○	□	→	□	□	▽	QC of bike	0.7 x 0.6 x 0.4						Final check that all components are functioning correctly
8 Completed Bike	1	○	□	→	□	□	▽	Receive built bike box	5 x 1.4 x 0.3	10	2.9	29	29	0.145	Box built in GIO by operator and ready for bike to be rolled in
9 Boxed Bike	1	○	□	→	□	□	▽	Pack bike into box	5 x 1.4 x 0.3						
10 Boxed Bike	1	○	□	→	□	□	▽	Move to completed area	5 x 1.4 x 0.3						Consider weight and dimensions when lifting onto trolley
11 Boxed Bike	1	○	□	→	□	□	▽	Store for batch to move to ship	5 x 1.4 x 0.3						
12 Boxed Bike	5	○	□	→	□	□	▽	Move to ship	5 x 1.4 x 1.5	2	6.6	13.2	13.2	0.066	Completed bikes on trolley for courier service
Total:												96.2		0.48	

APPENDIX 14 FLOW PROCESS CHART ASSEMBLY

Flow Process Chart

Process Name: Bike Components

Charted Unit	Units per load	Action						Description of Action	Size (m)	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Boxed Components	50							Components from supplier	1.2 x 1 x 0.6						
2 Boxed Components	50							Move to Stores	1.2 x 1 x 0.6	1	10	10	10	0.05	Transported on pallet truck due to size and weight
3 Boxed Components	50							Remove from box and place shelves	1.2 x 1 x 0.6						
4 Boxed Components	1							Store for build schedule	0.1 x 0.1						
5 Boxed Components	1							Update ERP System	0.1 x 0.1						
6 Build kit	1							Create build kit	0.1 x 0.1						
7 Build kit	1							Move to bike assembly	0.7 x 0.6 x 0.4	10	7.3	73	73	0.365	Could be moved on roller racking to reduce repeated journeys

Total: 83 0.42

APPENDIX 16 FLOW PROCESS CHART BIKE COMPONENTS

Flow Process Chart

Process Name: Bike Box

Charted Unit	Units per load	Action						Description of Action	Size (m)	Number of Trips per Day	Distance	Distance per day	Time per Day	Cost per Day	Notes
		Operation	Handling	Transport	Inspection	Delay	Storage								
1 Palletted Bike Boxes	50							Components from supplier	1.2 x 1 x 0.6						
2 Palletted Bike Boxes	50							Move to Stores	1.2 x 1 x 0.6	1	10	10	10	0.05	Transported on pallet truck due to size and weight
3 Bike Box	50							Remove from pallet and place shelves	1.2 x 1 x 0.6						
4 Bike Box	1							Store for build schedule	0.1 x 0.1						
5 Bike Box	1							Build bike box	0.1 x 0.1						
6 Bike Box	1							Place on box station	0.1 x 0.1						
7 Bike Box	1							Move to bike assembly	0.7 x 0.6 x 0.4	10	7.3	73	73	0.365	Could be moved on roller racking to reduce repeated journeys

Total: 83 0.42

APPENDIX 15 FLOW PROCESS CHART BIKE BOX

Labour Bike

Job Title	Workload per bike (m)	Av working time (m)	Req Labour	Hired Labour	Cost per Day	Cost	Hrs/Bike
QC/TC Kitting	124	420	4.72	5.00	112	560	2.07
Goods in/out	122.5	420	4.67	5.00	84	420	2.04
Bond Assistant	131	420	4.99	5.00	84	420	2.18
Bond Lead	143	420	5.45	6.00	112	672	2.38
Bike Assembly	250	420	9.52	10.00	112	1120	4.17
Total of employees	770.5		29	31		3192	
Cost per bike	12.84					199.50	

APPENDIX 17 LABOUR CALCULATION