The Use of Computer Simulation in Facility Layout Planning

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Abstract

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Abstract

The aim of this thesis is to create a better understanding of how computer simulation is used in industry especially in the area of facility layout planning. The project in which this thesis is based upon concerns the development of a factory layout which will be created in a production line simulation. The research will give a background on the techniques and current practices used by engineers in layout planning today.

Background research was conducted in the field of simulations including the history, advantages, current capabilities, steps of development, and current uses. Research also concerning layout planning will also be reported in the research sections of this thesis.

A case study concerning the layout planning and simulation of a production line for a motorbike will be followed to prove the benefits of simulation in facility layout planning. The thesis will follow the steps taken by the Engineering team to construct the layout used in the simulation as well as touch upon the actual construction of the simulation. The results will be used to further develop the facility layout as well as help other colleagues visualize and understand the production system.

Keywords
Simulation, Layout planning, Material Management, Assembly line, Production Planning

CONTENTS

1 INTRODUCTION

Computer simulations have evolved over time to become one of the most useful and multi-faced tools used in industry today. As computer processors become more powerful, simulation models become more useful in calculating complex probability and algorithms to help solve many problems faced by Industrial Engineers every day. With simulation, we are able to imitate just about any business, production, or manufacturing system which helps engineers better understand the system at hand and allows them to improve that system through the process of experimentation.

Simulation gives Industrial Engineers the possibility to see and evaluate any possible development or changes in a production system. It allows them to instantly receive crucial data at incredible speeds which will allow them to make an educated decision concerning the production processes. The advantages simulation can bring to an industrial company can dramatically affect the level of success a company has in today's fast paced, global economy.

A project an Industrial Engineer may be involved with is the design and development of a facility layout plan. With production needs today, especially involving JIT (Just in Time) storage systems, mass production facilities have intense strain to perform fluently to keep production flowing. One factor that greatly affects whether a production system will be a success or failure is the facility layout, almost every system running within the factory is influenced by its layout. Many Industrial Engineers have devoted their careers to facility layout planning by developing different techniques and ideas to optimize production with a well-planned facility layout.

1.1 DigiBranch Project

The DigiBranch Project was started in 2009 and involves a number of different research areas related to production and productivity. The applied research mainly concerns digital production and focus specifically to the following topics

- Development of virtual production, assembling, and manufacturing management specifically concerning the supply chain viewpoint

- Using simulation and remote programming of production and production systems
- Planning, Building, an d testing of virtual and real prototypes including augmented reality.
- Development of process ability and productivity in the supply chain
- Personal Learning Environment (PLM) will be created using the digital production technologies and related to business processes.

The project in which this thesis is concerned with includes the development of a factory layout to be used in a production line simulation. The project was in need of an industrial engineering student due to the fact all current members were mechanical engineers and had no experience with production or facility layout. The industrial engineering students would be responsible for the layout planning process and must provide a finalized layout plan for the simulation. The layout produced by the students would then be seen in a 3D computer simulation to be used by the mechanical engineers involved in the project.

1.2 Outline

This thesis will go into depth on how simulation can be used as a very useful tool when developing a successful facility layout. The advantages of simulation and the history of its development will be discussed in the beginning chapters as well as a background on facility layout planning. Different layouts and techniques used by engineers today will be researched and analysed which will help the reader understand how much effort actually goes into facility layout planning and how it can greatly affect the success of the production system.

The final chapters will include a case study done at Savonia UAS in Kuopio, Finland. The case study involves the planning of a facility layout for the mass production of a prototype motorbike designed by the Mechanical Engineering Department at Savonia UAS. Once the layout is complete, a simulation model will be built using the final layout plan as blueprints. The simulation will be as detailed as possible for the students to understand and study the production line and possibly be used in future projects and learning at Savonia UAS. The simulation will allow further development of the facility layout and allow other students to use the results given by the simulation to optimize the layout even further.

1.3 Scope of Thesis

This thesis examines the use of simulation software as a tool to develop and improve manufacturing systems. The tools within simulation software will be discussed as well as certain packages simulation programs include and how specific tools have become tailored to certain manufacturing circumstances. Specifically, it will follow the project of designing and developing a product line for the mass production of a motorbike. Simulation software will be used to aid in this project, specifically in the comparison between certain changes within the factory layout. A breakdown of the steps taken to build the model as well as conclusions given by the model will be reported and analysed throughout this thesis. This thesis covers the following areas:

- Advantages of using manufacturing simulation software.
- Description of facility layout methods specifically planning of a production line.
- Background of motorbike project used as an example throughout the thesis.
- Report of the final layouts chosen for motorbike project.
- Steps taken to build a successful simulation model to compare the various layout plans.
- Report and analysis of the results taken from the simulation model.
- Conclusion of the study and further development of the project.

2 MODELING AND SIMULATION

2.1 What is a System?

Before getting more into depth on the subject of simulation and its applications, we must first define a system (which a simulation portrays). A system is defined to be a set of elements which interact or interrelated in the same fashion (1). These elements within the system are called entities. Other components of a system include attributes, activities, states, and events (1).

Attribute: is a property of a system.

Activity: represents a time period of a specified length.

State: of a system is defined to be a collection of variables necessary to describe the system at any time, relative to the objective of the study.

Event: is defined as an instantaneous occurrence that may change the state of the whole or part of the system.

Entities: Components within the system that interact or interrelate in the same fashion.

An example we can use to define these components further is a production system. If we think of a production line, machines are considered the entities. These machines are all working together within the system to fulfil a need. The speed, capacity, and breakdown rate of these machines (entities) are considered attributes. The attributes can be realized as properties of entities in our system. If our system were to breakdown, this is called an event because it is an occurrence that changes the state of the system instantaneously (1).

2.2 What is modelling?

A model can be defined as a system that is used as a surrogate for another system. Broadly, there are two types of models we use in the planning process, physical and mathematical (1). A physical model is usually a smaller replica or prototype of structure or system. These models can be either made by hand with concrete material, or more commonly on 3D computer aided drawing software (4). These physical models help the design team visualize what the final product should look like and help with the detection of future problems. Mathematical models are generally used while calculating analytical queuing, linear programs, and simulation. These models are typically shown in equation form and are used to generate useable output data based on the constraints and regulations of the equation.

As you can imagine, there are many reasons why design teams decide to build models of their ideas before actually constructing them in real life. The primary reason to build a system model is to conduct experiments in order to answer questions about that system. This will help us understand the system better (2). An example of this is testing car designs in wind tunnels. We are able to control the inputs of the system (wind direction, speed) to record how our car will react in real life (outputs). In other words, we are conducting experiments on model cars to help us better understand the properties of air dynamics.

2.3 What is Simulation?

Previously, the importance of conducting experiments on models was introduced. This is actually one of the main uses of models and is denoted by the term simulation. We can define a simulation as an experiment performed on a model (2). Within these experiments, the model is amendable to manipulation which would be impossible, too expensive, or too impractical to perform on the system which it portrays (1). In this day and age where companies are investing millions of dollars on cutting edge facilities which contain complex assembly lines, expensive machinery, and depend on precise timing, simulation is becoming more and more important to help the company's investment reach its maximum potential.

2.3.1 Types of Simulation Models

When we consider the different types of simulation models, three categorizes come to mind.

- Physical or mathematical
- Deterministic or stochastic
- Continuous or discrete

The first category describes the type of model we will use in our simulation. As mentioned previously, a physical model merely portrays what a system looks like and will not be discussed further in this thesis. A mathematical model is the numerical description of the behaviours of the elements of the system (9).

Our next category will describe two different types of mathematical models. A deterministic model is a model that has no variation or randomness, when we input our data, the results will be the same every time. Deterministic simulations are usually used in experimenting with digital circuits (1). A stochastic simulation is a simulation that contains random or probabilistic elements. Most systems are considered to be stochastic, and variables are controlled using statistical distributions (9). An example would be a simulation of a service desk. A random variable would be the amount of time it takes the clerk to help each individual customer (1).

Continuous and discrete simulation describes how the state changes within the simulation over time. A simulation with continuous features will display changes inside the system smoothly as time goes on. A discrete simulation model is only concerned with the state of a system at certain points in time (9). Because most manufacturing systems are classified as stochastic and discrete, most simulation software available revolves around these concepts.

2.4 History of Simulation Models

Simulation today is arguably one of the most multifaceted topics faced by an Industrial Engineer. It is used in so many areas including in the office, manufacturing floor, or warehouse and aids with issues including quality, productivity, and safety (3). The development of simulation has increased significantly since its birth. With the help of high speed computer processors and vivid graphics, software companies are constantly updating and improving simulation software with new features and applications. This chapter will describe the advances in simulation and simulation software throughout history and highlight a few key breakthroughs which help to create what simulation is today.

The first record of simulation dates back to World War II when two mathematicians, Jon Von Neumann and Stanislaw Ulam were experimenting with neutrons in the laboratory (3). Their experiments were very expensive and too complicated for analysis. To solve the problem, the two mathematicians put their heads together and came up with the

Roulette wheel technique. Because they knew the basic data of the occurrence of the events, they used probability to make a model of a step by step analysis to predict the outcome of the whole sequence of events (3). After its success for the mathematicians, they began to use this technique in many simple business and industry applications.

2.4.1 The Formative Period

The time between 1955 and 1970 is known as “the formative period” (8). In this time, simulation was not a useful tool due to the time it took for the computer to give the results and the amount of skilled people it took to create and run the simulations (3). Because of the lack of computing power available at this time, simulation software just wasn’t a practical tool. According to R. W. Conway, B. M. Johnson, and W. L. Maxwell (early pioneers of simulation) the problems with computer simulation fall into two broad categories, the construction of the simulation and the use of the simulation (8). Technology and underdevelopment of simulation concepts are to blame for these problems.

The characteristics of this period were quantities of simulation language developments but there were few efforts to coordinate and compare the different approaches. This led to the first simulation conference in 1964 on the campus of Stanford University which lead to a number of different conferences in locations such as New York and Pennsylvania (3). These different conferences brought together all the different programmers from all over the world to discuss their different languages and applications for simulation. These conferences stretched from 1964 to 1966 where the need for a narrower conference on the uses for simulation was needed (3).

In November 1967, a conference on the applications of simulation using the General Purpose Simulation System (GPSS) was held. This conference really gave simulation the boost it needed by revealing its true potential. In 1968, a broader conference on applications of simulation was conducted. There was over seven hundred attendees as well as a 368 page published digest of the topics covered. One of the topics discussed were the many aspects of Discrete Event Simulation which is obviously a breakthrough for the simulation community. Other topics included random number generation, simulation tutorials, manufacturing applications, reliability, distribution systems, communications, job shops, and facility planning models (3). After the discussion of these various concepts, there were major revisions of the different simulation languages (7). Languages such as Simscript II, ECSL, and SIMULA led the way into the 70’s and had no intention on looking back (7).

2.4.2 The Expansion Period

The time between 1971 and 1990 is known as “The Expansion Period” (8). It was during this time when developers attempted to simplify the modelling process and to eliminate the severe limitations of program generators (7). In the early 70’s simulation was introduced to Industrial Engineers at school but was rarely applied in real life applications.

Throughout the 70’s, the popularity of simulation as a powerful tool increased with the number of conferences and sessions. The amount of these conferences and sessions had doubled by 1971 and continued to rise to about sixty sessions in 1983, compared to 12 in 1967. By 1980, there were more tutorials and papers organized into tracts of sessions for beginners, intermediate, and advanced which allowed the use of simulation to more people around the world (3).

Although simulation was continuously improving throughout this era, there were still two major problems with simulation in the early 80’s. The first is the fact that even though there were helpful tutorials and instructions on how to create and use simulations, it was still extremely complicated. If you were interested in building a useful, accurate model, an expert was necessary. The other problem with simulation was the amount of time it took to build due to programming and debugging. Because of these problems, the cost of building a simulation on a computer was quite high and the results just weren’t worth the price (3).

In 1982, most simulation software only concentrated on timing and sizing of orders which was good for material requirements planning but did not consider capacity limitations. This meant the simulation was unable to calculate the utilization of the machines used in the simulation. As a result, companies spent millions of dollars on expensive, computer-controlled equipment that were underutilized and misused. None the less, developers were able to realize the problems and begin improving (3).

The next major breakthrough happened in 1983. The reason for the breakthrough was the introduction and movement to mini and PC computers. These computers were able to hold and process much more data than before which allowed simulation for production planning more feasible (7). SLAMI by Pritsker and associates was also developed in 1983 to be run on the new IBM PC. This software provided three modelling approaches.

1. Network

2. Discrete event
3. Continuous and flexibility to use any combination of them in a single model.-

Because of these new features and its low price of 975 dollars, it is now when simulation was considered to be a powerful tool in the industrial field (3).

As the capabilities of the PC increased, so did simulation. By the late 80's simulation was as powerful as ever with new features such as self-documenting code, easy-to-use menu, expanded drawing features, real time plots, and frequency graphs. The increasing power of the PC also aided with the development of discrete event simulation which was very important for companies interested in modelling manufacturing systems. With the improvement of discrete event applications in simulation, management was able to assess cost-benefits of alternatives concerning maintenance strategies, equipment repairs, and capital replacements (3).

As the decade came to a close, so did the expansion period. Modelling and simulation had made huge advances due to the wide spread of different ideas by early developers in the 70's. Cutting edge technology in the 80'shad also played a major role in the advances made in simulation software. As we head into the 90's, more advances in technology are made which will help aid simulation developers shape simulation into what it is today.

2.4.3 Maturation Period

During the Expansion Period, technology had finally caught up to the developers. They were finally able to use computers with enough memory and process power to build and simulate their models of processes. It was this time when people began to realize the possibilities of simulation and started to see how important of a tool it could become. Because this was a relatively new technology for its time, there was plenty of room for improvement and with the continuous improvement of computers, simulation is constantly refining. The time between 1991 and today is known as the maturation period.

In the early 90's, simulation was starting to be used by companies to help design new facilities, conduct supply-chain experiments, and to optimize total production. Companies also took advantage of the graphics that some simulation programs had to offer. They were able to demonstrate the advantages of their systems as well as giving their clients a better understanding. Because technology had improved so much during this period, simulation became quicker, cheaper and much more responsive to the designs of the model constructor (3).

In 1998, Micro Saint Version 2.0 for Windows 95 started to break away from the rest. It included features such as automatic data collection, optimization capabilities, and included the new Windows interface. Over the past decade, simulation has advanced to such a stage that the software enables the user to model, execute, and animate any manufacturing system in any desired level of detail. The newest features include pop-up guide menus to direct the user through the modelling process, 3-D graphics are automatically updated as the user inputs data, built in material handling templates come pre-installed which increases user productivity, and results can be communicated in real time animation. (3).

2.4.4 Summary of Simulation History

During the formative period, simulation was considered a useful tool with a lot of potential; there were many different ideas on the uses of simulation from all parts of business. The true potential of simulation was realized by a couple key developers which helped to coordinate the creation of simulation by bringing together the various ideas and applications through a series of conferences throughout the 70's. It was this time when simulation was known by industrial engineers but not entirely practical due to the technology of this time.

It was during the expansion period when simulation started to turn heads and becoming considered as an intensely powerful tool, especially in the field of manufacturing. New applications were constantly being created as well as old applications being put to use solving real life problems. With the introduction of the PC in the 80's, simulation became more powerful than ever with access to powerful processors and the ability to store all the data needed to simulate complex systems. At the end of the expansion period, we were able to solve many complex problems using simulation due to the development of discreet event scenarios as well as many other applications during this time.

As we entered into the 90's simulation entered a time called the maturation period. It was during this time when technology was continuously improving. With the help of increasing processing power, users were able to create and run extremely detailed simulations in a much shorter amount of time. Also during this time, simulation becomes more user friendly with easy to use menus and pop-up windows to direct the user on how to build his or her simulation. With the new features developed, simulation became an extremely powerful tool and much easier to use.

2.5 Steps to Making a Simulation Model

Although different simulations may have different objectives or goals, the creation process must follow certain steps to ensure a successful simulation study. The following briefly describes the basic steps in the simulation study process and will be used throughout this thesis (1,5).

- Problem Definition.

  The initial step is to come up with goals we want to accomplish and think about what problem needs to be solved with the simulation model. In this step we also must identify what inputs, elements, constraints, and attributes will make up our simulation environment. When we are creating our goals for the simulation, we must also take into consideration whether simulation is the appropriate tool to use. Perhaps the solution is simple and can be resolved with common sense or a cheaper, faster method.

- Setting Objectives and Plans

  Once simulation is decided to be the best method to solve the problem stated in step one, we must break down tasks into work packages. Milestones are often introduced so the project can be properly tracked. This step will also help the project team realize if there is sufficient time and resources to accomplish their goals and objectives.

- System Definition

  Often, the system we are trying to model is very complex. This step usually involves an experienced simulator to evaluate and identify the various components in the system. It is important to realize which are important and which can be disregarded. Once these components are sorted, the designer can then evaluate the appropriate level of detail the simulation must include to reach the goals set in step 2.

- Model Formation

  Now that we have defined the necessary components within our system, we must now develop an abstract representation of the model. In other words, we must organize these different components and processes them into some type of model that will help give us an understanding of exactly what system we are trying to simulate. Usually some type of flow or process chart is used in this step.

- Input Data Collection and Analysis

  With a rough model, we can now start to decide what data we need to collect and from where. Sometimes the data needed already exists which makes this step easy, but this is not always the case. Usually, data needs to be collected from existing systems or from research. Once the data is collected, we then input it into theoretical distributions. An example would be an arrival rate, with the data we have collected; we are able to fit it into a normal distribution curve.

- Model Translation

  In this step, we need to transform the model into computer recognizable format. We can use special purpose or general purpose language such as Arena (popular simulation software)

- Verification and Validation

  We now have our model with all the necessary data put into our simulation; naturally the next step is to see if it works. This is done with the process of verification and validation. First we verify the model works like we intended to, the animation looks correct and everything seems to be running like the team thinks it should. The next process is validation which ensures the model is working as if it were a real life model. We can validate our model by taking our results and comparing them to a real life system through statistical analysis.

- Experimentation and Analysis

  It is in this step where all our hard work pays off. We are able to run our simulation where we are able to evaluate results, analyse different alternatives, and test different scenarios. We are finally able to answer our questions and make final decisions that will impact our real life systems.

- Documentation and Implementation

  Documentation consists of a report/presentation of the steps taken by the design team and their concluding results. Results are discussed and analysed to determine the best course of action.

2.6 Advantages of Computer Simulation

Although simulation modelling and software has become much cheaper through the years, it is still an expensive tool which may cause managers to second guess if it is really worth the investment. According to a SIEMENS (Global industrial competitor) representative, “Plant simulation enables experts to model, simulate, visualize and optimize your factories productions systems and logistic processes. You can use plant simulation to optimize the flow of material, throughput, resource utilization, and logistics for all levels of plant planning from global production facilities to specific lines” (4). These various applications within simulation models are used by global companies every day to give them a competitive edge.

2.6.1 3D Graphics

One of the greatest advantages of using simulation today is the ability to visualize your system. Most simulation software produced today has some kind of 3D graphics which allow the user to see their model as they build it as well as aid in the presentation of their concluding work. Being able to see your design will also allow you to check for sufficient space within your facility. Collisions between personnel, machines or robots are easily spotted in the simulation which otherwise may have gone unnoticed until the construction of the actual factory. Because this problem can be realized within the simulation, we are able to make modifications to correct the problem before any equipment is installed, saving both time and money (6).

Animation in simulation can benefit three different groups within the manufacturing company: the model builder, the model user, and the decision makers (10).

For the model builder (which is usually an expert with simulation or computers), the animation of their system can point out many errors he or she could have made. By running the simulation and being able to actually watch the system as time carries on, the designer can quickly point out any obvious mistakes they could have made. This way of correcting mistakes within the simulation is much faster than sorting through code which will save time and money for the company (10).

The model user is usually a person who is familiar with the system in which we are trying to simulate. This model user may not be very familiar with simulation programs and may be hard for him or her to understand the information the simulation is processing. Being able to watch the simulation and realize what is actually happening, his or her knowledge can be very useful in the verification and validation steps which will cause the results of the simulation to become much more useful and reliable (10).

Then of course there are the decision makers. This group of people mainly will consist of management personal who will ultimately make the final the decision on whether the change to their production system will help the company. The visualization effect of the simulation allows this group to see the whole picture and help better understand the system which they may not be too familiar with. Being able to watch the system changes will better help them understand the impact of the changes and in a way educate them into making the correct decision.

2.6.2 Optimization Tools

Another great advantage simulation gives us are optimization tools. Many software packages come with an optimizing tool to help aid the user in creating the most efficient model within the parameters set by the designer. These optimization programs can determine the necessary inputs within our system to produce at its maximum capacity. Things such as buffer size, material handling, and machine utilization are all areas where simulation helps manufacturing lines reach their highest potential.

Even though simulation software packages may come with automated optimization features, there are still many useful tools designers and users can use to optimize the system themselves. Simulation shows results of our systems (buffer size, schedules, and resources) in ways we can easily understand. An example would be a simulation concerning human resource utilization, we understand it is impossible for a human worker to be 100 present productive and take this into consideration while designing the components of the system which require human resources. Although the optimization software does not recognize this situation, we as industrial engineers are able to recognize and react to problems like this which may be overlooked by the optimization software. Even though the simulation may not be able to understand these situations, they help designers and developers realize with statistical analysis tools (10).

2.6.3 Factory Layout

While developing a simulation to represent a manufacturing system, the advantage of being able to manipulate and change things in a “make believe” world is a very important advantage. We are able to move process cells, storage locations, and large machines within our virtual world with the click of a mouse. As you can imagine, this aids the process of designing a factory layout tremendously.

With the ability to change our factory layout so easily within our factory simulation, we are able test our various ideas, change material flow plans, see buffer / storage system problems before we actually invest in a multimillion euro facility which will be used for many years and could be very expensive to change once constructed. Because these facilities are designed to be used for many years, it is very important to have a flexible and reliable factory layout for future growth and possible new production lines.

With the shift to Just-In-Time manufacturing, a factory layout must be nearly flawless to keep production continuously going and keeping product orders on time. JIT operations are very dependent on the restricting level of work in process inventories permitted between operations. When a JIT production line is continuously moving, it can be very common for machines to become idle due to an empty in buffer or a full out buffer. Things like processing requirements, setup times, and routings are all different aspects we must think about to avoid idle machines within our layout. Computer simulation allows us to test various process placements and orders to help ensure buffers are kept at the correct level while machine utilization is kept to a maximum (6).

Later in this thesis, there will be a case study where simulation will be used to help design and optimize a productive facility layout for motorbike production. Basic layout plans will be developed and then tested in the simulation to see which layout is more productive and by how much.

3 FACTORY LAYOUT PLANNING

Although computer simulation is a very powerful tool, it is only as powerful as the user makes it. Yes the computer simulation is able to do calculations and give us results at the drop of a dime but there is also a great amount of planning and research that goes into each simulation which requires the user to use his or her experience in the industrial field. In most cases, the factory layout is the most thought out component of the simulation. The decision on what will go where will dramatically change the simulation results as well as in the real world. The difference with simulation is it is not real, making it easier to correct mistakes or optimize our layout very easily.

There is a lot to consider while planning a facility layout. A good facility layout can be the difference between a success and failure as a company. We can use simulation to test our layouts but that's it, we as engineers must plan and design the layout to input into the simulation.

3.1 Factory Layout

A factory layout can be defined as follows "ideally involves allocation of space and arrangement of equipment in such a manner that overall operating costs are minimized" (11). Throughout the years, different factory layouts have been developed to meet certain production needs, whether you are production goal is one airplane per 6 months, or 20 cars per day, there has been some facility planning to help optimize the production of the product. Whichever methods you choose for your facility layout, you must remember that it represents a long-term investment.

3.1.1 Choosing Layout Type

Of course we know that plant layout will differ from site to site, industry to industry, but in most cases they can be classified into four basic categories. These categories include Process Layout, Product Layout, Fixed-Position Layout, and Combined Layout. When choosing the layout design that will best suit our production, we must consider the positives and negatives of each layout that will define the basic principles of which we base our layout.

Process Layout

In this type of layout, machines of similar type are grouped together. This layout is typically found in job shops where production requires the same type of machines but can produce different products. This type of facility gives the company flexibility and allows them to produce a variety of different products quickly and efficiently. When designing a process layout, the minimization of transportation cost, distance and time is always taken into consideration when deciding which machine will go where (11).

Pros

- Flexibility. The company can handle a variety of different processing requirements
- Cost. When purchasing the machinery for your facility, general-purpose equipment is often less expensive to purchase and maintain than specialized equipment.
- Motivation. When thinking about the employees, this layout will allow them to do various tasks in their work day rather than a repetitive task found on assembly lines.
- System protection. Because there are usually many machines that do the same thing, breakdowns/machine failures do not impact production too much. (12)

Cons

- Utilization. Equipment can often become underutilized in a process layout
- Cost. Costs could be high if batch processing is used. Low production volume mean higher-per-unit costs. Setting up the different machines for different products takes time and costs money. Accounting, inventory control, and purchasing costs are usually having a high cost as well.
- Confusion. There are no routines with this process, schedules, products, and routings are continuously changing. (12)

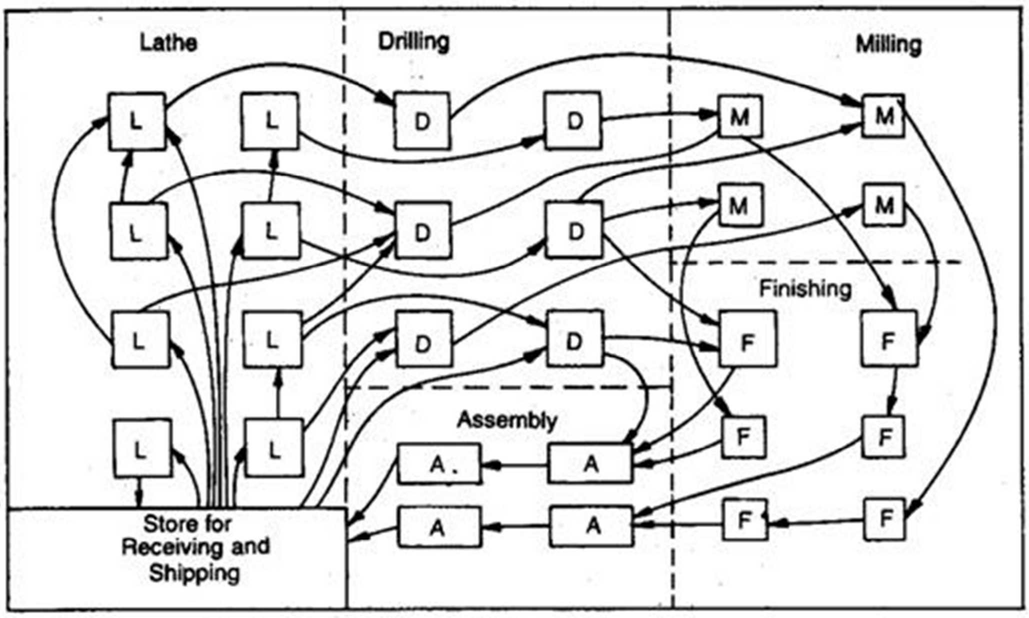


Figure 1) Example diagram of a Process Layout (transtutors.com)

The diagram shown in figure 1 is an example of a machining facility's process layout. As you can see, the similar machines are grouped together in different parts of the layout. You can also see the path in which the product will travel throughout the facility as it manufactured. This technique is often used to show the different relationships between the machine areas and is used to make decisions about the positioning of each machine group to limit the amount of material handling from area to area.

Fixed-Position Layout

In this type of layout, the major product being produced remains on one place from beginning to end. All equipment, labour, and components are strategically place around the work cell. This layout is typically used if the product is very large and is too big or expensive to move. An example would be the production of an airplane or cruise ship. In both cases, the product will not be moved until it is finished (11)

Pros

- Product does not need to move (there is no other choice in most cases). (12)

Cons

- Space. The work area around the work cell is usually crowded and little storage space is available causing tight working conditions. This can also lead to material handling problems

- Management. The administrative burden is much higher in a fixed-position layout. There is often little chance for control and coordination is very difficult. (12)

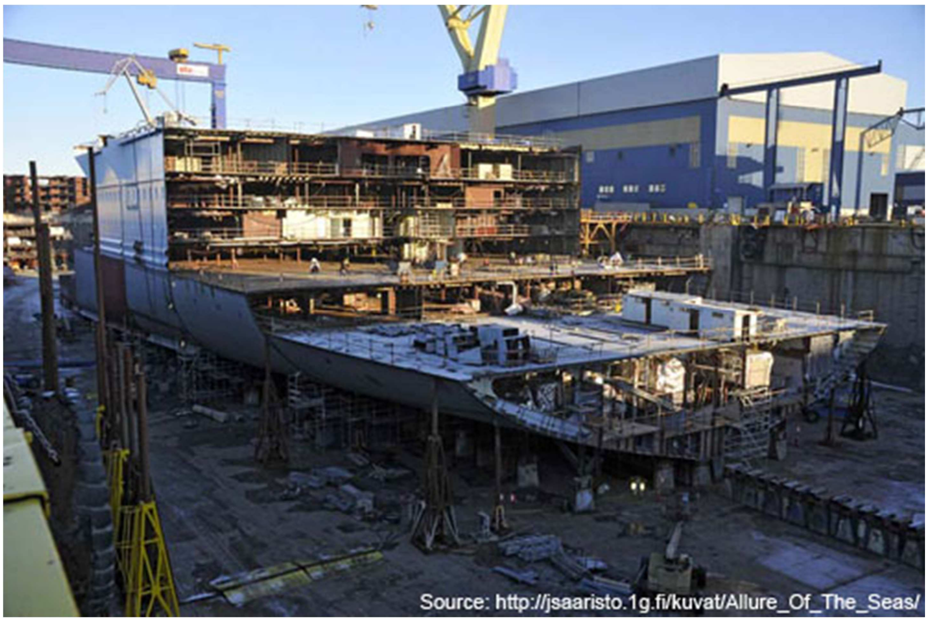


*Figure 2) Example of a Fixed-Position Layout (*ship-technology.com)

As you can see in the figure, the boat will remain in the same place until construction is completed. All the different components are brought to the sight and assembled directly onto the boat. The picture also shows how this layout can become very disorganized and hard to manage but in reality, there isn't much of a choice for the production of something so large.

Product Layout

In this layout, machines and equipment are arranged in a line based on the sequence of production required for the product. The materials move automatically from one process to the next. At each process, a task is completed and the product is one step closer to being finished. In this layout, there is a very small work in progress storage and material handling. When using this layout, we must keep in mind all machines and equipment needed to complete the task must be located in the correct place along the sequence of production. We must also remember every aspect of production must be included within this sequence of production which includes packaging, testing, and quality inspections (11)

Pros

- Output. With this layout, we are able to produce a large volume of products in a short time.
- Cost. The unit cost is quite low due to the high volume of production. Labour specialization results in a reduction in training time and cost. A wider span of supervision also allows us to cut labour costs. Accounting, purchasing, and inventory become routine.
- Utilization. There is a high degree of labour and equipment utilization. (12)

Cons

- Motivation. Employees are often found doing the same job day in and day out which can result in dull, repetitive jobs which prove to be stressful. Also, incentive plans are often hard to administer in this type of layout
- Flexibility. Product layouts are very inflexible and cannot adapt to changes such as product change or process improvement.
- System Protection. Production layouts are particularly vulnerable to breakdowns, absenteeism, and downtime due to maintenance. (12)

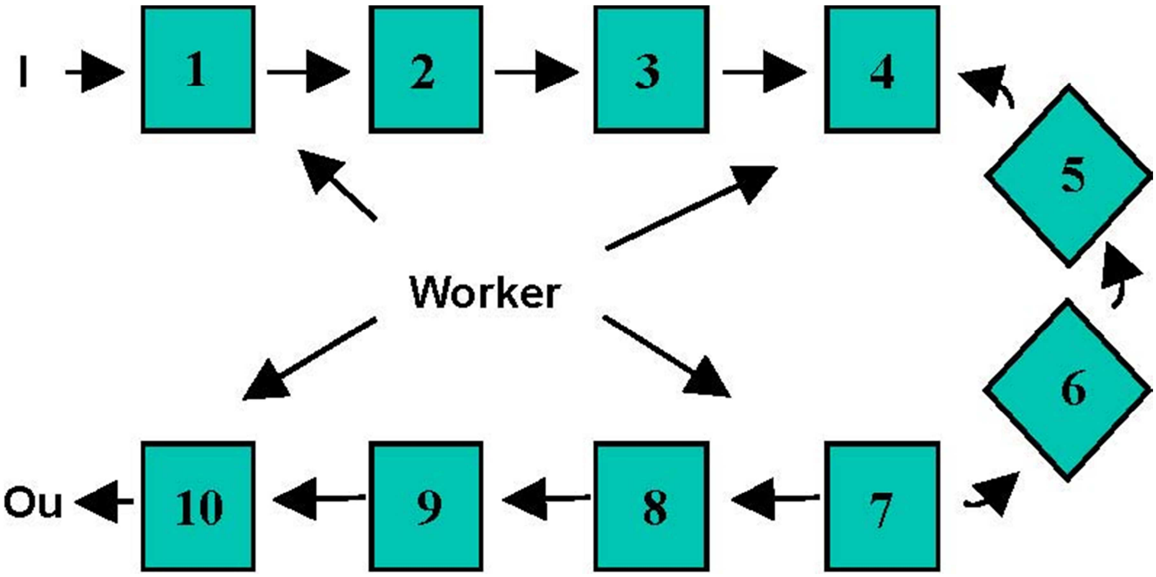


Figure 3 Example of a simple production line (Product Layout). http://free-books-online.org

This is a rather simple product layout; it shows the different processes in the order of production as well as the flow of raw materials from process to process. The diagram also shows a production line does not need to be a straight line, production lines now a days come in many shapes and sizes due to facility size restriction and the length of complex production lines.

Combined Layout

In reality, it is very hard to find a purely process, product, or fixed-position layout. In most cases there is some type of combination (most commonly between process and product layouts) in the facility. Although in the combined layout, one of the layouts is noticeably dominant. An example would be a production line that requires fabricated steel parts. The part of the factory were the fabrication takes place is often set up as a process layout but the part of the factory where the assembly takes place is considered a product layout.

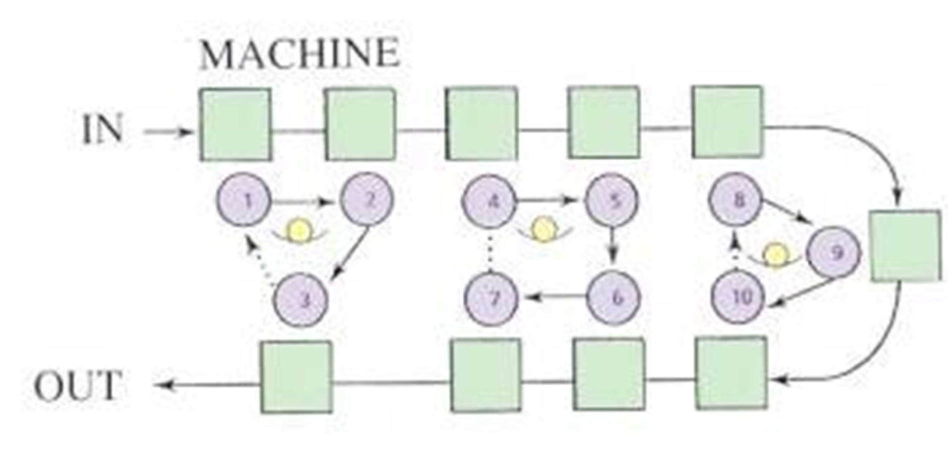


Figure 4 Diagram of Process / Product Facility Layout
*(*http://218.189.210.187/ApparelKey/Document/Cate2/2.6.2/cellular_layout.htm)

The facility layout shows an assembly line around the outside of the factory but also includes a process layout in the centre. The processes in the centre of the factory may be responsible for making certain components needed for the assembly of the product.

3.1.2 Factors Influencing Layout

Of course when we think about investing millions of euros in a new facility or making changes to our current facility, there are plenty things to consider. A few of these considerations include factory building, nature of the product, production process, type of machinery, repairs and maintenance, human needs, and plant environment.

When we look at our layout, we need to decide the amount of floor space we may need. The factory structure determines the nature and size of the building which will determine the amount of floor space available for our floor plan. When thinking about the physical building, you may also need to consider special requirements such as air conditioning, dust, and humidity control. The location of the building must also be taken into consideration because it may affect your plans for the transport and distribution system (11).

Next we need to think about the product we plan on producing. Will our product be custom made or relatively uniform? If we think our product is more custom made, we may decide on the process layout where as if we think our product is more uniform, a product layout would be much more reasonable (11).

The location and type of machinery we choose will greatly influence the production process. If we think about the process layout, more general machines seem to be most convincing because they allow us more flexibility where as in a production layout, we know exactly which machine will be used for each task allowing us to specialize in which types of machinery we purchase. We must also think about repairs and maintenance of these machines. In the facility layout we must think about how these machines will be placeed so mechanical personnel are able to perform maintenance and repairs quickly and easily to reduce possible downtime (11).

Human needs are also a large concern while considering different possibilities for facility layouts. Certain amenities such as dressing rooms break area, lockers, drinking fountains, toilets, and garbage’s should be included in our layout if necessary. Safety of the personnel is also a large concern especially in the event of an emergency. The proper placements of emergency exits are very important while thinking about safety (11).

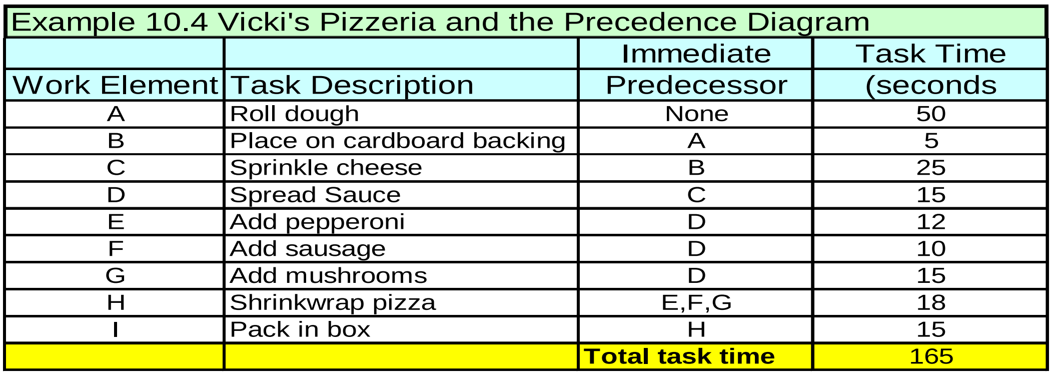
4 PRODUCT LAYOUT PLANNING

Due to the further research of this thesis, it is necessary to look into the product layout more thorough. We will go over what details will be important to investigate, as well as techniques to help industrial engineers make the most educated decisions. Process planning, process layout, phase time calculations, assembly line balancing, material management techniques, and resource management are all areas that will be considered.

4.1 Defining Processes

When developing an effective product layout, it is important to understand the product in which you are producing and how it is made. Knowing how it is made will help the designer develop and define the different processes within the layout. It will also allow him/her to come up with a sequence of events to manufacture the different parts of the product. Because this is the first step to designing the product layout, it is often a very broad idea of what the layout / process order will include and can be used as a general outline throughout the project.

To identify tasks, the design team will usually collect data from the current the manufacturing system. They will not only be able to get a rough idea of the different processes needed for manufacturing but also time calculations and the correct order in which the processes must be placed in their layout plan. With this information, designers will be able to make a process table. The table will include all the different processes in the correct order and a rough estimate on how long it will take (13). An example of this is shown in *figure 5*.



Example 10.4 Vicki's Pizzeria and the Precedence Diagram			
Work Element	Task Description	Immediate Predecessor	Task Time (seconds
A	Roll dough	None	50
B	Place on cardboard backing	A	5
C	Sprinkle cheese	B	25
D	Spread Sauce	C	15
E	Add pepperoni	D	12
F	Add sausage	D	10
G	Add mushrooms	D	15
H	Shrinkwrap pizza	E,F,G	18
I	Pack in box	H	15
		Total task time	165

*Figure 5, Vicki's Pizzeria and the Precedence Diagram (*http://mdcegypt.com)

As you can see from “Vicki’s Pizzeria and the Precedence Diagram”, designers were able to list the different tasks needed to put together a frozen pizza. It also shows how long it will take to complete each task as well as the immediate processor which will be found useful in the next step to product layout design.

Another technique used by facility design engineers at this stage is a flow diagram. The flow diagram is a little more graphic than the table and can be a little bit easier to follow. Although this is only a rough diagram used as a reference outline, the final assembly line could look very similar to this diagram (13). An example of a flow diagram can be seen from *figure 6.*

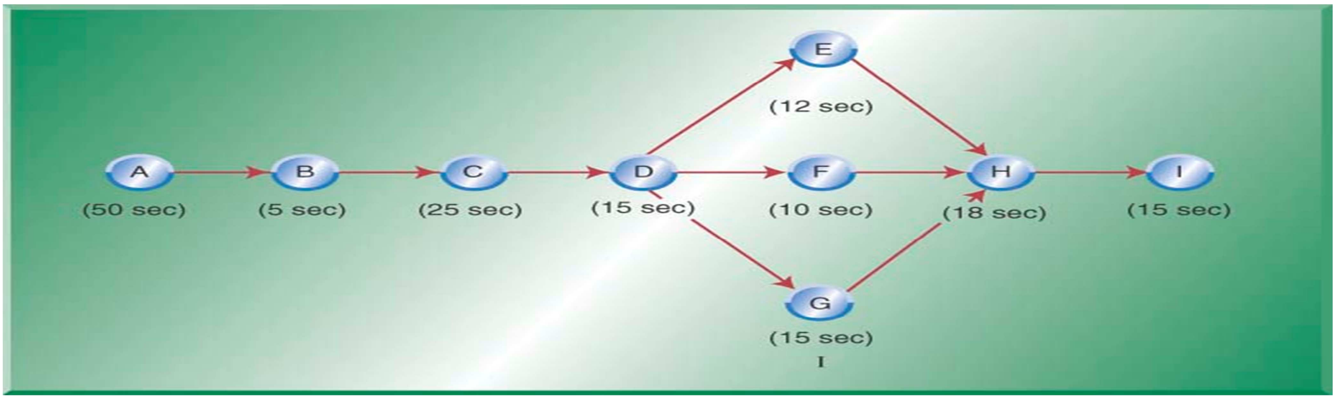


*Figure 6 “Flow Diagram of Vicki’s Pizzeria Process (*http://mdcegypt.com)

As you can see from the diagram, it will show the same information as in the chart in Figure 5 but is organized in a different way. This more graphic technique may take a little bit more time but may help the team better understand the process as well as give ideas on what their facility may look like at the end of the project.

4.2 Assembly Chart

Now that we have a general outline of our assembly line, we need to go a little bit more into depth on what tasks will be completed during these processes which we have defined in the previous stage. This will allow us to understand which parts of the product assembly will be needed at the different processes. Again, designers are able to watch how the product is currently being assembled and which parts are needed at each phase.

To help organize these different parts into the correct phase, it is good practice to develop an assembly chart. The assembly chart shows the sequence of operations in putting together the product (14). In some complex assembly lines (automobiles, construction machinery) an assembly chart is very necessary to help plan certain subassemblies and reasonable buffer storages. Defining which tasks will needed to be completed at each process with detailed time standards will be very useful while in the assembly line balancing stage of our production line planning (14).

4.3 Process Time Calculation Theories

Now that we have defined our tasks, determined the order of those tasks, and collected the data on how long each task will take, we are ready to do some calculations that will help us define our layout and processes even further. The next step is to define the goal of our production system in terms of how many products we plan to produce in a certain amount of time. This will ultimately decide many things such as conveyor speed, phase time, and bottle neck situations.

With our production goal in mind, we can now calculate our cycle time. Cycle time can be defined as the amount of time each work station is allowed to complete its tasks (13). In other words, the cycle time is the amount of time each phase of our assembly line must be completed to meet our production goals. We can continue with our example of Vicki's pizzeria as an example. Let's assume the goal of this production line is 60 pizzas per hour. We can calculate the cycle time as follows…

$$\text{Cycle time (sec./unit)} = \frac{\text{available time (sec./day)}}{\text{desired output (units/hr)}} = \frac{60\ \text{min/hr}\ \text{x}\ 60\ \text{sec/min}}{60\ \text{units/hr}} = 60\ \text{sec./unit}$$

The equation shows the amount of available time (60min/hour x 60 sec/min = 36000 sec/hour) divided by the desired output which we assumed is 60 units per hour. For us to reach this goal of 60 units per hour, the conveyor must move every 60 seconds with a finished pizza coming off the conveyor (13).

During this step, we can also define the bottleneck in the production line. A bottleneck can be defined as a phenomenon where the performance or capacity of an entire system is limited by a single or limited number of components or resources (14). The bottleneck in the system can be simply put as the process that takes the most time in the assembly line. The production is only as fast as its worst bottle neck for there is usually a large buffer of the product at that station. We can calculate the bottle neck in our pizzeria example by taking our available time and dividing it by the longest process in our production line…

$$\text{Maximum output} = \frac{\text{available time}}{\text{bottleneck task time}} = \frac{3600\,\text{sec./hr.}}{50\,\text{sec./unit}} = 72\ \text{units/hr, or pizzas per hour}$$

The equation shows us that with our current production line structure, we are able to produce 72 pizzas per hour maximum. Although this is over our desired production outcome, bottle necks such as these can cause large process buffers which may cause problems to our production line (13).

4.4 Assembly Line Balancing

All of the steps leading up until now have been more or less collecting and organizing data. This step requires analysing that data and making decisions based on those results to make the production line as efficient as possible. Assembly line balancing is a technique to group tasks among workstations so that each work-station has, ideally, the same amount of work (14). With the data collected from the actual construction of our product, we have set up a very realistic flow chart that shows how long each task will take. We were also able to take our production goals and calculate exactly how much time would be available at each phase. Now we must arrange these tasks into our workstations to try to equalize the times it takes to complete each process on our assembly line.

Assembly line balancing can be a difficult task. Engineers must think about how to speed tasks up, or slow them down. To do this, things like extra machinery or workers can be a useful tactic in balancing the different process times. If one process in our assembly line takes around twice as long as the rest, perhaps hiring an extra worker or machine to complete the same task would be a reasonable investment. Using the technique of subassembly can also be a useful tactic. One work station could be the sub assembly of a certain part of the product and the other the actual attachment of the subassembly to the final product. Both tactics have been proven very useful and are used on many modern assembly lines today (14)

Another entity assembly line balancing is used for is to establish the speed of the assembly. Once we determine exactly how long it will take to complete each phase in our assembly line, we can determine how much time the product will need to spend in one place (14). If we combine this with our goal of how long we intend our assembly line to be, we are about to use a simple calculation to determine the actual speed of the assembly line. If we look at our pizzeria example again, we were able to balance the tasks within the 4 processes to 15 seconds per process and have room in our facility for a 10 meter assembly line, we can calculate the total assembly is 60 seconds. We can divide 20 meters by 60 seconds and come up with .16 meters/second conveyor speed. This can be useful when considering certain facility size constraints within the layout.

4.5 Material Management

Material management is a very important component to consider while planning a facility layout. In this day and age with systems such as JIT (Just in Time) inventories and small in process storages, planning how incoming and outgoing material will be handled and stored within our facility has a large influence while planning a facility layout. Keeping this in mind, storages must be placed strategically within the facility as well as easily accessible and transferable to the various sites around the facility to keep materials flowing quickly and efficiently (14).

Of course there are many different things to consider while planning a material management system. Some of the different components we must consider while planning our facility layout include receiving areas, aisles, transportation methods, packaging finished goods for shipping, and storage placement / requirements. These various aspects of material management will be greatly affected by the facility layout (14).

A technique used by engineers to evaluate material flow within a certain layout is a string diagram. A string diagram represents the amount of material flow being transferred from one workplace to another. This diagram allows engineers to see what materials are coming from where and where they will go next. The diagram also shows the amount of materials being transferred between stations.

When there is a rough idea on which layout engineers feel would benefit material management most, we can also use the diagram to calculate the total distance travelled by a single product from beginning to end. Engineers can recognize which processes should be near each other to limit the amount of transportation time keeping production costs down and ensuring efficiency. An example can be found from figure 7

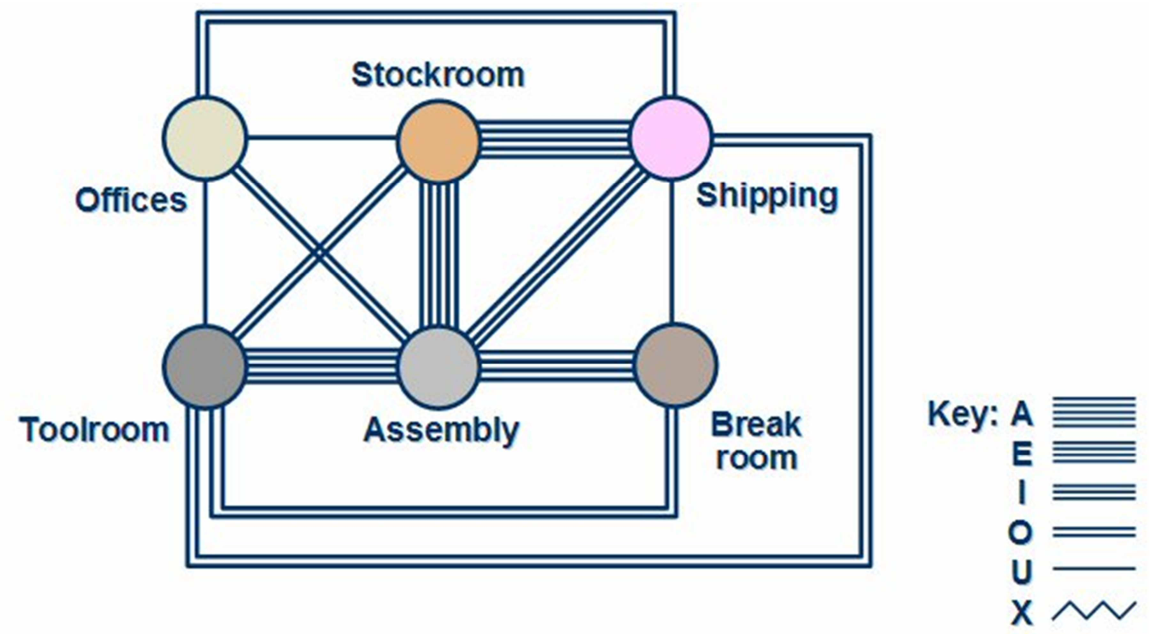


*Figure 7 String Diagram (*http://www.resourcesystemsconsulting.com)

Figure 7 is an example of a simple process layout but the same principals can also be found in a product layout. The green boxes represent the different processes within the facility. The lines connecting them represent the material flowing between them. You may also notice the lines are different thicknesses; this represents the material flow frequency. If there is a thick line between the two processes, there is a large material flow and therefore should be near each other.

4.6 Shape of Product layout

One of the most important things to consider while planning a product facility layout is the actual shape of the production line in which the product is being assembled. Thinking about an assembly line, a picture of a straight line typically comes to mind. Of course this is a very efficient layout and still used today but, in recent years, engineers have explored different shaped assembly lines which have proven to be much more efficient than the typical straight line production line. Some shapes being used today in manufacturing include S, U, O, and L shapes (13).

When defining the shape of a production line, there are many factors that may influence a decision. One factor may include the actual shape of your facility, perhaps your production line is too long to fit in your facility. If there is no way to shorten the production line or extend the facility, using an S shaped production line may be a reasonable alternative. The production line will be able to remain the same length as well as fit nicely into your facility (13).

Another factor that may influence production line shape could be the need for supervision or communication. If all assembly line workers were places along the inside of a U shaped assembly line, it would be much easier to supervise the whole line which can cut supervision costs. The U shaped assembly will also make it easier for workers to communicate to one another. Being able to communicate will help to eliminate mistakes and create a safer and more efficient working environment (13). An example of the U shaped, production layout can be seen from Figure 8.

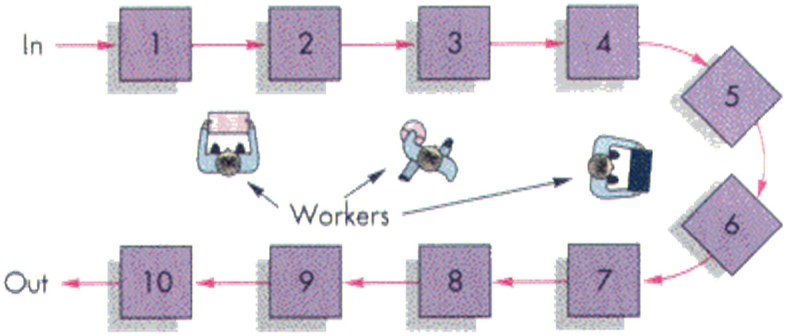


*Figure 8, Example of U shaped assembly line (*http://mdcegypt.com)

In figure 8 we are able to see how the U shaped production line enables workers from all stations to communicate with one another. The diagram also illustrates how the U shape allows them to share common resources.

5 SIMULATION PROJECT

5.1 Introduction to the Project

This next chapter of the thesis will follow a project where a computer simulation will be constructed to help optimize certain aspects of a proposed production line facility layout. There will be a background on the project which will include goals and the expected results of the simulation. It will also give the specific details given to the facility design team from which the parameters of the system will be set. The design team will use the steps as described before on how to build a proper and successful simulation. The team will also use the researched material on facility layout planning to present a successful layout plan to represent in the computer simulation.

The first part of the project will include the gathering of information on the product. The team will research how the product is currently manufactured and try to identify different processes that would be included in the production line. The team will also research how current production lines manufacture similar products and try to improve those methods. Once the team has a good understanding of the product at hand, they will begin to use a number of different strategies to organize and analyse the data to produce a facility layout with a detailed description of each process in the facility.

Once the facility layout is presented, the construction of the computer simulation will begin. CAD drawings of various parts and machines will be imported into the simulation software to make it as realistic as possible. Logistics will also be imported into the program to represent different statistics and times which will mimic those set in real life.

After the simulation has been completed, the design team is able to use it to test and analyse their layout. Things like resource utilization, buffer sizes, and throughput time will all be recorded and analysed. It is also at this point that we are able to evaluate the layout and determine whether the simulation model has met its expectations.

5.2 Background of SavoniaDrive2 Project

The project consists of the design and construction of a new, customizable street bike called the “Streetbee”. The bike was totally designed and built by students in the Savonia Mechanical Engineering Program located in Kuopio, Finland. When the construction of the motorbike was near completion, the design team was interested in learning how their motorbike design would hold up on a mass production line. With this new interest, the idea of a discrete-event simulation model of the production of the Streetbee came into consideration. The project managers' decided to act upon this interest and recruited industrial engineering students to develop a product facility layout and construct it in a computer simulation. The tasks for the project include

- Defining the actual factory layout
  - What is being produced and how (defining work processes)
  - Defining resources (work cells, human resources) and material flow
  - Timing of the different work processes (welding, assemblies)
- Creating a simulation model with 3DCreate 2010 program

5.3 About the Product / Facility

The Savonia mechanical engineering students designed a street bike which consists of about 400 different parts and comes in three basic colours along with a number of different customizable options chosen by the customer upon their order. It was decided all fabrication would be done within the facility and then sent to an outside subcontractor for finishing and painting. The fabricated parts would then be sent back to the factory to be assembled. It was also decided all mechanical (motor, carbonator, cooler) and electrical parts (batteries, lights) would be provided by outside suppliers and delivered to the assembly line.

The plan for the ordering system was quite simple. The team plans to use an ERP system within the factory which will be connected to a website based ordering system. The plan is to have a website designed so the customer is able to choose different customizable features for their particular bike. The order from the website is then sent to the factory for screening which will ensure the order is reasonable. Once the order is confirmed by the personnel, it is then entered into the ERP system and built according to the order given by the customer. With this type of ERP system, we able to calculate workload, inventories, and storage levels giving details on reorder points and production time.

A factor concerning the ERP system and material handling system within the factory was the idea of a "front of the line" feature. This feature allows customers to place their order at the front of the production line for an additional fee. If this option is chosen, the customer would be able to depend on their bike being done within 24 hours. Because of this feature, every customizable feature for the bike must be ready and available in the factory storages. This must be taken into consideration when designing the material management system and storage sizes as well as the future design of the ERP system.

The facility in which the layout was being planned was quite flexible. There was no pre-existing structure or set boundaries in which the layout had to be housed, therefor, the layout would decide the shape and size of the factory building. Of course while designing the layout, keeping things compact as possible was always a concern in an attempt to keep the total cost of the facility as low as possible.

The goals set by the production team were quite general with the idea to make the production line very flexible. In the beginning of production, the goal was 6-8 bikes per day but the production line must be capable to produce much more to satisfy the demand in the future. This flexibility factor played a large part in designing many parts of the layout. Storage size and resource utilization were a few such factors affected by the designing of a flexible production line and will be touched upon later in the case study.

5.4 Building the Factory Layout

This next part of the case study will be based on the actual techniques and strategies to plan a facility layout as previously mentioned in this thesis. The first step is to gather information about the product parts and how they are assembled. Once the necessary data is collected, it will be organized into flow charts to help organize this data. The charts will be analysed and used to help define the different processes incorporated into the production line.

The processes defined will then need to be organized in a progressive order which will become a rough outline of the production line. The production line diagram will list the different parts assembled at the workstation as well as the different tasks involved. Using this diagram, we will give an idea on how many processes will be needed to complete the production and will be able to begin a number of different time calculations to give us cycle time and phase time which will be necessary to balance the assembly line.

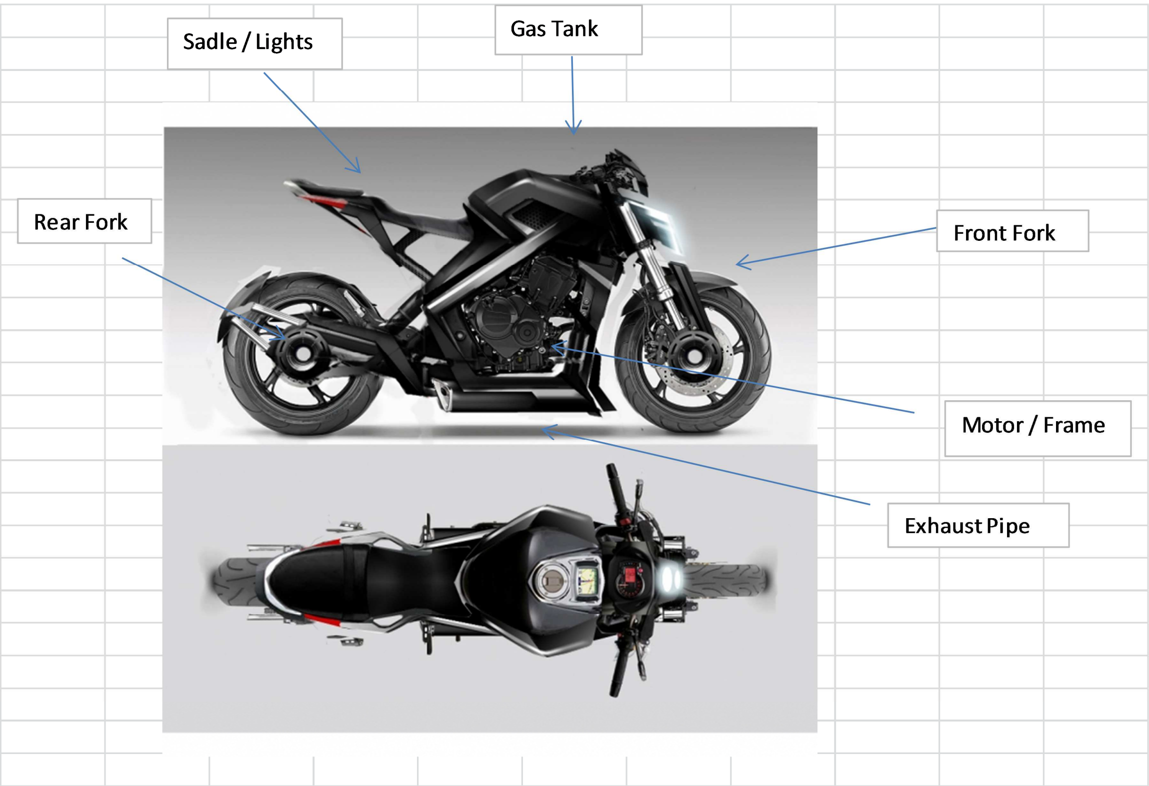
The next step to building the layout, once the assembly line is balanced, is to determine the location and sizes of the different storages and buffers. To aid the design team, an organized diagram will be used to show which parts will be coming and going from the different places in the layout. This diagram will help engineers determine total transportation time of the different parts within the layout. With this information, they are able to place the different components in logical and strategic places in the layout.

At this point, they will have a pretty sophisticated facility layout and have a good idea on the placement of the different work cells as well as how materials will flow within our facility. There will be enough information to begin building our layout in the computer simulation. Things like buffer size, resource management, and machine utilization will be calculated by the simulation and will help the design team finalize the layout.

5.4.1 Collecting Data

Data for the facility layout was collected from the workshop where the bike was designed and built. The layout planners were able to meet with the mechanical engineers to go over the motorbike and how it was built. Once the layout planners understood how the motorbike was assembled, they were able to group together the different parts of the bike and generalize them into different processes. Those processes included,

- Frame and motor installation
- Rear Fork
- Front Fork
- Electronics
- Exhaust Pipe / Gas tank assembly
- Saddle / Lights
- Covers



These different processes will need to be broken down by the layout team so they will be able to define the different tasks and parts needed for each work cell. This in mind, the next step would be to define the parts involved in each process and organize them so there will be some idea on what will happen in each work cell along the assembly line.

5.4.2 Defining Processes

To break down the different processes, the layout team will look at what will need to be done in each process work cell and investigate different ideas on how to do it safely and efficiently. The different parts being assembled as well as the resources at each work cell will be defined and considered while investigating each work cell.

Motor Installation.

The first step to the assembly would be the installation of the motor to the frame. When we install the motor, there are two other parts to consider, the carbonator and the cooler. They are parts of the motor but must also be attached to the frame and the motor once it is installed to the frame. To attach the motor to the frame, the motor must be held in place and bolted in place. Because of the weight of the motor, it would be impossible for the worker to hold in place which is why a crane jib is going to be used. The layout team decided to use a crane jib due to its relatively low price and its ease of use. Another tool the team may consider would be some device to fasten the bolts that will hold the motor in place. A simple torque wrench would be sufficient.

Rear Fork Assembly with Wheel

The next step to the assembly would be the rear fork to the frame. Since it was decided to attach the rear fork to the frame already with the wheel attached, a subassembly work cell idea was developed. The wheel and all its components (brakes, axel, and gears) will be preassembled in the work cell. The motorbike frame will then be in place for the rear fork assembly to be easily attached. The reason for this subassembly is to eliminate the worker from going back and forth from the bikes to the part buffers. This will allow the worker to finish the process easier and more efficiently.

Front Fork with Wheel

The same technique is to be used for the assembly of the front fork as the rear fork due to the similarities to the two work cells. There are many parts being assembled to make up the front fork but attaching it to the bike was proven to be quite an easy process. The front fork is made up of components such as upper tubes, lower tubes, suspension, upper triple tree, and lower triple tree. All of which are easy to handle and so power tools or a handling device will not be necessary. As done in the rear fork process, the front fork will be sub assembled in the work cell and then attached to the frame on the assembly line.

Electronics

The next process involves installing all the electrical components such as the battery, gauges, wiring, and sensors. All parts must be brought to the bike and installed in the correct place. Leads must be spread throughout the bikes to power the lights and other electrical components. Although there may be some complicated procedures when dealing with the electrical components, the team will simplify the process so a specialist (electrician) will not be needed. Simple “click in” connections will be used to connect the various electrical connections keeping the process simple and above all, safe.

Exhaust Pipe / Gas Tank

With the electrical components in place, we are able to install the exhaust pipe and gas tank which will help to hide the electrical leads throughout the bike. Attaching the gas tank is a relatively simple process, a few fastening bolts will be used to secure the tank and the fuel injection hose will connected to the motor. The exhaust pipe will also be attached to the motor exhaust output and securely fastened to the bike.

Saddle Frame / Lights

The saddle frame will be attached to the motorbike next. Again, simple fastening bolts will be used to connect the saddle frame to the bike frame. The saddle frame will be the component which will support the saddle pad where the rider will be seated. The lights will be put into place and attached with the simple “click in” as described in the electronics process.

Covers

Installing the outside covers will be the last step to the motor bike assembly. The covers will give the bike its final look as well as protection to vital parts of the bike from outside elements. The covers will come in three different colours and will have many different pieces. To keep things simple and organized for the worker, a “batch” system will be used for each bike. In each batch, the worker will find all the correct pieces he or she may need for that particular motorbike.

The team was able to research the different processes and brainstorm the best techniques to complete the tasks within the work cell thinking about both the workers and optimization. Once this brainstorming was complete, they were able to put together an outline of a process and the different parts which will be assembled as shown in figure 10. This chart will aid the team in assembly line balancing and material management of the bike’s different parts.

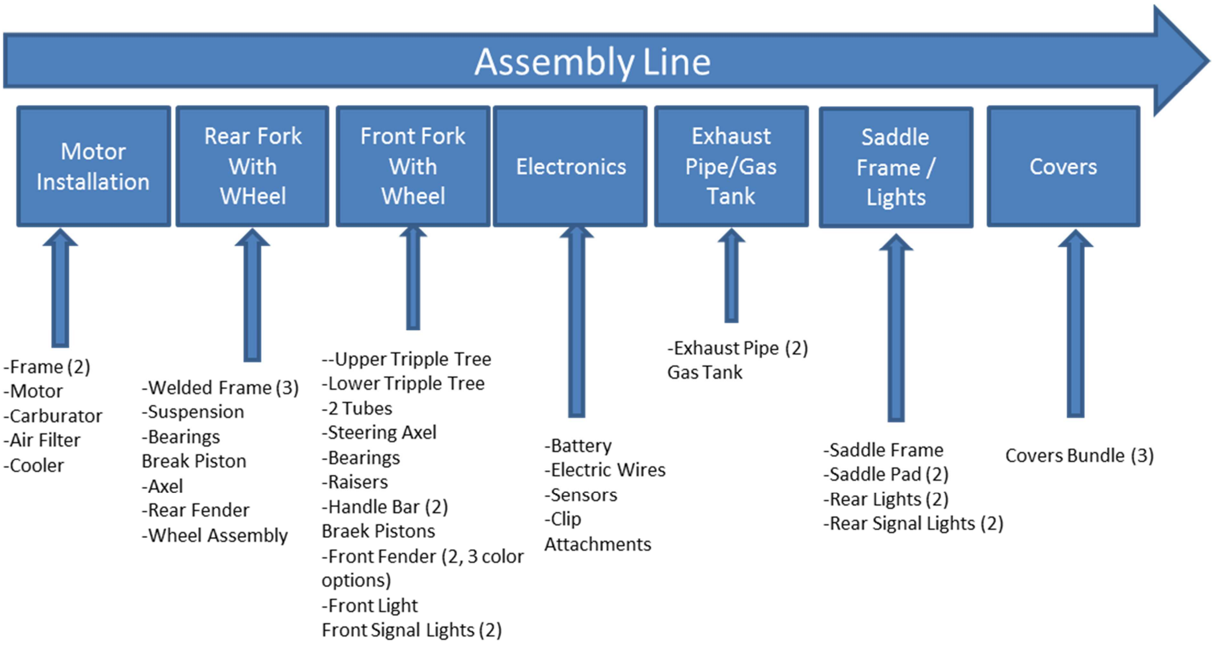


Figure 10

Figure 10 is the process map made by the design team to set up a general outline of the assembly of the motorbike. They also included the different parts of the motorbike that will be assembled in each work cell.

Another useful diagram used at this time is a table to organize the different times of the processes. The table will give the team an idea on how balanced the assembly line is as well as help to recognize the different bottle necks. The table will also come useful when calculating certain aspects of the assembly line which is necessary in layout planning. The table can be seen below in table 1.

Table 1

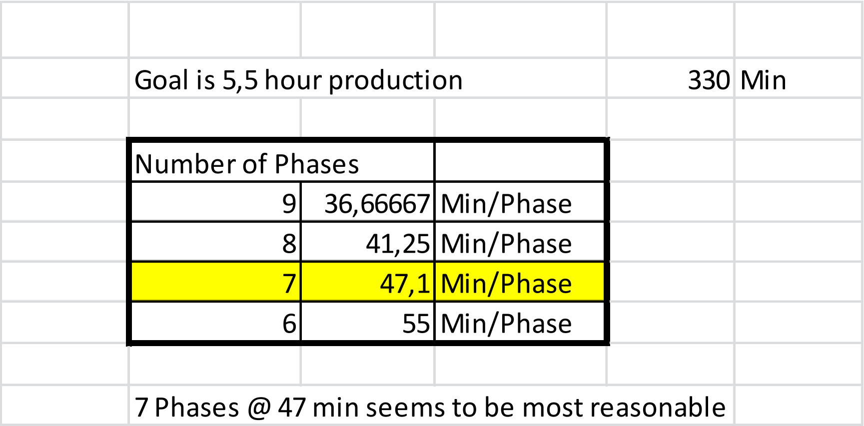
	Phase List	Time (min)
1	Engine	45
2	Rear Fork/Tire	45
3	Front Fork/tire	45
4	Electrics	46
5	Exhaust Pipe/Gas tank	40
6	Saddle/Lights	45
7	Covers	45

5.4.3 Time Calculations

At this point, the team knows how many processes they need to include in the assembly line and how long it would take to complete the tasks within the individual work cells. With this information, and the goals of our production line, the team is able to calculate critical timing information used for layout planning.

The first calculation the team was able to make is the total amount of time could that could be devoted to each process. Because they knew the assembly was going to be 7 phases and the total assembly time needed to be less than 5, 5 hours, they were able to calculate this data in excel. The team simply divided the total assembly time by the different number of different processes to see if it would be possible to complete each process. This calculation can be found in table 2

Table 2



Goal is 5,5 hour production 330 Min

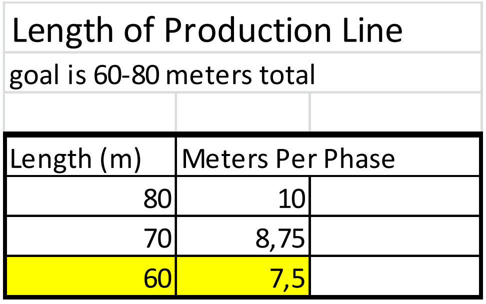
Number of Phases		
9	36,66667	Min/Phase
8	41,25	Min/Phase
7	47,1	Min/Phase
6	55	Min/Phase

7 Phases @ 47 min seems to be most reasonable

Table 2 is the excel calculation to show how long would be allowed for each process. The calculation with 7 processes is highlighted and shows each process would have 47 min to be completed. We compare this to the amount of time each process takes from table 2 and find all processes will be completed within the allowed time.

Another useful piece of data we are able to calculate is the physical length of our assembly line. The size of the assembly line is often a very crucial component to factory layout planning and can help shape the rest of the facility. This calculation will also allow the design team to recognize if the line is too long to fit in the actual facility. If so, the line would need to be transformed into a shape other than a straight line. To find the total length of our assembly line, the team will input a desired total length of the assembly line then divide that length by the total number of phases. The answer will give us the amount of space each phase will have to work with on the production line. The answer will also give us the distance which the assembly will have to travel every 47min (determined in the last table). This table was made in excel and can be found below in table 3

Table 3



Length of Production Line

goal is 60-80 meters total

Length (m)	Meters Per Phase	
80	10	
70	8,75	
60	7,5	

Table 3 shows the different inputs put into the equation. The input is the length of the assembly line and will decide how much of the assembly line will be devoted to each phase. After examining the results, the team decided 7, 5 meters per phase was reasonable giving the total length of the assembly line to be 60 meters long.

The team now has a good understanding of the processes and the crucial times necessary for the assembly line. Using the information calculated in this step, the team can now conclude that the assembly line will move 7,5 meters every 47 minutes allowing each phase to have 7,5 meters space to work and will have 47 minutes to compete the tasks at hand. The total length of the assembly line was also determined to be 60m long. With these facts, the team can now build the material management strategy around the assembly line as well as other processes to finish the facility layout.

5.4.4 Material Management Planning

Facility layout dramatically affects the production’s material management system which is why the facility design team must strategically place the different storages, buffers, and transportation routes to ensure the material handling system is a success. Parts and materials must be easily accessible as well as have a low “in facility” transportation time. When designing the motorbike facility layout, the team was able to take these concerns into account and came up with a reliable and efficient storage / material management system. Of course material management is a much broader subject and concerns many other components but for the sake of the project, only components considering facility layout will be considered.

In the factory, the design team had recognized there are three different types of materials incoming into the factory. There were shipments coming from the paint subcontractor, the mechanical parts from the mechanic contractor, and then the electrical parts coming from the electrical contractor. The team used this information and incorporated it into the layout by planning to have three smaller storages rather than one, large storage. This will help to reduce the total transport time of the materials as well as keep the facility more organized. With this idea in mind, the design team made yet another diagram to help visualize their idea and confirm it would be successful. The diagram can be seen in figure 11 below.

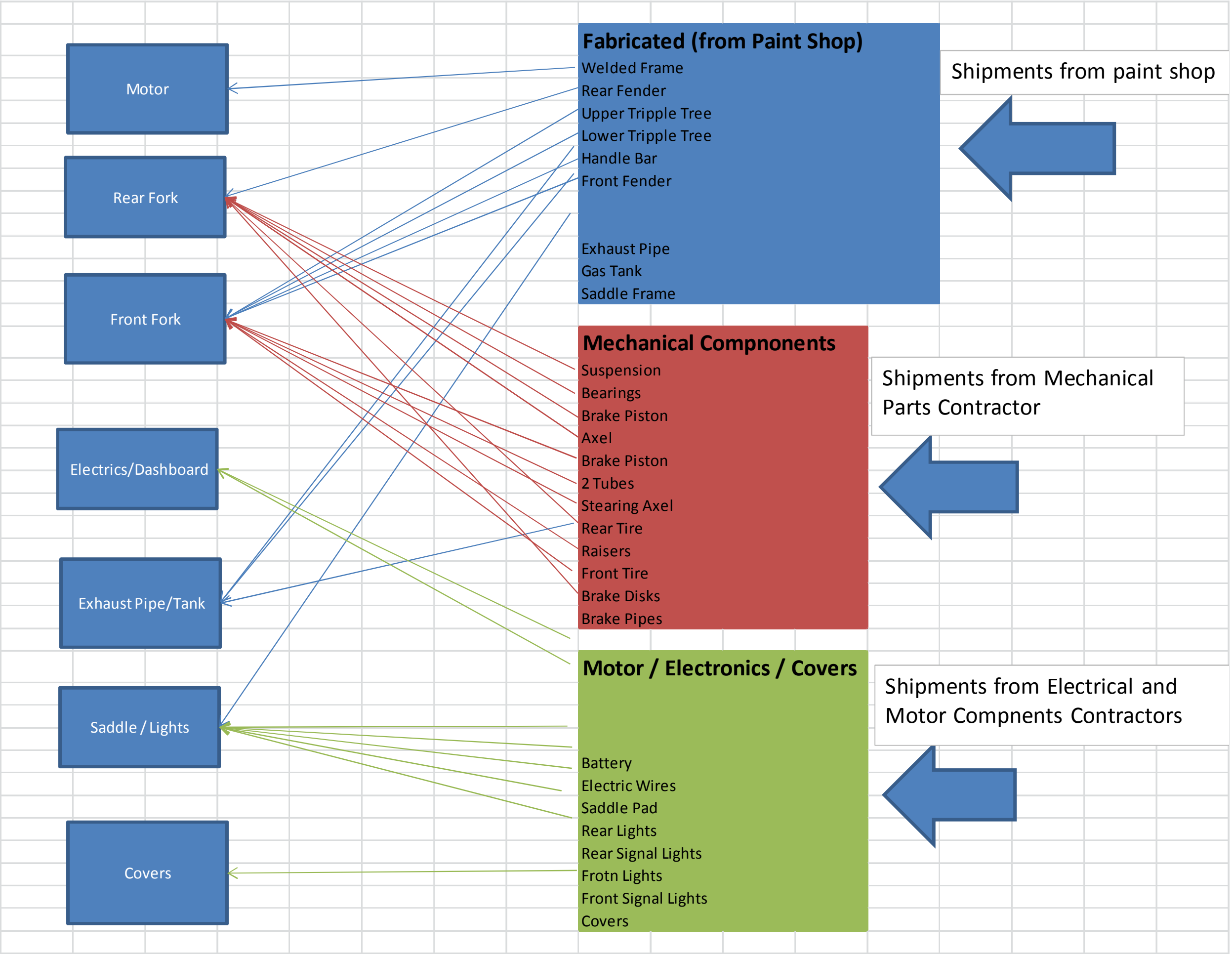


Figure 11

In figure 11, you can see the incoming painted materials are in blue, mechanical parts in red and electrical components in green.

The idea of this system was to have the larger storages placed away from the assembly line and a smaller buffer at the actual work cell. This will help to keep overall storages low with frequent shipments from the different providers to keep the storage costs down. The storages are also placed in a place where most of the materials will be transported. As you can see, the painted materials will be assembled at the beginning of the assembly line which is why the painted material storage was placed near these beginning processes. This would ensure a low transportation distance for the materials. The same concept was applied to the mechanical parts being placed in the middle and the electrical storage being placed at the end.

The information gathered in this part of the project allowed the design team to put together a fairly detailed drawing of the overall factory layout. This so called “master layout” will aid the simulation designers in devising a plan on how the simulation should look like and a good idea on the logic needed to simulate the material management system within the factory. A copy of the master plan can be found in appendix 1 and 2 at the end of this thesis.

5.5 ERP System

The factory layout master also allows students to design an ERP system represents the material managing system within the factory. The outline gives the students the ability to see which parts will be needed at each phase at a particular time during production. With this information, the students developed a routing system for each part associated with the assembly line. The software used to produce the ERP system of the factory is known as IFS and is considered a popular software used for these types of systems in the real world.

The ERP system would take the order specifications and ensure all the necessary parts are available in the stock. If the part is not in stock, the system will produce a purchase order for the parts needed for the production. The system ensures all parts are available for the bike assembly before the particular bike is put on the assembly line.

The ERP system also records valuable data from the production line such as parts used, work time. With this data, we are able to calculate exactly how much it cost to build that particular bike and how long it takes to build it. This data will help the future development of the production line and business areas concerning accounting, financing, and marketing.

Currently, the implementation of the ERP system is in the early stages of development and will continue to improve as the routing systems are improved. The simulation will also aid in the process of the development of the ERP system. The goal is to have a fully functional ERP system within our simulated factory which will represent the material management system as well as record data about the production line which will further improve the function of the factory.

6 BUILDING THE SIMUALTION AND ANALYZING THE RESULTS

Looking back to the previous chapter on simulation in this thesis, we can recall there are nine basic steps to building a successful simulation. The first four steps we can assume are completed and focus more on the actual construction of the simulation by the simulation experts.

6.1 Steps to Build

The first challenge encountered by the simulation team was the collection of the necessary components needed in the simulation. These different components consist of the different machines, parts, and tools needed to manufacture the bike. The machines and tools the team wants to show in the simulation must be constructed in computer 3D format (Inventor or Solidworks software is often used) so they can be added into the simulation layout. In this particular project, the mechanical engineers had very detailed drawings of their prototype bike as well as a collection of the various machines and tools used in their workshop. With most of their components already drawn in 3D format, the simulation team just had to convert them into the correct format and use them in the simulation.

The simulation team is then able to place these different components in the simulation world with the help of the master layout plan designed by facility design team. It is in this stage of development where the factory layout begins to take form in the 3D environment and can be known as a “model” of a factory. When the basic layout is made in the simulation environment, it is important the simulation and facility planning team communicate to ensure there are no problems either team may be able to recognize. Most of the problems at this point involve the visual components and the level of detail in the simulation which must be corrected before the logical components are added.

The next steps of the construction of the simulation involve the logical components. Each element in the simulation will have some logical component added which will give it a job or role in the simulation. The different logic components include probability, speed, frequency, and moving paths. This information is usually quite difficult to obtain and is usually calculated with educational estimates or taken from real life statistics from a system currently in place. This step usually requires quite a bit of understanding of the simulation program and may require extensive code writing which is why an expert is needed to design this part of the simulation. This step requires allot of time spent playing trial runs to ensure all the bugs are worked out. It is also important the production personnel involved in the project aid the simulation team in obtaining the correct, necessary data for the logical components in the simulation.

This thesis will not go further into depth on the construction of the actual computer simulation in this project due to the main focus being planning the factory layout used in the simulation. Further investigation in this matter would include a detailed process in the different strategies on data collection, simulation software description, and examples of the different machines / tools / resources inserted into the simulation.

6.2 Verification and Validation

A very important step taken by the project team is the verification and validation of the simulation. This step ensures the simulation correctly portrays a facility the motorbike could be manufactured in.

To verify the model, various professionals are called upon to look for flaws in the simulation. Production engineers who know the manufacturing system the best are large assists due to the fact they can easily identify informalities in the simulation when compared to a real life manufacturing system. Since there are no experts included in the project team, the engineers who designed and constructed the prototype bike were called upon to ensure the steps taken to manufacture the bike are in fact realistic and could exist in reality.

Validation of the model is similar to the verification but involves reading the results given by the simulation and determining if they are realistic. This is done by comparing the results with expected values and goals set by the project team as well as the comparison to other manufacturing systems similar to the one in the simulation. To validate the simulation of the motorbike production, the design team looked at other motorbike production line and compared the simulation model. Since the results were quite similar, the team can see the simulation is realistic and the data can be used to make educated decisions

6.3 Results and Analysis of Simulation Model

The goal of the simulation model was to design a production line to assemble a prototype motorcycle which was designed and constructed by the mechanical engineering departments at Savonia UAS. The simulation was intended to be used by the manufacturing engineers to visualize their prototype bike on a production line and later used as a learning tool to help mechanical engineering students realize what factors of their designs will affect the production of the product.

6.3.1 Did the simulation meet expectations

The design and construction of the simulation was indeed a success. The mechanical engineers were able to see their prototype motorbike being manufactured on a very accurate and detailed simulated production line. They were able to watch the production line in 3D which helped them pin point the certain aspects of their design affected the production line and how to improve this design with the idea of mass production in mind. This learning experience will help the engineering students in future projects where the mass production of their prototype would be the ultimate goal.

Another factor in which the simulation succeeded was the education of the industrial students involved in designing the factory layout which was used in the simulation. Although the layout was used in the simulation world, the industrial students were able to use techniques used in every day production to help develop the production line and facility layout. The industrial students were also able to learn about simulation software and how its capabilities can greatly benefit a project concerning project layout and facility planning.

The simulation model will also be a useful learning tool to future engineering students. Students will be able to give their input about the model and perhaps start new projects based on making improvements or other factors concerning production (supply chain, ERP systems).

6.4 Results received from the simulation

Due to the topic being the use of simulation to aid in the process of facility layout, it is important to discuss how the simulation model helped the layout design team improve their layout. The simulation allowed the industrial engineers to run different scenarios concerning different storage sizes, reorder points, placement of different work cells, machine utilization, and throughput time. The team was able to change different factors of one part of production and see how it affected everything else and decide which situation would fit their production goals best.

An example of how the simulation aided the facility design team in this study is the determination of amount of human resources necessary at each work cell to meet production needs. Because the simulation is able to run different production mixes, we are able to see the amount of human resources necessary to meet production goals even if the factory is not running at full capacity. Being able to manipulate these different factors with a click of a mouse saves a lot of time and money in real life situations. If it weren’t for simulation, it would take weeks of trial and error to realize what human resources are needed where at different levels of production.

The simulation will also allow further research of different, future techniques used in industry. It will allow the production engineers to test these new techniques without disturbing the current production line. An example of this could include an automated warehouse and storage system. As the simulation project was finishing up, talk among the different group members raised questions about this automated system and how it would affect future production of the motor bike. The simulation model would allow the team to compare their current human operated material handling system to the new automated material handling system to see if this investment would be cost effective. Although this project is for educational purposes, this type of testing and comparing different manufacturing techniques is one of the primary advantages of simulation.

6.5 Conclusion and future discussion of the project

The simulation built in this project was quite a learning experience for all the students involved. The mechanical and industrial engineering students had to work together throughout the facility planning process which was good exercise for real world situations. Throughout industrial engineers studies, communication within the project, idea sharing, and flow of information are stressed multiple time in many different ways. Students involved in the project were able to take the theory learned in their class work and use it in real life situations.

The design of the factory layout and simulation model will not only benefit the students who built it, but also for future students who will be able to learn from future projects based on the simulation model. The simulation of the motor bike opens many new doors for future student projects which may include not only engineering but business and computer science students as well. Projects focusing on the economics cost, and marketing processes can be focused upon by business students and FMS or ERP systems working within the factory would be developed by the computer science students. Although building the simulation model was a large project, we are able to see how it will provide much more to other students at Savonia UAS.

Due to the short time period of the project, the project team was unable to test many different scenarios in the simulation concerning the facility layout. Further studies can be conducted on the simulation where the optimum production can be calculated. Further research concerning the simulation could also include the automated warehouse system as mentioned previously in this thesis. Other layouts may also be developed in the simulation world and compared to the layout designed by this layout planning team. The layouts could then be easily compared by analysing the results from the simulation.

Overall the project goals were met. The industrial engineering students were able to produce a detailed and successful factory layout plan which was then used to create the 3D simulation model. In this process, the students were able to use facility planning techniques used today as well as learn to communicate with one another to successfully complete the project. The simulation has also proven to be an educational tool which was also one of the primary goals of the project.

7 CONCLUSIONS

The purpose of this thesis was to show the importance of facility layout planning and give techniques used by Engineers to ensure the success of the layout. The thesis was also supposed to outline how simulation models can greatly improve a facility layout as well as test the layout under extreme circumstances.

The thesis first investigated the development of simulation models through time and the current position it is in today. Its capabilities were discussed and a step by step explanation of how to build one was mentioned and used in the Savonia Drive2 case study. Although simulation is a multi-faced tool and has many purposes in business, the description of how simulation aids in the facility planning process was discussed in detail and was also proven in the case study.

The following chapters went into detail about different facility layout designs used in industry today. A number of different designs were discussed and analysed. Due to the case study, the product layout was talked about in greater depth and different techniques were introduced and later used in the case study.

The case study used in this thesis utilized the different techniques researched in earlier chapters and allowed the industrial engineers to build a detailed layout of the motorbike factory. The simulation is planned to be used as a learning tool for Mechanical Engineering students as well as for future projects concerning the production line. The project was also a success with helping the industrial students understand the process of facility planning and helping the mechanical engineering students to realize what factors to consider while developing a product to be mass produced.

7.1 Further Discussion

This thesis provides a platform for further research in several areas; supply chain management, cost analysis, and ERP systems. Due to this thesis being more focused on the facility layout, the supply chain to and from the facility was neglected. This could allow for further research on how the material management system will work on a micro and macro scale. The cost analyses would also be an area for future research. Topics concerning finances in all areas of production as well as an estimated calculation of the size of the investment needed to actually build this production system. The simulation, will also improve the ERP system design.

Further research could also be conducted on the simulation to improve the layout plan further. The project concerned the development of the layout but left out many simulation evaluation techniques used to improve facility layout. Research could include evaluation techniques and how changing the layout will affect the results of the simulation. A comparison of the simulation results could also be included in this research.

8 References

(1) Dey, A. K.. (). *Introduction to modelling and simulation*. : .

(2) Fritzson, Peter. (). *Principles of objects-oriented modelling and simulation with modelica*. : .

(3) Shinde, S.. (2000, April 7). Historical perspectives. Retrieved from Http://www. Uh. Edu/~lcr3600/simulation/historical. Html.

(4) Siemens, Initials. (2008,). Factory layout simulation. Retrieved from Https://www.Plm.Automation. Siemens. Com/es_mx/images/7656_tcm903-64291. Pdf.

(5) Rabuya, L. C.. (2000, April 7). Basic steps and decisions for simulation. Retrieved from Http://www. Uh. Edu/~lcr3600/simulation/steps. Html.

(6) Shide, S.. (2000, April 7). Applications of simulation for integrated logistics. Retrieved from Http://www. Uh. Edu/~lcr3600/simulation/mfg. Html.

(7) Banks, Jerry. (2009). *Discrete-event system simulation 5th edition*. : Prentice hall.

(8) Goldsman, David. (2009, June 1). The history of simulation in industrial engineering. Retrieved from Http://www. Ise. Ncsu. Edu/jwilson/files/ierc09p. Pdf.

(9) Nikoukaran, Jalal. (2009,). A hierarchical framework for evaluating simulation.software.RetrievedfromHttp://graco.Unb.r/alvares/doutorado/omega. Enm.Unb.Br/pub/doutorado/disco3/papers/primeira_pesquisa_bibliografica/telemanufatura140. Pdf.

(10) Jones, K. C.. (1992,). Manufacturing simulation using virtual reality. Retrieved from Ftp://ftp. Hitl. Washington. Edu/pub/publications/th-93-3/th-93-3. Pdf.

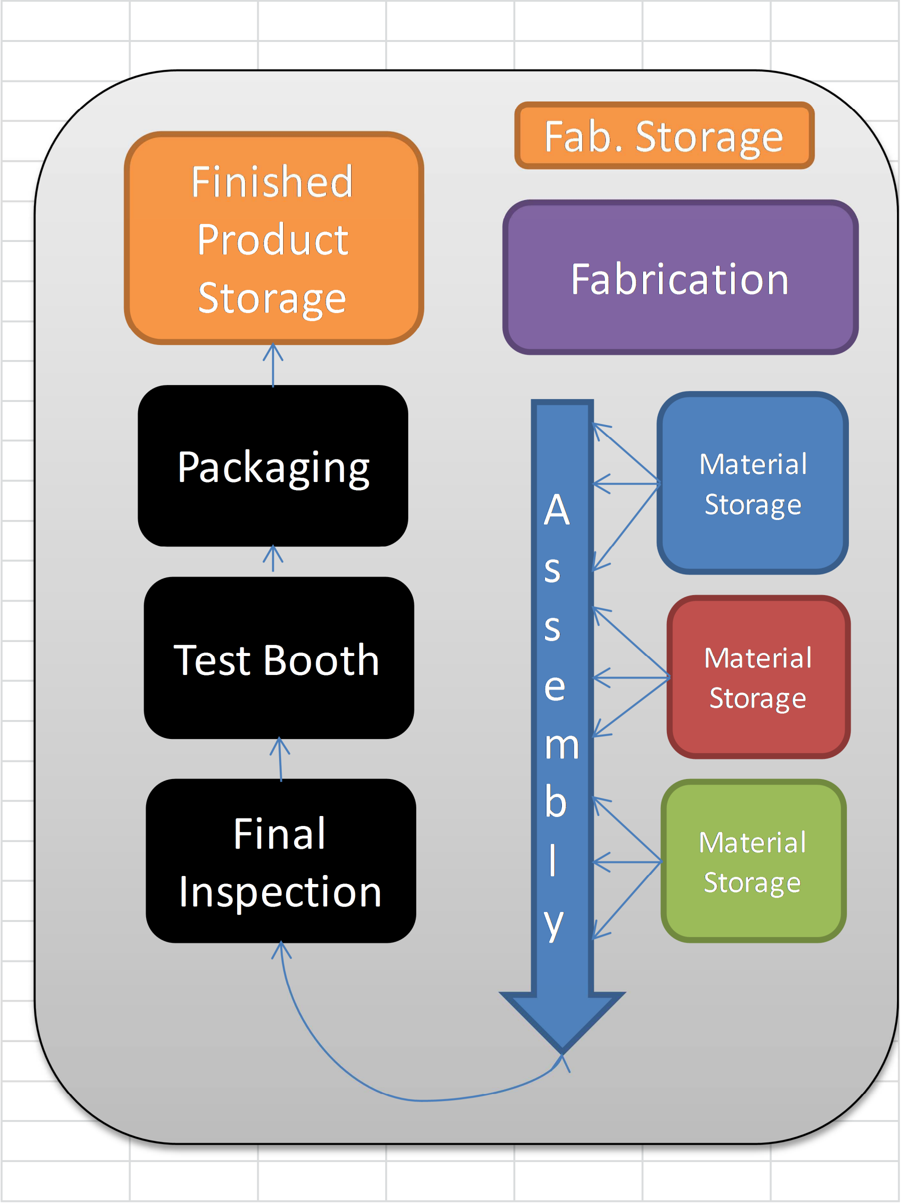
(11) (,). Factory layout. Retrieved from Kisi. Deu. Edu. Tr/sebnem. Demirkol/coursenote/factlay. Doc.

(12) Inman, R. A.. (). Layot. Retrieved (2011, Febuary 10) from , . (,). Factory layout. Retrieved from kisi. Deu. Edu. Tr/sebnem. Demirkol/coursenote/factlay. Doc.

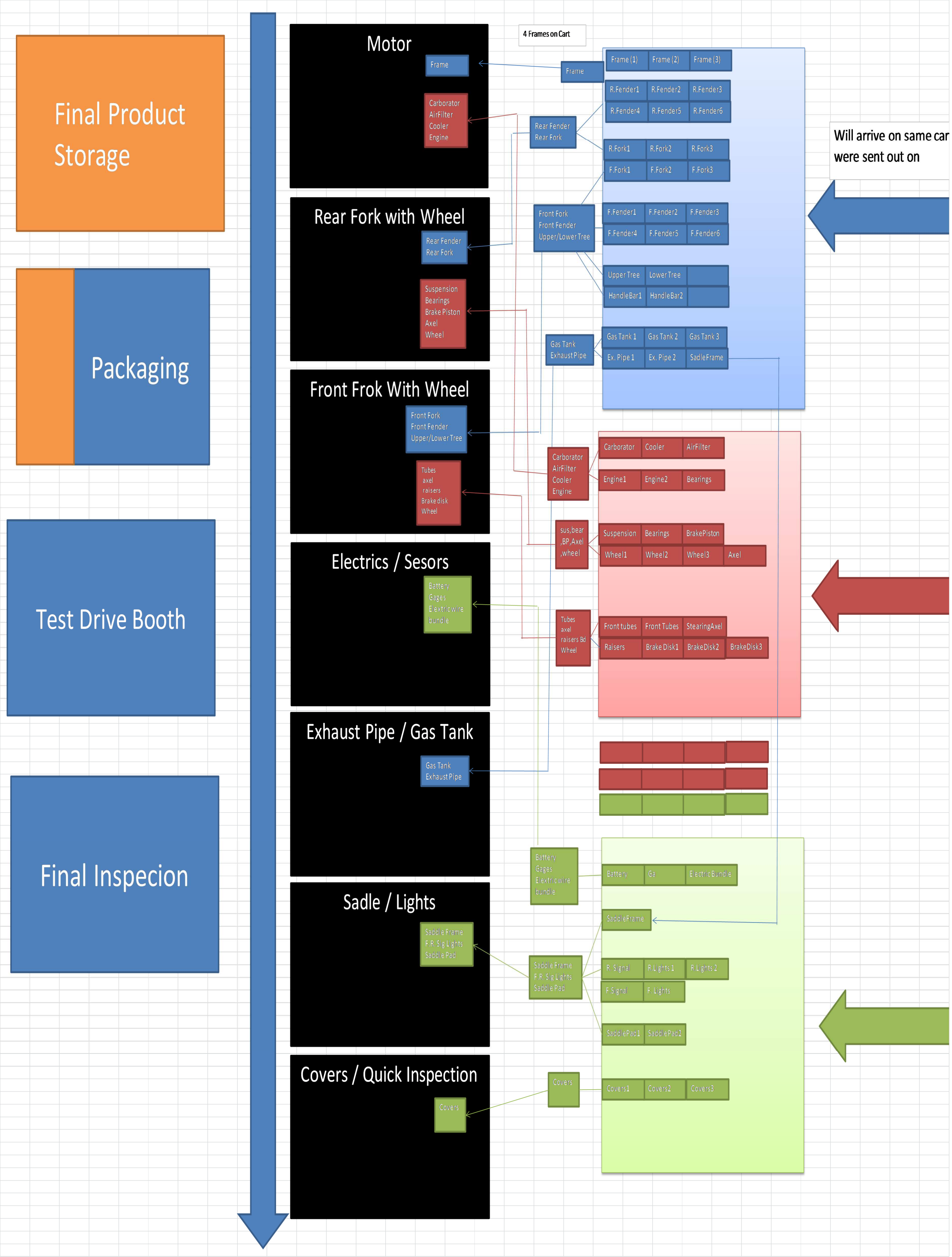
(13) Reid, D. R.. (2007,). Chapter 10 - facility layout. Retrieved from Www. Clt. Astate. Edu/asyamil/reidsandersom3rd/ppt/ch10. Ppt .

(14) Meyers, Fred. (2005). *Manufacturing facilities design and material handling*. Columbus, Ohio: Prentice hall.

Appendix 1


Fab. Storage
Finished Product Storage
Fabrication
Packaging
Material Storage
Test Booth
Material Storage
Final Inspection
Material Storage
Assembly

Appendix 2


Final Product Storage
Packaging
Test Drive Booth
Final Inspecion
Motor
Frame
Carborator
AirFilter
Cooler
Engine
Rear Fork with Wheel
Rear Fender
Rear Fork
Suspension
Bearings
Brake Piston
Axel
Wheel
Front Frok With Wheel
Front Fork
Front Fender
Upper/Lower Tree
Tubes
axel
raisers
Brake disk
Wheel
Electrics / Sesors
Battery
Gages
Elextric wire
bundle
Exhaust Pipe / Gas Tank
Gas Tank
Exhaust Pipe
Sadle / Lights
Saddle Frame
F.R. Sig Lights
Saddle Pad
Covers / Quick Inspection
Covers
4 Frames on Cart
Frame
Frame (1)
Frame (2)
Frame (3)
R.Fender1
R.Fender2
R.Fender3
R.Fender4
R.Fender5
R.Fender6
Rear Fender
Rear Fork
R.Fork1
R.Fork2
R.Fork3
F.Fork1
F.Fork2
F.Fork3
Front Fork
Front Fender
Upper/Lower Tree
F.Fender1
F.Fender2
F.Fender3
F.Fender4
F.Fender5
F.Fender6
Upper Tree
Lower Tree
HandleBar1
HandleBar2
Gas Tank
Exhaust Pipe
Gas Tank 1
Gas Tank 2
Gas Tank 3
Ex. Pipe 1
Ex. Pipe 2
SadleFrame
Will arrive on same car
were sent out on
Carborator
AirFilter
Cooler
Engine
Carborator
Cooler
AirFilter
Engine1
Engine2
Bearings
sus,bear
,BP,Axel
,wheel
Suspension
Bearings
BrakePiston
Wheel1
Wheel2
Wheel3
Axel
Tubes
axel
raisers Bd
Wheel
Front tubes
Front Tubes
StearingAxel
Raisers
Brake Disk1
BrakeDisk2
BrakeDisk3
Battery
Gages
Elextric wire
bundle
Battery
Ga
Electric Bundle
SaddleFrame
Saddle Frame
F.R. Sig Lights
Saddle Pad
R. Signal
R.Lights 1
R.Lights 2
F.Signal
F. Lights
SaddlePad1
SaddlePad2
Covers
Covers1
Covers2
Covers3