THE COMPLEX SYSTEMS OF HIGH-TECH MANUFACTURING – 2040

Graduate Submission

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INTRODUCTION

Industry makes leaps of progress on a daily basis. As we move towards a technologically advanced industry, there is also a need to rethink the structure of industry. This paper highlights the different characteristics, needs, operational capabilities, and research challenges of a high-tech design and manufacturing company in the near future. The year 2040 is less than eighteen years away and we will be seeing some major reforms in the way we perceive industrial space. These reforms will be highly scientific in nature and will explore strategic partnerships between industry, research organizations, and more.

CHARACTERISTICS OF A HIGH-TECH DESIGN & MANUFACTURING COMPANY

The keys to success in product production involve producing a quality product and courting the consumer. As demographic and sociopolitical trends develop, non-competitive companies are falling by the wayside. Companies that embrace these core characteristics will not only survive but thrive in the changing marketplace. The core characteristics that will govern a high-tech design and manufacturing firm in the near future are agility, sustainability, ethics, inclusivity, and openness.

AGILITY

Technology is only moving forward and those that fail to keep pace often perish. Pop culture is riddled with examples of this such as: Blockbuster failing to buy Netflix or move to streaming [1,2]; Sears's failure to improve their merchandise [3]; Kodak failing to immediately move to digital cameras, despite inventing them, out of fear that their print business would be cannibalized [4,5]. Those that took their place and continued to change are still industry leaders. Agility also produces resilience needed to weather the storm and adjust as needed. With social media accelerating trends faster than any point in history, it is essential for a high-tech design and manufacturing company to be agile.

SUSTAINABILITY

Climate change is an undeniable reality that impacts everyone and everything on this planet. Unfortunately, decades of inaction and/or insufficient action have worsened sea levels, global temperatures, smog, and animal breeding patterns. It is the responsibility of every company to take a critical look at their practices. As a whole, younger generations are more environmentally conscious and people "vote" with their dollars [6,7]. The public is also beginning to hold companies responsible for the entire life cycle of their products, from sourcing to sunsetting. As the push for environmentalism increases, the need for companies to become sustainable will only grow [8].

ETHICS

In addition to sustainability, ethics are deeply important. Consumers place their trust in institutions that act in the best interest of others. As a result, a design and manufacturing company has to aim towards cruelty- and conflict-free production. This may involve investing in developing countries and/or divesting from unethical regimes. This also includes protecting privacy and data of users. In the pursuit of ethical business, companies earn the respect of the labor and consumer markets [9,10].

INCLUSIVITY

Next, a thriving enterprise must recruit and retain the most skilled individuals. Studies show that diverse companies generate the best ideas. Diversity of knowledge, experience, age, ethnicity, and nationality will lead to a greater creative output. Diversity in the boardroom and at the drafting table leads to products that are made with a wider consumer base in mind. If the company has talent that designs for the most restrictive disabilities, the products can also be used by those without disabilities [11]. Additionally, it can curtail cultural and racial public relations embarrassments prior to their occurrence. For

example, this greatly reduces gaffes such as soap dispensers that fail to detect darker-skinned people [12]. Diversity also builds consumer trust and connection to the brand and products. To retain this diverse talent, **inclusive** actions and environments must be at the heart of the company.

OPENNESS

Lastly, in this global market, taking advantage of open design and innovation will increase creativity and opportunities by bringing in ideas and resources from outside of the firm. Additionally, turning consumers into prosumers can lead to a more loyal customer base as well as "unpaid" beta testers [13]. These prosumers willingly provide feedback and ideas, as well as encourage the adoption of products to others. An example of this is Linux [13]. Openness also engages many sectors, which can be engaged as partners. The Quadruple Helix model (**Figure 1**) shows the connectedness between the government, academia, civic, and industry. When combined with the environment, this forms the Quintuple Helix and interacts as shown in **Figure 2**. By forging these partnerships at home and abroad, scaling across geographic and cultural boundaries can more readily occur; this increases the potential customer base as well as the diversity of the organization.

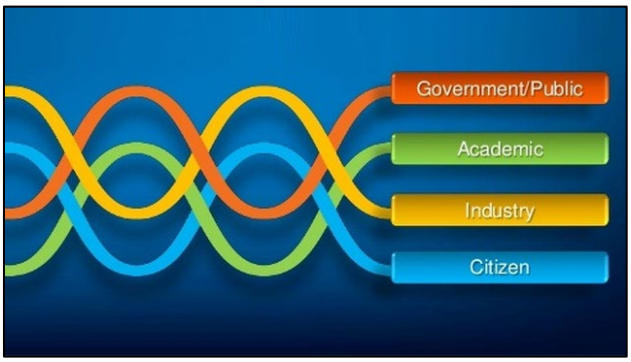

Figure 1: Quadruple Helix: The Interconnectedness of Government, Academic, Industry and Citizens. [14]

OPERATIONS

A high-tech product design and manufacturing company would need to have a strong user experience team, quality department, and customer feedback channels. The company would produce a wide array of consumer products, to diversify their portfolio and, for anti-trust reasons, avoid gaining too much ground in one area. The data gained from consumer tastes can be cross-pollenated to improve products and marketing in the future.

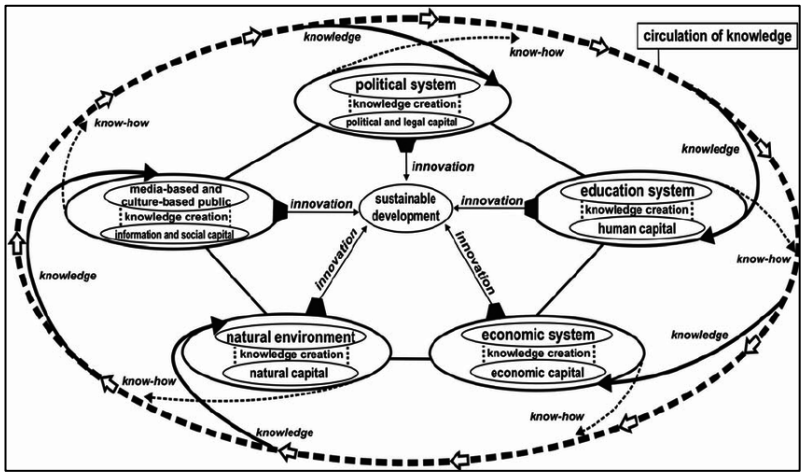

Figure 2: Quintuple Helix showing a system of Academia, Industry, Government, Citizens, and the Environment. [15]

This global firm would seek to improve conditions of workers in every country of operations, or strategic market. This means ensuring employees have good work-life balance, non-exploitative wages, and investments within the communities.

RESEARCH CHALLENGES & SPECIFIC NEEDS

The characteristics listed are also challenges that the company may face. Taking the easy way by being stagnant, lax with ethics, environmentally exploitative, apathetic towards inclusivity, and closed, might support the company in the short run, those short-sighted gains will not extend far into the future. It is best to be proactive wherever possible. These are challenges that are also opportunities, if overcame. Additionally, as the company matures, it will face challenges related to staffing, efficiency, social responsibility, and the cyber-physical-social system.

STAFFING

Proactively working to produce and retain a world-class workforce is vital, since the younger wave of employees that will join in 2040 have birthdates between 2018 and 2022 As previously stated, retaining a technically proficient and diverse workforce, is going to be a challenge. With wages and business costs increasing, offering competitive salaries is part of the strategy. The other part of the strategy is creating an environment that encourages people to stay with the company. Proactively, the company can do diligence to build facilities in inclusive areas and ensure full ADA-compliance on all buildings, built or acquired.

Investing in local education will also help to skill the future workforce. The best manner to accomplish this is to work with local universities or K-12 school districts to create make-a-thons, hack-a-thons, early talent shadowing week and other collaborative programing and events. This will drive innovation within the industry, allow the company to spot talent earlier than their competition, and increase the name recognition of the company. These programs might also be subsidized through governmental or civic organizations aimed at STEM education.

EFFICIENCY

Bill Gates is quoted as saying, "The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency." [16] Prior to automation, this company should audit all processes and take employee feedback to determine ways to optimize production and developmental activities. Once these have been implemented, automation can be examined.

Automation often brings a loss of jobs and a destitution of cities. To curtail this, reskilling opportunities should be made available to workers during the transition. This is a civic responsibility owed to the communities the company invests in. Often, partnerships with the state workforce commissions can help to offset costs and provide other support.

Efficiency also means reducing unnecessary tasks and timewasting. This calls for the elimination of a set eight-hour work week for salaried employees. Instead, time work should depend on tasks completed. This rewards workers that can produce quality work in less than eight hours per day. Freeing up workers who are killing time until 5:00:00 P.M. allows them to do other tasks that are fulfilling. When time crunches are needed to complete a project, the total work week should be capped at sixty hours per week, which a small bonus for hours worked beyond forty hours per week. This encourages employees to put forth their best and allow the company to accurately gage staffing needs.

Another way of improving efficiency is by encouraging the design team use the product they are developing. This helps smoothen the rough edges and helps build trust with the consumers by showing them that the company believes in their products.

CREATION AND MANAGEMENT OF CYBER PHYSICAL SOCIAL SYSTEMS

According to Yilma, et. al., there are five core themes of Cyber Physical Social Systems (CPSS) as "inspired by the emphasis given by majority of the works: Command and Control, Social Sensing, Self-organization [sic], Big Data, and Networking." [17] Yilma also describes the CPSS as a combination

between the individual systems plus the relationships between the systems (**Figure 3**)[17]. This specialized company should aim to address all five themes to remain competitive and well-known within the industry.

Smart manufacturing is aided by command and control and well as social sensing. As machine learning and AI becomes more prevalent and intelligent, having machines that adjust to environmental conditions and execute tasks that improve societal and physical conditions is looking less like science fiction. These smart machines can manufacture parts quicker, more reliably, and for longer contiguous periods of time, while also adjusting for conditions such as excessive heat. These machines often come with temperature and humidity control settings that allow for production of sensitive materials under ideal conditions. These devices will continue to learn using self-organization to classify the input information. This technology is still evolving and certainly needs to be invested in, but it is the future of manufacturing.

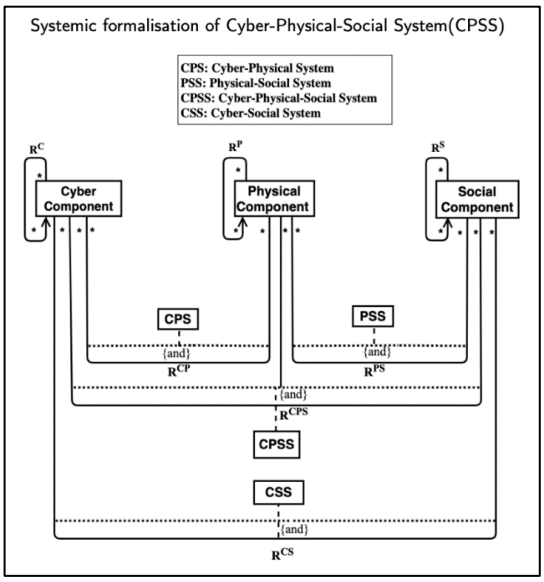

Figure 3: "Systemic formalization of Cyber-Physical-Social Systems (CPSS)" [17]

Digital manufacturing uses "uses an integrated and computer-based system to create product and manufacturing process definitions simultaneously." [18] All of this will require tons of data generation, sharing and processing. Big data has been the talk of industry, academia, and government for over a decade. Cloud computing, cryogenic computing, and the Internet of Things will have greater importance. Investing in or partnering with organizations advancing information security and offsetting the environmental challenges with high power computing will be beneficial in sculpting a cutting-edge manufacturing facility.

SCIENTIFIC FOUNDATIONS OF PRODUCT REALIZATION

The scientific foundations of product realization will be rooted in applying Open Innovation 2.0 to the Age of Industry 4.0.

OPEN INNOVATION 2.0

Open Innovation 2.0 is next generation of open innovation. As shown in **Table 1**, instead of small-scale collaboration and small deviations from conventions, the system demands the consideration of the ecosystem, a highly complex value network (termed a value constellation) and experimentation [19]. The seemingly disorderly manner of Open Innovation 2.0 is needed to disrupt the manufacturing industry to bring it to the next level. This ambitious feat is marked by Martin Curley's 12 Principles for Open Innovation. The principles from the model accompanied by the 2040 high-tech

PURPOSE	• Mission statement • Vision
PARTNER(SHIPS)	• Quintuple Helix
PLATFORM (FOR COMMUNICATION)	• Social Media • Workplace
POSSIBILITIES	• Culture moving towards Open Innovation 2.0
PLAN	• Business Plan • "the 'four Us': utility (value to the user); usability; user experience; and ubiquity (designing in network effects)" [19]
PYRAMID	• Empowering users to become prosumers
PROBLEM	• Needs/wants that are ripe for solving
PROTOTYPE	• Product experiments
PILOT	• Rigorous point-of-use testing
PRODUCT	• Commercial-ready
PRODUCT SERVICE SYSTEMS	• Integration of product into service line • Development of services complimentary to product.

Figure 4: Martin Curley's 12 Principles for Open Innovation

manufacturing company's deliverables to achieve this are listed in **Figure 4**. While some of these of these points have been discussed throughout the paper, special attention must be paid to the plan. Specifically, the "Four Us" (Utility, Usability, User experience, and Ubiquity) will govern the failure or success of the company (**Figure 4**). While ubiquity is not required, especially in early days, working towards it will greatly improve the brand and the security of the company.

Table 1: A Comparison of Innovation Models from Closed to Open 2.0 [19]

Closed innovation	Open innovation	Open innovation 2.0
Dependency	Independency	Interdependency
Subcontracting	Cross-licensing	Cross-fertilization
Solo	Bilateral	Ecosystem
Linear	Linear, leaking	Nonlinear mash-up
Linear subcontracts	Bilateral	Triple or quadruple helix
Planning	Validation, pilots	Experimentation
Control	Management	Orchestration
Win–lose game	Win–win game	Win more–win more
Box thinking	Out of the box	No boxes!
Single entity	Single discipline	Interdisciplinary
Value chain	Value network	Value constellation

AGE OF INNOVATION 4.0

The fourth age of innovation fits perfectly with the interdisciplinary nature of Open Innovation 2.0. As shown in **Figure 5**, as time passes, Design Engineering and Industry have become more intertwined. This is similar to the continued complexity in actor-network and value maps. Jiao, et al. wrote, "Design should be more than just dealing with pieces of hardware, but rather should be enacted as co-design of the product and its realization in the context of an entire smart factory ecosystem, including fulfillment, services, user experience, and human satisfaction at both the individual and the community levels, which are fulfilled coherently in a smart and connected manner" [20]. Designing a high-tech manufacturing firm is no exception. Using co-design and co-development principles will give the users the seamless connection that is continuing to gain traction in today's markets [20].

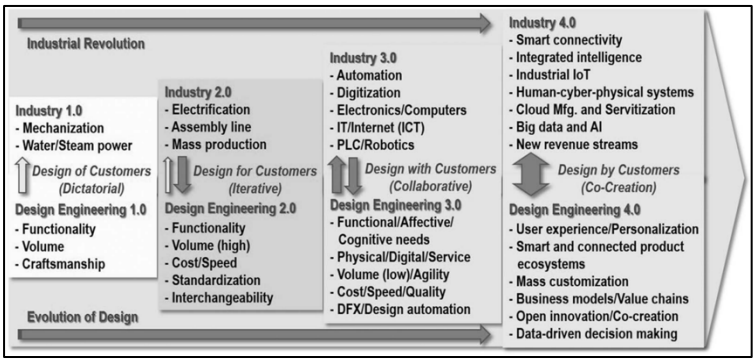

Figure 5: Evolution of Industry and Design Engineering [20]

STRATEGIC PARTNERSHIPS

To adequately address the research challenges and embody the characteristics of a high-tech manufacturing firm by 2040, it is necessary to build strategic partnerships across the Quintuple Helix. Partnering with collegiate educational institutions with research interests aligned towards product realization, smart manufacturing, and industrial/systems engineering will ensure the underlying science behind the company is solid and continuing to evolve. As previously stated, selecting a few K-12 schools in areas of operation will pay dividends through exposure to the future workforce.

Secondly, forging partnerships with impactful citizens' STEM organizations such as those in **Table 2** can provide insight into challenges and opportunities impacting the lives and work of employees and customers. These organizations also provide a rich hiring pool and support for future and current

professionals. By investing time and capital, the company can help create the workforce it wishes to employ in the future.

TABLE 2: STEM Organizations

Acronym	Name
AISES	American Indian Science and Engineering Society
ASME	American Society of Mechanical Engineering
IEEE	Institute of Electrical and Electronics Engineers
NSBE	National Society of Black Engineers
STEM	Out in Science, Technology, Engineering, and Mathematics
SHPE	Society of Hispanic Professional Engineers
SWE	Society of Women in Engineering

Cooperation with state and federal governments' workforce agencies and grant offices would greatly benefit the bottom line of the company and the communities of operation. Additionally, the American Disabilities Act (ADA) standards, which are issued by the Department of Justice and the Department of Transportation, will provide invaluable insight into designing for people of varying abilities.

Industry partnerships can be useful, provided each party has equal investment and stakes in the venture. A partnership between smaller companies who have proprietary predictive or generative design or manufacturing software would be invaluable when it comes to improving increasing the excellence and sophistication of the product offerings.

Hiring a Chief Environmental Engineer to work with the Chief Health and Safety Officer will fortify our Safety, Health, and Environment departments and shape our plans and practices. The oversight of this CEE will help the company to move closer to sustainability.

CONCLUSION

In 2040, the company the most lauded company in manufacturing will be the company most successful at building connections. These connections could be those that govern the product service systems, the cyber-physical-social system, the company and the user, the company and the members of the Quintuple Helix. By understanding interactions, their value, and the consumer, while remaining agile, sustainable, ethical, inclusive, and open, the company can weather the changes that Design Engineering and Industry 4.0 will inevitably bring.

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