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Process plan optimization: A case of plastic manufacturing company

Charles Chikwendu Okpala[1], Austin Kelechi Okonkwo[2], Ezeanyim Okechukwu Chiedu[3]
[1, 2, 3] Department of Industrial/Production Engineering, Nnamdi Azikiwe University, PMB. 5025 Awka, Nigeria

Abstract
Achieving manufacturing excellence through the reduction of production metrics such as lead time and cost is one of the objectives of having an efficient process planning system. Computer Aided Process Planning (CAPP), a very robust and efficient process planning system that involves the application and use of computer technology to aid in process planning can help manufacturers come close to achieving this manufacturing excellence. The systematic and empirical approach used throughout the paper studied and identified performance areas of improvement in a plastic products manufacturing facility, with emphasis on its process planning. The existing manual process planning was actually replaced with MIPLAN, a retrieval CAPP system. Though CAPP thrives in a production facility that produces a wide variety of products, just as was the case with the case study facility, the MIPLAN CAPP was applied in planning production of two of their products, as a pilot test. The results obtained were emphatic; 13.4%, 22.2%, 92.1%, 36.2% and 62.5% improvements were observed for raw materials cost savings, direct labor, scrap volume, production lead time and delivery lead time respectively for the manufacture of a given quantity of plastic chair. Also the CAPP program was applied in the manufacture of 25 Liters jerry can with the following improvements observed; 6.5 %, 22.2%, 95.1%, 36.4% and 48.5% respectively for the same configuration of performance metrics. These very significant improvements observed when manual process planning is replaced with CAPP at the case study facility are in agreement with postulates of theoretical framework that process planning can be optimized with CAPP.

Keywords: computer aided process planning (CAPP), plastics, route sheet, process sheet, computer aided design (CAD) computer aided manufacturing (CAM)

1. Introduction

A manufacturing system comprises of a lot of activities, and to be able to fully utilize the system, it is very important to plan the manufacturing process, as good planning increases the chance of production success in any industry. Little wonder management of industries pay adequate attention to the planning and control function within their supply chain. Process planning sets the center stage for manufacturing, and it is so important that the success or otherwise of achieving manufacturing goals largely depends on it.

Also known as production planning, process planning dictates such manufacturing performance metrics as production lead time, delivery lead time, throughput, process and plant optimization, quality, production cost, sales, revenue, etc. Usually beginning at the product design stage, process planning involves also the selection of the raw materials best suited for the production, identification of the production operations and their sequencing, estimating time and cost, establishing which machines will be used, the machine process parameters: such as feed rate, working temperature, dimensioning etc.

Process planning puts product design into work as depicted in figure 1.

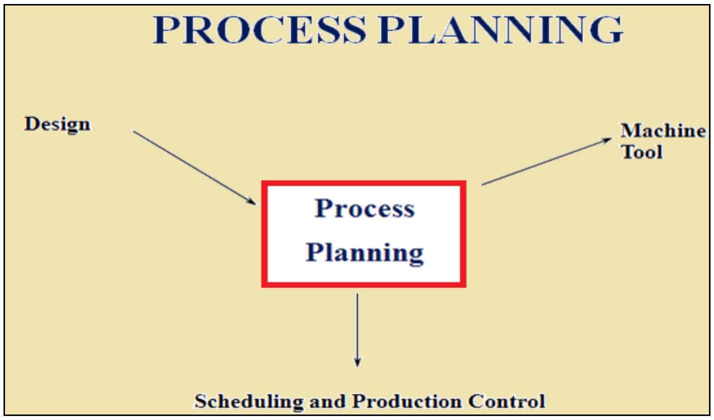

Fig 1: Process planning

The ultimate aim of all process plans is to develop a road map which best depicts how a work material will be converted to a finished product in accordance with its engineering design and drawing. Although process planning may vary from one planner to another; the underlying principles remain the same: establishing an efficient and optimum sequence of operations, selecting proper equipment and tooling, and specifying their operations in such a manner that the product will meet the requirements stipulated in the design specifications.

In most manufacturing organizations, developing process plans is a task of the production manager who uses both his experience on the job and technical ability to plan various products manufacturing and come up with a process/ production plan result on a paper known as a route sheet or process sheet. Arora (2004) [1] defined a route sheet as the map or blueprint of the manufacturing process in production unit which determines the sequence or order of arrangement of various departments in a facility. Thus, a route sheet is a document which has information and data inputs and a step wise listing of all the processes or transactions performed. It also contains details such as date and time, remarks, log in/out, point of contact, etc.

A route sheet is one of the two elements of process planning documentation. The other element is the operations lists, which carefully details the various operations: in what order, what clamps, tooling feeds, and speeds that are necessary for the manufacturing.

Table 1: A route or process sheet is illustrated in table

S N	Operation Description	Work Station	Machine Setup	Machine tool	Estimated time (mins)	Start Date/time	End Date/time
1	Mill bottom surface 1	MILL01	See appendix	Face mill 6 teeth, 4” Ø	3 for setup 5 machining		
2	Mill top surface	MILL01	See appendix	Face mill6teeth, 4” Ø	2 for setup 6 machining		
7	Drill 4 holes	DRL02	Set on surface	Twist drill 0.5” Ø, 2” long	2 for set up 3 for machining		

Process Plan	**IBM Inc.**
Part/Product No:	Material:
Part/Product Name:	Changes/Date:
Checked/Date:	Approved/Date:

In order to develop process plans, the process planner or process planning department must work closely with the marketing/sales department, who provides sales forecast or listing of customer orders. The work is usually selected from a variety of various product types which may require different resources and serve different customer segments, as process planning involves strategic decisions and careful analysis. The purpose of process planning is to augment and modernize the business methods of a company; this is because it is performed to transform design specification into manufacturing instructions, in order to manufacture products within the function and quality specification at the least possible costs. The application of process planning will lead to the following advantages:

reduced costs as a result of fewer staff that are required to complete the same process, higher competence by eradicating process steps such as loops and bottlenecks, greater precision by including checkpoints and success measures to make sure process steps are completed precisely, and better understanding by all employees to fulfill their departmental objectives.

Firms that offer similar products and services are distinguished from the others by the creation of competitive advantage. As shown in figure 2, effective process planning greatly facilitates a competitive edge by reducing time to market, production cost, and product price.

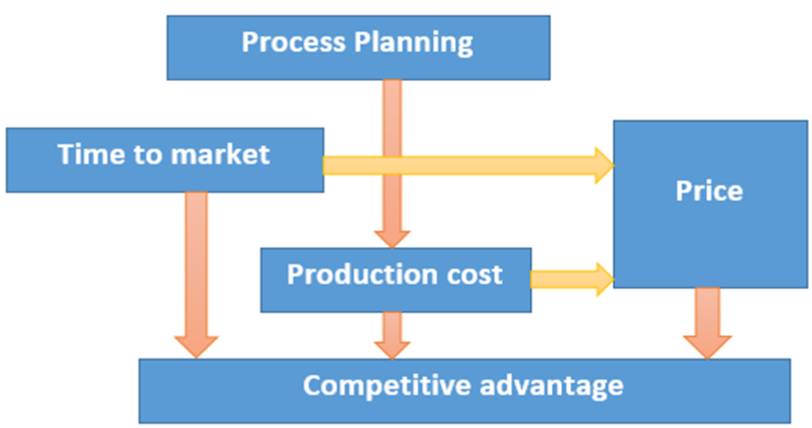

Fig 2: Process plan fosters competitive edge

Process plan can be done traditionally/manually or through an automated approach by the application of a computer software. The automated process of process planning is usually referred to as Computer Aided Process Planning (CAPP). The manual process planning can be very time consuming and also prone to errors and inconsistencies. However, manual process planning is what the vast majority of Nigerian manufacturing companies are still practicing.

Ronald (1981) [5], observed that 45% to 80% of manual process planning task is clerical in nature, and this implies that at least half of the production manager's time is spent on clerical tasks and not on manufacturing tasks – this is viewed as inefficiency. An optimal proposition however exists in automated process planning which promises to eradicate all the problems inherent in the manual process planning and also significantly improve tangible manufacturing metrics of lead times, throughput, machine idle time and material cost, as well as intangible metrics of quality, customer satisfaction, competitive edge etc. This paper demonstrates that CAPP can be used as a tool to optimize manufacturing process planning and consequently enhance productivity through a research conducted in a plastic manufacturing facility.

2. Concepts of computer aided process planning

Computer Aided Process Planning (CAPP) is the use of computer technology to aid in the process planning of parts/products for production. Quite distinct from the manual process planning, CAPP exists as computer software used to efficiently and effectively generate process plans, thereby simplifies the work of process planning. According to Okpala and Okonkwo (2018) [4], CAPP "entails all the activities that convert the specifications of a part design from engineering drawing into the required production procedures and strategies to translate a crude workpiece to a desired finished product." They noted that as a key factor of manufacturing cost and profitability that it focuses on industrial processes, and also involves the application of computer technology like Computer Aided Design (CAD), and Computer Aided Manufacturing (CAM), to design physical products.

Yusri and Kamran (2014) [7], identified Variant/Retrieval CAPP and Generative CAPP as the two approaches or types of CAPP systems. The variant/retrieval approach uses a Group Technology (GT) code to select a generic process plan from existing master process plans developed for each part family, and then edits it to suit the requirements of the part/product at hand. It works on the premise that similar parts have similar process plans. Figure 3 depicts the Retrieval/Variant CAPP algorithm.

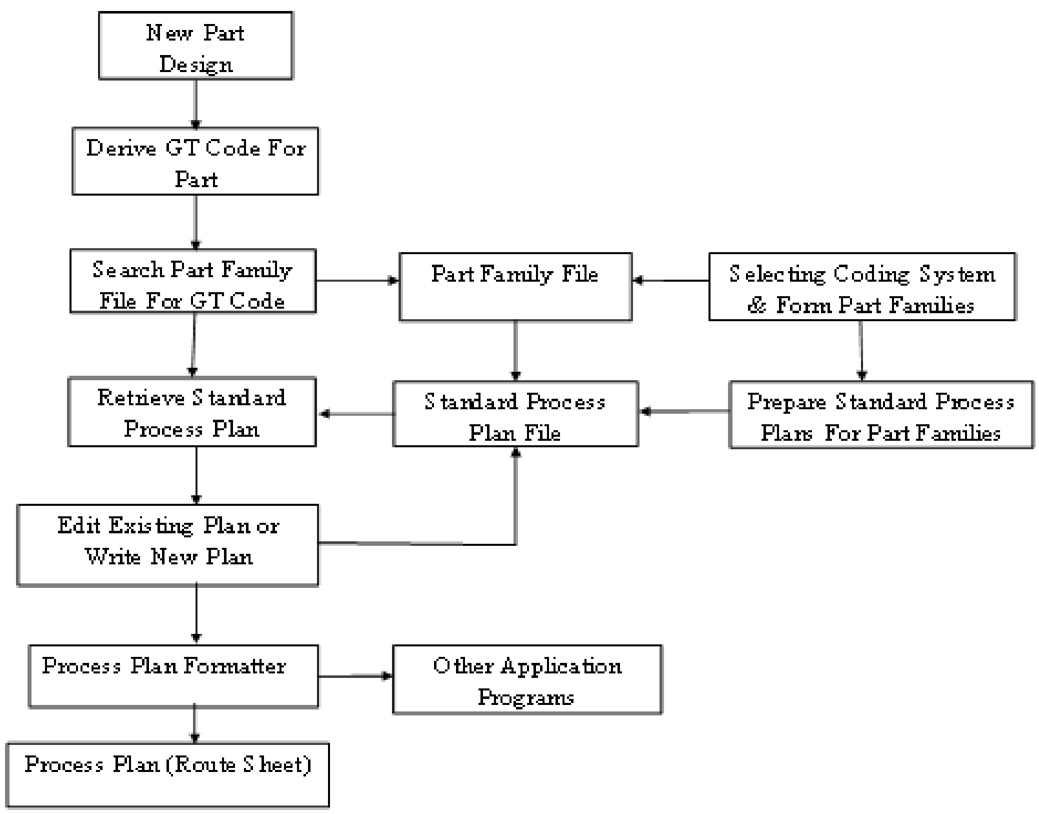

Fig 3: Retrieval/Variant CAPP algorithm. Source: Sehgal (2013)

However, the generative CAPP system manifests Artificial Intelligence (AI), and creates process plans for individual parts/products from the very scratch without human intervention, by automatically synthesizing process information using computer logic. Manafi *et al*. (2017) [3], explained that when compared to retrieval or variant CAPP, generative CAPP is more accurate in result and more flexible for all sorts of parts to be manufactured. Also, it creates an optimal process plan easily than the retrieval type, although it is a far more difficult approach to implement than the variant CAPP.

According to Yusri and Kamran (2014) [7], all CAPP software systems are designed to function on one or more of the following technologies: feature based, knowledge based, neural network, genetic algorithm, fuzzy set theory/logic, Petri Nets, agent based, internet based, STEP-compliant, and functional blocks. These technologies as shown in figure 4 also help the CAPP system to interact with other application systems in manufacturing such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and

Computer Numerical Control (CNC). For example most retrieval CAPP systems base their design and function on feature based technology, knowledge based technology and genetic algorithm technology.

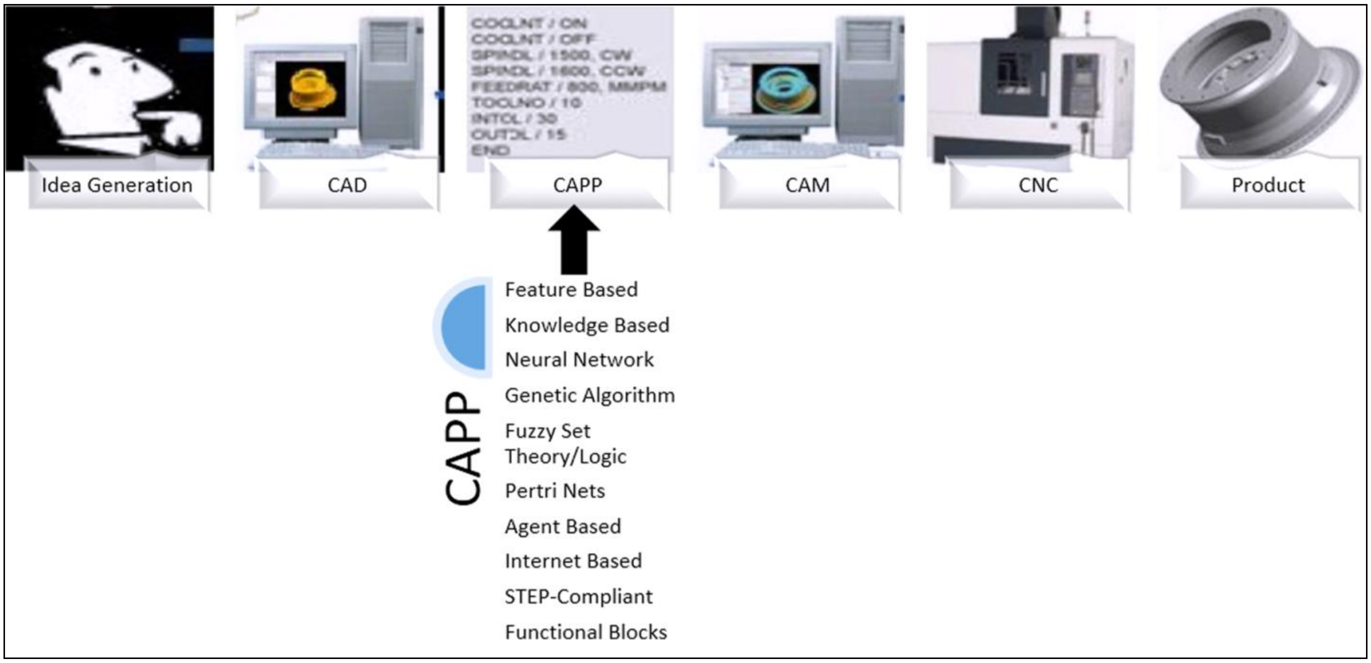

Fig 4: CAPP application in manufacturing cycle. *Source*: Yusri and Kamran (2014) [7]

A CAPP software for application in optimizing manufacturing process planning can be developed in-house or sourced commercially. Either way, it will require the skill of a seasoned computer scientist to customize the application software to the specific company, based on their operations and processes. Amongst other things, CAPP when properly implemented will have positive impact on manufacturing through improving cost estimations and reducing the following: production costs, calculation and quotation errors, production and delivery lead times, scrap, defects, and reworks.

It is important to emphasize that batch, job shop, continuous/mass production processes will have different approaches of process plans even if it is the same part/product being considered. Plastic products manufacturing is a mass/continuous production process. Beaudreau (1996) [2], defined mass or continuous production as a production process of replicating large amounts of standardized products very quickly, usually with the use of assembly line techniques.

3. X plastics

X plastics, a division of X Group of companies started operations in the wake of the new millennium. Located in the harbor industrial layout of Onitsha, a commercial city in South-Eastern Nigeria, X plastics is one of the market leaders in the manufacturing of all sorts of plastic products.

A research was conducted at the company's facility to have an insight into their manufacturing processes, with the aim of reviewing and improving the company's process planning process and productivity through the use of Computer Aided Process Planning (CAPP).

The company's output which are plastic products have many applications in a wide range of areas such as in automobile parts and fittings, consumable commodity packaging, household items: buckets, jerry cans, plates, spoons, tables, chairs, storage tanks etc., casings/housings of electrical and electronic devices, plumbing items etc.

The raw materials are chemicals and petrochemicals such as polymeric resins and additives. These resins are usually supplied in powdered and pelletized forms. The type and function of the product to be manufactured will determine the particular petrochemical resin to use. For example in the manufacture of plastic bottles for packaging drinks, pellets of Polyethylene Terephthalate (PET) is usually used; in the manufacture of plastic chairs, tables, cabinets, seals and automobile fittings, Poly Propylene (PP) is used; in the manufacture of electrical cable coatings and plastic pipes, Poly Vinyl Chloride (PVC) is used.

Also depending on the type and function of the product to manufacture, the company use different production techniques such as injection molding, extrusion blow molding, injection blow molding, extrusion processes, etc.

The research and analysis were performed on plastic chairs and 25 litres jerry cans whose general methods of manufacturing involves: product design by an engineer/draftsman, mold fabrication by a tool-maker using steel or aluminum, machining of mold to precision to detail the features of the product, fixing the mold unto the molding machine, pouring the polymer pellets/powder and necessary additives into the heating chamber where they are heated to the required temperature, and the hot liquid made to run into the mold under a pre-determined pressure. The setting is later allowed a certain time to cure before the mold is opened up to release the finished product. Thereafter, additives are added to modify physical and/or mechanical properties of the manufactured product.

The plastic chairs and the jerry cans are manufactured as shown in figure 5 with PP and PET pellets that are heated to about 220˚C on the molding machines.

Fig 5: Plastic chair and 25 litres jerry can

The analysis of the firm's manufacturing processes revealed that the products are designed by a seasoned draftsman either in black and white or using Computer Aided Design (CAD). The production manager manually plans the production and prepares the process/route sheet and set out to accomplish the production. Using the features, specifications and features, the company's workshop unit using cast iron will fabricate and form the mold.

The mold is then clamped unto the injection molding machine, where the pelletized Polypropylene and all the necessary additives have been added in proportions stipulated in the process sheet.

The mixture is melted at a temperature of 220˚C and then driven under pressure by a rotating and sliding spindle shaft into the mold through the mold's gate and runner. The molten mixture then takes the form of the mold, sets and cures after a given time. The machine automatically opens up the mold and releases the plastic chair as a finished product.

A standby attendant is tasked with collecting the finished product as it leaves the machine and then keep it aside from where it is taken to storage. Because of the inconsistency in the quality of molds and also due to some variations in the operating conditions, it is very common that most of the manufactured chairs leave the machine with some excess plastic outgrowth, usually on the edges or sharp ends. This constitutes scrap and it was identified by the research team as a waste.

The time spent in making the molds and developing the various process plans for all range of products is of interest as they constitute far greater percentages of the total production time. The activities of manufacturing jerry cans were studied as well and it was realized that they follow similar trend as those of chair production. However, some slight differences exist which are summarized in the table 2.

Table 2: Chair and jerry can production

	Chair	**Jerry can**
Polymer/type	Polypropylene/thermoplastic	Polyethylene terephthalate/thermoplastic
Additives	Fillers, heat stabilizer, impact modifier, light stabilizer, color pigment, reinforcement	Bio stabilizer, blowing agent, heat stabilizer, light stabilizer, color pigment, reinforcement
Processing technique	Injection molding	Injection blow molding
Mold material	Cast iron	Cast iron
Production planning method	Manual process planning	Manual process planning

Data and information about the company's manufacturing of the products were obtained by visual inspection at the production shop floor and from interactions with the production manager.

A production planning and control assessment done on the activities of the company showed that production lead time and delivery time are usually not met. This has a significant negative effect on customer loyalty and satisfaction.

It also showed that production cost is quite high and this has a negative effect on product prices and effective competition.

4. Results

After the painstaking and methodical analysis of the subsisting operations of the facility, the team decided to replace the manual process planning method with MIPLAN – which is a type of retrieval/variant CAPP system.

To successfully implement CAPP program in the company, and also optimally plan the different processes that are needed to produce the products, the following activities were conducted by the research team:

- Engineering drawing interpretation: Engineering drawings are created with the purpose of showing dimensions and tolerances that are necessary from a design and functionality point of view. The process planning team with the help of the company's production manager was able to interpret engineering drawings to understand which dimensions are important from a production viewpoint.
- Materials selection: Having a good knowledge of properties of engineering materials and also having the ability to choose from them is important both from design and production perspectives. This is because the choice of materials directly affects the type of machining processes and tools selection. Here, economics of cost and functionality were considered and evaluated side by side.
- Manufacturing processes: The process planning team demonstrated a good understanding of various machining or manufacturing processes that are needed, with the help of the production manager
- Fixtures, Jigs and Fastening of work piece: Fixing/fastening the molds to be used on the machine was considered and made part of the CAPP decision making files.
- Reference data and catalogue: The process planning team read, understood and made reference to different types of

catalogues of manufacturing tools and their machining capabilities so far existing in the company.

- Cost analysis: Comparative cost analysis was done so as to ascertain which is more economical between the existing method and the proposed method.
- Quality assurance and methods for standards: Provisions were made for quality assurance and quality control. This way, there will be very little or no deviation of the produced product from that depicted in the engineering drawing and will durably serve the function it was intended for.

The purchased MIPLAN CAPP software was deployed and customized specifically for the operations of plastic products manufacturing by a computer scientist relying on the guidance and wealth of knowledge of the research team and the company's production manager.

The MIPLAN CAPP pilot test was run for the production of 1000 units each of the chair and jerry can using one injection molding machine and one injection blow machine respectively. Consequently, results were obtained and compared with what was obtained when manual process planning is used under the same set of conditions. The facility operates on a day shift only of 8 hours of machine uptime, working 6 days a week. Based on these conditions, table 3 summarizes the results obtained.

Table 3: Results for 1000 units of chair

Performance metric per 1000 units	With manual process planning	With MIPLAN CAPP	Percentage of improvement
Raw materials (NGN)	2,125,000	1,840,000	13.4
Direct labor	9	7	22.2
Scraps (Liter)	152	12	92.1
Production lead time (hr)	417	266	36.2
Delivery lead time (hr)	40	15	62.5

Table 4: Results for 1000 units of jerry can

Performance metric per 1000 units	With manual process planning	With MIPLAN CAPP	Percentage of mprovement
Raw materials (NGN)	3,670,000	3,430,660	6.5
Direct labor	8	6	22.2
Scraps (Liter)	185	9	95.1
Production lead time (hr)	261	166	36.4
Delivery lead time (hr)	33	17	48.5

Note: The injection mold and the injection blow mold machines at the facility operate for an uptime of eight (8) work hours and five (5) work hours respectively.

The significant improvements recorded in raw material consumption, scraps reduction, reduction in lead times after implementing Computer Aided Process Planning (CAPP) in a pilot test of 1000 units of the two products has demonstrated that CAPP is a reliable tool for optimizing process plans.

5. Conclusion

Computer Aided Process Planning, CAPP is an automated tool that effectively impacts on manufacturing process planning. The concept of CAPP was examined and then implemented in the production activities of X plastics facility in Anambra state. A study done on the facility revealed that despite the fact that the firm produces a wide range of plastic products, they still use manual or traditional process planning, which constitutes a lot of wastes.

The successful replacement of the manual process planning method in the company with MIPLAN CAPP confirmed the benefits of CAPP recorded in the reviewed literature. By applying CAPP to a selected quantity of plastic chair and jerry can, it was observed that it significantly optimized the performance metrics of raw materials cost, direct labor, scrap volume, and lead times when compared with the manual process planning method.

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