

Historical Analysis to Build a High-Tech Global Design and Manufacturing Enterprise

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Abstract

As global markets continue to evolve, technological advancement change the way approaches to business and production must be taken. With this constant advancement, it is imperative that businesses and enterprises stay updated on tools to use to their advantage and current trends. This essay presents a forward-looking strategy using historical evidence, theories, and models to restructure a manufacturing enterprise to a design and manufacturing enterprise. Set in the year 2040, industrial trends from 15 and 30 years before this paper, being written in 2025, are drawn on to gain reference for what problems may occur in the future and how to succeed by preparing for that future. Key areas of research include manufacturing system evolution, strategic globalization models, and the integration of AI-assisted customized manufacturing. Using the historical data, trends, and observations, this essay proposal a structural reorganization that includes Industry 5.0 principles of human-centric machine collaboration, AI-drive predictive modeling, and smart factory implementation, with the intention to deliver an innovate and applicable solution.

1 Introduction

The year of 2025 and the years preceding have been a time marked by ever-changing developments in technology and an exponential growth in knowledge[1]. Aided by improving communication technologies, the general awareness of current global events is constantly increasing, leading to change in social climate more often than ever. As of recently, there has been a boom in the exploration and use of Artificial Intelligence(AI), with platforms such as ChatGPT taking centerstage in the newest form the obtain information quickly or solving problems. The world is driven and guided by new innovations, either providing solutions to problems or distracting from them. With the speed at which these changes happened, a logical question to ask would be what is next?

This essay seeks to devise a solution to transitioning a manufacturing enterprise to a successful design and manufacturing enterprise in the near future, which will be in the year 2040, operating on a global and domestic scale. With the specific goal of identifying the most important challenges that the company will face, this approach will look at an extensive history of significant struggles and issues faced in engineering to present how those struggles can be used at an advantage to model and predict issues that may arise in the future. Comparing the different issues, specifically focusing on 15 and 30 years ago, implementation of AI will be used to observe trends and produce solutions alongside humans, which will then be shown in a conceptual enterprise structure.

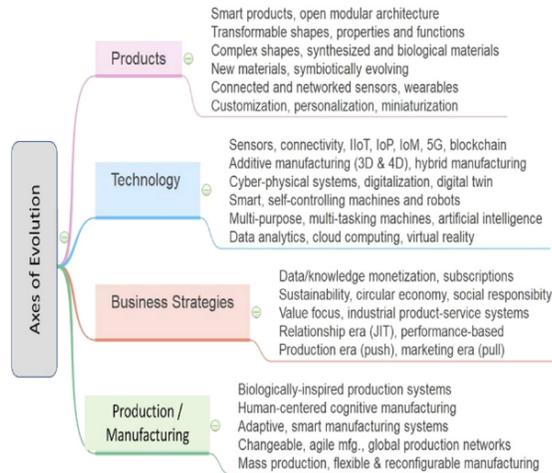


Figure 1: Four axes of manufacturing evolution(Adapted from Duderstadt et al., 2008)

2 Evolution in Manufacturing Systems

What does success look like in a manufacturing enterprise? In manufacturing, there are many challenges to face. Consideration must be taken in the areas of technical application, economic sustainability, overall strategy, and their business plan[2]. Most of all, within and company or enterprise, the manufacturing side of the organization must be able to evolve as technology improves and demands change.

Initial manufacturing systems emphasized the need to be flexible and reconfigurable to cater to production size and variability[2]. This was then followed by systems were made into smart and adaptable systems, led by disruptive advances along the four axes of product evolution, technological evolution, business strategy evolution, and production and manufacturing evolution. The specification of these can be seen in Figure 1.

A manufacturing system will inevitably see a change in consumer demand while also seeking to create the most innovative next big thing. Technology has become more intricate as time has passed, causing a need for intricate shapes and different materials to be desired. This production evolution caused a need for manufacturing evolution, hence it being one of the four axes of manufacturing evolution.

The first and second industrial revolution saw significant change in the method by which a production system is operated via technical evolution. Originally being comprised of standalone machinery controlled by individuals, production lines shifted from direct human operation to being automated and changed to be more flexible and reconfigurable. Automation technologies expanded, creating a wide array of tools to ensure production lines could automatically communicate using computer-controlled programmable machines. Integration of these tools were seen such as global position systems(GPS), utilizing an industrial internet of things(IIoT), cyber-physical systems which aided in data acquisition, processing, and decision making, and decentralized network of

manufacturing resources using cloud manufacturing. Each tool managed to enhanced the overall performance of production lines, whether that be in eliminating faulty products, ensuring uniformity, or being able to share data and re-correct.

Consumer demand directly affects how an enterprise will have to create their business model. Because of this feedback system, to satisfy customer requirements, manufacturing mass and customization were created to allow customers to choose a variety of specified features predetermined by the manufacturer to increase efficiency while limiting variability of product manufacturing.

There have been different methods of manufacturing over time, starting with variety-oriented manufacturing. Focusing on a low quantity to meet exactly the user’s needs, this method was common before the introduction of dedicated manufacturing systems(DMS). DMS brought about the movement of assembly lines, where the variety between products became limited, with a focus on standardization and mass production while also maximizing efficiency and minimizing cost. Such systems were the introduction of unmanned machining, as they were the first step into factory automation. Flexible manufacturing systems(FMS) are controlled by a central computer with one or more integrated groups of machines with the intention of being able to perform different functions traditionally completed by humans. Made in response to a renewed need for customization in products, FMS offered mid-volume and mid-variety production, capitalizing on smaller differences between versions of products to maximize efficiency. Reconfigurable manufacturing systems (RMS) aim to achieve changeable functionality and scalable capacity due to their modular structure. A new aspect of manufacturing systems was introduced in which units could be added, removed, upgraded & reconfigured, allowing problems to be more easily diagnosed and integration much easier.

Being a culmination of FMS, RMS, and other methods, changeable manufacturing (CM) is able to accomplish foresighted and economic adjustments. Reconfigurability, transformability, and agility are other aspects of CM which allow it to be such a versatile method of manufacturing, as they open the door for adaptive production planning, which would be important in an enterprise looking to prepare for a future over a decade away. Figure 2 displays a feasible framework of CM, where it is broken down into physical components and logical components.

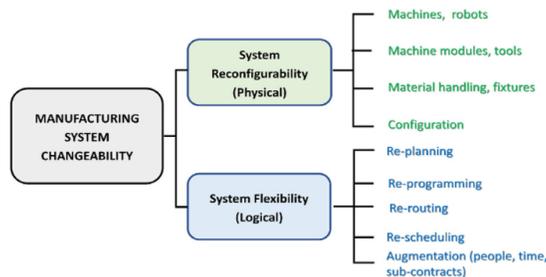


Figure 2: CM comprehensible framework (Adapted from ElMaraghy et al., 2021)

Presenting the axes of evolution in manufacturing as well as the types of manufacturing systems gives the opportunity to decide who would be most ideal for transitioning the aforementioned enterprise. These aspects of evolution have helped to define what success in manufacturing looked like throughout time to address the pressing demand for certain products. The next factor to consider when determining the future of this enterprise would be what pressing matters have existed in the past and the resolution to said matters.

3 Transition to Global Manufacturing Enterprise

With the goal of transforming this company into a global enterprise, it is necessary to understand how past companies have expanded globally and what globalization models to apply.

There are two traditional models of globalization to consider first. Assuming the initial company initially started off in the U.S., the Vernon Product Cycle Model proposes that the said company already has appropriate capital, engineering, and labor resources to create products domestically [3]. With some maturing, the product will then be transferred overseas to become a commodity, transferring production in those locations for a cheaper cost, owned by a third part license. Though the product cycle section of the model is seen to be outdated, many of the aspects of the model can still be applied.

The second of the traditional models, being the Generic Internationalization Model, globalizes gradually as they become familiar with foreign markets. The gradual approach reduces information cost while also increase their global involvement over time[3]. A hypothesize approach from Roberts and Senturia takes liberties from both models, utilizing external market forces to drive globalization as well as internal managerial readiness and aggressiveness. From the Vernon Product Cycle, products are made domestically but manufacturing is not transferred overseas, making most exports come from the U.S. Adopted from the Generic Internationalization Model, the perceived risks of foreign markets are varied, but eventually this approach would jump directly into global engagement as opposed to easing in.

Outside of analyzing business models for globalization, it is said that the key to success in globalization is managerial aggressiveness [3]. In companies that experience their first exposure to overseas marketing, there are two patterns to follow: territorial scope and internationalization. Territorial scope refers to the extent and distribution of a company's presence across global markets while internationalization reflects the degree to which a company has internalized its global activities and how aggressively.

The previously mentioned models and modes of internationalization are relevant as the *Globalizing the Emerging High-Technology Company* was published almost 30 years before today. When predicting how to transition a company for future success, it is important to study past models that have experienced both success and failure and learn. It is also necessary to observe what global events lead to the issues markets addressed at given times. Although innovation does not progress linearly, it may be relevant to look into past

events from 15 and 30 years ago to see how problems in the world of manufacturing have been addressed to prepare for problems 15 years into the future.

4 Manufacturing Strategy Changes Through History

Looking into past manufacturing strategies in response to different world events, this essay seeks to observe strategies taken 15 years into the past, being 2010, as a reference to use in preparation for the year 2040. In addition, looking back another 15 years from 2010, being 1995, to compare differences in strategies and responses to events for understanding of what can be implemented in the design and manufacturing enterprise.

From the birth of the third industrial revolution, spanning from 1962-1990, emphasis was placed on defining theoretical models for manufacturing strategy. With many of the keywords being product planning, strategic manufacturing, and competitive priorities, it is evident that high-volume, low-variety production and maximized efficiency were a priority.

Those priorities laid the groundwork for events taking place from the 1990's - 2000, where advanced manufacturing technologies and performance improvement were a focal point. Bringing the theoretical models to life from the previous revolution, planners realized manufacturing was not only a support function, but it could be a competitive driver in business operations. The empirical applications of the theoretical models matured manufacturing systems, with new structured manufacturing improvement programs being Agility and Lean practices, Just-In-Time production, and Total Quality Management[4].

With improved manufacturing performance reduced waste, accelerated workflow, and increased flexibility, causing a new and growing interest in measuring and enhancing manufacturing performance. Quality, lead time, and customer responsiveness were all new dimensions to account for where tools such as benchmarking, data envelopment analysis, and simulation were used. To develop and improve such tools, the applications of advanced manufacturing technologies brought about computer-integrated manufacturing, flexible manufacturing systems, and robotics. In addition, early adoption of AI concepts were introduced to support decision-making in manufacturing, proposed by the increasing need to respond to market volatility.

The 2010's saw the birth of Industry 4.0, where manufacturing strategy was retooled to accommodate smart technology, data-driven decision-making, and resilient and sustainable operations. Cyber-physical systems and IIoTs were introduced as well as AI to drive and direct production, reducing the area for human intervention. It can be assumed that AI-driven operational efficiency was promoted in response to the global financial crisis aftermath taking place from 2008-2011. Companies rushed to devise risk mitigation strategies with the intention of streamlining supply chains, leading to interconnected systems and real-time data-driven decision making were taken advantage of.

Within this time frame, the rise of smartphone usage took place, transforming user behavior and expectations. Increasing mass-customization in products and lowering lead

times were the goal as well as the sharing of real-time consumer data for industries to use. This mass customization-mass production was made possible with the aggressive outsourcing leading to more widespread globalization.

The year of 2025 takes place shortly after the introduction of Industry 5.0, which has the model focusing of sustainability, human-centricity, and resilient European Industry. Being in a post COVID-19 pandemic world, global supply chain vulnerabilities and misplacement in human labor were revealed, producing a need for systems to now be adaptive and withstand shocks and disruptions. The application of human-machine interaction prioritizes worker well being and skills as well as creative decision making working alongside data-drive decision-making to tailor products and maintain adaptability.

5 Leveraging AI for Smart Factories

One critical component of a new manufacturing and design enterprise existing in today's world will be its ability to act fast on new trends and user demand. In the year of 2025, AI has become a common tool used by the general public for information retrieval, data analysis, and task managing. In a growing and changing market, set on not only keeping up with current demands, but also predicting and catering to future needs, the logical solution would be to implement AI into such systems.

Changeable manufacturing, mentioned previously, refers to being able to cater to specific needs when manufacturing a product within specific bounds. Sharing many similarities with the term customized manufacturing, moving forward these terms will be used synonymously.

AI has already been shown to have many benefits in manufacturing, including AI-driven customized manufacturing(AI-driven CM). Using machine learning(ML) algorithms, decisions and analysis can be ran to optimize production in a wide variety of ways. To further expand on advantages AI-driven CM, this tool can:

- Reduce the uncertainty or supply chains using predictive ML
- Improve production quality through automation made to reduce human intervention where decision can be made and actions can be reconfigured to fit a solution
- Utilizing sensors to ensure maintenance is ensured using ML algorithms

With how useful AI has the potential to be in manufacturing applications, it is necessary to consider exactly how implementation is to be carried out due to the limitations. Because of high performance computing GPUs require and accelerated training process on large-scale data set that many facilities cannot support, organizations must resort to cloud computing which risks data breaches[5].

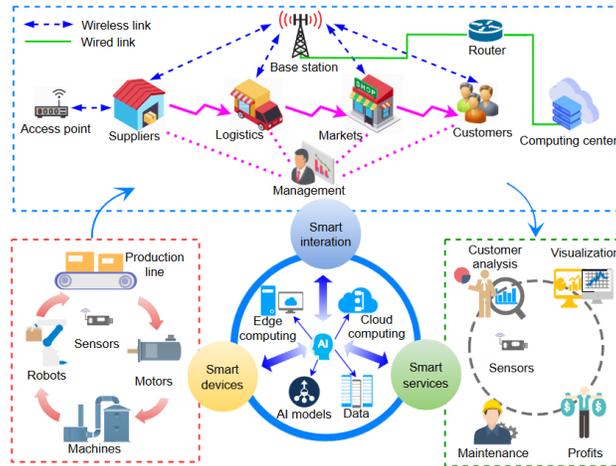


Figure 3: AI-assisted CM framework (*Adapted from Wan et al., 2023*)

With a properly implemented AI system in a CM factory, different frameworks have been proposed, optimizing each component differently. Seen in Figure 3, a comprehensive framework for an AI-assisted CM factory where cloud computing is used for time sensitive data analysis. The figure also presents the use of smart robots, acting as “physical layer” of the system, consisting of motors and moving platforms. ML algorithms aid in ensuring timing of each device is correct to complete production within a desired time frame. Smart interactions connect the AI layer, device layer, and services layer, creating a network of communication, containing protocols and information interaction. The sample framework presents how many moving components of AI-assisted CM factory to create a smart factory.

Smart factories are highly digitized production facilities capable of manufacturing with efficiency, flexibility, and responsiveness, sharing many capabilities of AI-assisted CM factories. In these factories, while automation was mentioned to take over in the place of humans in many areas, it should be emphasized that smart factories must still have elements of human-centricity, given the shift from Industry 4.0 to 5.0. Although Industry 4.0 emphasized the automation of manufacturing, being a technology dominant approach to production, Industry 5.0 emphasized the importance of harmonious interaction and collaboration between humans and machines [6].

With a human-centric focus, automated tasks assigned to robots would include repetitive actions with no need for critical analysis. Human intervention would take place in situations that require creative thinking and/or problem solving or issues relating to maintenance. In such roles, human-robot interaction would be essential for worker safety with the introduction of collaborative robots(cobots). In smart factories emphasizing the need for CM, human intervention will be key to creating variety between products.

6 Structuring a New Design and Manufacturing Enterprise

With consideration and substantial research for different manufacturing systems, there is a variety of information to use, replicate, and improve on. Being knowledgeable in manufacturing system evolution, consumer-driven business models, globalization methods, manufacturing strategies, and using current technology, the structure of a new design and manufacturing enterprise successful in the year 2040 can be conceptualized.

6.1 Manufacturing to Design and Manufacturing

The initial company used is essentially a manufacturing company. With the goal of transitioning to an enterprise focused on design **and** manufacturing, parts of the company will need to be restructured while new departments will need to be added entirely. This goal will encompass not only an expansion of consumers but also an expansion of resources and capabilities.

With a different focus in both production and innovation, corporate facilities would need to be established to have collaborative design spaces. Diverse talent would be **required**, as the company needs to reach global markets, meaning a wide array of cultural knowledge and understanding of different business and design practices would be needed within this space.

Limited AI assistance would be recommended for this initial design stage, as emphasis would be placed on Industry 5.0 standards of maintaining human-centric workflow.

6.2 Smart Factories with Predictive Modeling

6.2.1 Foresight Intelligence Lab

A foresight intelligence lab would be an AI-driven tool that uses data analysis to produce predictive models and solutions for the enterprise. With the need to keep up with current trends, user demand, and consumer volatility, the implementation of this system could predict and prepare solutions, design suggestions, and direction to take the enterprise using historical and current data. This lab would be especially important to use if implemented in the enterprise now to prepare far ahead of time for deducing problems and creating solutions for the year 2040. In Section 4, *Manufacturing Strategy Changes Through History*, an analysis of global demand and its effect on manufacturing took place. The same approach would be used for both humans studying and creatively approaching solutions and with AI creating logical solutions. This tool would need quantifiable data from observation of past trends and create answers comparable to human solutions in the categories of manufacturing solutions, restructuring the business model, and refocusing labor.

One issue can be proposed that industries will face would be Industry 5.0 not succeeding as intended with the rapid growth and increasing dependence on AI. This could

mirror the reasoning for the shift from Industry 4.0 to Industry 5.0 in the late 2010's. Human labor and input becoming obsolete is already present in academic spaces, which is most concerning given those spaces house the next leaders of society. To avoid repeating history, extensive measures and mandates will take place to ensure much of the production is human-centric, especially as a high-tech manufacturing and design enterprise will likely prioritize heavy customization in their products.

6.2.2 Current Affairs Team

Similar to the Foresight Intelligence Lab, this section of the enterprise will consist of humans collaborating with AI to monitor and stay updated with current trends and user demands. While forward-thinking is essential for the enterprise's future success, this team is necessary to ensure the enterprise remains grounded in present day issues. Individuals skilled in understanding, responding, and marketing to modern audiences will be the bridge between consumers, stockholders, and the engineers and manufacturing teams. The Current Affairs Team will use AI-driven decision-making to aid in logical solutions, but will be mandated to strictly not be the final result.

6.2.3 Modular Production R&D Department

The research and development department of this restructured enterprise would consist of two teams: one derived from Current Affairs Team, focused on current innovations in products and manufacturing ability. The section of the department derived from the Foresight Intelligence Lab will use be AI-driven, using logical solutions from the Current Affairs Team, historical-based decision making, and predictive modeling to develop solutions to educated hypotheticals. In addition, the AI pair with this department will propose problems that could arise in near or far futures, training the teams to prepare.

Part of the R&D Department will have a pro-typing sector, with the same 2 teams, derived from the Current Affairs Team and and Foresight Intelligence Lab. Having open lines of communication with both divisions, a low-cost method a producing prototypes would be used. Additive manufacturing with recyclable materials will reduce waste while creating a non-outsourced version of the product. This would be beneficial as time would be reduced wit having all necessary materials present.

6.3 Manufacturing Model

The manufacturing model would have a model similar to the customization manufacturing model. This department would work closely with both prototyping teams, having to be flexible at the turn of user demand. In this, production lines would have modular components controlled by humans occasionally, but most often completing repetitive tasks while monitoring their own performance. Live performance data would be recorded, interpreted, and inform each machine to re-correct themselves. Working in tandem would

be humans, operating in high skill-level or problem solving areas that require creative thinking, dexterity, or communication that machines would not be capable of.

6.4 Increasing Globalization

The Generic International Model will be adopted for globalization. With implementation taking place as soon as possible, the gradual approach created from this model will allow the enterprise to have global engagement increase as the success if the enterprise becomes more prevalent. An ever-growing team of international relations officers will have to be in communication with stockholders and manufacturing engineers to allow the enterprise to communicate with foreign countries to promote their outsourcing. This approach will be aggressive, as competing enterprises have been shown to have success when making their presence and desire to have global relations known.

7 Conclusions

The rise to become a high-tech, global, design and manufacturing enterprise would be gradual. Implementation would be costly, but a worthy investment. With the assumption of that the initial company is inherited, many of the systems will have to transition, especially if there were standards upheld with Industry 4.0 principles. Using a historical approach to gauge what methods could be recycled and improved upon will be useful when implementing AI to understand and prepare for future projections. Designers and manufacturers will have the ability to respond to these potential outcomes to mitigate the waste of resources and money. Though every problem cannot be solved ahead of time, the solution yielded a practical framework for guiding a company's transition to become a successful enterprise.

References

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Appendix

I initially wanted to limit my use of Chat GPT to evaluate the goals of this essay and help myself understand what direction I thought best. After writing down the factors and reasoning for the topics I wanted to introduce, I compiled every idea I had to make an initial statement.

“Using past models of success in manufacturing and design enterprises, what information can we gather from the past 30 years while looking at current trends and problems today to create a successful global and domestic design and manufacturing enterprise? In this, we can address that while these things do not improve linearly as one could infer this essay intends to given the time intervals, they can serve a notable points in time where markets have specific goals given the states of the world.”

This final initial statement initialized my next step: to consider what I was thinking about “wrong”. After evaluating specifically the time frame I wanted to look at, I asked Chat GPT:

Using this prompt from the NSF/ASME Student Design Essay Competition for this year, I want to use the approach of look back both 15 and 30 years to see what defined a successful manufacturing enterprise then, look at what current problems manufacturing and design enterprises have, and culminate that research to produce some type of data system that informs what would be needed to execute a successful improved version of what came before, while also outlining the execution of it on a surface level technical scale. Is that good? Am I looking at it from the wrong perspective? What do you suggest?

To which it responded that I had a strong narrative plan with a good use of historical context to back what I intended to do proposed. It suggested that I frame the essay around a central question, define what success meant in the different time periods I suggested, and highlight key breakdowns to understand why certain strategies were time-period specific.

Throughout my writing process, I asked many questions regarding the direction of my paper, grading the language behind what I was writing, if my statements contradicted any earlier statements or messages in my sources, and for elaboration on different papers I was reading. Before this paper, I had no idea what Industry 5.0 was, but I had Chat GPT give me many breakdowns of what it was and its intentions.