POLITECNICO DI TORINO

Master In Mechanical Engineering

Department of Mechanical and Aerospace Engineering

Design of Lean Manufacturing with the use of Discrete Event Simulation

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Abstract

In their strive for success in competitive market companies often turned to Lean Philosophy. “Creating value without waste” is still the central idea of Lean Management. Traditional Lean tools analyze the current situation and or help Lean implementation. With time companies are seeking a tool that can enhance the evaluation of Lean Proposal in such a way that decision is supported by quantitative data.

This thesis Purposes that how Discrete event simulation can be used as an evaluation tool in order to identify which Proposal best suits in Lean Requirement. In this Thesis, a new mode of transport named AGV has been introduced. A Manufacturing plant has been analyzed in different possible scenarios in terms of transport items inside the manufacturing plant.

The results of this study show that the use of Discrete Event Simulation in Lean assessment applications requires the organization to understand the principles of Lean and its desired effects. However, the use of traditional static Lean tools such as Value Stream Mapping and dynamic Discrete Event Simulation complement each other in a variety of ways. Discrete Event Simulation provides a unique condition to account for process variability and randomness.

Acknowledgement

This master thesis has been performed at the Engineering and management department of Politecnico di Torino. I appreciate that both of Co-supervisor Prof. Giulia Bruno and Prof. Gianluca D’Antonio was helpful and agreed to observations to share important information with me. Without this information, this thesis work would not have been possible. I also thank Prof Franco Lombardi for giving me the opportunity to perform this thesis work and that he took on the role as my supervisor.

I would like to express my gratitude to DIGEP for the opportunity to develop this project and thanks to all people who supported me from time to time with some technical issues.

1.Introduction

Before the Industrial Revolution, Manufacturing Industry simply Meant to Create Products and Goods by hand. The Industrial Revolution Brought Major Changes and inventions which we are still using today. Modern Manufacturing Industry Includes the Process which is Necessary to produce Product and Its Components. In the 18th-19th century, an Industrial Revolution came Which brought Technological and Socioeconomic Transformations. In the beginning, it started with Britain and it replaced the labor-intensive textile production with the mechanization and use of fuels.

The manufacturing industry is a key sector of an economy for any nation. The manufacturing industry is important for an economy because it employs a large amount of labor force and it produces material required by sectors such as national infrastructure and defense. But sometimes things go wrong and the manufacturing industry turns out to be a huge loss, which cost more for a nation then benefits. Manufacturing industries include various industries like Construction industries, textile industries, energy industries, metalworking industries, plastic industries, Transport, and telecommunication industries.

In today's world, the Manufacturing industry is gearing up. The world manufacturing industry is incorporating several technologies. From the beginning, manufacturing is blamed for environmental issues and to damage the surrounding. The world manufacturing industry did the implementation of an eco-friendly environment and it has taken several important measures to ensure the manufacturing industries worldwide to follow eco-friendly norms. In other words, the world manufacturing industry is nowadays known as lots of wealth with the generation of lots of employment, introducing new techniques and this has put the world manufacturing industry in a favorable position. From the defense sector of the country to the Production of daily life products world manufacturing industry is fulfilling all the needs. As a result of this world manufacturing industry seems to be an important contributor to global GDP and Nation GDP.

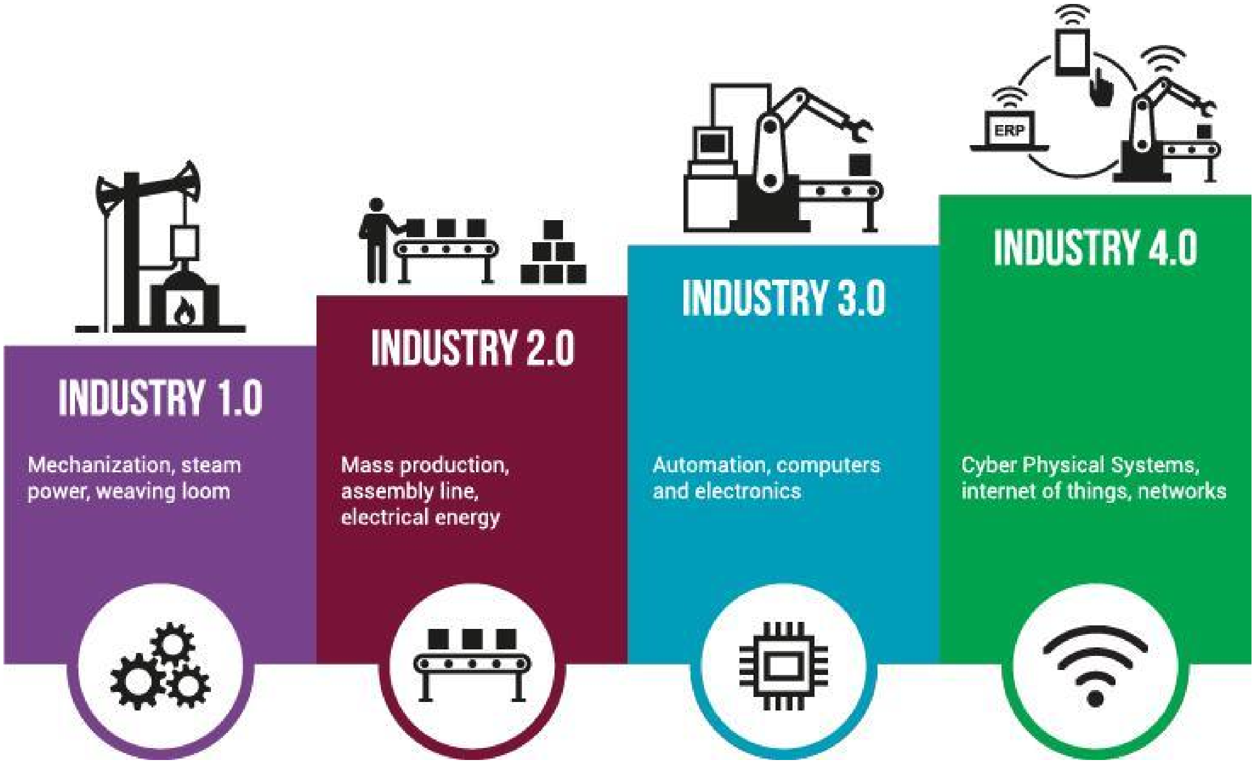
Background

Globalization has come to be one of the prominent features of the current trend of the evolution of national economies (Requier-Desjardins, Boucher, & Cerdan, 2003). It links companies and customers all over the world and affects industrial activities including final products and inputs such as raw material, intermediate goods, machinery, finance, technology, as well as human resources (Grossman & Helpmann, 1991). The resulting industrial competitiveness forces companies to value production flexibility more than ever as time-to-market has become critical due to shortened product life cycles and variation in customer demand (Zhang, 2010). To benchmark how to manufacture in a more productive and efficient way under Lean Principles, companies have followed the Toyota Way. (Liker, 2004).

In the meantime, new emerging concepts appeared so-called Lean Manufacturing. The focus of Lean manufacturing has been eliminating wastes as much as possible by guaranteeing high quality and satisfaction to the customer. The focus shifted from the perspective of the firm to the point of view of the customer. Hence, on one hand, western industries are drawing inspirations from lean best practices, and on the other hand, there is a technology push for automation, as it represents a key resource for manufacturing firms. The principles of Lean and its documented benefits are enticing. Yet the decision to implement Lean manufacturing is a difficult one because of the substantial differences between traditional production and Lean manufacturing systems in employee management, plant layout, material, and information flow systems, and production scheduling/control methods (Detty & Yingling, 2000). There exists a natural resistance to adopt principles that seem to contradict the status quo. Understandably management teams require tools that may provide information regarding the benefits, or lack thereof, of Lean initiatives when compared to traditional methods of production.

If implemented, traditionally Lean initiatives have focused on identifying value-adding operations, and waste reduction through the use of tools such as Value Stream Mapping (VSM) that may support the analysis of information and decision-making process. VSM is a very effective tool in mapping the current and future state of an organization's Lean activities. Despite its many benefits VSM may only go so far, and its powers are bounded to technical restrictions such as being time-consuming, its inability to detail dynamic behavior of production processes and to encompass their complexity, have spurred us to turn to simulation (Lian, 2007), or its limitations in calculating variability information that describes system variations and uncertainty means that more powerful analytical tools are needed (Mahfouz, 2011). Not only is it time-consuming to generate a VSM analysis but its outcome might need at least a few months of continuous monitoring to observe the effects of changes and improvements (Hines P. R., 1998).

Below is a small overview of the transformation of the manufacturing industry:



Currently, experts say that we are under the 4th Industrial Revolution, as this process of intense competition and technological continuous improvements has accelerated. Tools such as simulation may fill up the void that exists from non-dynamic analysis methods such as VSM. In particular, the reduction in the cost of the most computer and sensor hardware, the computational upgrades in semiconductors, the spread of mobile telecommunications networks keep pushing the bar higher. On one hand, for the manufacturing sector, these phenomena enable companies to refine their production system. In addition to these benefits, a simulation may provide insight into possible outcomes given certain inputs before decisions are made and investments committed. Simulation makes it possible to optimize operations and visualize processes logically or in a virtual environment, outcomes are saved in terms of costs, time, and resources (Heilala, 1999). Thus simulation not only complements Lean concepts but highlights feasible and reasonable initiatives Lean practices.

Early technology adopters viewed simulation as a method of last resort to be employed when everything else had failed (Singh, 2009). The advancement of computer sciences, software access and proficiency in the use of simulation tools by end-users have propelled the development of this field. Simulation has witnessed a change of perception in its applicability to the industry, and refinement is many fields as is the case of Discrete Event Simulation.

Discrete Event Simulation (DES) is used to model systems that are composed of real-world elements and resources that interact when specific events occur. Modeling includes a combination of elements and a series of logically related activities. All this is organized around events to achieve a specified outcome. Practitioners who engage in DES build comprehensive models of industrial and commercial systems to analyze, design, and document manufacturing, service, and other discrete processes. Whether current operations are modeled or proposed changes are tested, the resulting models make it easy to find operational bottlenecks, estimate throughput, and predict utilization (Imagine That Inc., 2010)

Now, I would like to frame the specific problem dealt with in this thesis. The aim is to investigate the Autonomous Guided Vehicles (AGVs) technology available and to exploit this technology to develop effective material handling and transporting systems inside the manufacturing unit. The objective is to autonomously develop manufacturing layouts, where AGVs are used as material handling instruments and to compare effectiveness with another mode of transports such as a conveyor. 4 different scenarios have been selected for the comparison which will be discussed later in detail in the coming chapters.

Most manufacturing companies, especially for mass production, are characterized by a serial layout, as workstations are positioned on straight lines, according to a precise sequence. They are connected by means of a conveyor, which is mechanical handling equipment that moves material from one point to another. There are various types of conveyors, but most of them consist of fixed tracks or binaries that allow the efficient transport of material. Once they are built, it is impossible, or extremely expensive, to modify their layout.

In a line, sometimes, automatic machines are followed by manual backup stations, that enable the continuing of production, when the manual ordinary stations are not available due to damages or maintenance. However, the introduction of a backup workstation requires additional planning as the manufacturer must know in advance, where to place these backup stations (usually where the corresponding station is of key importance or breaks up more often than others). This does represent a rigid feature of the system and it is as a source of the additional cost.

2.State of Art

In this chapter, the focus will be on the most important elements used in this thesis like AGV technology, the importance of simulation, Lean manufacturing. Later, the focus will be on the design of the manufacturing plant layout to optimize the efficiency of the plant.

2.1 Process Modeling

According to Hoppet Spearman, authors of Factory Physics and theorists of Manufacturing Management, a production system is a network of processes and stock points through which parts flow, according to a prespecified objective. By studying the production system, one can analyze the network and the flows along the routings, so that it is possible to have a centralized view of the system and it is possible to improve its performances. It would be useful to recap a few important definitions.

- A **part or raw material** known also as workpiece, component, sub-assembly or assembly is a piece of raw material, that after getting through the production line then will be transformed into an end-item and the final product that can be sold to the customers.

- An **operation** is a step to utilize the raw materials in an efficient manner in order to transform it into an end-item. The operation can be melting, refining, casting, etc. depending on the end-item demand.

- The **BOP (Bill of the process)** is a process of taking the idea of the product by first visualizing with engineering design, followed by the creation of BOM (Bill of Materials).

- A **workstation** is a work area that is set up to perform a task that has been deemed as an essential step in the manufacturing process. In the real world, a workstation can be of various types: Manual, automatic or semi-automatic.

- **Routing manufacturing** sometimes referred to as production routings, is the route to be followed during each step of the manufacturing process when transforming components and raw materials into a final product. Routings show the production flow that needs to be achieved. This can be done in one or more facilities or sent to an external vendor for specialized tasks.

Due to faults and wrong precisions sometimes defects occur. During the measurement of the performance of the system, it is very important to take these faults into account. There are proper terms that define these faults in a clear manner like throughput, cycle time, work in progress, takt time, etc.

By using little’s law we can have relationship between above mentioned quantities:

$$\boxed{WIP = TH \cdot CT}$$

WIP: work in Process

TH: Throughput time

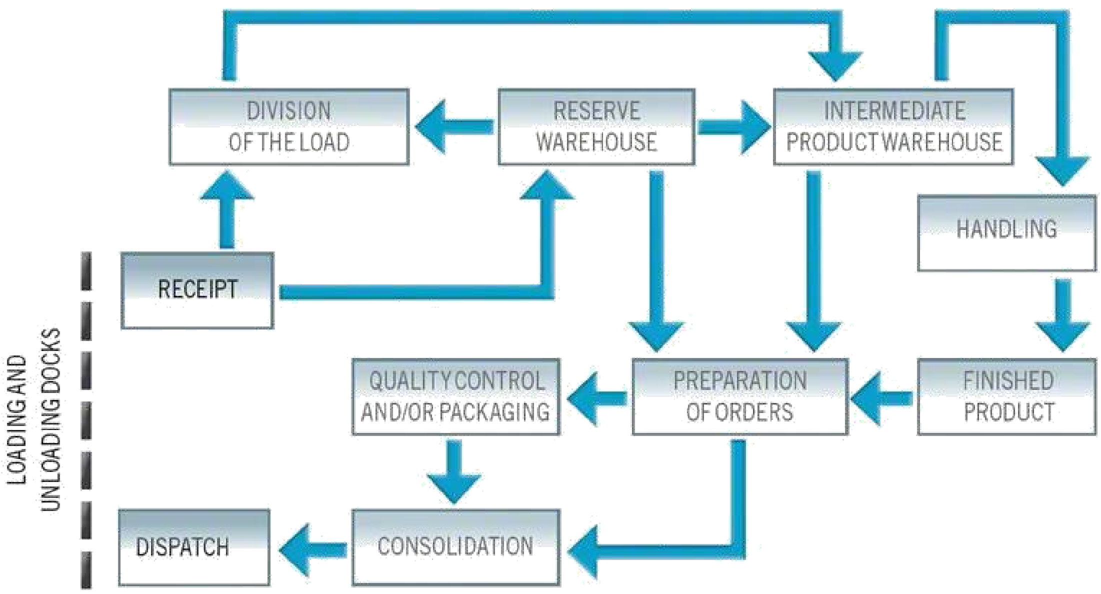
CT: cycle time

The analysis of a current production system and of the aforementioned quantities is known as Benchmarking. This practice evaluates line performances, based on data gathered inside or outside the line. When there are just one product and a singular productive line, this task turns out to be relatively simple, so that one can well understand the behavior and act where needed to improve the efficiency of the system.

2.2 The AGV technology

An **automated guided vehicle or automatic guided vehicle (AGV)** is a portable robot that follows along marked long lines or wires on the floor or uses radio waves, vision cameras, magnets, or lasers for navigation. They are most often used in industrial applications to transport heavy materials around a large industrial building, such as a factory or warehouse. Application of the automatic guided vehicle broadened during the late 20th century.

Estimates report that roughly 20-25 % of total manufacturing costs are related to material handling. Material handling is an integral part of the manufacturing industry. The protection, movement, control of materials, and end products throughout the process of manufacturing, disposal, distribution, warehousing, and storage comes under material handling. That is how crucial material handling is to any industry. Even though there are several types of material handling systems, the manufacturer must restrict its choice only to a set of those, due to the characteristic of the material, i.e. the part that must be moved in the productive system. Parts can have different size, weight, shape, physical state, risk of damage, etc. In the case of our problem, parts are solid objects, with weight in the order of 300-400 kilograms, so the manufacturer has the possibility to choose between AGV and conveyor. Below flow chart represents that handling is one of the most important parts in the manufacturing process to transport material to and from the warehouse.



The first AGV was brought to market in the 1950s, by Barrett Electronics of Northbrook, Illinois, and at the time it was simply a tow truck that followed a wire in the floor instead of a rail. Out of this technology came a new type of AGV, which follows invisible UV markers on the floor instead of being towed by a chain. The first such system was deployed at the Willis Tower (formerly Sears Tower) in Chicago, Illinois to deliver mail throughout its offices.

Due to advancements in automation and technology, the AGV market is continuously growing. Current estimates report that the market is expected to reach USD 2.68 Billion by 2022, at an annual compound rate of 9.34 % between 2017 and 2022 [9]. If one wants to classify AGVs, a rough schematization would consider

- **Towing vehicles** for driverless trains, employed in the movement of heavy and bulky loads over extended distances.

- **Pallet trucks**, for the transport of pallets along predetermined routes.

- **Unit load carriers**, used for the motion of unit loads between workstations.

AGV can be guided by various means like with the use of wire, guide tape, laser target navigation, inertial (gyroscope) navigation, vision guidance, Geoguidance. It is also possible to have multiple AGV on the same path, so it is important to implement a good organization of traffic to avoid collision and other problems.

It is also important to consider safety factors but most of the AGV is already equipped with safety measures like emergency braking, warning light, etc.
AGV has to make decisions on path selection. This is done through different methods: Frequency select mode (wired navigation only), and path select mode (wireless navigation only) or via a magnetic tape on the floor not only to guide the AGV but also to issue steering commands and speed commands.

In this research, a specific model of AGVs has been considered, produced by a technology provider. The item is Comau Agile1500, produced by Italian company Comau S.p.A., a product that was recently released (2016) and that is remarkable for its performances. It is an AGV of the unit load carrier's category, that moves around thanks to the presence of laser guidance. Hence, it can move around the manufacturing system free, correctly identifying and avoiding possible obstacles. The AGV possesses two rear wheels and a front wheel, that enables point full rotation. Apart from being a scalable and configurable product, its main strength lies in the large payload to size ratio, that has been specifically developed for manufacturing applications. Indeed, despite its small size, it can carry parts up to the weight of 1500 kilograms.

2.3 Simulation and Lean

As a production management tool, Lean production theory describes a system that delivers a finished which is free from defects to a customer in zero time and with nothing left in inventory. Moreover, it can summarize into three main points:

1. Eliminate and remove all those activities which do not add value to the final product
2. Pull Material through the process (instant delivery of required materials)
3. reduce variabilities by controlling uncertainties within the process.

A **simulation** is an approximate imitation of the operation of a process or system, that represents its operation over time. Manufacturing represents one of the most important applications of simulation. This technique represents a valuable tool used by engineers when evaluating the effect of capital investment in equipment and physical facilities like factory plants, warehouses, and distribution centers. Simulation can be used to predict the performance of an existing or planned system and to compare alternative solutions for a design problem. The assumptions and information are represented by mathematical, logical and symbolic relationships between the entities or objects of the system. Once the model has been validated and verified, it can be used to investigate a wide variety of 'what if' questions about the real-world process. Potential changes or disruptions of the system can first be simulated in order to see the effects and impacts on the system's outcomes. In addition, simulation can be applied in the design phase of a process, before it is built. Therefore, simulation can be used as an analysis tool for predicting effects on the system as well as a design tool for predicting the performance of such (Fishman, 2001).

As this, it still rather general in terms of possible beneficial information outcomes, Pegden et al. (1995) listed a more detailed overview:

1. New policies, procedures, and flows can be tested without interrupting the ongoing process of the real system

2. New physical layouts and transportation systems can be tested without their costly acquisition

3. Hypotheses about what affects what and why things occur can be tested for feasibility

4. Time can be compressed or expanded to allow for a speed-up or slowdown of the system under investigation

5. Interactions of variables and their importance can be observed

6. Bottleneck analysis can be performed

7. It provides an understanding of how systems operate rather than how people think they operate

8. 'What if' questions can be answered

The fusion of Lean and DES is not common in the manufacturing field (Robinson, Radnor, Burgess, & Worthington, 2012). Often simulations are played out only manually to visualize Lean principles or sometimes computerized games are carried out for training purposes. However, nothing comes close to the DES models and these attempts cannot represent the actual system.

The decision to implement Lean manufacturing is often not an easy task as there is a big step from traditional to the Lean manufacturing when employee management, plant layout, material and information flow systems, as well as production scheduling and control methods, are considered. As changes are enormous, companies and managers in charge find it difficult to grasp the magnitude of the benefits that might come along. Thus, the decision of whether to implement the Lean techniques or not is often based on faith in the philosophy, rule of thumb on anticipated results, and experience from other parties.

A reason that might support the distance between simulation and Lean is that simulation is time-consuming. It is the perception that creating, running, and analyzing a simulation model is a lengthy and time-consuming process, not well aligned with for example a quick VSM creation process. Companies may be inclined to rearrange a production line, check for feasibility, and switch back to the previous state, in case of need, in the same time window as it would develop a simulation model. However, especially with the use of recent simulation software, actual programming time is often held to a minimum, in consequence, a shorter –complexity withstanding– model development time ensues.

Comparison between Muda and DES.

Seven Original Wastes	Role of DES
Transportation: moving products that are not actual required for the process	Modeling process flow and measuring transportation times
Inventory: all components in process	Modeling queues
Motion: extra movement of people or equipment that is not necessary for the process	Modeling the interconnection between resources and the process
Delay: Waiting for next production step	Modeling queues that evolve as a result of variability in interconnected processes
Overproduction: Production ahead of demand	Modeling the interconnection between variability in demand and production
Over processing: Resulting from poor tool or product design creating activity	Modeling the process flow and measuring utilization of resources and activities
Defects: effort in inspecting and fixing defects	Modeling of activity breakdowns

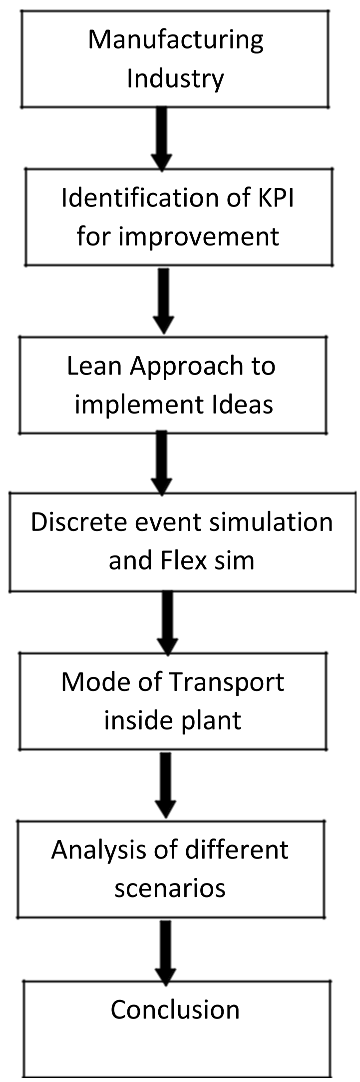
DES is capable of generating resource requirement and performance statistics whilst remaining flexible to specific organizational details; moreover, DES handles uncertainty and creates dynamic views of inventory levels, lead-times, and machine utilization with a high degree of flexibility. Although VSM allows users to see the desired process in a static sense, simulation provides a dynamic visualization.

3.Research Methodology

The Research of This thesis is based on theoretical and empirical studies. Literature Review helped to define and understand the problem. Already published Research helped to understand the Current situation of Field.

Weather Discrete Event Simulation can be Consider as a tool for Lean Analysis? To answer this Question a Research Approach has been Adopted. As Name Suggests Discrete event which means a large problem has been divided into small pieces and analyzed.

Below Flow chart explain the whole process of this thesis:



A deductive approach was selected to answer the question of whether DES provides a tool for Lean proposal analysis. This thesis considered necessary the reduction of a larger problem to specific areas of analysis. To do This various Question raised like:

Question 1. A group of elements was identified in the evaluation of future state Lean proposal implementation when using Discrete event simulation.

Question 2. In addition to this a qualitative comparison between Value Stream Mapping, a traditional tool for Lean production assessment, and DES were made.

Question 3. How different mode of transport inside a manufacturing plant makes a huge difference in increasing production efficiency and to improve other KPI's.

Question 4. Finally, a qualitative analysis was performed regarding how DES can assist in analyzing different Lean proposals.

Question 5. In what way can simulation aid manufacturing plants to move from intuition-based short-term solutions to fact-based long-term solutions to improve their manufacturing systems?

Because of an intensive study of a single unit of analysis was pursued with the purpose of understanding a larger concept, the evaluation of Lean manufacturing proposals through DES, a case study method was selected (Gerring, 2004).

After KPI analysis, few important factors were considered throughout the thesis project. Furthermore, the method required that the research focus on contemporary phenomena of Lean production principles that already exist and extend them to the future production context within the realm of their current real-life shortcomings and needs. Finally, the case study was preferred as it is closely linked to its answering the questions of "how" and "why" phenomena occur (Yin, 1993).

For an effective case study, I adopted the approach of yin. with the help of the Discrete event model method, I collected simulation data and analyzed it. Later conclusions and implications were established. As the main motive of this research was not to explore a new field of research so I went with an explanatory case study strategy.

The benefits of that, the study took on a mostly inductive approach, was that I did not have to limit me to a predefined hypothesis, as the deductive approach uses, but instead, I could investigate how simulation could affect the manufacturing system without any prevision of what the outcome could be. However, I realized that the inductive approach came to some difficulties to find the right and relevant theory for our particular case. I considered a Qualitative study approach also to understand the system and factors at a deeper level. With this approach, it became more possible to understand the system in a better way which leads me to process mapping and the simulation modeling side.

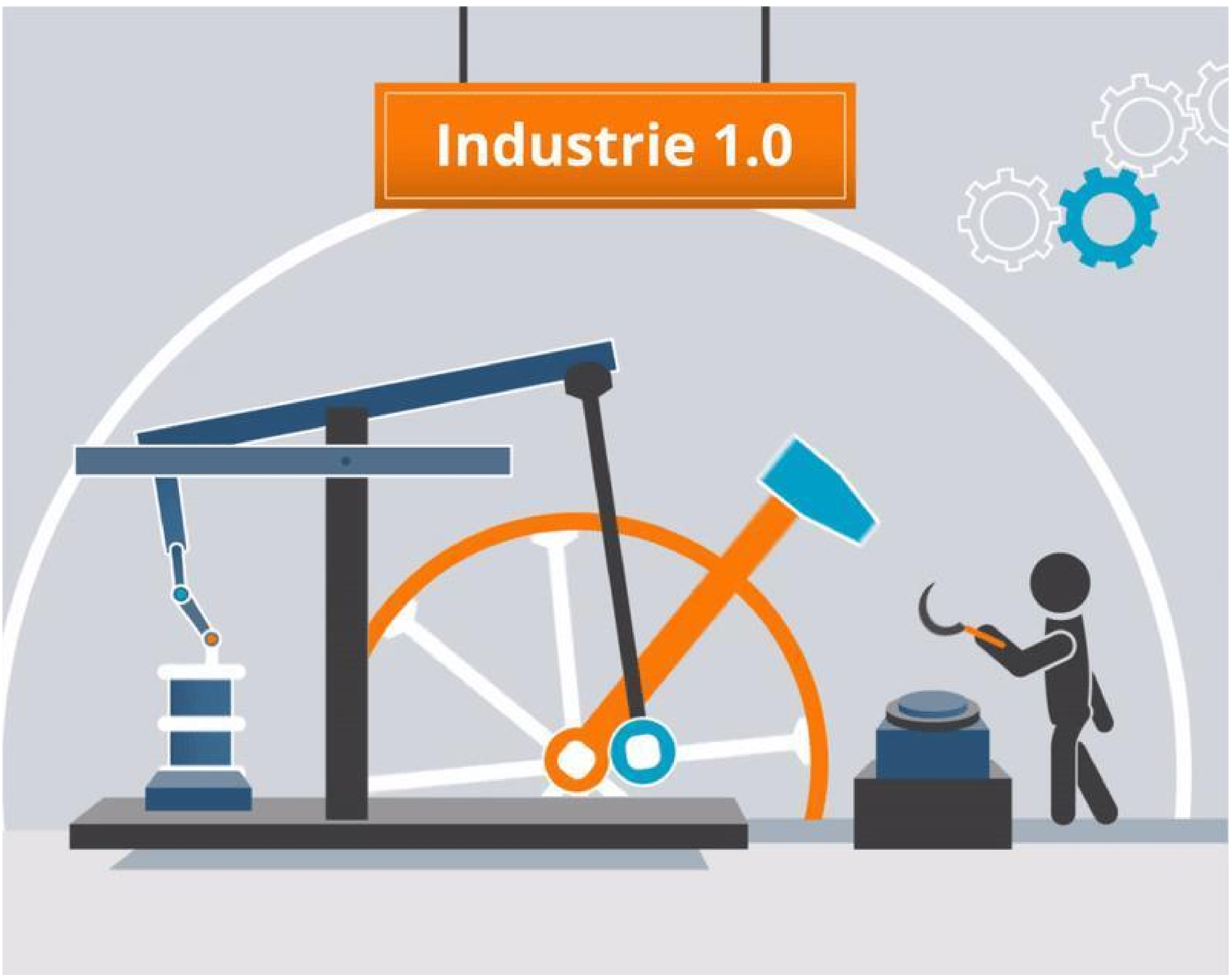
4.Analysis of Manufacturing Process

There is many types of Manufacturing process exist today like Repetitive manufacturing, Discrete manufacturing, job shop manufacturing, Process(continuous), Process manufacturing (Batch). In this thesis, I worked for a Process manufacturing where manufacturing was continuous. I gathered some data on the manufacturing industry where there was a production line with a total of 19 machines. The production line is a traditional method in which people associate with manufacturing. The production line is arranged so that the product is moved sequentially along the line and stops at work centers along the line where an operation is performed. The item may move along the conveyor, or be moved manually by staff, forklift or by another means of transport. In this thesis work mainly two modes of transport have been used one is a conveyor and the other is Automated Guided Vehicle. In this thesis, the Manufacturing process involves 19 machines which have been placed in sequence according to the work order. There is the main source from where the raw material comes and one by one that piece of raw material passes through all the machines.

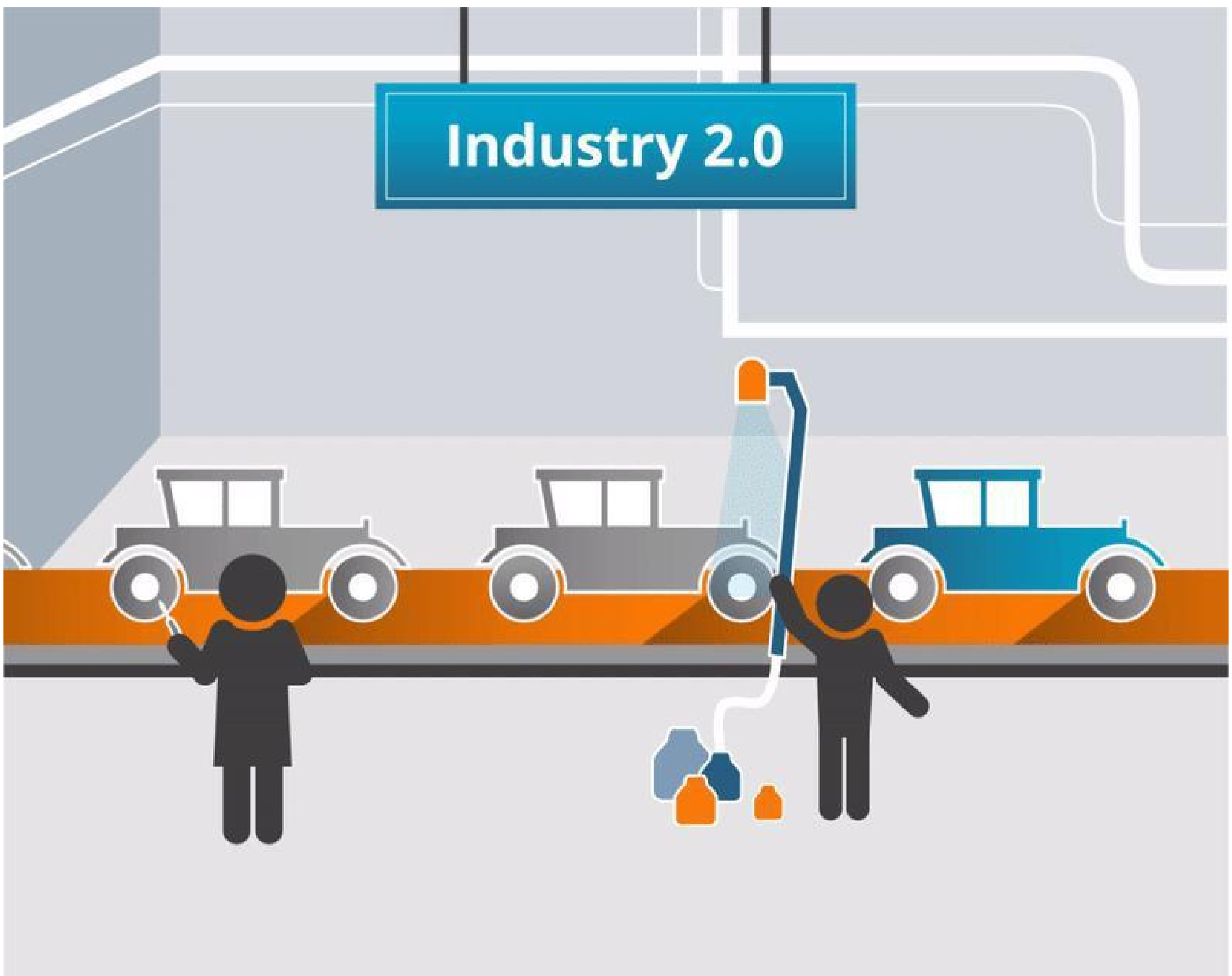
As I mentioned earlier, I used two modes of transport in my thesis work which were Conveyor and automated guided vehicle. In addition to machines, source, and sink there are other items like Buffer, Queues, and sinks. Buffer has been mainly used just next to machines to not block the production line because processing and set up time of all the machines is different. Buffer here considered one of the main KPI to enhance the production capacity. As I mentioned earlier it was continuous manufacturing so at every machine item was coming in batch to get work done on the main raw material. To contain those lot of batches I used queues next to every machine where I programmed like once 80 % of the lot is consumed queue send a message to the main warehouse and warehouse call AGV based on Request. new batch comes from the main warehouse with Transporter, which I used in all scenarios Automated guided vehicle. After finish, the product has been carried from the manufacturing plant for delivery to the customer. In the next section, I am going to talk more about the basic structure of the Discrete event model which I made with the help of flex sim. Before I move to my thesis work in detail I like to highlight some improvement in manufacturing and lean techniques in recent years.

4.1 Transformation in Manufacturing

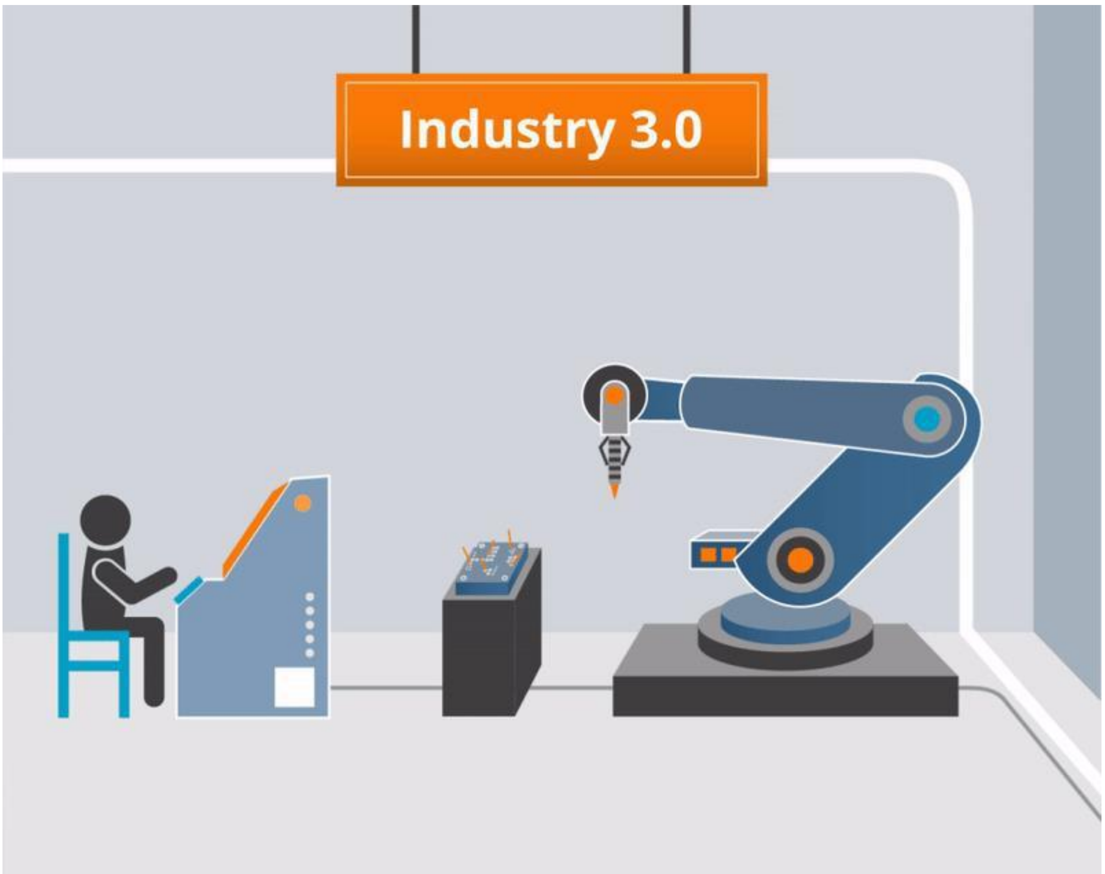
The first Industrial Revolution began in the Latter Half of the 18th Century. The Industrial Revolution started with the Textile industry where skilled workers who crafted products by hand were replaced by workers who make Products with the assistance of water or steam Powered machinery. After the Textile industry, the Industrial revolution got extended into other areas like transportation and communication. Below Is a typical Representation of the Situation of the manufacturing industry in the 18th century which we know as industry 1.0.



The Second Industrial Revolution is referred to as the end of the 19th century and the beginning of the 20th century. It was first characterized by new technologies such as electrification. Additionally, breakthroughs in the organization and management-innovations like assembly lines and interchangeable parts-made mass production possible during this time. Taylor's "principles of scientific Management" were applied to organize the labor of humans and machines, as well as to increase the productivity of the industrial workforce through training. Below Is a typical Representation of the Situation of the manufacturing industry in the 19th century which we know as industry 2.0.



The third Industrial Revolution or in other words we can call it digital Revolution, started in the later half of the 20^{th} century. Advanced Materials and innovative production technologies got matured and still are maturing. In manufacturing automation with computer Numeric control (CNC) machines, and the programmable logic controllers(PLCs) significantly improved quality, reliability and Productivity. Below Is typical Representation of Situation of manufacturing industry in 20^{th} century which we know as industry 3.0.



The fourth Industrial Revolution is already underway. Today, emerging technologies, like cyber-physical systems (CPS), Big Data and Analytics, Computer Modeling, Cloud computing, and mathematical optimization are being synergized to produce large gains in efficiency, flexibility, and reliability. These technology trends are offering manufacturers new ways to compete, innovate, and grow profitably even as they face challenges from volatile energy costs, workforce shortages, proliferating regulations, and a host of evolving risks. Large amounts of data related to industrial operations are being collected using sensors. This data allows us to precisely determine the current state of operations, as well as to accurately archive historical performance. This real-time and historic information is used for analysis and decision support.

Below Is a typical Representation of the Situation of the manufacturing industry which we know as industry 4.0.

Using Big Data, Analytics, and actuators, the autonomy of control and execution systems can be increased, thereby reducing human intervention, decreasing response time, and mistakes, while on the other hand increasing flexibility, reliability, and accuracy.

The technology trends that present new possibilities and questions for manufacturers include:

- <u>New production processes</u>: New processes such as additive manufacturing (for instance, 3D printing), Light-based Manufacturing, Embedded Metrology and Simulation are influencing everything from product design to material selection to supply chain configuration.

- New materials: Advanced materials with high-performance characteristics, such as carbon fiber composites, ceramics, and nanomaterials, are increasingly finding uses in large consumer-oriented markets such as automobiles, building materials, and clothing. Global demand for carbon-fiber-reinforced plastic, for instance, is expected to grow 15 percent annually through 2020.

Digital manufacturing: A new generation of digital design and collaboration tools is enabling manufacturers to digitally simulate the appearance, performance, interoperability, and even manufacturability of products, saving time and money throughout the product development and production process. In a cutting-edge example of digital manufacturing, Steelcase is employing augmented reality on an assembly line to boost the productivity of its workers.

4.2 The Role of Lean Manufacturing

Lean manufacturing is defined as "A philosophy, based on the Toyota Production System, and other Japanese management practices that strive to shorten the timeline between the customer order and the shipment of the final product, by consistent elimination of waste". All types of companies, manufacturing, process, distribution, software development or financial services can benefit from adopting a lean philosophy. Waste is regarded as non-value adding operations such as transport, inventory, motion, waiting, over-processing, overproduction and defects which are irrelevant for a customer. Some studies suggested that added value takes place around 5% of the time within operations and the remaining 95% is waste.

A key difference in Lean Manufacturing is that it is based on the concept that production can and should be driven by real customer demand. Instead of producing what is hoped to be sold; Lean Manufacturing can produce what your customer wants with shorter lead times. Instead of pushing product to market, it is pulled there through a system that is set up to quickly respond to customer demand.

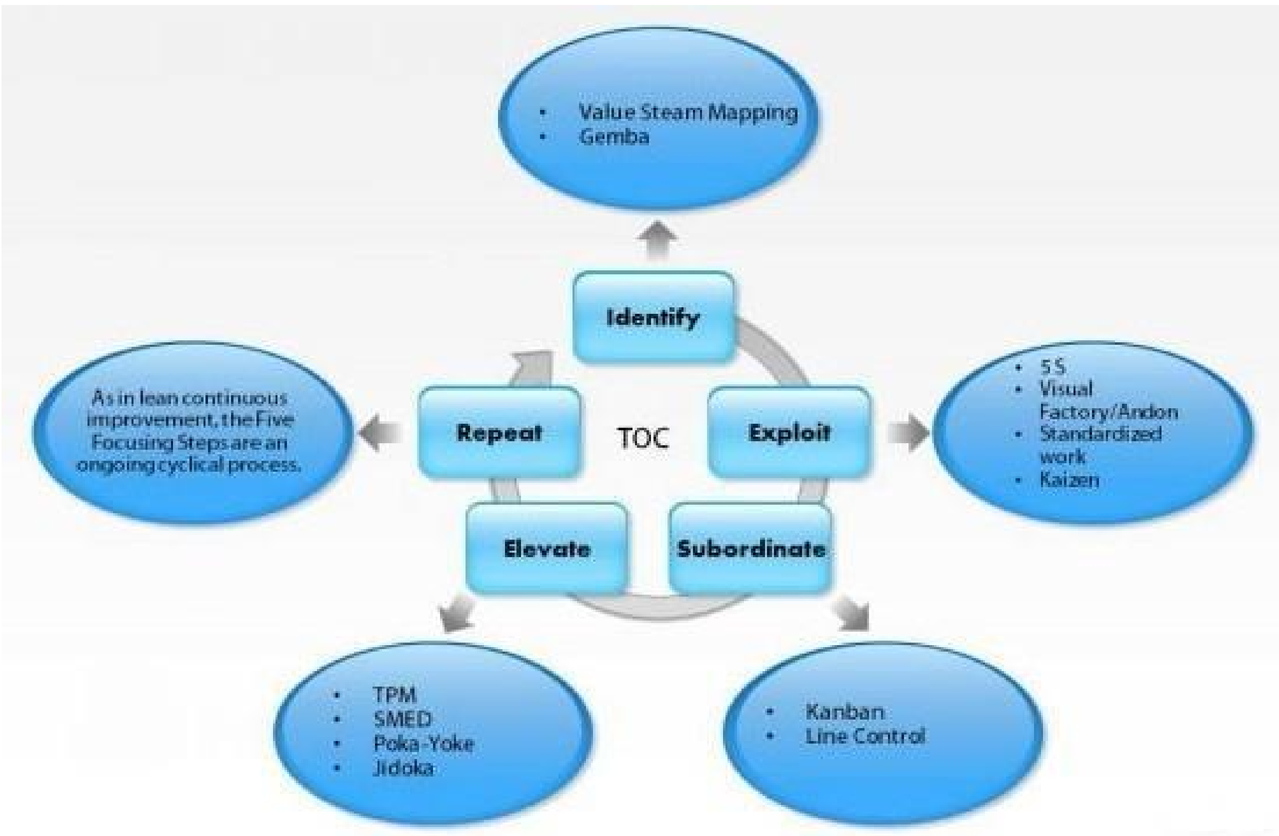
Methods of Manufacturing of Traditional Mass Production

and Lean Manufacturing

Manufacturing Methods	**Traditional Mass Production**	**Lean Production**
Production schedules are based on	Forecast-product is pushed through the facility	Customer order-product is pulled through the facility
Products manufactured to	Replenish finished goods inventory	Fill customer orders (immediate shipments)
Production cycle times are	Weeks/month	Hours/days
Plant and equipment layout is	By department function	By product flow, using cells or lines for product families
Workers are typically assigned	One person per machine	With one person handling several machines
Inventory level are	High-large warehouse of finished goods, and central storeroom for in p staging	Low-small amounts between operations ship often
Flexibility in changing manufacturing schedules is	Low-difficult to handle and adjust to	High-easy to adjust to and implement
Manufacturing costs are	Rising and difficult to control	Stable/decreasing and under control

Once companies pinpoint the major source of waste, tools such as provided will guide the companies through corrective action to eliminate wastes.

Lean Manufacturing Tools and Techniques



Initial concept of Lean was more extensively defined and described by five key principles (Womack & Jones, 1996):

1 Specify value – Define value precisely from the perspective of the end customer in terms of the specific product with specific capabilities offered at a specific time.

2 Identify value streams – Identify the entire value stream for each product or product family and eliminate waste.

3 Make value flow – Make the remaining value-creating steps flow.

4 Let the customer pull value – Design and provide what the customer wants only when the customer wants it.

5 Pursue perfection

By using Above mentioned Techniques it is easy to Implement the Lean principle inside any type of organization. Lean Manufacturing is a business philosophy that has proven highly successful since it can reduce costs, eliminate waste, increase productivity, maintain high levels of quality and thus make a significant increase in your profit.

4.3 Digital Transformation of manufacturing

Manufacturing has always been an industry that harnesses technology to deliver greater efficiency and productivity. Several driving forces of digital transformation in the manufacturing industry are relatively similar to those in other industries. It's a trend which we're set to see increase especially as more manufacturers adopt digital technologies and Industry 4.0 gains traction. Moreover, industry initiatives and national initiatives across the globe such as Industry 4.0 or the Industrial Internet accelerate transformations with IoT and the integration of IT and OT as key components. In fact, IDC research suggests that by the end of 2019, 75% of large manufacturers will update their operations with the Internet of Things (IoT) and analytics-based situational awareness.

The changing expectations of consumers impact the entire supply chain as various manufacturers obviously depend on each other so even manufacturers that don't produce consumer goods are impacted by these consumer changes. Moreover, manufacturing decision-makers also have different expectations as, in the end, we are all consumers. It leads us to the data-intensive and (semi-)autonomous evolutions in Logistics4.0 where speed and connectivity, with again IoT and cyber-physical systems being key.

Manufacturers are increasingly using data to improve their production processes, achieve greater consistency, and to create safer working environments. The combination of the IoT and the increasing digitization of information has resulted in an explosion of data. With systems and devices exchanging vast amounts of information, manufacturers need to ensure that robust real-time integrations are in place – as information is constantly being shared with supply partners and those within the distribution chain. This level of activity is likely to place substantial strain on IT infrastructure, especially the software-defined wide-area network (SD-WAN) which supports communications spanning large geographical areas.

Many of these existing networks are long in the tooth and were designed before digital manufacturing became commonplace. For Industry 4.0 to be successful manufacturers must have the appropriate network infrastructure in place which can priorities applications and workloads to ensure appropriate service levels. With so many moving pieces, it's important that IT teams to build a strategic digital infrastructure platform that can support all the initiatives enabling Industry 4.0.

Many CIOs in the manufacturing sector view increasing operational efficiency and transforming the business as imperative to driving technology investments. With this in mind, IT platforms should provide the integration and coordination required for success. However, it's likely that the IT team will also utilize partners with specific expertise, skills, and technology. Managed service providers (MSPs) are a key component to any effective IT strategy as they offer leading solutions and the skills to deploy, administer, and manage them.

5.Simulation for Lean Organization

"The lean approach provides firms with a framework and a set of principles to identify and eliminate unnecessary sources of variability and to improve the performance of their production" (Bokhorst and Slomp 2010)

As we know, Lean helps to find a new and effective solution to improve efficiency but simulation itself is not seen as a tool to improve the manufacturing process. It has become very common that industries implement the lean philosophy into their operations, as it is comprehensive and comprises structuring, operating, controlling, managing, and continuously improving industrial production systems. The lean philosophy is derived from the Toyota Motor Company in Japan where they established the Toyota Production System (TPS). Many companies have embraced TPS and converted it into their own systems, so one could say that the philosophy is now well established within the manufacturing world.
Process stability, Level production, Standardized work, Just-in-time, Production stop policy, Quality-at-the-source, Continuous Improvement, and Visual control are all key concepts within the lean philosophy (Detty and Yingling 2000). Lean also contains several control principles such as takt time control and Pull control. The advantage of the pull control system is that this could limit the amount of work in progress (WIP) that can be in the system.

There are so many benefits with lean but at the same time, there are few weak points also. Few times we come to know about that weakness after implement the lean philosophy. In this manner to avoid those negative effects simulation help to achieve that goal. The author like Uriarte et al. (2015) claims that organizations could improve their performance in a more efficient way by integrating simulation within the lean toolbox and let it be a key tool. Some lean experts admit that lean helps the industry to be better but if simulation comes in play to implement lean is even better. Optimization is a relatively new concept compared to lean and simulation. Lately, it has been more and more common to combine simulation and optimization but lean is still not included in this context.
Lean, simulation, and optimization all together could be more powerful for the company. As we know simulation help to understand the situation and it can give us multiple solutions to one problem but the optimization tool helps us to choose the best possible solution even if the configuration is complex. There could be few problems to integrate lean, simulation, and optimization all together but a good team of experts, negative experiences, Involvement of managers could avoid the problem some times. Some disadvantages with lean are that the philosophy does not consider variation, lack of dynamicity, and the philosophy is not so good

when it comes to evaluation of a non-existing process before implementation. So, simulation and optimization could help to avoid these kinds of problems.

5.1 Discrete Event Simulation

"Discrete Event Simulation (DES) in particular has been widely applied to model and optimize complex manufacturing systems and assembly lines. DES is particularly well suited for modelling manufacturing systems as DES can explicitly model the variation within manufacturing systems using probability distributions. DES is thus capable of answering key operational questions relating to throughput, resource allocation, utilization and supply and demand." (Prajapat and Tiwari 2017)

Without interrupting the Real ongoing Manufacturing System, Simulation plays an important role in order to review procedures, changes, Information flows, etc. A fully developed and validated model can answer a variety of questions about real questions. DES is useful for gaining an in-depth understanding of a system to improve its performance. The DES software models a distinct sequence of state changes that occur in time. In order words, any system that involves a process flow where events change in time sequences can be simulated. Lean assessment must be done by key performance indicators such as lead time, Overall Equipment Effectiveness and works in progress (WIP). Yet, modeling lean practices are possible within the various building blocks of most DES software, such that the simulation can be used to provide information about the effects of altering and improving lean practices while considering the trade-offs that exist between them. There is in fact more to DES/lean assessment relationship than just lean KPI analyses.

The general behavior of a discrete event simulation can be described as following; it starts with an initial state and when an event occurs the system will directly change to a new state. This behavior will then continue over time considering that it will stop within a state for a duration of time (Mansharamani 1997). "Of all the simulation techniques, DES is the one which models the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system" (Sharma 2015).

In order to be able to construct a simulation model, one must first gain knowledge of how the actual system to be simulated looks like. To gain this knowledge there are some tools to characterize an operation, such as characteristics for high- and low volume serial production (Ziarnetsky et al. 2014). They provide aspects to think about when modeling a system for a simulation, which they developed building blocks for simulation models for assembly lines. Then they apply these building blocks onto a real case to validate the model and conclude that these could be used to successfully simulate the real case system to demonstrate the importance of inventory management.

5.2 Advantages and Disadvantages with DES

Advantages of simulation:-

1) One of the primary advantages of simulators is that they are able to provide users with practical feedback when designing real-world systems. This allows the designer to determine the correctness and efficiency of a design before the system is constructed.
2) Simulation helps to understand the complex system or a subsystem within a complex system.
3) Simulation makes it possible to show the benefits with lean manufacturing throughout the whole system and can give a good picture of how the new system could look like in the future, which in turn can be useful information for the management.
4) It is possible to study a problem at several different levels of abstraction. By approaching a system at a higher level of abstraction, the designer is better able to understand the behaviors and interactions of all the high level components within the system and is therefore better equipped to counteract the complexity of the overall system.
5) Simulation can save time within the line balancing process, and that fact model simulation has led to an increase in line balancing ratio, which in turn has led to an improvement in work efficiency.
6) It is possible to observe the outputs in different situations by changing the input parameters and other key factors.
7) It Is possible to verify analytical solutions by using the simulation.
8) By using simulation we can visualize the actual behavior of our system.
9) It can be used to experiment with new designs before implementation to prepare for what might happen
10) Simulation saves a lot of time and cost like in our case we will simulate one manufacturing plant with make changes in reality.

Disadvantages of simulation:-

1) The simulation takes a lot of time to simulate things so it is not a good option for a small time span.
2) A few times system is very complex which we can’t define in the simulation model.
3) Few times there is no possibility to define and validate the model.
4) A few times the cost of simulation exceeds the possible savings.
5) Special training is required for simulation.

6.Flexsim

FlexSim is a discrete event simulation software package developed by FlexSim Software Products, Inc. The FlexSim product family currently includes the general purpose of FlexSim product and FlexSim Healthcare (FlexSim HC).

As general-purpose simulation software, FlexSim is used in a number of fields:

Manufacturing: - Production, assembly line, job shop, etc.

Material handling: Conveyor systems, AGV, packaging, warehousing

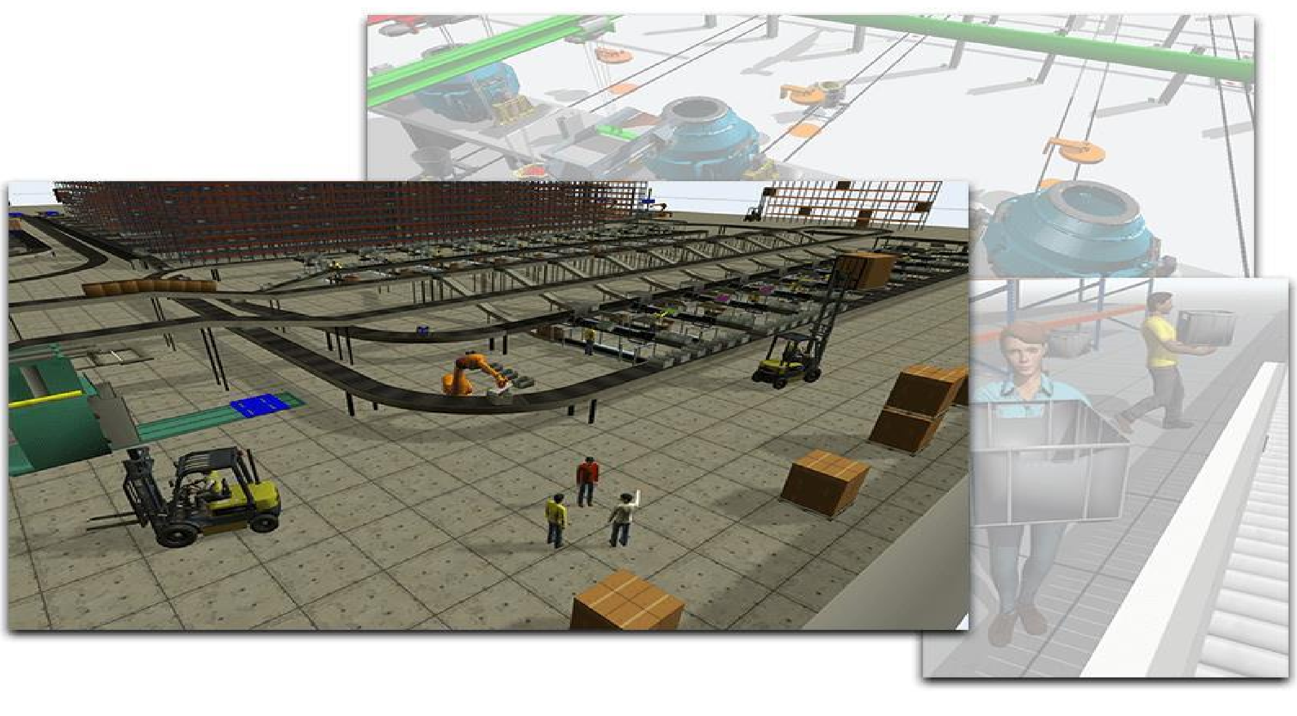
Logistics and distribution: - Container terminal operation, supply chain design, distribution center workflow, service and storage layout, etc.

Transportation: - Highway system traffic flow, transit station pedestrian flow, maritime vessel coordination, custom traffic congestion, etc.

Others: - Oil field or mining processes, networking data flow, etc.

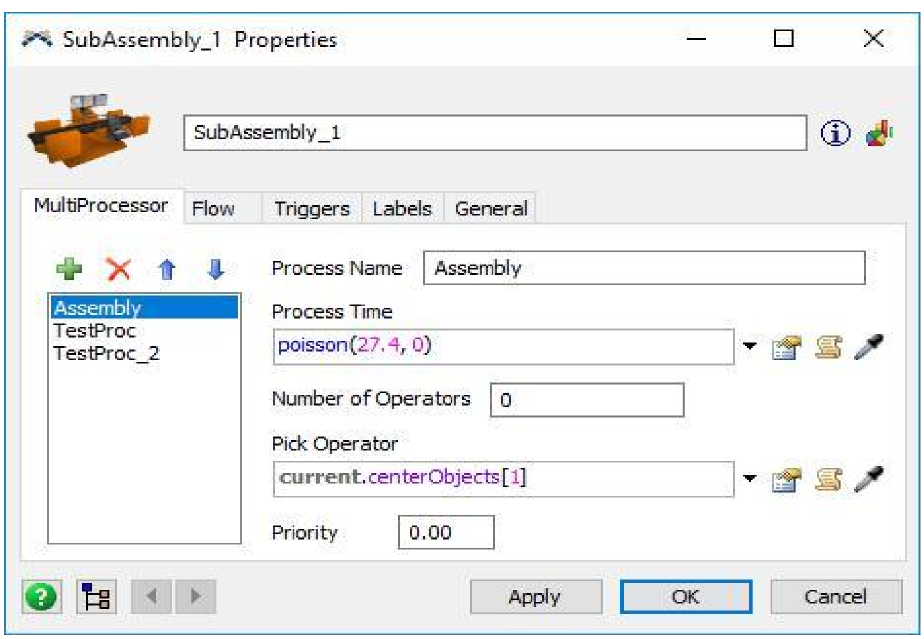
Main Features of Flexsim are as: -

1) **3D Simulation**: - FlexSim comes with all the proven benefits of discrete-event simulation—but with the added bonus of highly realistic, immersive 3D graphics. FlexSim's 3D models help you emulate the look and feel of the real system, so it's easier to see and understand what's going on.



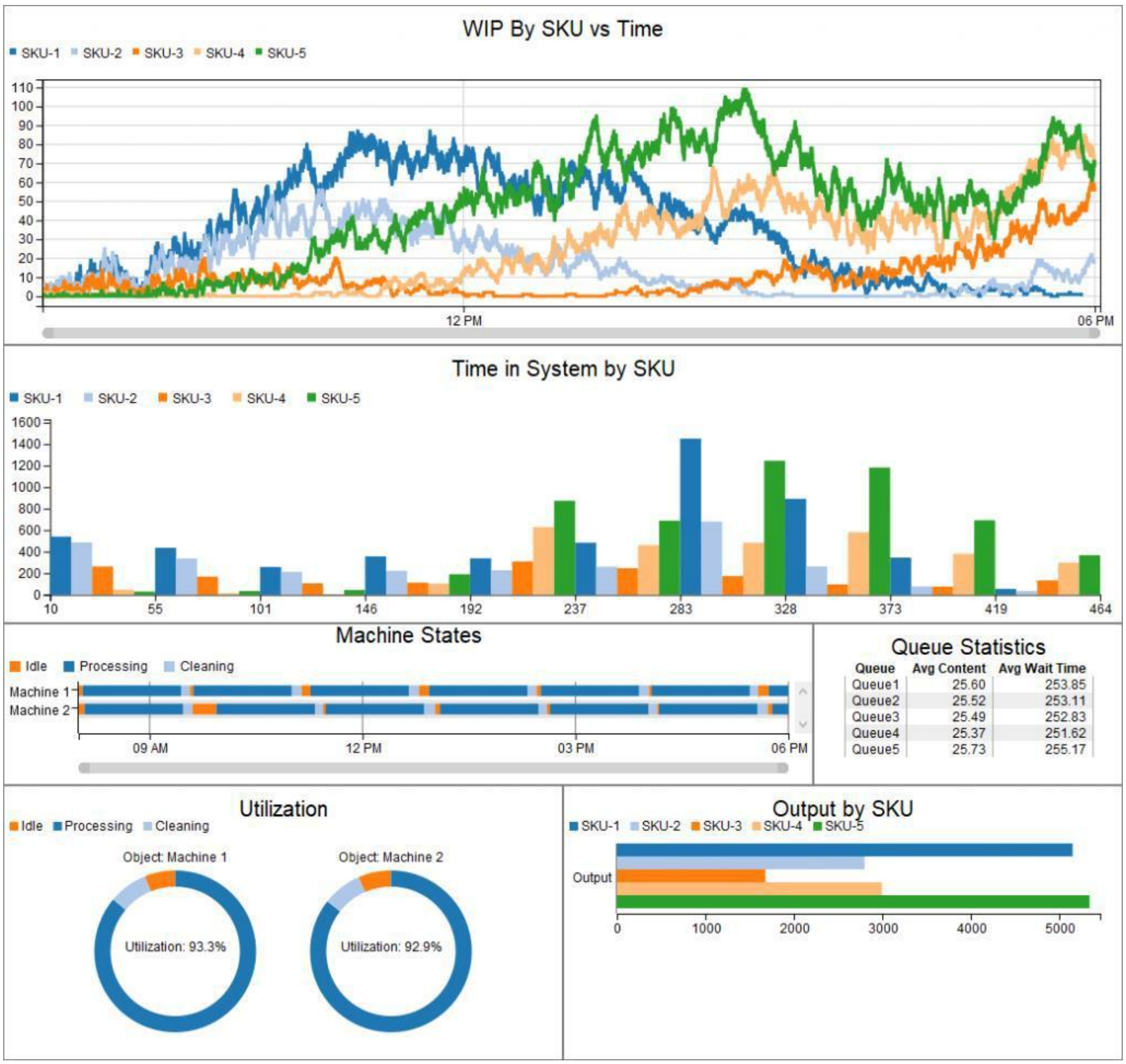
2) Model Layout: - FlexSim makes it as easy as possible to replicate the look of your system while preserving the details necessary for accurate analysis. Just use the simple drag-and-drop controls to place objects and resources directly into the 3D environment—no post-processing needed.

3) Model building: - FlexSim toes the line between ease-of-use and capability to model even the most complex systems. The Standard Object Library contains a variety of objects that be used to immediately build models. Customization is simple—just choose from the preconfigured behaviors, mix-and-match options, and even create your own behaviors.

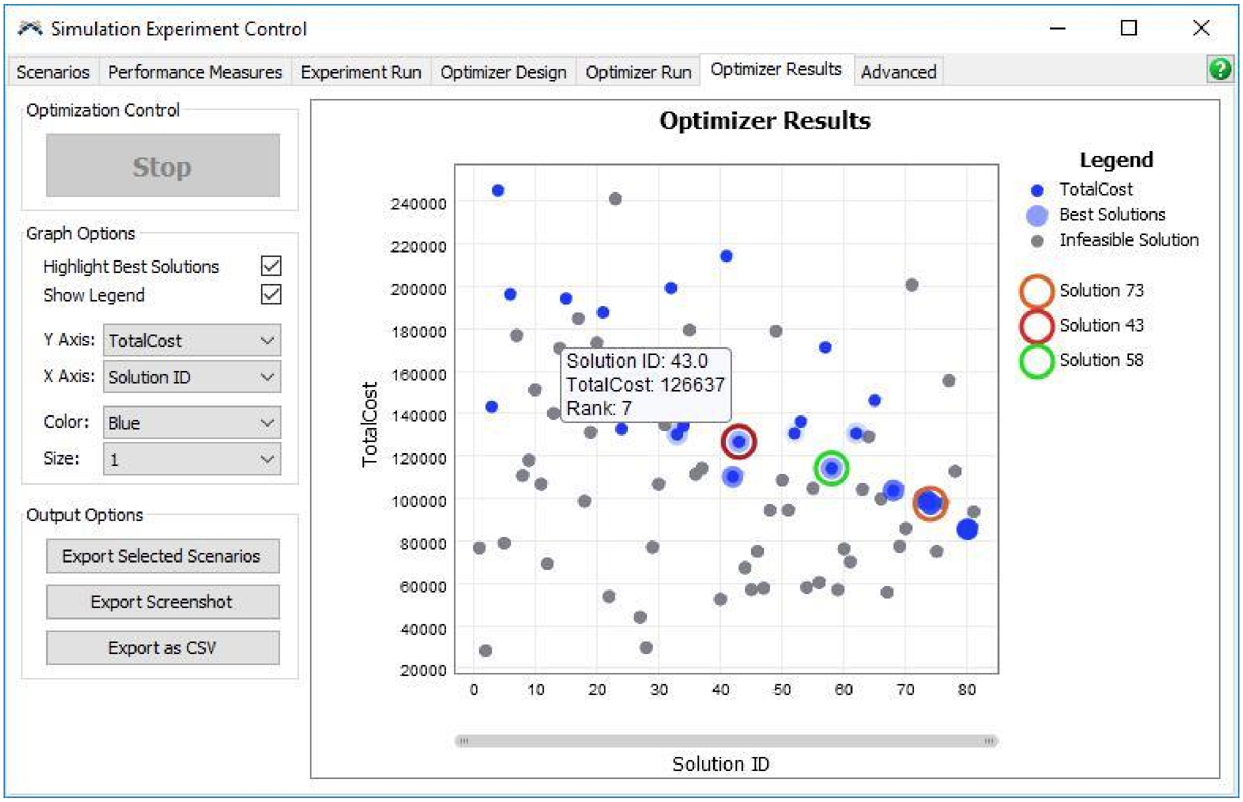


4) Model Analysis: - Once you're ready to simulation using your model, our full suite of analysis features will help you get a deeper understanding of what's going on

- A deep roster of charts and graphs to help you visualize data from a simulation run.
- The ability to track a wide range of data points and then export to your favorite spreadsheet application.
- Greater flexibility for data gathering through powerful tools like the Stats Collector object and Zone activity.



5) Optimization: - Where the money is made (or saved)! Test "what if" scenarios to find the best possible choices to make in the real world.



7.My Model

A flexsim model is a system of queues, processes and transportation. As it is mentioned before that total four scenarios has been considered. Structure of model changed based on the scenarios. Before moving to the model structure, I would like to define few parameters that has been used in all scenarios.

7.1 Parameters

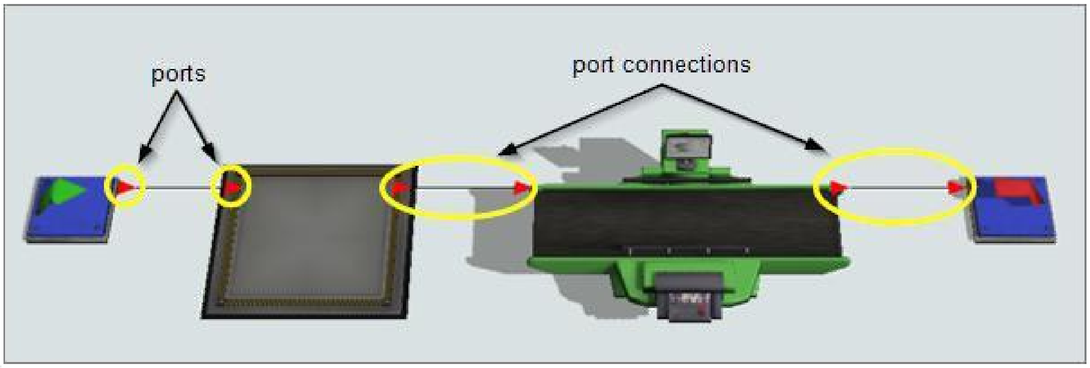
1) Source: - Sources create flow items. I used the source to create items, which will represent their arrival as the raw material.
2) Processor: - Processors process flow items, which is typically simulated as a time delay. The processor will represent how much work is done on how many items.
3) Queue: - Queues store flow items until they can be sent to another object. The queue will represent the waiting line of the items.
4) Sink: - Sinks remove flow items from the simulation model. I used sinks to represent items leaving the manufacturing plant.
5) Conveyor: - in my model, I used straight and curved conveyors. Conveyors are solely used to transport items from one place to another place.
6) AGV: - automated guided vehicles are used to transport items between two points. Nodes are used to guide the vehicles inside the manufacturing plant.

Object classification: - different kind of objects has been used mainly are: -

1) Fixed resources: - objects which send or receive items. Sources, processor, conveyors, sink and queues come under this category.
2) Task executers: - these are mobile resources that perform assigned tasks. AGV comes under this category.
3) Flow items: - The entities that are passed from one fixed resource to another within a model. Flow items are actually Flexsim Objects. Flow items hold information that can be set and queried in the model.

Object port connections: - different types of connections were made between fixed resources and task executers. Some of them are below in detail: -

1) **Output/Input ports**: - output/input ports connections define possible flow items routes to/from the fixed resources.



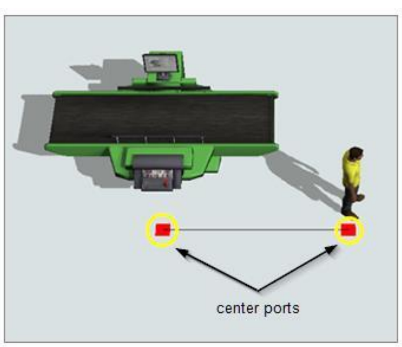
Input/Output Ports (A-Connects)

Input/output ports are the most common types of port connections. These ports are usually used to connect two fixed resources together so that they can exchange flow items. The output port of an upstream object is connected to the input port of a downstream object. An output port is where the flow item exits the object and an input port is where the flow item enters the object. The above image shows a simple input/output connection.

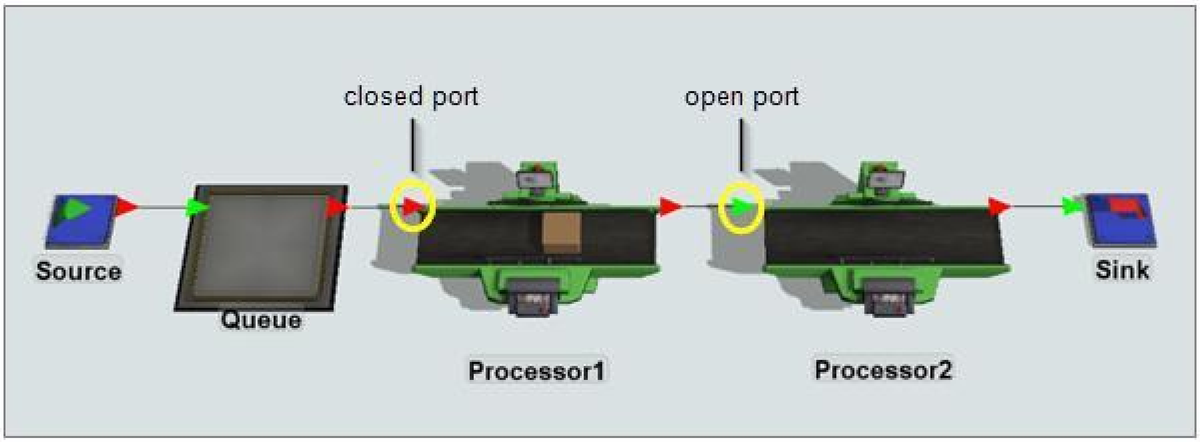
2) Center Ports (S-Connects)

Center ports are usually used to connect task executers to fixed resources, but they can connect any two objects that need to reference each other. When the center ports of two objects are connected, it creates an abstract reference point between those two objects. Center ports enable objects to communicate or interact in complex ways:

- **Transporting flow items** - Fixed resources can use the task executers connected to their center ports to transport flow items to a downstream fixed resource.
- **Setting up and processing** - Some fixed resources have setup and processing times (processors, combiners, separators, multi-processors). These objects can require the presence of a task executer connected to their center ports during setup and processing times.
- **General reference** - Objects can have center port connections in order to communicate with or reference each other.



3) **Open and closed ports: -** Another important concept you should understand about ports is how to know when a port is open or closed and why. Simply put, an open port is ready to push or pull flow items. A closed port is not ready to push or pull flow items. During a simulation run, open ports are green and red ports are closed:



Triggers: - A trigger is a logic that is implemented whenever that event occurs in the model. we can assign logic to a trigger, which means that when that trigger fires, it will cause a chain reaction of other behaviors or events.

Labels: - Labels are a crucial component of building a model's logic. At its most basic level, a label is a way to store information on a flow item, token, or 3D object. Labels are key to the overall functionality of FlexSim because they can track important information or dynamically change what happens during a simulation based on different conditions in the simulation model.

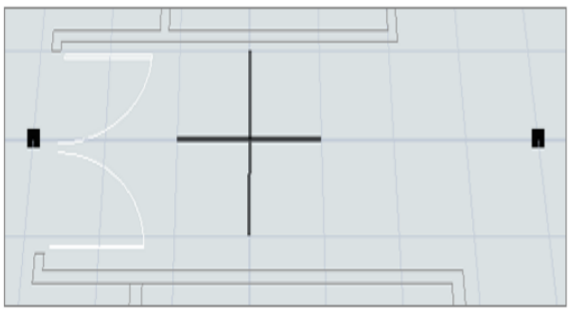
Every label has three items: -

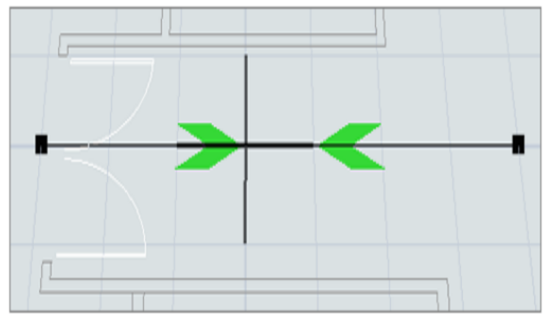
1) Owner: - Every label belongs to a specific flow item, token, or 3D object. You will need to know which item, token, or object owns the label in order to reference that label during a simulation run.
2) Name: - Every label has a name that describes the type of information it contains. You'll use this label name to refer to the label and get information from it. The name of the label is assigned when the label is first created, and it won't change throughout the simulation run.
3) Value - Every label has a value that contains information about the label's owner. Labels can vary from item to item or from token to token. Values can be any type of data, such as text, numbers, references to other objects, and even arrays.

Four basic labels used in my model are: sorting and conditional routing**,** Linking Tokens to 3D Objects or Other Tokens, Conditional Decision Making and Getting Data from a Model.

Travel Network: - By default, when a task executer travels between two objects, FlexSim will simply choose the shortest distance between two points: a straight line. In my model, this default travel didn't meet my requirements because if I could use the default travel system were ending up traveling through other objects or through barriers such as walls. This issue came especially where I needed to use AGV. I used network nodes instead to go for default settings.

1. **Add network nodes to the model** - I dragged out the network nodes (from the Library) and placed them at key points in the simulation model. I did put network nodes next to fixed resources to which task executors will need to travel and then, I did put network nodes at the beginning and end of a path. The following image shows an example of two unconnected and connected network nodes at the beginning and end:





Based on the requirements I used A connection and S connections.

7.2 Design of Experiment

As I mentioned before in this thesis 4 different scenarios have been considered. Before starting with plant design, I would like to present a few details about components used in plants. Below is the list of main components used in this model: -

1) Main source
2) Main Queue
3) Buffers
4) Processors
5) AGV
6) Conveyor
7) Sink

The main components which vary from one scenario to another one are the only use of conveyor and AGV. Properties of all other items almost stay constant. Below are more details: -

- **Source: -** This is the main source of raw material from where the initial workpiece comes with a uniform distribution. Properties of Source stay constant throughout all scenarios.
- **Queue: -** This is the main queue that is placed just after the main source and it works as the main buffer if the machine and its buffer are not available to receive the items. Properties of the Main queue stay constant throughout all scenarios.
- **Buffers: -** The setup and process time of each machine is different so it not guarantee that all machines will be available at a constant interval, this property of machines forced me to use buffers with every machine so that the items may wait there if machine if blocked with other items in processing. At the same time, I considered buffer as one of the main KPI that I will discuss in detail in the result section later.
- **Processor: -** This is the main component of the plant. Every machine has different process time, set up time, batch size request, etc. but these properties stay constant throughout all scenarios. Main properties have been considered in model as the main variable is process time, set up time, and batch size requirement of each machine. Below are all details of every machine used in this model:

Table 1

Cluster	Description	Average time [s]	Setup time [s]	Batch size
LOAD_H	Load cylinder head to pallet	10	8	50
Sealant and Lubrication	Lubricate valve guide bores or valves	15	8	300
INSERTION	Install intake and exhaust valves	25	4	500
LEAK TEST	Valve blow-by leak test	25	8	infinite
ROLLOVER	Turnover 180°	10	8	0
LOAD	Load camshafts to pallet	15	8	200
LOAD	load camshaft caps and bolts to pallet	20	8	500
INSERTION	Assemble valve stem seal	25	4	500
PRESS	Press valve stem seals	15	8	0
INSERTION	Assemble valve springs, valve spring retaine	25	4	800
PRESS	Key-up	15	8	300
Sealant and Lubrication	Apply sealant	25	4	300
LOAD	Assemble camshafts, camshaft caps, bolts and pre-torque	10	4	400
TIGHTENING	Torque camshaft cap bolts	20	8	500
MEASURE	Torque to turn	25	8	infinite
PRESS	Press camshaft seal ring	15	8	400
TIGHTENING	Torque intake, exhaust and/or injector studs	25	8	500
MARKING	Cylinder head label	15	8	500
LOAD	Unload cylinder head assembly	10	8	50

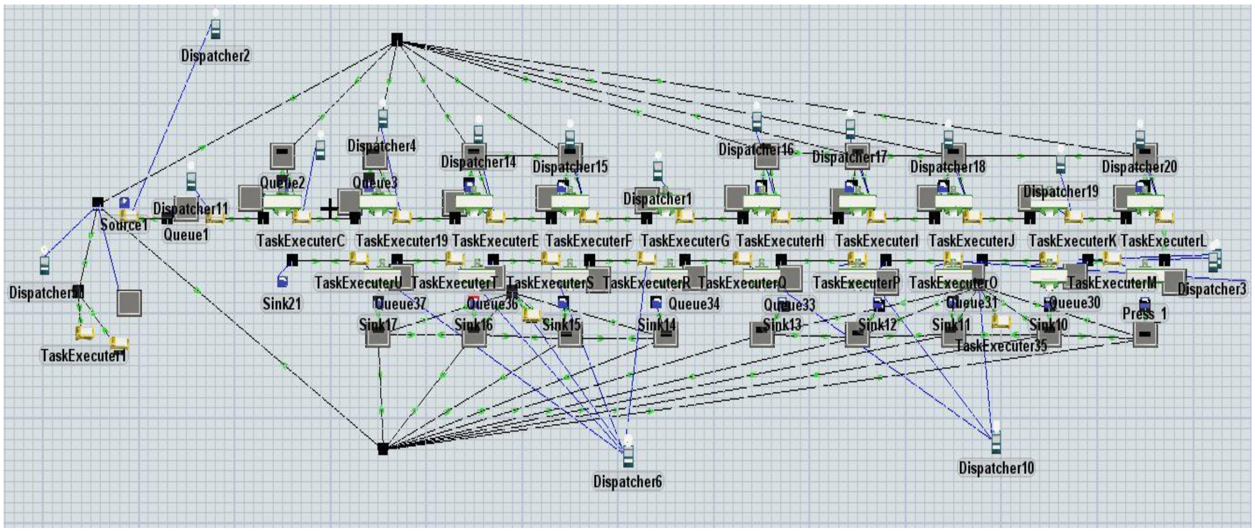
- **Automated guided vehicle: -** AGV has been used as one of the main modes of transport between machines and to transport lots from the warehouse to buffers and to machines. Different numbers of AGV have been used based on scenarios. For example, in the case of full conveyor very few AGV have been used. As I mentioned before the AGV used in this thesis is Comau Agile 1500 model. I made all the necessary calculations for battery consumption based on my model that I will discuss in the result section.

- **Conveyors:** - like AGV conveyors have been used as one of the main modes of transports mainly between machines and to get lots from the buffers. Length of conveyor varies from model to model for example in case of full AGV scenario no conveyor has been used and in case of full conveyor scenario only conveyor has been used at maximum points.

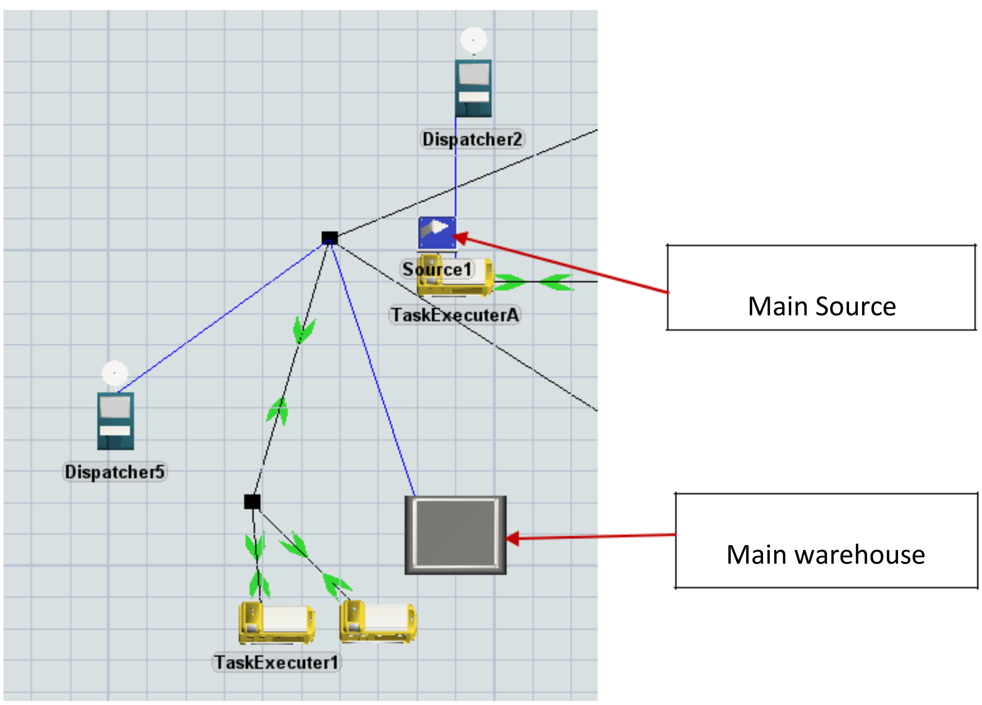
- **Sink:** - it is the main sink where final ready workpiece is going for the delivery to the customer. This component is constant for all the scenarios.

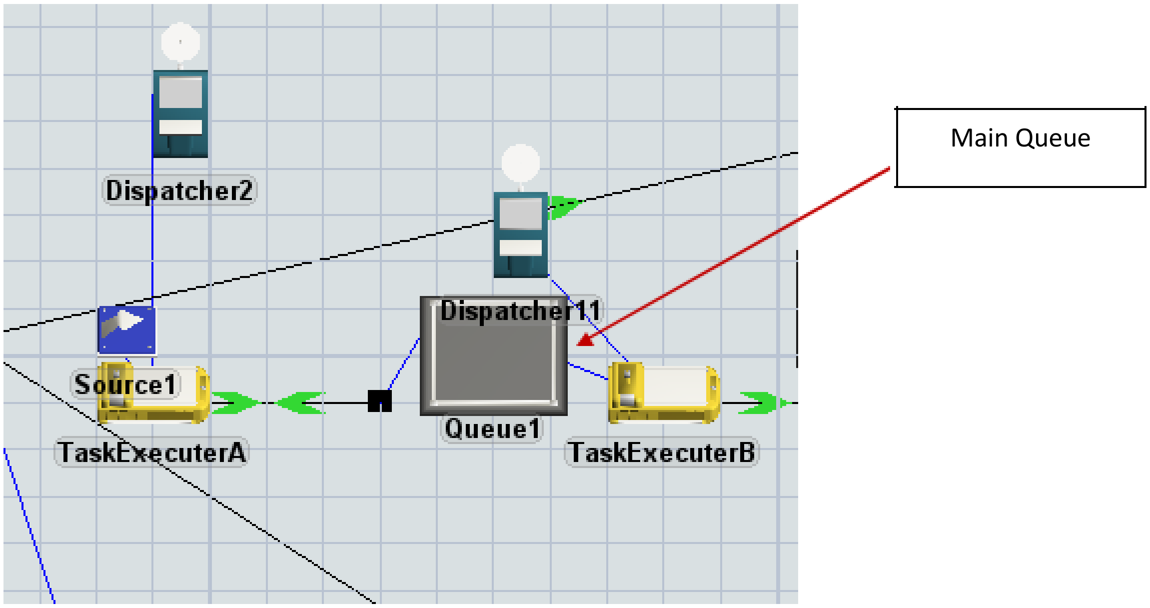
Now I will discuss one by one layout of all the scenarios. I will represent the top view in all 4 cases, and I will highlight that specific part of the model which is different in all scenarios.

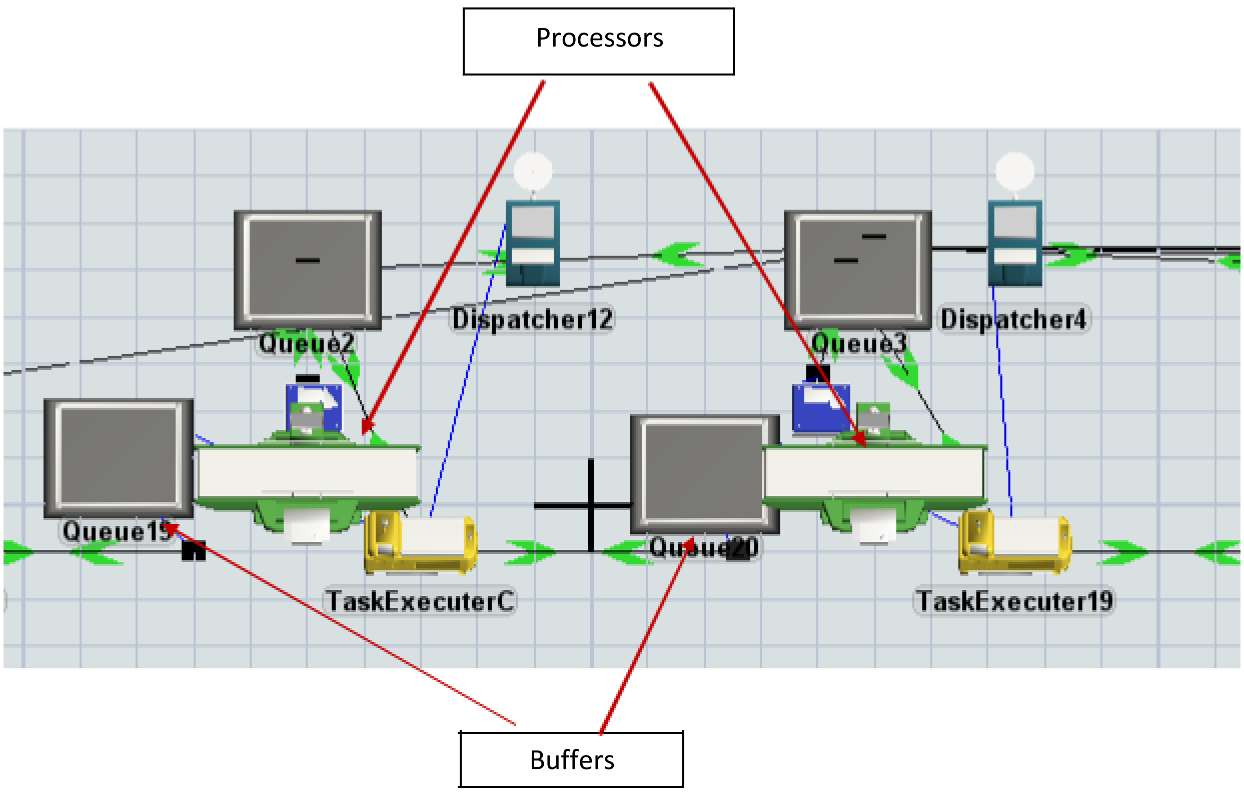
1) **Full AGV model: -** in this model, only AGV has been used for any kind of transport. Below is the top view of the full AGV model: -

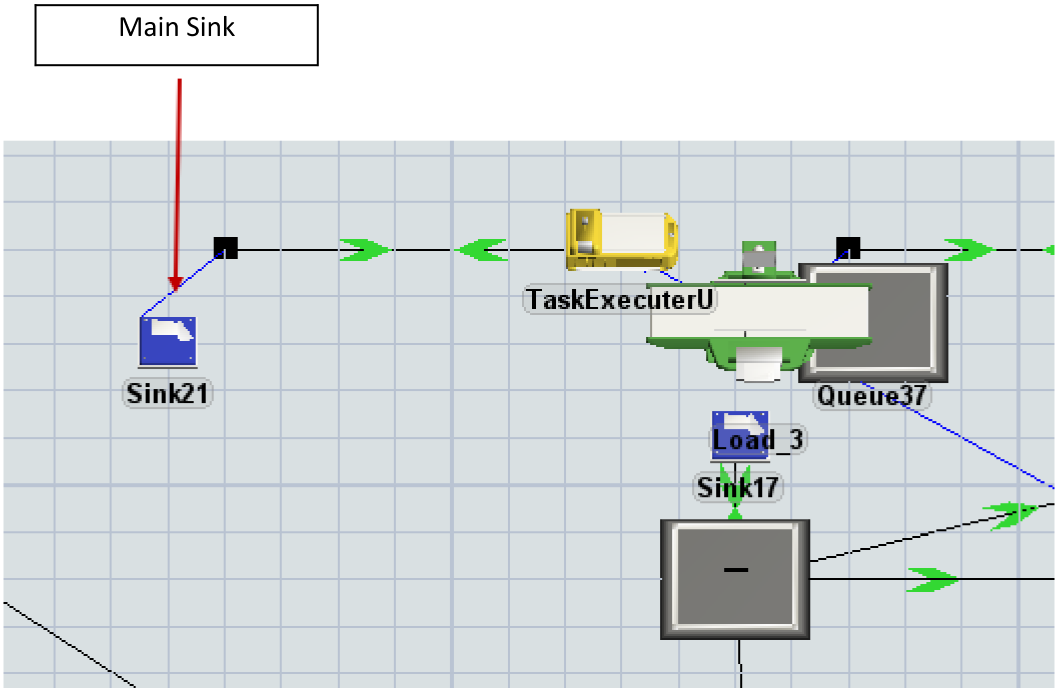


Below are the details with the zoom version where main components of the model have been highlighted:

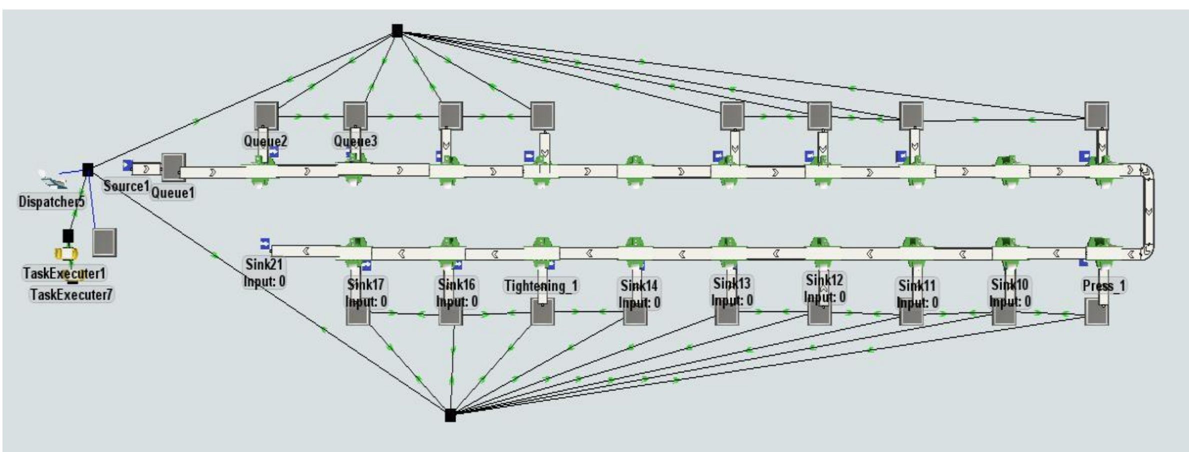



Main Queue
Dispatcher2
Dispatcher11
Source1
Queue1
TaskExecuterA
TaskExecuterB

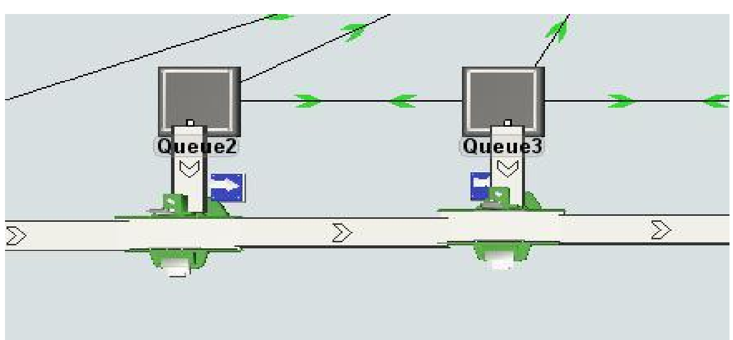

Processors
Queue2
Dispatcher12
Queue3
Dispatcher4
Queue15
Queue20
TaskExecuterC
TaskExecuter19
Buffers



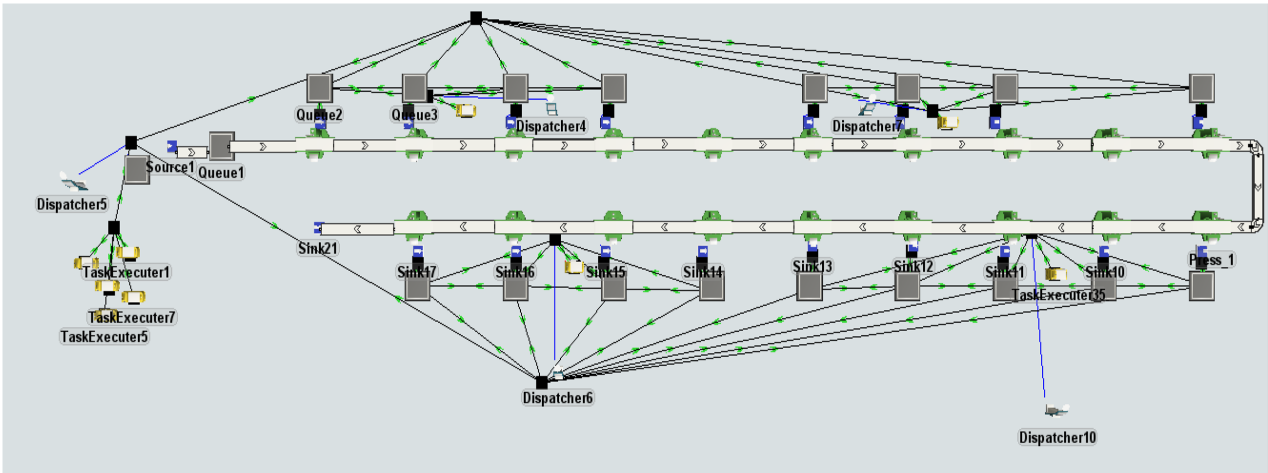
2) **Full Conveyor model:** - in this scenario is a major part of the model the only conveyor has been used. To transport lots from the main warehouse AGV has been used. Below is the top view of the model:



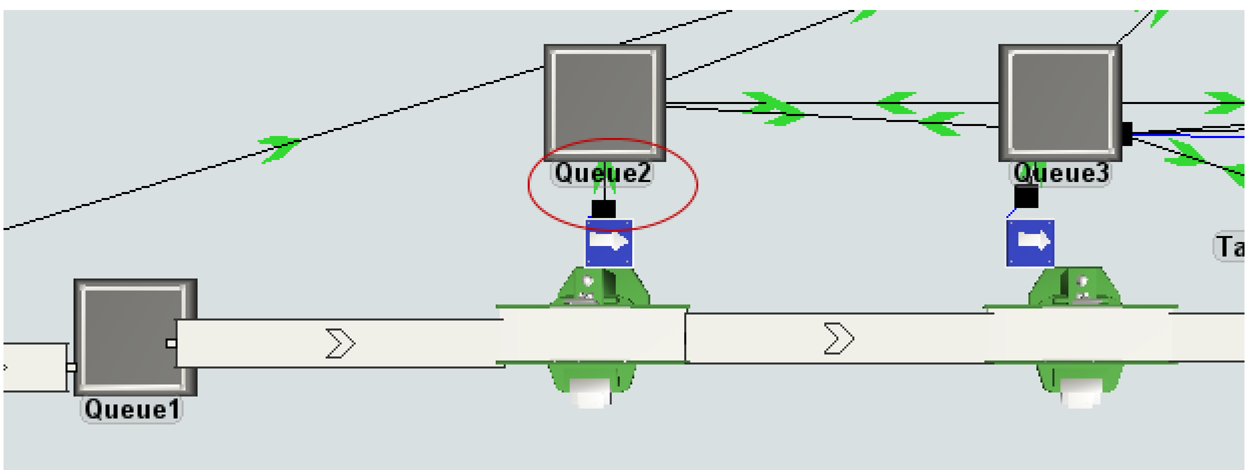
Below are zoom version of mode transport between machines:



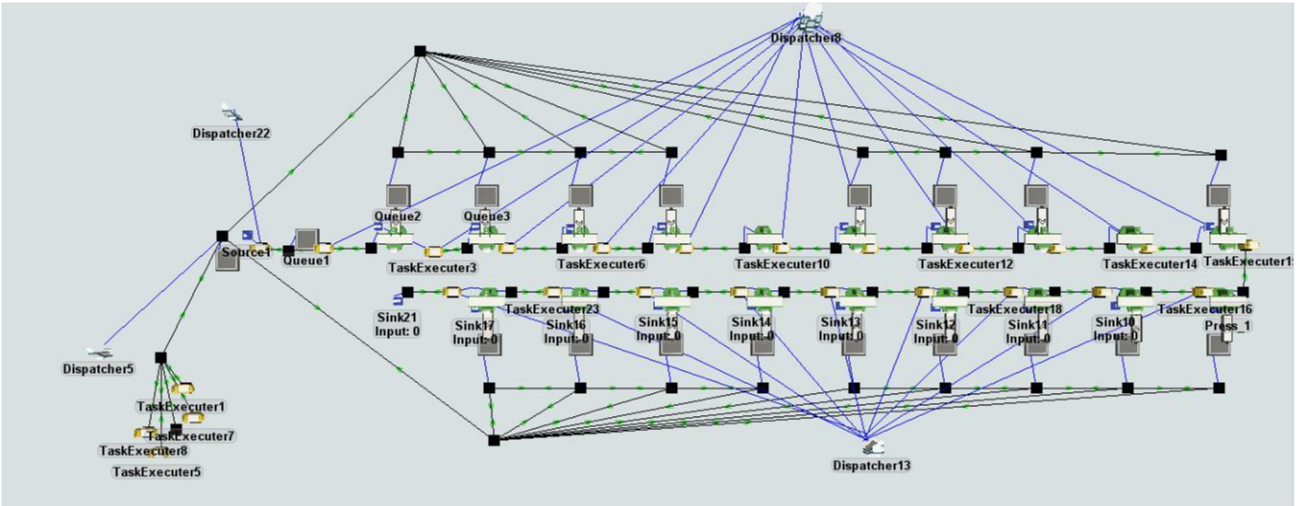
3) **<u>Lots with AGV: -</u>** In this scenario, conveyors have been used for the transport between machines and AGV has been used for the transport of lots from the main warehouse to the buffer and from buffer to the machines. Below is the top view of the model:



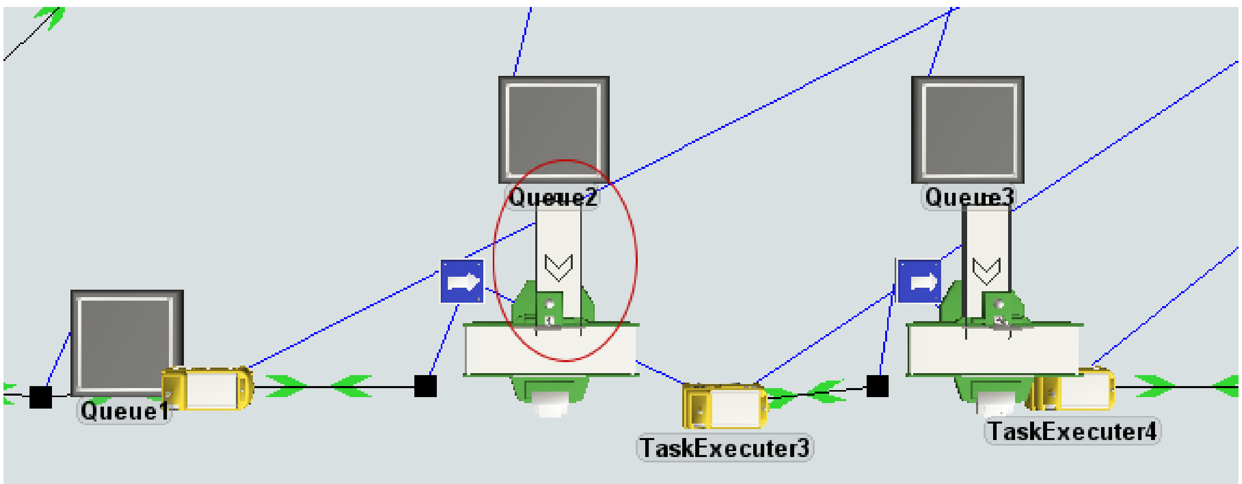
As mentioned before the main difference here is lots have been transporting with AGV.



4) **Lots with Conveyors: -** in this scenario, AGV has been used between the machines and for the transportation between the main warehouse to the buffers. Below is the top view of the final model:

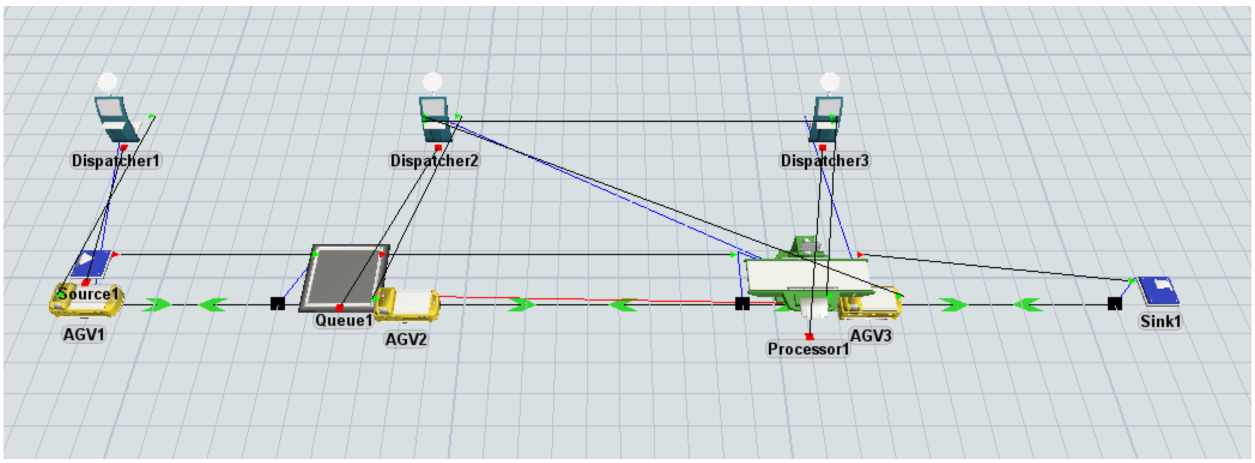


The main difference here is the lots have been transported to the machines with the help of conveyors:



In addition to the general overview of the different layout, I would like to highlight also two specific problems with regards to the usage of AGV in all different scenarios. for AGV usage the main concern is about battery charging and Breakdown during the operation. Also, here discrete event simulation played an important role in analyses the impact of charging time and breakdown time on the whole operation. Here I will explain one by one both issues.

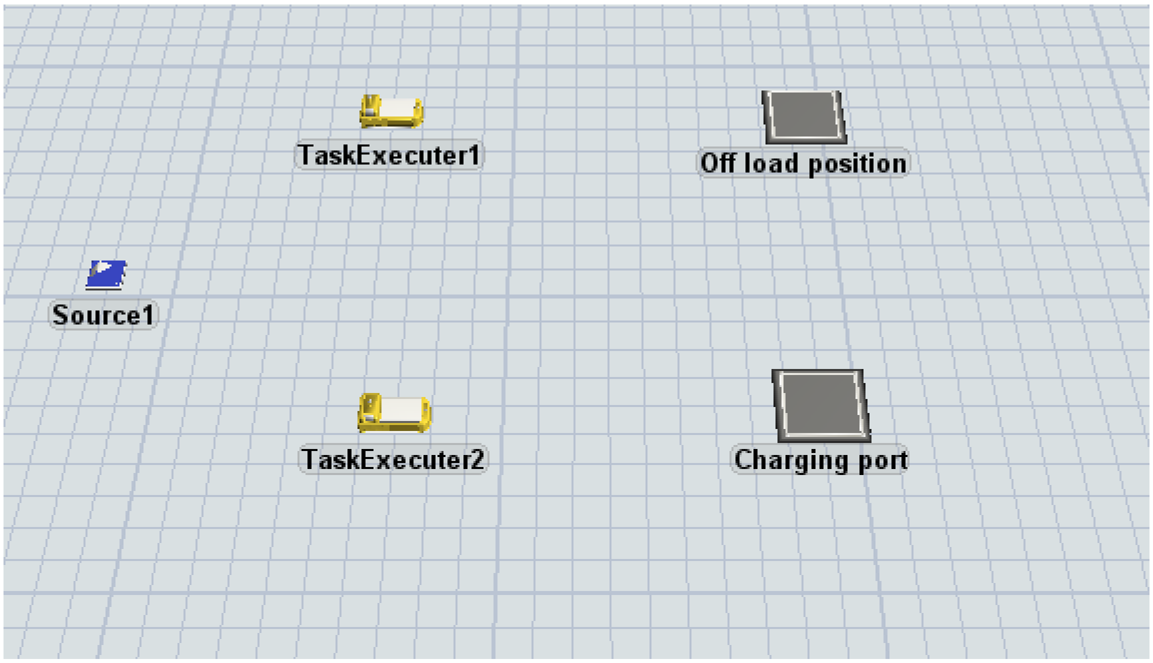
1) **Breakdown: -** The breakdown is bad for the efficiency of the plant and it delays the finishing of the final product. Of course, every organization tries to avoid breakdown as much as they can by doing regular maintenance. Even after regular maintenance, few times breakdown happens and sometimes the organization is not able to respond quickly enough to minimize the loss. I tried to simulate the small demo model to see how quickly it is to resolve the breakdown issue in the case of the AGV model. Below is the overview of the model:



Here in this model, I took three AGV's and three Dispatchers which control the movements of AGV's. there is the main source, a queue where items may wait, one processer, and final sink. Thanks to the breakdown option in the logic tab of AGV, I pushed AGV3 to breakdown after some specific time to see its impact on the operation. As you can see in the model dispatcher2 and dispatcher 3 are connected with each other and AGV3 is connected with both dispatchers2&3. After assigned time AGV3 stops working then it sends the message to dispatcher2 via dispatcher3 and dispatcher2 push AGV2 immediately to go at the place of AGV3 to perform the operation of AGV3 too. Of course, it stresses the functionality of AGV2 but one important thing to notice here is that operation didn't stop fully. Of course, the output would be a bit less as compared to a normal one, but it is much better than full block of the whole operation.

If we compare this breakdown issue here with the one of conveyor one, then no doubt if there are breakdowns in case of conveyor model it fully blocks the operation. Without fix the issue of the conveyor it is not possible to continue the operation. Depends on the breakdown level it could affect the operation even for several hours. In the case of AGV, as I explained, nothing will be fully stopped. This is one of the main advantages of using the AGV mode of transport.

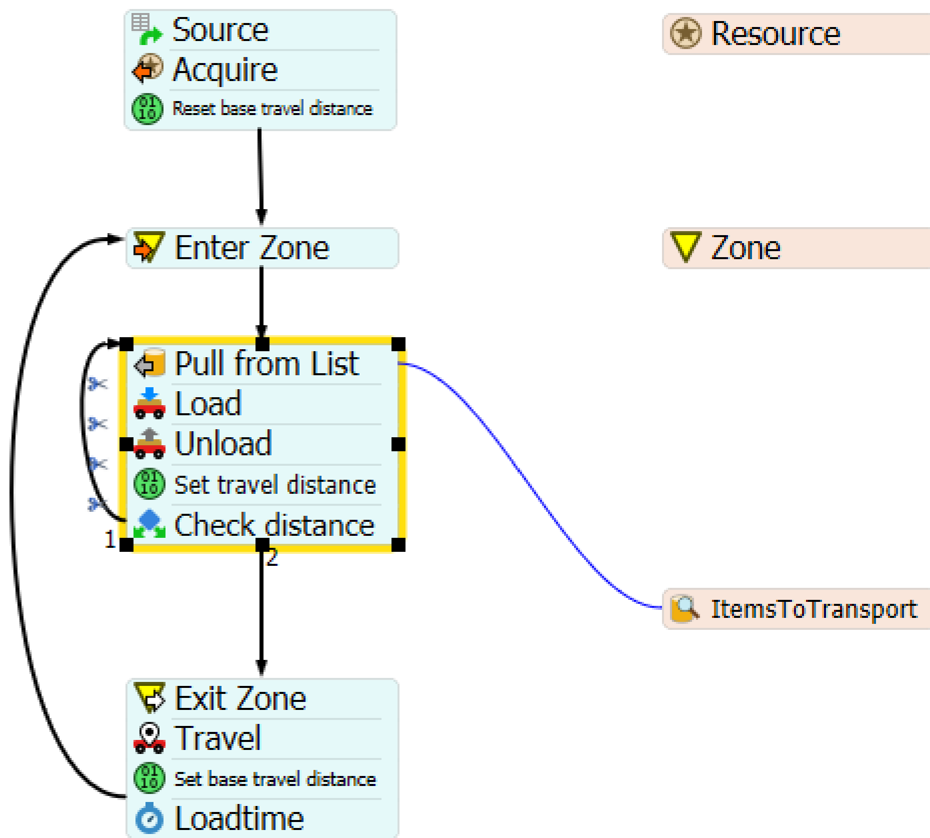
2) **AGV Charging issue: -** the main concern behind using the AGV mode of transport is the charging time of AGV's. charging time issue doesn't exist in the case of conveyors. With the help of discrete event simulation, I tried to analyses also this issue. Thanks to the process flow option in Flex sim I made a small demo which explains how charging could be resolve in the case of the AGV model. Below you may see the overview of the charging model for AGV:



In this model, I used two AGV's, one main source from where AGV's are transporting the items to the destination. Particularly in this model AGV2 is the dummy AGV which performs when AGV1 goes for the charging. One dummy model could be used for several AGV's if charging of all AGV's doesn't finish at the same time. In this model, I pushed AGV1 to go for charging after cover the 100-meter distance. Once AGV1 cover 100-meter distance it goes to charging port and AGV2 immediately take the place of AGV1 and start performing the same operation of AGV2. It would be a good option to leave one AGV always on the charging for example during the operation time of AGV1, AGV2 may get charge. AGV2 can be used also for other issues like the breakdown of AGV or overwork for AGV1.

Of course, this type of flexibility Is not possible in the case of conveyors. If something happens it is mandatory to repair or replace the broken conveyor with the new one. Based on the parameters of all different scenarios, one AGV could work continuously for 10 hours with 390 kg weight which is a good time. Of course, dummy AGV would increase the fixed initial cost but they would be saving the breakdown loss and provides a lot more flexibility than the conveyor models.

Specifically, this demo model of charging is simulated by using the process flow method. Below you can see the whole process flow chart:



The process flow is quite simple to read. In the first step, it pushes to provide the initial item through the source, and after every reset of the model, the base travel distance is reset to zero. Once the item is available from source AGV1 move to take the item, during all this check distance command is controlling the travel distance of AGV1. Once total travel distance reaches equal or more than 100 meter it pushes the AGV to exit the zone and AGV1 moves to the charging port. Once AGV1 reaches at charging port, AGV2 start performing the work of AGV1. After completing the charging time again with the help of set travel distance command AGV1 get assign next charging after travel some specific distance which is 100 meters in this case.

After all the structure of the different model of different scenarios I would like to speak about the outcomes of all scenarios.

8.Results

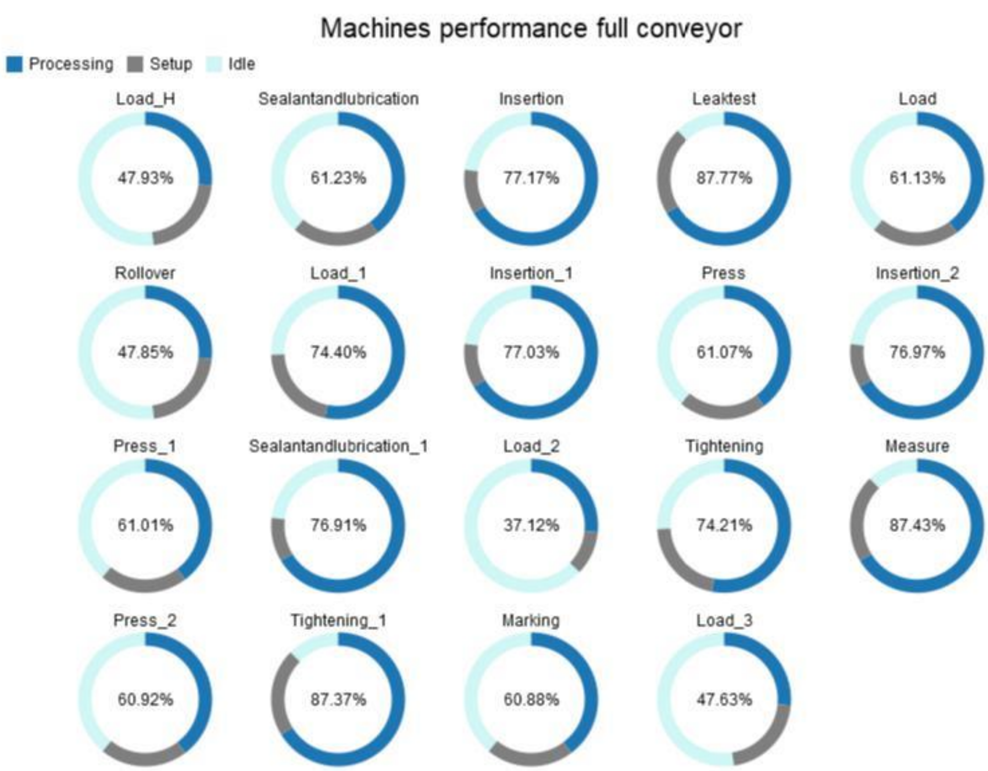
Before going for results I would like to point out that the final output of all 4 scenarios is the same. The final output was the main target and then by keeping that target I analyzed 4 scenarios based on finance, energy consumption and the complexity of plant layout.

Results are mainly divided into four main categories: -

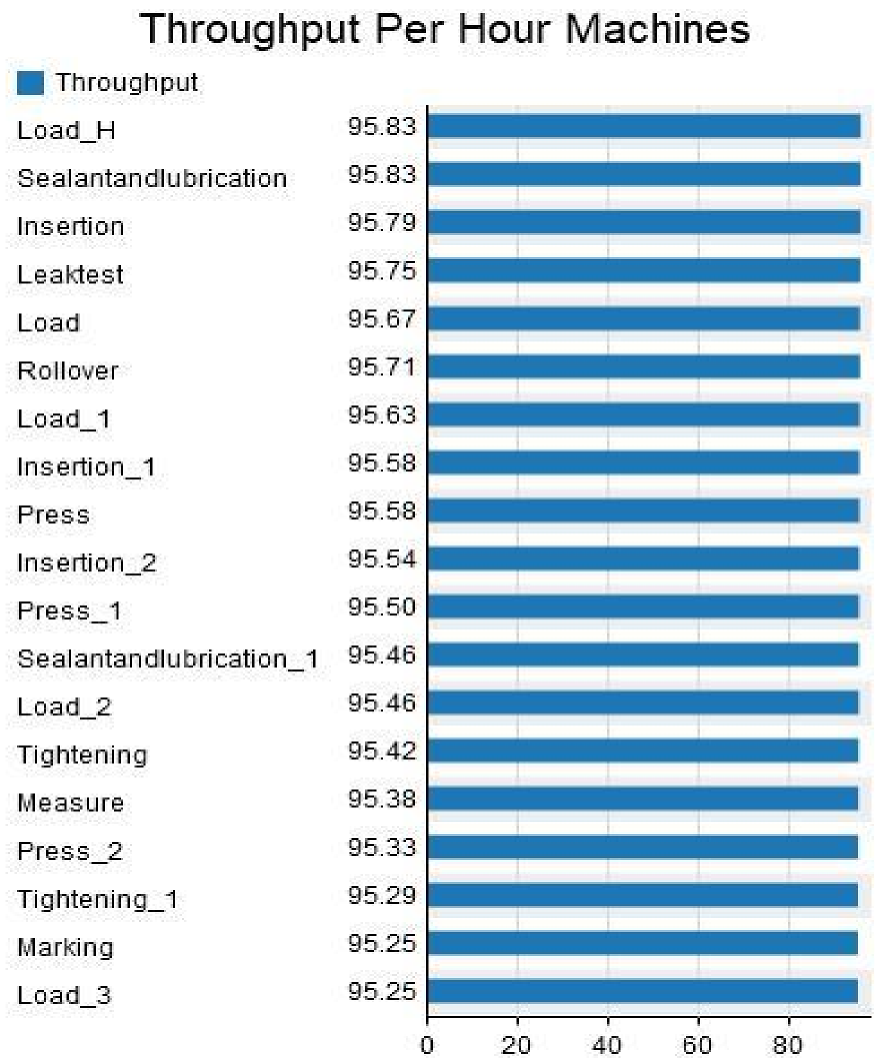
1) Processor Performance
2) AGV Performance
3) Conveyor Performance
4) Final Sink throughput

I will discuss the outcomes of results one by one based on the above categories for all different 4 scenarios.

1) **Processor Performances: -** The parameters of processors are the same in all 4 scenarios which are mentioned before in table 1. As I mentioned before the final output of all 4 scenarios is the same despite different modes of transport. Below is the processor performance chart for the case of the full Conveyor model. As we may notice that most of the time maximum processors were in idle situations this was because of various factors like travel time of workpiece, few machines process time is more as compare to others, so it was not possible to call new items until the previous one is not processed.



As the final output is constant in all 4 scenarios so the output per hour for all the machines is almost constant in all 4 different scenarios. Below is the output per hour of all the processors:



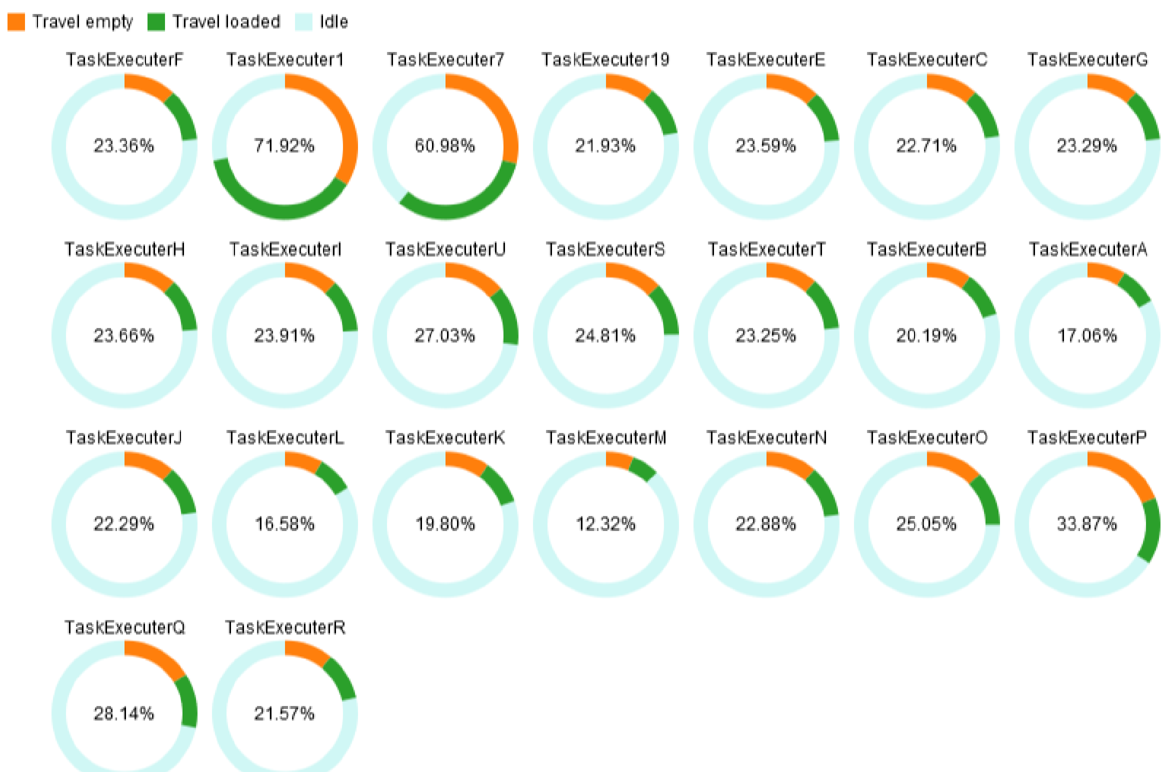
This was the main result that belongs to processors. Despite modes of transports, I didn't notice any impact on processor performances which is a good thing because my main goal was to make the mode of transport better then processor performances. So here I can say plant machines output and the final output is not affecting.

2) AGV Performance: - Automated Guided vehicle performances varied from one scenario to another scenario. Based on the requirement different numbers of AGV has been used for example in case of full AGV model maximum AGV has been used which is 27 in total.

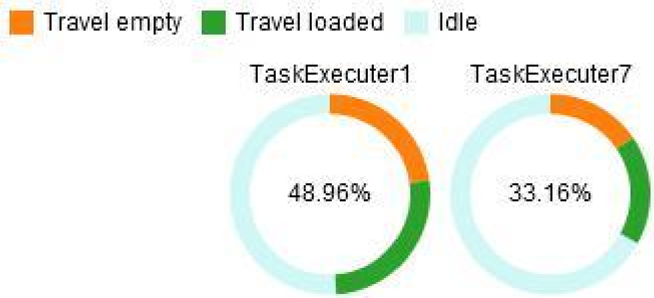
One AGV has been used with each machine to avoid the waiting time of processors and crashes between AGV's. transport from the warehouse always done by AGV as it was complex to install a conveyor from the main warehouse to each machine. Based on the operation the logic has been assigned to AGV.

Now I will present AGV performances one by one.

- **Full AGV: -** Below is the performance of all AGV which is assigned to each machine. We may notice that the performance of all AGV is almost constant in most of the cases except AGV 1,7 and 19 because they are assigned to main warehouse.

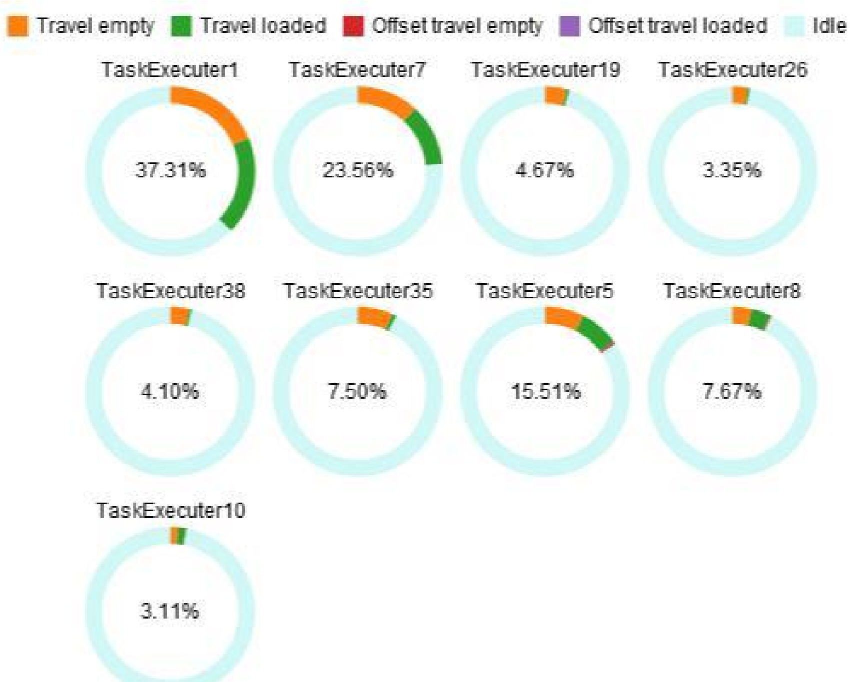


- **Full conveyor: -** in this model AGV has been used only for the transportation of lots from the warehouse.

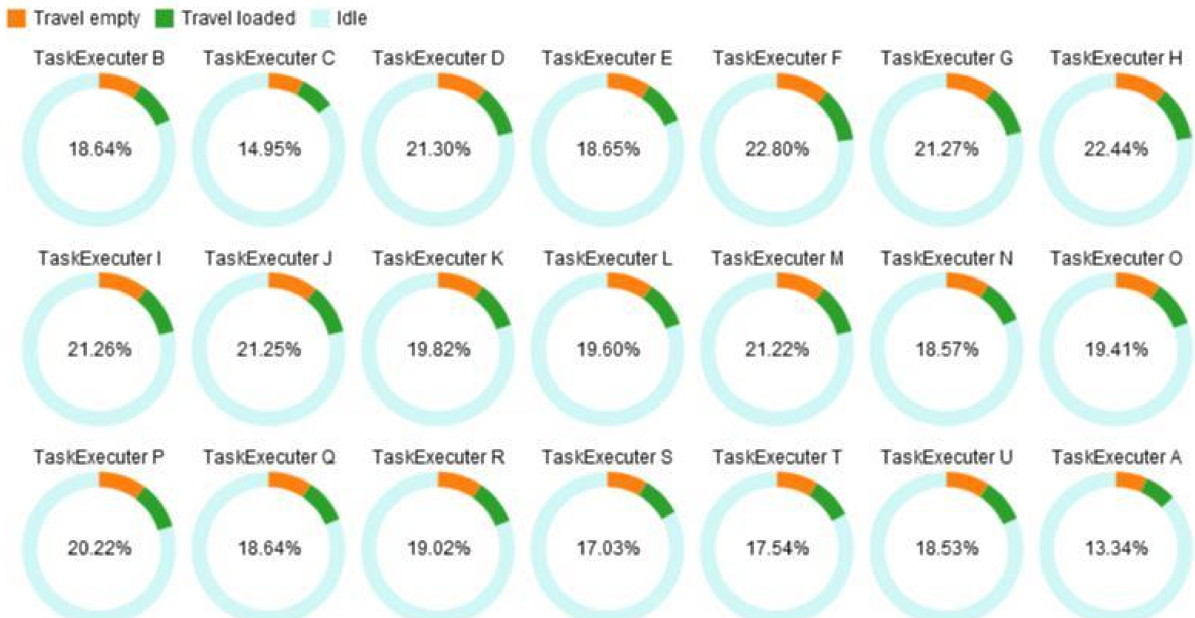


The main reason behind the increase of usage of AGV1 and AGV7 in the case of the full conveyor model is because of the plant layout. In the case of full AGV model AGV's needed to travel more as compare to the full conveyor model.

- **Lots with AGV: -** in this scenario, AGV has been used for the transportation from the main warehouse to the respected queues to processors and then from queues to the processors. AGV1 and AGV7 have been used for the main warehouse. Also, here we can notice that the performance of AGV1 and 7 is in between full conveyors and full AGV which signify model layout was the main parameter. AGV 5,8,9,10,19,26,35 and 38 have been used for the transportation of lots from queues to the processors.



- **Lots with Conveyors: -** In this scenario, conveyors have been used only to transport lots from queues to the processors. AGV has been used between machines and for the main warehouse.

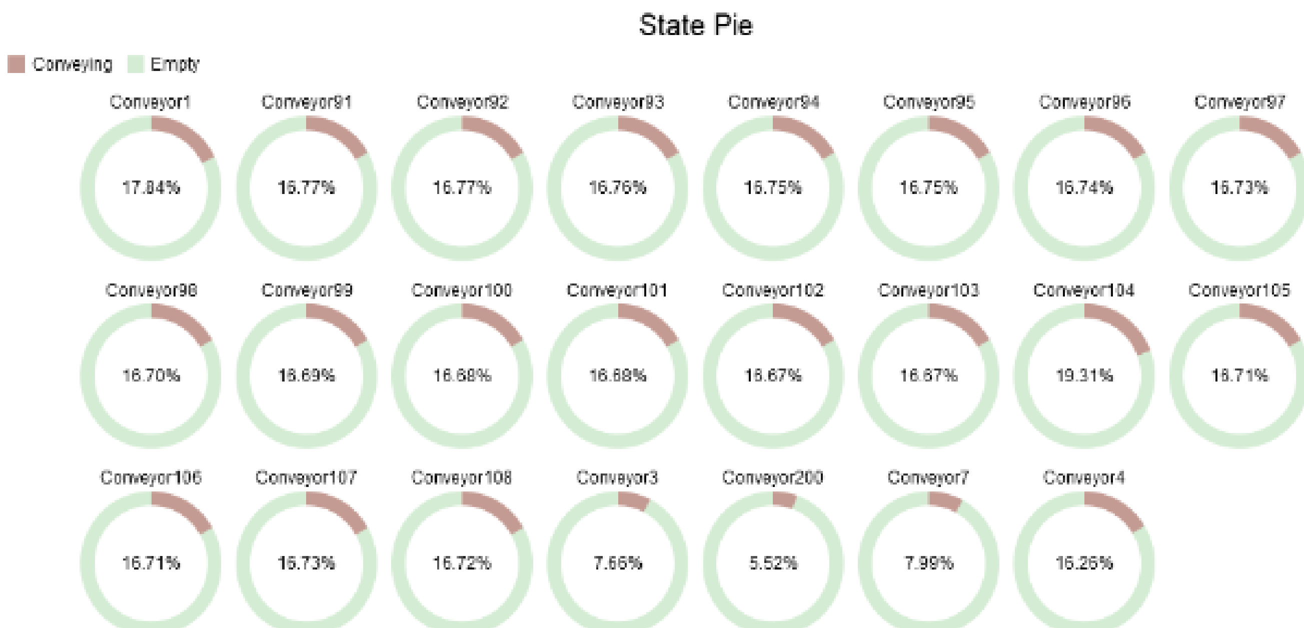


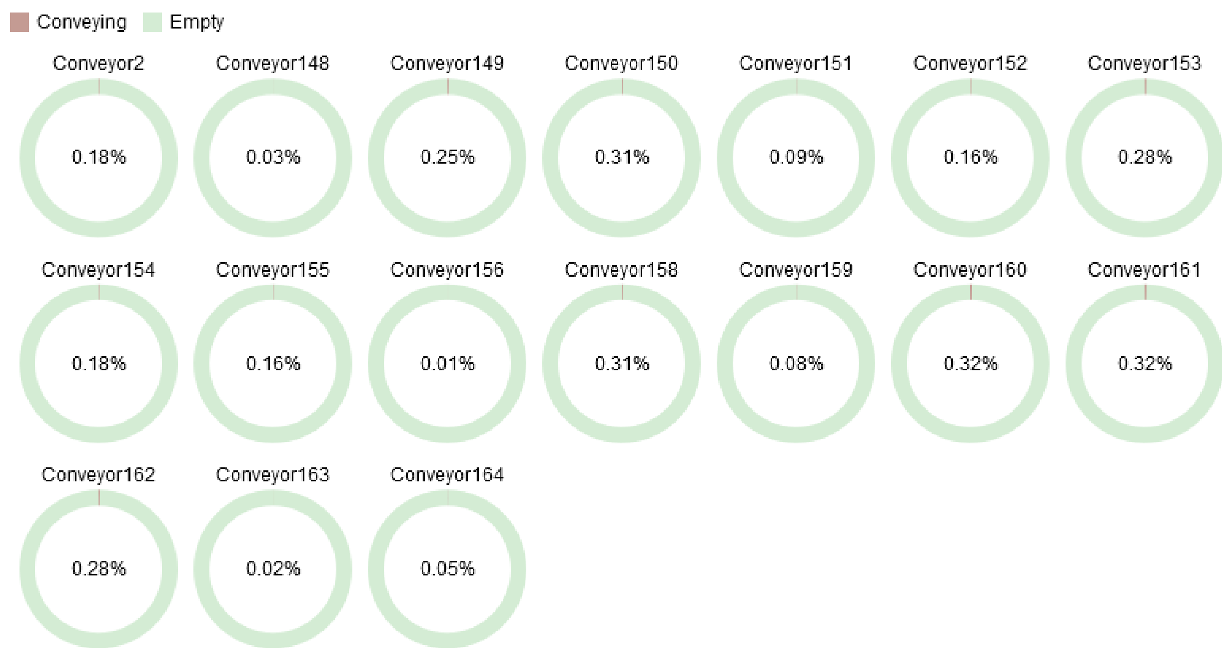
Below is the performance of AGV used for the main warehouse:

3) **Conveyors Performance: -** like AGV, conveyors length varies from scenario to scenario. In the case of full conveyor model maximum conveyor has been used between machines and between queues to machines for lots.

Below is the performance chart of conveyors which differs from different scenarios.

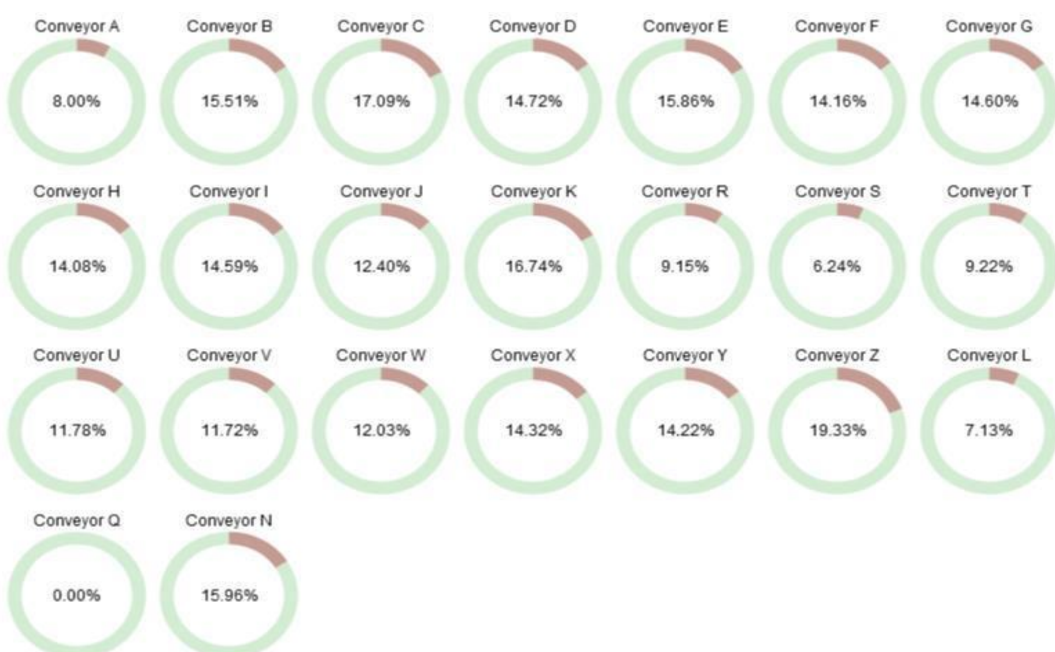
- **Full conveyor: -** as we can see below that most of the time Conveyors are empty that is because of set up time and process time. We may notice that the utilization time of conveyors is less then AGV that is because of AGV moves both in loaded and unload situation.



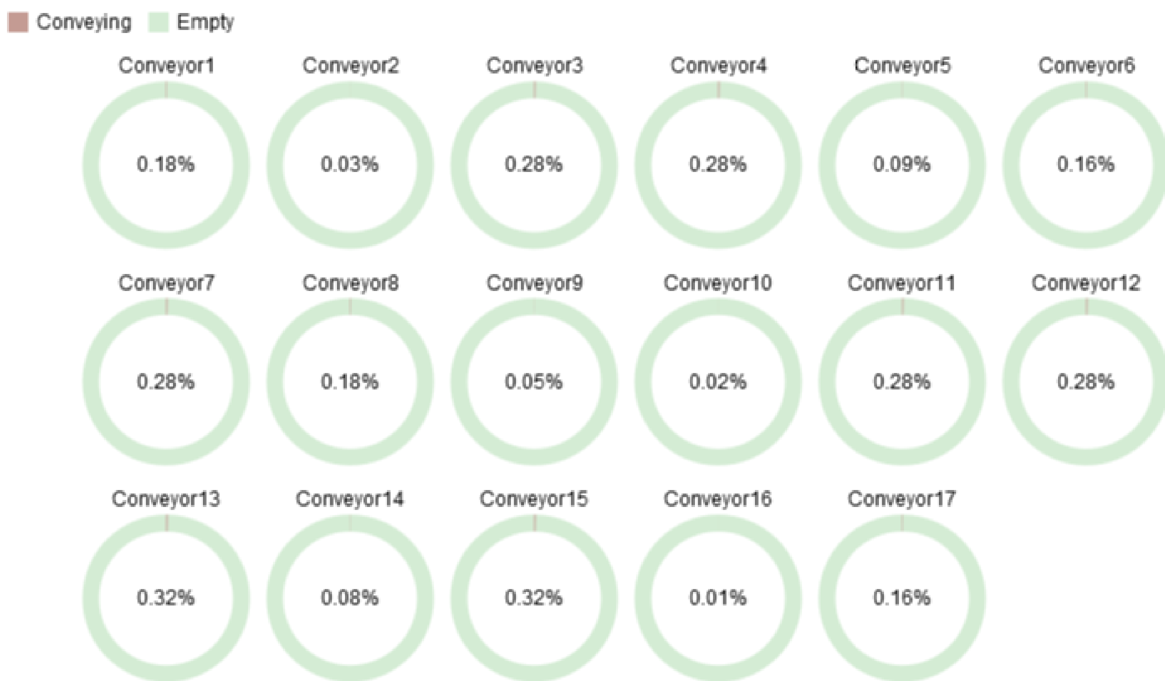


As I mentioned before the utilization time of conveyors and AGV for the transportation of lots from the queue to processors is very less. It can be noticed from the upper performance chart

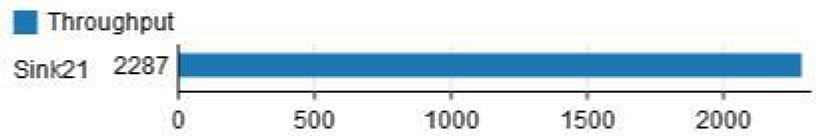
- **Lots with AGV: -** in this model, conveyors have been used between the machines as it was in the full conveyor model. Below is the performance chart for this scenario:



- **Lots with conveyors: -** in this scenario, the conveyors utilization rate is very low because here conveyors have been used only to supply the lots.



4) **<u>Final Sink throughput: -</u>** as I mentioned before that the final output in all the scenarios kept constant which is 2287 items. Below is the unique representation of throughout:



After all, the above-explained result now I would like to represent a unique combined picture of all the scenarios. After all the different results of different scenarios, I decided to make an analysis that mainly focuses on the comparison of energy consumption and financial situation. For both energy and financial factors, I considered only AGV's and Conveyors not processors, queues, and warehouses because the main aim of this thesis is to evaluate an effective mode of transport using lean principles. The cost of processors, warehouses, and queues don't change if we change the modes of transport.

After all the analysis of energy consumption and fix cost, I conclude that the Full AGV model is the most effective model in terms of energy consumption and for an initial fixed cost. Below you may see details of energy consumption and fix cost for each scenario:

1) **Full AGV model**: - in this model as mentioned before that at every point the mode of transport is only AGV. In terms of energy consumption and fixed cost, this scenario is the most reliable one. I considered the fixed cost of one AGV as 14.000 euro and energy consumption is calculated by considering the weight of AGV as 350 kg. the average weight of items considered here is 40 kg. The full details of the energy calculation will be explained in the later chapter. Below are the specific details:

Full AGV Model		
	Total Energy Consumption/Hour (KJ/H)	Fix cost
AGV	11635.64	€ 322,000.00
Total	11635.64	€ 322,000.00

2) **Full conveyor model: -** in this model conveyors have been used except for the transportation of lots from the main warehouse AGV has been used. I considered the fixed cost of the conveyor as 600 euro/ feet. In this model total, 600 feet of conveyors have been used which transport almost 100 t/h. the weight of the item is the same here also which is 40 kg. below are the specific details:

Full conveyor		
	Total Energy Consumption/Hour (KJ/H)	Fix cost
Conveyors	25771.00	€ 361,974.24
AGV	1091.38	€ 28,000.00
Total	26862.38	€ 389,974.24

3) **Lots with AGV model: -** the fix cost, in this case, is almost the same as the one of the full conveyor model but it is more convenient in terms of energy consumption. Here AGV has been used for the transportation of lots from queues to the machines. Below are the specific details:

Lots with AGV		
	Total Energy Consumption/Hour (KJ/H)	Fix cost
Conveyors	18818.00	€ 263,042.88
AGV	2002.42	€ 126,000.00
Total	20820.42	€ 389,042.88

4) **Lots with conveyor: -** this model is the most inconvenient one in terms of fixed cost because only 4 AGV is less if we compare with the full AGV model but at every queue's conveyor has been used for the supply of lots which increased the fixed cost. Regarding energy consumption, this model is the second most convenient model after full AGV. Below are the specific details:

Lots with Conveyor		
	Total Energy Consumption/Hour (KJ/H)	Fix cost
Conveyors	6711.00	€ 100,368.00
AGV	9177.35	€ 350,000.00
Total	15888.35	€ 450,368.00

Energy calculation of AGV: - Below is the full details about how energy consumption is calculated for the AGV and results has been used for all the scenarios because weight of items didn't change throughout the scenarios.

1 Weight

Weight of the Vehicle = 350kg
Approx weight of item which AGV has to Carry between Machines = 40kg
Maximum Approx weight including vehicle and item = 390kg

2 Battery

Battery for comau Agile 1500 = 24V and 205 AH
Power Available from Battery =

$$24 * 205 = 4.92KWH$$

3 Vehicle Energy and power calculation

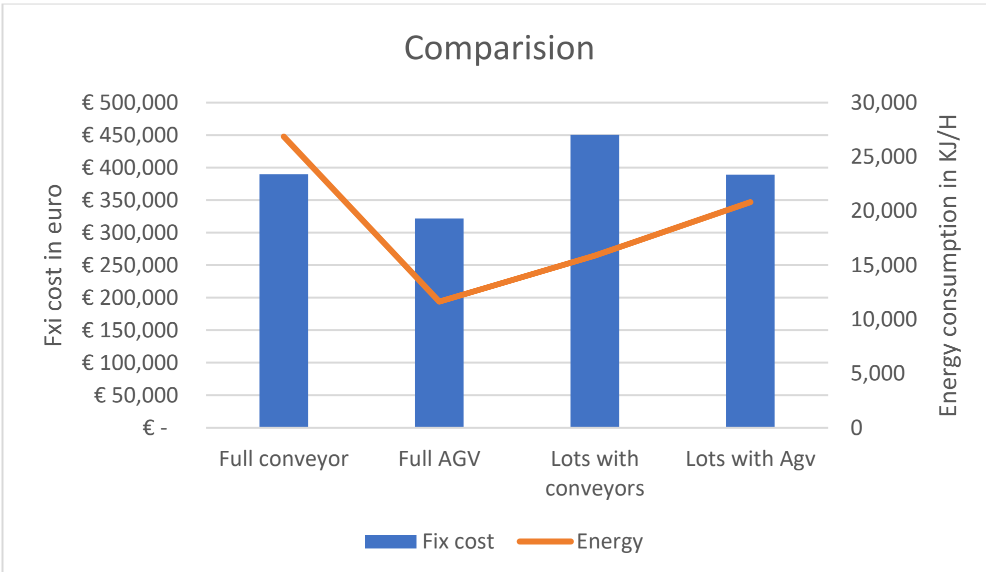
Total weight to carry = 390 kg
Maximum speed = 1.7 m/sec
Energy Required to move AGV In loaded condition=

$$1/2 * 390 * (1.7)^2 = 563.55J$$

Total Energy Required by vehicle in one hour = 563.55*3600=2028.78KJ
Total Energy which battery of AGV is available to give is = 4.92KWH

$$4.92Kwh = 17712KJ$$

After careful analysis of all 4 scenarios, the Full AGV model is the most convenient one. Flexsim AGV properties option helped to simulate the model more precisely. The full AGV model provides more flexibility, less labor cost, easy to expand, and increased accuracy and productivity. Below is the final presentation of all 4 scenarios together.



9.Conclusion

After the design of the experiment and results, the aim of this thesis has been achieved which was to use discrete event simulation for the implementation of Lean principles especially in the manufacturing perspective. A group of elements (different modes of transport, buffer, financial concept, etc.) has been identified in the evolution of future state Lean proposal implementation when using Discrete event simulation. A comparison was made between the Value stream mapping, a traditional tool for Lean Production assessment, and discrete event simulation. As it is represented in previous sections that how different modes of transports make a huge difference from energy and financial point of view. Simulation of all different scenarios proved that how discrete event simulation could be effective in analyses the different Lean principles. DES also proved that it could be used as a fact-based long-term solution to improve the manufacturing system. At this point, I can say this thesis work answered all the research question which were introduced in chapter number 3.

It is clear that DES is not a Lean specific tool, but it helps to implement the Lean principles. Within the concepts of Lean waste, identification is perhaps the most important one when pinpointing to a Lean principle when DES is used as a tool of evaluation. Developing a simulation model is the first step towards Lean implementation, simulation helps direct expected results of factory settings once machines and production processes are modified.

VSM and DES are two different things and they compete with each other in a variety of ways. VSM gives a good look at how the system works and the product flow. VSM gives an excellent foundation to build the first steps of a DES model. On the other side, the DES software has an interface that allows the user to see the system operating on the screen. It is extremely helpful to see changes in future layouts and product flows.

The simplicity of a VSM identifies the key critical issues and at the same time sets the data basis for modeling in DES. The simulation then delivers in-depth performance data over time and functions as an add-on to the VSM. DES is a complex method for the simulation that allows for very broad flexibility in the design and evaluation of models; models that may reach beyond the scope of Lean production and into new paradigms in manufacturing. Further studies on this subject would be beneficial for the fields of simulation and manufacturing. Further studies are necessary to understand the reasons as to why DES is viewed as a consultancy experience rather than an everyday tool.

Before the conclusion, it would be worth discussing the role of AGV in the current and future manufacturing industry. In this thesis simulating different modes of transport by using DES was the main aim. Conveyors have been a common sight in manufacturing plants for almost 100 years. There are a lot of disadvantages also to work with conveyors like a person is often forced to work around the conveyor system and the conveyor system is very complex and expensive. As we are forced to work around the system it limits the implementation of new Lean principles and continuous improvements.
Improve safety, remove floor constraints, decrease cycle time are a few challenges that the manufacturing industry is facing nowadays. In case of breakdown, AGV transportation is easier and quicker to resolve as compared to the conveyor's system. The initial cost of AGV’s is higher than the conveyor system but if we compare usage of AGV with conveyor for a long-time span, no doubt AGV is a better choice.

From the energy and financial analysis, it is clear that the full AGV model is the most beneficial one. Of course, the matter of charging and the initial high cost is a disadvantage for this mode of transport but if we see the situation for a long time then it is worth it. One good advantage of AGV is that one AGV could be used on the production floor and later the same AGV can be used inside the warehouse or for some other transport purposes. For conveyors, we don’t get this advantage of multipurpose use.

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