OPRE 6340-001

MECH 6335-001

FLEXIBLE MANUFACTURING STRATEGIES

PROFESSOR KATHRYN E. STECKE

(FALL 2021)

PROJECT REPORT

TOPIC:

PRODUCTION PLANNING, CONTROL AND MANAGEMENT IN FLEXIBLE MANUFACTURING SYSTEMS (FMS)

GROUP MEMBERS:

Abishek Ravichandran

Darya Fardi

Jevin Viral Solanki

Kevin Christopher Sebastian

Pranoti Maharnawar

Shraddhesh Subhash Kamal

PROJECT SUMMARY

A flexible manufacturing system is an integrated, computer-controlled complex of automated material handling devices and numerically controlled machines that can simultaneously process medium-sized volumes of a variety of part types. Production planning and management is one of the more tedious and difficult aspects of manufacturing, which is what our project will focus on. The control of FMS is achieved through computer-implemented algorithms which make the operational decisions. These algorithms and the man-machine interfaces necessary for control are discussed. We will be researching companies that use flexible manufacturing systems and look at their management practices. Our goal is to outline ways to plan production for custom as well as standard units, while saving cost and increasing utilization. Our research will focus on standards that managers have implemented to maintain a lean environment; especially considering that employee engagement and training is challenging to implement. We will look at different incentive programs for employees and how corporations utilize metrics to track employee outcomes. The project report would consider the challenges and problems associated with FMS and the information that is necessary for their control and efficient operation. Additionally, we discuss the implementation and operation phases of FMS, where the user requires adjusting and fine-tuning of the FMS to the best operating conditions. Furthermore, the importance of production schedule and Material Handling System schedule in FMS is highlighted. This research would involve a comparison analysis of production planning, control and management scheduling after FMS emerged in its chain of processes. The analysis would also include challenges associated with working strategies and automation advancements in industries. To achieve desired results, we need to update the work culture along with production techniques. Work culture change can be implemented by training all levels of an organization. Consequently, this change may provide other benefits like quick introduction of new products and also satisfy changing needs of the market (flexibility).

Our report focuses on the sub-divisions involved in FMS, which are production planning, control and management. These sections play a critical part in any manufacturing system and should be highly efficient and flexible in order to satisfy company as well as customer needs. Therefore, these sections are described in detail with focus to current industrial applications with relevant examples

WHAT IS FLEXIBLE MANUFACTURING STRATEGY?

A flexible manufacturing system is an integrated system which is capable of processing variety of jobs simultaneously with the help of automated workstations assisted by an efficient material handling system. For an effective use of an FMS, integration of flexibility, efficiency and multifunctionality of the system is required. But like all systems, FMS also has certain limitations. In order to minimize those limitations and make the system efficient, many companies use Manufacturing planning and control systems (MPCS) as a key condition to deal with them.

MANUFACTURING PLANNING AND CONTROL SYSTEMS (MPCS) DECISION HIERARCHY

The approach to MPCS is divided mainly into three subcategories as explained below:

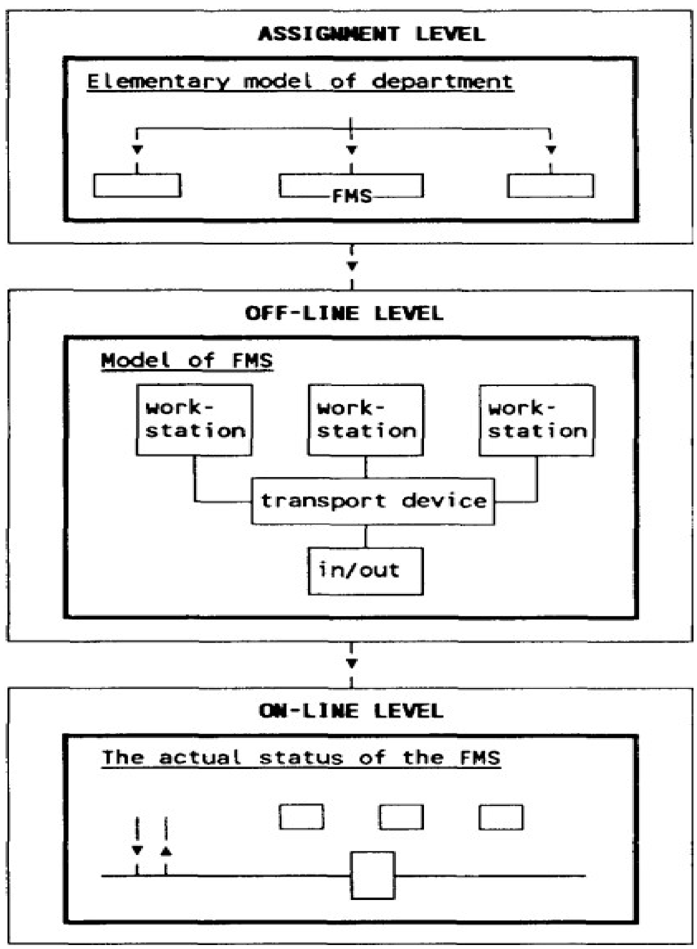
- Reduction of complexity - Complex interrelated problems are divided into small solvable problems which make them easier to deal with.
- Separation of goals as per their respective nature – The categories are:
    - Short term goals – Usually called as operational goals, are goals which can be modified easily and are flexible.
    - Medium term goals – They are termed as tactical goals in companies.
    - Long term goals – They are strategic goals which are aimed for longer period. In such goals forecasting method is used to predict ahead of time.

- Improving stability and controllability – If a problem is left unsolved, it multiples exponentially as it in a process, which affects planning at higher levels in a process. So, in order to avoid this, the problem is solved at a lower level without needing to replan at a higher stage.

MPCS DECISION HIERARCHY DIVISION

The decisions in MPCS (Manufacturing Planning and Control Systems) are distinguished based on the following three levels of hierarchy, namely

1. The Assignment Level
2. The Off-line Level
3. The Online Level.



1] **Assignment Level:**

- As the name suggests, at the assignment level, jobs are distributed and assigned among the various production units or workstations including the FMS.
- This helps us with the generation of realizable throughput times and for estimating a realistic workload on the FMS.
- This is executed by applying the MRP (Material Resource Planning) System at this level.
- Since these decisions are not required to be carried out frequently, they are executed either monthly or weekly.

2] **Off-line Level:**

- The jobs from the assignment level now move on to the Off-line level.
- Here, the jobs received are matched with the characteristics or limitations of the FMS to execute batching of jobs.
- These decisions are based on a pre-existing model of an FMS.
- The decisions at this level are also used for the assignment of tools and operations to the various workstations.
- Since these decisions are to be carried out more frequently as compared to the assignment level decisions, they are executed either weekly or daily.
- In certain kinds of MPCS, the off-line level for decision making can be completely absent.

3] **On-line Level:**

- The jobs from the off-line level now move on to the On-line level.
- On-line level decisions or activities are carried out for the management of dispatching jobs received from the Off-line level to the FMS and to decide the sequence of activities.

- These decisions are carried out based on two factors, namely the actual status of the FMS and the degree of detailed information received from the Off-line level.
- These on-line decisions can be executed at any point of time.

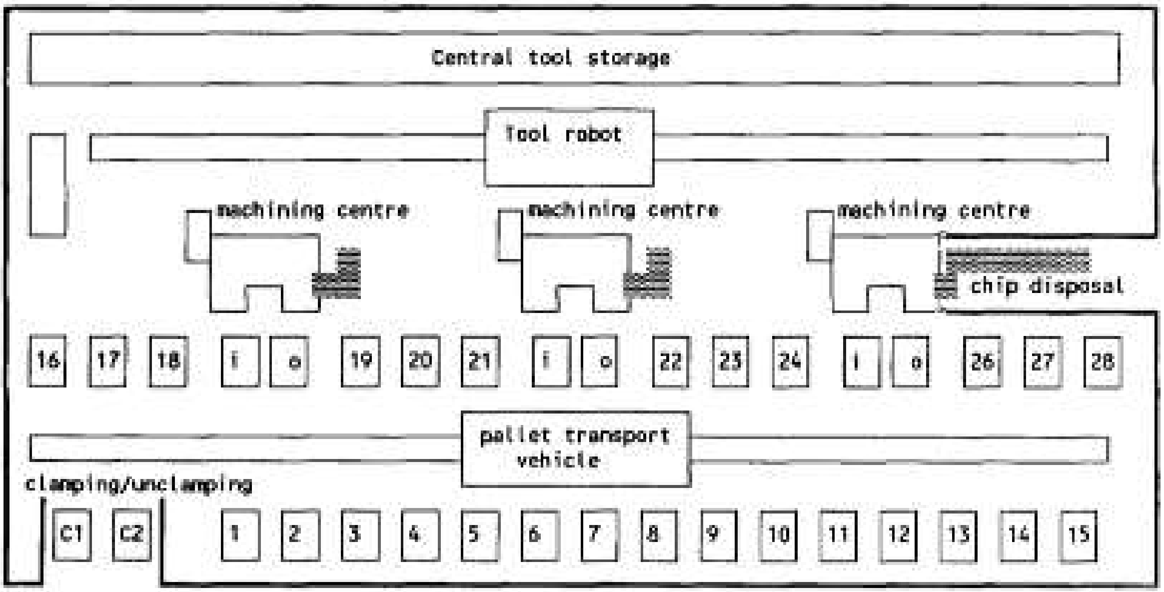
All the decisions in the above hierarchy are made with the assumption that the processing characteristics of the jobs are completely known. These processing characteristics might include things such as the number of tools and fixtures needed, process plans, processing times and many more.

These Levels of Decision Hierarchy Of An MPCS Are Explained Further With The Help Of An Example.

Example

To create a better understanding, in this section, we will try and walk through an example of how manufacturing planning and control can influence the overall process and help in improvements all around. We take an example referred in one of the papers we read for our survey and research of the topic. [11]

This company is a manufacturer for Pneumatic and electric actuators for valves. With rapid rise in demand for the product requires increase in volume. Along with this, there was also increase in diversity. This correlates to increase in volume as well as variety of products. This rapid rise has a knock-on effect of the required metal-cutting capacity, which also would have to increase. So, the diversity was mainly based on the actuator housing changes. Even with the increase in the demand, they want the lead time to be relatively short. So, an FMS system was installed to keep the lead time short. FMS was only installed to customer specific actuator housing. Total lead time for actuator housing is 8 weeks. 5 weeks required for the procurement of raw material and basic component manufacturing. After this in remaining 3 weeks are used for FMS operation, some finishing operation and final assembly. The observation here is, before the FMS system there were about 15 different housing, and after the FMS that went to 150. This then becomes a bottleneck in the system.



Schematic representation of FMS

Above figure shows a schematic representation FMS. Three identical machine centers are linked together by pallet transport vehicle. Capacity of pallet is 28. The 3-machine tool magazine have capacity of holding 40 tools each and tool changing process is automatic. Another point to note is that the clamping and unclamping operation is manual.

The Assignment Level

In this company every quarter, sales forecast is presented on aggregate level and planning department, converts that to master production schedule. While converting, planning department considers rough rules such as economic batch size quantities and estimation of required capacity on FMS.

ISSUES FOUND IN FMS

1. To avoid machine idle time, orders are manufactured in job mix routine. As mentioned earlier, the tool magazine holding capacity is 40 tools so we can deduce, the number of cutting tools required for a mix would be less than or equal to the capacity of the tool magazine.
2. A unique cutting tool cannot be used simultaneously on more than one machine.
3. A unique fixture cannot be used simultaneously for more than one job.
4. Even if three machine centers are identical there are some minor differences. Because of this differences accuracy of three machine center is different. Also, only third machine center has extensive chip disposable equipment. All these factors affect the interchangeability of the job.
5. As FMS is a capacity bottleneck, high utilization of FMS is essential. We know that the company runs in three shifts and the first and second shift is a manned shift with the third shift being partially unmanned. To utilize this unmanned shift, job which require long processing time are done in this shift.

Most of the above problems in FMS can be resolved using optimization algorithms and we are still searching better solution.

SCHEDULING

Scheduling is a quintessential part of the control process in any manufacturing system, which is highly essential to produce and manufacture a variety of products at the same period with the assistance of a common set of resources. As computer integrated manufacturing is more complex because of the large number of resources, information requirements and decisions as well as a larger variety of jobs involved, the scheduling of these manufacturing processes will increasingly require team effort to segregate the process parameters. In such an environment, the scheduling agents that could be used are flexible cells, machine centers, or human schedulers. Process planning provides the fundamental input parameters to enunciate scheduling. Process planning also accentuates the technological necessities of a task, while scheduling involves the precise timing aspects of it. To meet the burgeoning flexibility requirements of scheduling and control in FMS, process planning, being one of the primary inputs of scheduling, must provide more flexibility. Scheduling involves the precise time allocation for operations in the selected linear process plans with the objective of minimizing the completion period. An example is the usage of an integer linear program (ILP) formulation for scheduling. Although the formulation used in the scheduling stage is quite common, the fundamental variation is the concept of the working time of machine tool which refers to the time after which the machine tool is available or, in other words, the time until which the machine tool is busy. Machining, breakdown, or maintenance determine the busy time of the associated machine tool. The scheduling stage considers scheduling periods where any given order list can be scheduled in a predictive manner. The main purpose of scheduling is to assign the necessary machines and other resources to respective jobs, or operations within jobs, in a very productive manner, as well as to determine the moment when the jobs are processed.

SCHEDULING APPROACHES

The different approaches available to solve the problem of FMS scheduling can be divided into the following categories:

1. The analytical approach.
2. The heuristic approach.
3. The artificial intelligence (knowledge) based approach

Analytical Approach

Firstly, the rule is selected at the appropriate moment by simulating a set of pre-established dispatching rules and choosing the one that provides the best performance. The approach is basically the assimilation of the process into smaller solvable problems. The final step would be to combine those solutions into one final approach.

Heuristic Approach

The heuristic approach, belonging to the field of artificial intelligence, a set of earlier system simulations and training examples is used to determine which is the best rule for each possible system state. The approach would be to solve a problem with various shortcuts, that may not be optimal, but are sufficient, given a limited timeframe and reference.

Knowledge-Based Approach

Scheduling process in industries have taken a huge leap towards a precision and accuracy-based approach called the Artificial Intelligence approach or knowledge-based approach. The compilation of those acquired data of real time decisions is a key component of knowledge-based approach. In the years that followed, Industries commenced the usage of pre-coded robots, that also served as a general-purpose machine with anthropomorphic characteristics such as sensory stimuli response, inter-machinery communication, resemblance of human arm, decision making abilities, etc., to improve precision in production methodologies. These training cases are used to train a machine learning module to acquire knowledge about the manufacturing system. Such knowledge is then used to make intelligent decisions in real time. These scheduling systems are normally said to be knowledge-based. The process of machine learning uses these principles of data analysis.

Machine Learning

Machine learning is the use and development of computer systems that can learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data. Machine learning is a subfield of artificial intelligence, which is broadly defined as the capability of a machine to imitate intelligent human behavior. Artificial intelligence systems are used to perform complex tasks in a way that is like how humans solve problems. Machine learning (ML) techniques and applications have been strongly explored over the last two decades. ML applied to computer vision, speech recognition, and robot control, for example, have been broadly explored by several research groups worldwide. an increasing emphasis on the logical, knowledge-based approach caused a rift between AI and machine learning. Machine learning seeks to acquire knowledge about a specific domain from available data in an automated manner. The learning process may be supervised or autonomously guided. Machine learning techniques generally employ a small number of extremely general induction strategies coupled with some basic domain knowledge. The knowledge inferred may involve structural descriptions, procedural explanations, or even discoveries of new domain concepts. Knowledge may be stored as rules, semantic nets, logic predicates or frames. A working example is "Kiva robots", the ASRS robots incorporated in amazon warehouses, that uses knowledge of datum received to complete the task of moving inventory in perfect sync.

Example- Amazon's Kiva Robots

Amazon is one of the largest internet-based retailers in the United States offering domestic and international shipping services to its customers. The biggest influence of the use of robots beyond the realm of traditional jobs has been clearly being seen at Amazon- the biggest online retail stores the world knows. After the emergence of artificial intelligence and related new technologies, innovation has started triggering various e-commerce and the other related sectors significantly and is causing disruptive changes. The management of the US based retailer had adopted 15,000 Kiva robots across the U.S to deliver the entire warehouse racks to its employees. According to Amazon CEO Jeff Bezos, the enterprise had targeted an influx of 10,000 robots into the company's warehouses to help streamline efficiency and improve the workflow process. Adding more workstations, expanding the storage street grids, and quickly updating information about the environment were the major features of Kiva that attracted the retailer to adapt it in its day-to-day operations. The robot design was based on parallel processing such that if at any time the robot went down, the redundant robot could take its place. Along restocking the shelves, the robots could perform picking operations also simultaneously. Kiva robots could hold up to 750 lbs (340kg) of merchandise and track items on each shelf as orders come in. After using Kiva Robots, the company was able to help customers by picking a virtually endless variety of goods from warehouse shelves and delivering these selected items within the stipulated time. Due to shipping more than 700,000 items in a day, the firm would be in a better position to service its customers and meet the changing demands properly.

Amazon kiva robot model

Kiva carrying Inventory

MATERIAL HANDLING SYSTEMS

Material handling defined as an integrated source for moving, handling, storing, and controlling raw materials and tools in the industries. Material Handling is the important area of concern because more than 80% of time the material spends on the shop floor either in waiting or in transportation. For less congestion and timely delivery of material to workstations, a safe material handling system is required to reduce wastage.

Material handling equipment types:

1. Conveyor system
2. Cranes and Hoist
3. Industrial trucks
4. Monorails and other rail guided system
5. AGV system
6. Automated Storage and retrieval system
7. Industrial robots.

Most common Flexible material handling systems are Automated guided vehicles which are integrated vehicles which are integrated with Industrial robots, we further discuss on the types and new technologies in AGV transportation systems:

AUTOMATED GUIDED VEHICLE

An automated guided vehicle system (AGVS) is a material handling system that uses self operated, self-propelled vehicles guided along defined pathways. Vehicle guidance and navigation technologies in AGVs exploit the intelligence and control of material handling in batch production and mixed model production Automated guided vehicles can be divided into the following three categories: (1) driverless trains. (2) pallet trucks. and (3) unit load carriers. Driverless trains consist of towing vehicles moving heavy payloads over large distances in factories. Automated guided pallet trucks are used to move loads along predetermined routes. In the typical application the vehicle is backed into the loaded pallet by a human worker who steers the truck and uses its forks to elevate the load. Then the worker drives the pallet truck to the guide path, programs its destination, and the vehicle proceeds automatically to the destination for unloading. AGV unit load carriers are used to move unit loads from one station to another. They are often equipped for automatic loading and unloading of pallets or tote pans by means of powered rollers, moving belts, mechanized lift platforms, or other devices built into the vehicle deck.

AGVs are commonly used in Flexible manufacturing, Materials Parts are placed onto pallet fixtures by human workers in a staging area, and the AGVs deliver the parts to the individual workstations in the system. When the AGV arrives at the assigned station, the pallet is transferred from the vehicle platform to the station for processing. At the completion of processing a vehicle returns to pick up the work and transport it to the next assigned station. An AGVS provides a versatile material handling system to complement the flexibility of the FMS. New AGV technologies which are applied on the FMS based industries are discussed along with further details about the integration of guided vehicles with control systems.

“Vehicle Dispatching Rules (VDR):

- FCFS-first-come-first-served,
- MFCFS - modified-first-come-first-served,
- FEFS - first-encountered-first-served,
- MOQS - maximum-outgoing-queue-size-first,
- STTF - shortest-travel-time (distance)-first
- MOD FCFS - Modified-first-come-first-served,

- CLF - closest-load-first
- FLF, - furthest-load-first
- LIV - Longest-idle-vehicle,
- NV - nearest-vehicle,
- RV - Random vehicle.

OPERATING STRATEGIES OF AGV

Routing Practices: An AGV performs two kinds of trips; a loaded trip and an empty trip. At the end of each loaded trip, the AGV is assigned another loaded trip and routed directly for the next task. This routing practice is called direct routing. If the assigned trip is to be initiated from a different location, then an empty trip is inevitable even with direct routing practice. The AGV waits at the destination that it has been directed to. Another routing practice uses pick and place stations. The trip is initiated from a common loading pick and deposit station. This practice is called routing via load unload station. This leads to an empty move after each loaded trip. The location of the pick and deposit station influences the performance of the AGV. demonstrated that direct routing is more efficient than routing via load/unload station and is especially efficient when the ratio of average travel time. Early guidance systems consist of inducing a frequency through a wire buried in the floor that the AGV could detect and follow. Obviously, the floor modification for burying the wires supposes a high economical cost, Further, some variants were implemented to reduce it, such as wire installation through ceiling. Anyways, the modification of the physical guide-paths and, consequently, the workplace supposes a high economical cost. The new generation of industrial guidance systems, such as magnetic markers, reflective landmarks, or inertial systems, permit the AGVs to operate without physical guide-paths. Technologies focusing on increasing the intelligence of AGVs to perform actions like storing information about routes, traffic control in global systems, and making decisions. AGVs store the possible routes in a memory in conjunction with the map of the environment, and when an order is received, the navigation system decides which of the memorized routes is to be taken, normally in terms of the shortest path, to move from one location to another one. This model implies that the routes should be modified when the floor layout where the vehicle operates is modified. In the case that several vehicles are operating in the same manufacturing system, modifying routes implies computing and programming the paths in all the AGVs. In order to cope with the problem of guide-path networks design and its adaptation when some floor layout modification is performed, this work presents the development of a novel flexible AGV prototype designed from a service robotics perspective instead of a traditional factory automation one. The prototype permits performing typical transportation tasks in partially structured industrial environments by onboard real-time path planning while mapping workplace's modifications and avoiding non-modelled obstacles, techniques developed for autonomous mobile robots, such as path-planning, map building, localization and obstacle avoidance. The system design is especially focused on simplicity, flexibility and safety, which are critical issues in industrial environments. The system also satisfies the requirements of accuracy, repeatability and reliability needed for performing precise maneuvers in industrial applications. artificial intelligent techniques to increase the autonomy and flexibility of current commercial AGVs. The development is focused on flexibility and adaptability considering the simplicity and safe necessities of industrial applications Architecture, World representation, Path planning, Guidance system- Localization, path tracking, Obstacle avoidance.

Automated Storage Retrieval system (ASRS) is a type of material handling system which uses AGVs to transport goods and raw materials in storage centers and industries, ASRS consist of a storage structure (vertical or horizontal) and storage module generally pallets in which materials are stored based on the category. The storage retrieval machine collects the material from the pickup station and takes it to the workstations in the factories or deposit stations in storage places. The whole operation is controlled by an external handling system.

The newest technology of this ASRS system is implemented in a UK based Supermarket company called OCADO headquartered in Hertfordshire. OCADO is a grocery firm that uses ASRS in an advanced way, where there are battery powered robots, air traffic control system, connected with 4G technology that acts as the product retrieval component. Stocks are stored under the floor, AGVs pick each product based on the orders. The robots are programmed in ways that they don't collide with each other, the top speed of each robot is 4 meters per second. This is deemed one of the most flexible ways in implementing control processing in industries.

Ocado Storage Retrieval System

"The incorporation of advanced technologies, such as machine learning, AI, IoT, and robotics, into these systems is a major factor driving the growth of the automated material handling equipment market". "Flexible Autonomous Manufacturing (FAM) is the ability of manufacturers to change design for manufacture or implement product change seamlessly. Industry 4.0 removes the need for conveyor line production connectivity, instead using AIV to connect one manufacturing cell to another"

MANAGEMENT BY HID CARD MANUFACTURERS

Setting up the proper machinery equipment and having it well maintained is only half of the problem solving in production. What happens in the background is what most companies find the difficult task, managing employees and production, it's ongoing, ever evolving, and tedious. You can have the most flexible system with many chaining abilities but if the operations are not well organized a company can lose possible profits by functioning well under capacity and producing other forms of waste. One way to prevents these sorts of problems is to follow lean principles, this seems simple, but many companies fail to do so. Lean principles have also not been studied that long. They first started in 1926 with Toyota Production Systems where they implemented "just in time" inventory principles and jidoka, which means to have an automated process with the human touch. The human touch part is where management comes in. However, it wasn't really until 1991 when the first book on lean principles was published, "Machine that Changed the World "by James P. Womack, Daniel T. Jones and Daniel Roos. Since then, the word "lean" is more popularly used when taking about production. We also see programs and classes on learning tools such as lean six sigma

There are solutions to improve management in manufacturing that other companies have utilized, specifically focusing on one called HID, a security card manufacturer, who implemented a lean program using management tools at their manufacturing facility. HID is the largest manufacturer of key cards. They make custom security cards and distribute them worldwide. This company was founded in 1991 but in 2004 they saw that they could not keep up with demand, they were only meeting half their delivery times and overall found many deficiencies in the production process with quality control and unnecessary scrap. So much so, they had to tell their salespeople to stop prospecting new clients. They decided to implement a lean program starting at their Connecticut plant first, where they had the lowest output and customer satisfaction. Their first stop was looking at their metrics, reevaluating them, and giving themselves a timeline of one year to meet the newly proposed metrics. They started by tracking their analytics and determining a schedule on how and when they need to implement improvements. Although HID already had automation in their production process wasn't set up efficiently, they lacked employee motivation and had very few well trained production associates. There was a lot of room for improvement. The big question is, what did they do? HID established a mission statement, which is to "provide customers the highest quality product, on time, every time". They use a continuous improvement approach with training, production improvements and by continuing to hire new employees. They implement lean training programs for all new employees when onboarded to the workforce. One of the tools they implement for employee engagement is a point system. This is an incentive-based system that rewards employees with points. HID awards points when teams hit their metrics, when they assist others or when they are recognized for going above and beyond. With these points they are given rewards like plane tickets, gift cards, etc. HID recognizes that it starts with the people, and incentivizing them but also giving them a organized working environment, will help them to take pride in their work and want to maintain the organization. They also improved communications through their managers and gave them the confidence to lead their teams. One of the improvements they implemented right away was improving their cleaning standards and making sure all their staff were in proper safety equipment and following cleanliness procedures. Although these steps might seem simple in theory the outcome of this lien plan was astronomical. By investing into new technology and reconfiguring their production system they were able to increase ease-of-use. They also invested into training and have continued to have meetings to achieve ongoing improvement. They also brought their costs down by eliminating errors and producing less scrap and by increasing employee productivity. Before they started the lean initiative their sales force had to stop pursuing sales at the Connecticut plant, they had to tell customers they can't meet lead times and aren't taking on new business. Now the HID salesforce can be rehired to the Connecticut planned and be reeducated to go and get the plant new business. This plant went from shipping 400k cards per month to shipping 1.5M cards per month after implementing the lean procedures. After 1 year of implementing their lean program, they were able to get 99% of employees trained in lean & 99% participating on teams. HID had a 25-day lead time at the start of this initiative in 2004, and their goal was to bring it down to 10 days, they actually brought it down to 8.9 days, exceeding expectations. They were 2% short on their goal but were still able to get 93% on on-time-delivery, a big jump from only having on time delivery half of the time. Overall HID was able to greatly increase their productivity and so their revenues increased as well. They are now an example used by many other companies on how to implement lean procedures and change company culture.

We know today that what will separate a good company from a great company is the management, production and planning that takes place. These concepts must work in harmony to create lean successful manufacturing facility.

REFERENCES

1. Paolo Priore, David de la Fuente, Alberto Gomez, and Javier Puente "A review of machine learning in dynamic scheduling of flexible manufacturing systems" *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (2001), 251–263
2. C. Saygin and S. E. Kilic, "Integrating Flexible Process Plans with Scheduling in Flexible Manufacturing Systems" *The International Journal of Advanced Manufacturing Technology* (1999) 15:268–280

3. Paolo Priore, Alberto Go´ Mez, Rau´ L Pino "Dynamic scheduling of manufacturing systems using machine learning: An updated review" *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (2014), 28, 83–97
4. Mr. Yuvraj Sharma, Dr. Dhiraj Jain "Adoption of next generation robotics: A case study on Amazon" *A Case Research Journal Volume III* (2017).
5. Haldun Aytug, Siddhartha Bhattacharyya, Gary J. Koehler "A Review of Machine Learning in Scheduling*" IEEE Transactions on Engineering Management*, VOL. 41, NO. 2, MAY 1994
6. G. Uluso and U. Bilge, "Simultaneous scheduling of machines and automated guided vehicles", International Journal of Production Research, 31(12), pp. 285%2873, 19932
7. M. Srinivasan, Y. A. Bozer and M. Cho, "Trip-based material handling systems: throughput capacity analysis", IIE Transactions, 26(1), pp. 70-89, 1994
8. N. Raman, F. B. Talbolt and R. V. Rachamadgu], "Simultaneous scheduling of machines and material handling devices in automated manufacturing"
9. I. Global Market Insights, 'Automated Material Handling Equipment Market Size, Industry Analysis Report, Regional Outlook, Application Development Potential, Price Trend, Competitive Market Share & Forecast, 2019 – 2025', 2020.
10. (C. Cronin, A. Conway, and J. Walsh, 'ScienceDirect Flexible manufacturing systems using IIoT in the automotive sector', 2019, vol. 00, pp. 1–8)
11. J. SLOMP and W. H. M. ZIJM: "A manufacturing planning and control system for a flexible manufacturing system".