Computer Aided Strategic Planning for Rapid Deployment of Manufacturing4.0

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Abstract: Manufacturing 4.0, also known as Industry4.0, is supported by a wide range of cyber-physical solutions such as web portals, mobile apps, IoTs, robots and drones. These solutions need to be customized for different geographical locations with different capabilities and should be produced quickly and at massive scales to meet the specific demands of the SIDS and other countries. To complicate matters further, several government policies and industry guidelines regulate the deployment and use of many solutions. It is virtually impossible to handcraft the needed solutions individually and manually. This paper defines the key terms and concepts used in Manufacturing4.0, presents an evolution model for Manufacturing4.0 and then discusses the role of cutting edge digital technologies in accelerating Manufacturing4.0. It then presents a computer aided strategic planning toolkit for rapid deployment of manufacturing4.0. This toolkit, called SPACE, operates as a factory that can rapidly build highly customized solutions very much like the auto factories that build millions of highly customized cars to satisfy needed safety and ergonomic requirements.

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1. Overview of Manufacturing 4.0

Simply stated, manufacturing is the production of finished goods through the use of labor, machines and tools. The inputs to the manufacturing process are typically "raw materials" that are transformed to "finished goods" through a sequence of steps (stages). Finished goods of one manufacturing process may be used by another to produce more finished goods. Manufacturers have always relied on industrial technologies over the years to grow their businesses and gain competitive advantages. The First Industrial Revolution, initiated in the 1760s, was spurred by a transition from hand production methods to machines through the use of steam and water power. The Second Industrial Revolution was spurred by the extensive availability of railroad and telegraph networks around 1870s, and the Third Industrial Revolution occurred in the late 20th

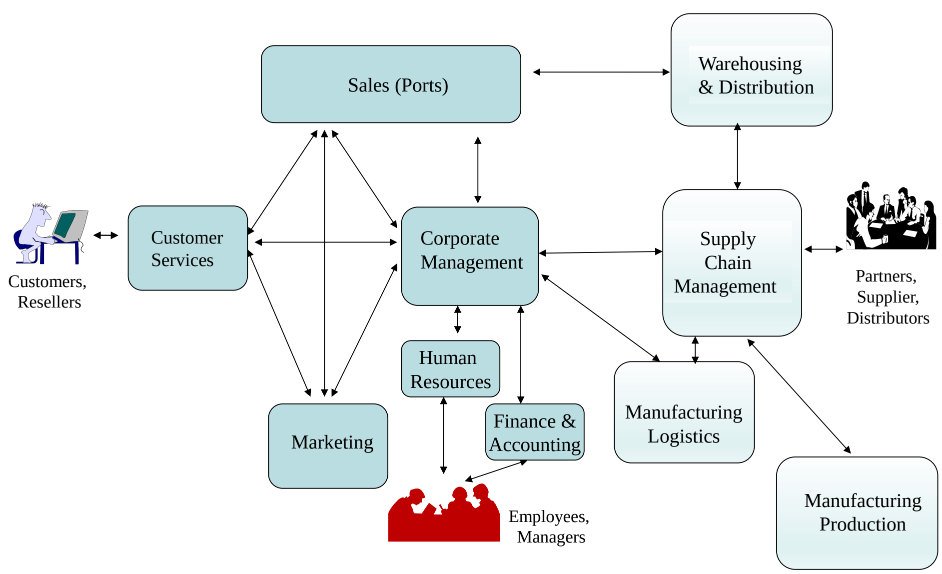

Figure 1a: High Level Business Pattern for Manufacturing Economies

century due to the digital computer and communication systems. The Fourth Industrial Revolution, now known as *Industry4.0*, was first introduced by a team of German scientists around 2015 to combine computer and communication technologies with biology (cyber-physical systems) and other breakthroughs in emerging technologies such as artificial intelligence, internet of things, robotics, autonomous vehicles, and many others.

The current manufacturing systems are heavily leveraging Industry 4.0 technologies. In fact, Manufacturing 4.0 has become synonymous with Industry 4.0. Other titles being used by Manufacturing 4.0 are Smart Manufacturing and Digital Manufacturing. For a broader perspective, Figure1a shows a high level business pattern for Manufacturing 4.0 organizations that combines common business services with manufacturing services. Most of the business services, shown as darker blue, are part of the core business services but four light blue boxes show the manufacturing related services. The manufacturing related services consist of Production that converts raw materials into finished goods, Logistics that makes sure that the needed materials are available and managed properly, and Supply Chain plus Warehousing services to support manufacturing processes. For example, in case of manufacturing by using 3D printers, the logistics is concerned with collecting and cleaning the plastic waste and the production is concerned with converting these raw materials into finished goods such as plastic slippers, handbags, sunglasses and the like. Supply chain plus warehousing services make sure that finished goods are made available to the customers.

Use of ICTs to accelerate *manufacturing economies* that offer an opportunity for SIDS (Small Islands and Developing States) and other developing countries to create new income streams and to diversify their economies Manufacturing4.0/Industry4.0. Figure1b shows a high level view of a Manufacturing Economy Portal that supports the business pattern shown in Figure 1a. Specifically, this portal provides the following ICT-enabled services:

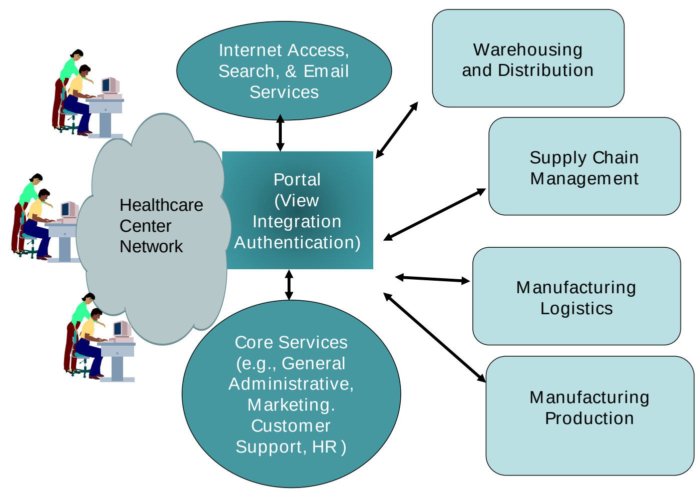

Figure 1b: Portal View of a Basic Manufacturing Economy Service

- General Internet access, search and email services
- Core services such as general administration, marketing and customer support
- Warehousing and supply chain management services
- The manufacturing specific services consist of production that converts raw materials into finished goods and logistics that makes sure that the needed materials are available and managed properly. These services are most heavily being influenced by Industry4.0.

2. Manufacturing 4.0 – A Closer Look

Figure 2 shows a detailed business-oriented view of manufacturing4.0 organizations that is a refinement of the view presented in Figure1. Figure 2 displays a "business pattern" that can be specialized and simplified for smaller businesses, towns and islands. This business pattern highlights the manufacturing 4.0 specific processes/services such as production, logistics, and others in the red circle. Although the main focus of this business pattern is on manufacturing related services, displayed in the red circle, Figure2 also captures the common business processes such as customer services, sales, marketing, finance and accounting, and corporate management. The common business processes (darker blue) are typically the same in any industry. However, some common services such as inventory management and supply chains are now concerned with the finished goods produced by the manufacturing organization. This business pattern presents a big picture but our main focus is on the following manufacturing specific functional areas (in the red circle):

Production that consists of

- Materials Planning
- Design (CAD) and Manufacturing (CAM)

- Raw Materials Inventory Purchasing and Management,
- Manual aspects of Manufacturing (e.g., packaging and shipping).

Logistics that consists of

- QA (Quality Assurance) and Risk Management
- PLM (Product Lifecycle Management) and PDM (Product Data Management) of the actual products being produced.

Warehousing and Distribution that consists of

- Managing the finished goods inventory
- Shipping the products to the customers

Supply Chain Management system that

- Monitors the incoming as well as outgoing raw materials and finished good (sensors)
- Schedules the incoming as well as outgoing raw materials and finished good

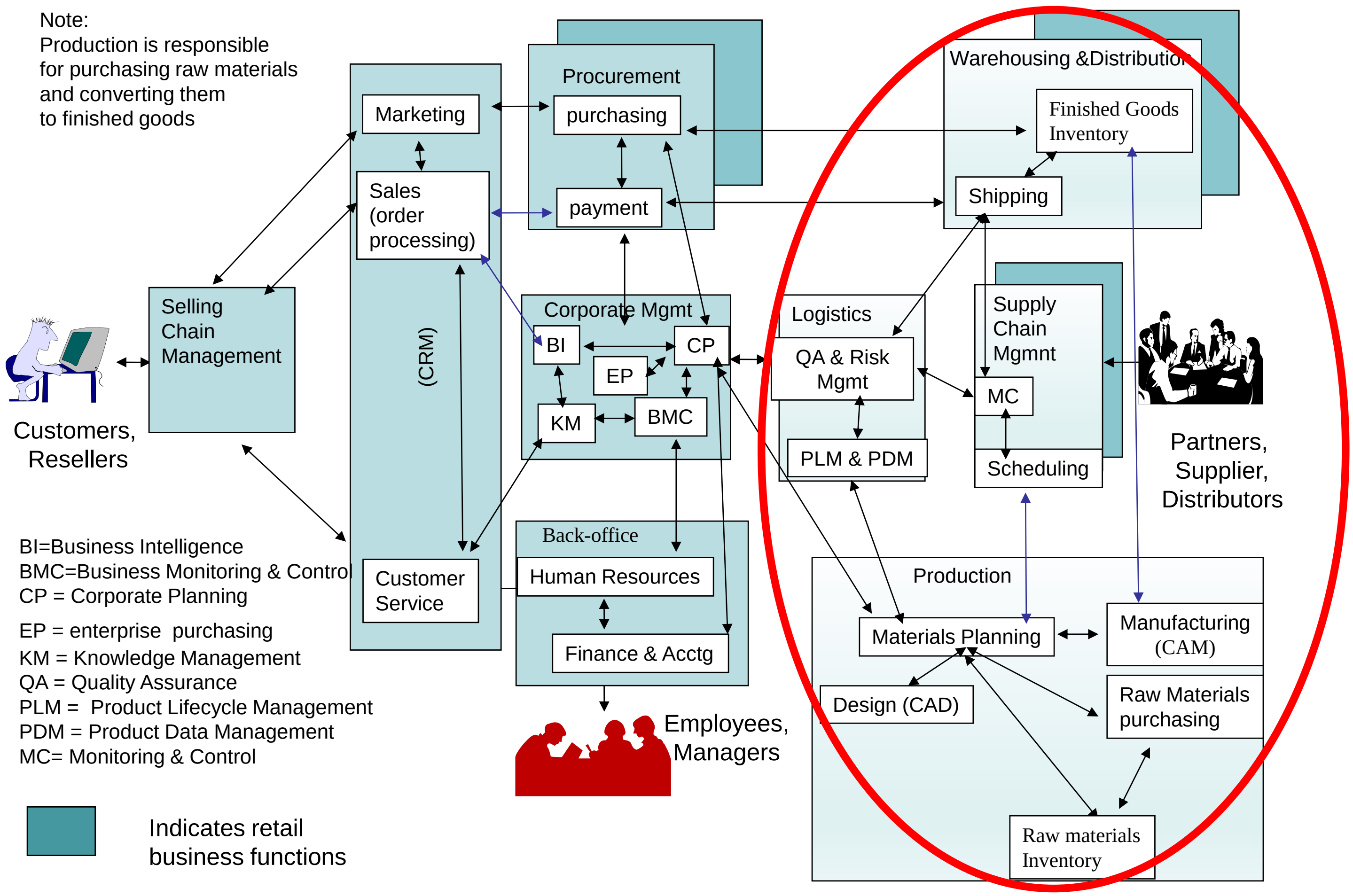

Figure 2: Manufacturing 4.0 Business Pattern (Detailed View)

3. Categories and Evolution of Manufacturing and Industry4.0 – A Quick Overview

According to the US Labor and Statistics (https://www.bls.gov/iag/tgs/iag31-33.htm), the manufacturing sector consists of the following subsectors:

- Food Manufacturing
- Beverage and Tobacco Product Manufacturing
- Textile Mills and Textile Product Mills

- Apparel Manufacturing
- Leather and Allied Product Manufacturing
- Wood Product Manufacturing
- Paper Manufacturing
- Printing and Related Support Activities
- Petroleum and Coal Products Manufacturing
- Chemical Manufacturing
- Plastics and Rubber Products Manufacturing
- Nonmetallic Mineral Product Manufacturing
- Primary Metal Manufacturing
- Fabricated Metal Product Manufacturing
- Machinery Manufacturing
- Computer and Electronic Product Manufacturing
- Electrical Equipment, Appliance, and Component Manufacturing
- Transportation Equipment Manufacturing
- Furniture and Related Product Manufacturing
- Miscellaneous Manufacturing

As displayed in Figure2, an actual manufacturing shop consists of common business processes (e.g., marketing, sales, customer support) and the manufacturing specific processes, shown in the red circle, that depend on the aforementioned subsectors. Examples of these manufacturing processes are production, logistics, warehousing and supply chain management. The digital technologies support business as well as manufacturing processes of a company but at different level of maturity. For example, a textile mill in Pakistan may heavily use web portals and digital marketing in business processes but still be in Industry1.0 in manufacturing operations. Figure 3 shows an approximate view that casts this evolution into the following two dimensional model:

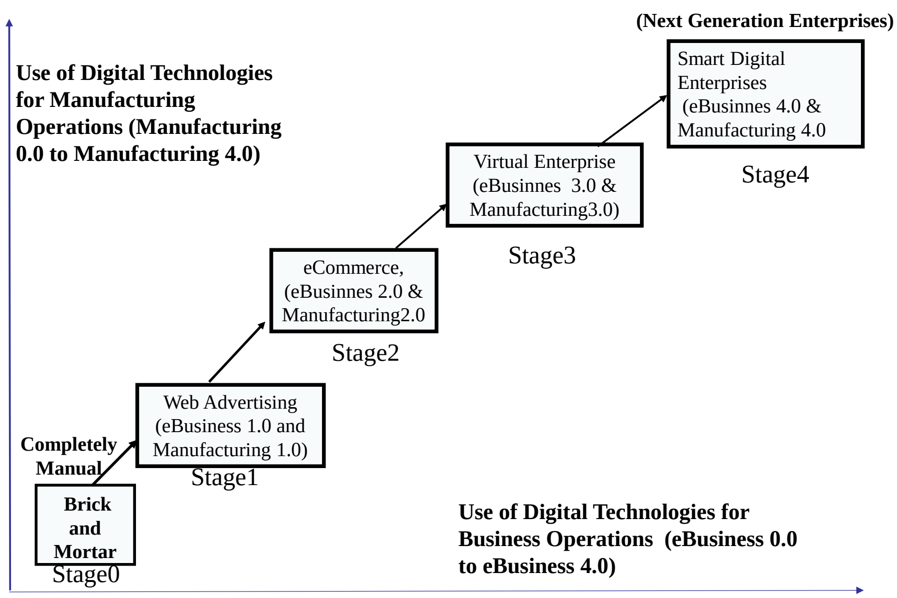

Figure 3: Stages of Digital Transformation: Brick and Mortar (Stage0) to Next Generation of Smart Digital Enterprises

- X axis represents the use of Digital Technologies for Business Operations (from eBusiness 0.0 to eBusiness 4.0)
- Y axis represents the use of Digital Technologies for Manufacturing Operations (from Manufacturing 0.0 to Manufacturing 4.0)

Thus different manufacturing organizations can be represented in this diagram as different points in a scatter chart in terms of their use of digital technologies in their business and manufacturing operations. It is expected that enterprises with high level use of digital technologies in business operations will be doing the same in manufacturing operations. This encourages us to introduce Stages 0 to 4 in this model to *roughly* represent the *normal* manufacturing organizations in different parts of the world as they evolve. Thus Figure3 provides us with a simple framework to evaluate the progress of industrialization in different parts of the world. Although this idea needs further discussion and debate, we will use Figure3 to briefly describe Stages 0 to 4 of manufacturing organizations in the following discussion:

- **Stage 0: Brick and Mortar Enterprises.** Organizations in this stage practically use no digital technologies. Many organizations in the rural areas of developing countries fall into this category.
- **Stage 1: Simple Web sites for Advertising.** The basic idea is to use the Web sites to display /advertise company products. All other company operations are largely unaffected. For example, a restaurant can just display its menu on a website for advertisement.
- **Stage 2: eCommerce sites.** In this stage, the enterprises use digital technologies for online purchasing and other business operations. The company does use some digital technologies in manufacturing operations (e.g., logistics and supply chains).
- **Stage 3: Virtual Enterprises.** In this stage, the enterprises use digital technologies heavily for most business operations and perform B2B operations over the Web (virtual enterprises). The company does use digital technologies in manufacturing operations (e.g., CAD, CAM, some robotics, logistics and supply chains). In this stage, digital technologies take a central role in gluing services across almost all organizational units spanning multiple organizations.
- **Stage 4: Next Generation Enterprises (Smart Enterprises and Manufacturing 4.0).** This stage goes beyond stage 3 and fully exploits the latest digital technologies to quickly detect, adjust & learn in a highly competitive marketplace. The digital infrastructure *drives* all the company business and manufacturing operations in this model. NGEs are the ultimate in digital transformation and they push the limits of digital technologies in their business and manufacturing operations. We will review such organizations in the next section.

It should be noted that there are several benefits for organizations to move from Stage0 to stage4 (i.e., become Manufacturing4.0). However, there are several challenges too, as summarized in Table1. Organizations in developing countries especially need to carefully examine both aspects of evolution before investing in Manufacturing4.0.

Table 1: Challenges and risks of Manufacturing4.0

Potential Benefits of Manufacturing 4.0	Challenges in Implementation of Manufacturing 4.0
• Potential for economic growth • New opportunities and partnerships • More productivity in a competitive industry • Manufacturers can bring new products to market faster by reducing production lead times • Manufacturing Production benefits such as fewer machine failures, reduced scrap and downtime issues, and improved throughput • Better decisions are based on actual data that is generated by IoTs instead of just personal feelings and biases • Clarity in identifying production challenges (e.g., equipment failures) because everyone can see the same data on cycle time and bottlenecks through detailed traces.	• High economic costs and excessive investment • Unclear economic benefits in many cases • Privacy concerns and possible distrust about too much technology controlling technology • Loss of many blue collar jobs to automatic processes and IT-controlled processes • Shortage of trained workforce (education gaps) • Unclear legal issues, regulations and data security • Numerous organizational and governance issues such as oversight and complexity of diagnosing problems when large number of machines are collaborating with other machines

4. How Cutting Edge Digital Technologies Can Accelerate Manufacturing 4.0

Manufacturing 4.0, also known as *Smart Manufacturing*, fully exploits industry 4.0 that relies powerful computers interconnected through intelligent networks communicate with one another to make decisions without human involvement. Thus smart machines will keep getting smarter as they get access to more data and the overall factories will become smarter and more productive over time. Thus it is the *network* of these machines that supports direct collaboration and learning from each other that distinguishes Industry 4.0 from Industry3.0. Industry3.0 mainly relied on powerful computers (e.g., super computers) but not that much on the intelligent networks between the computers.

Definition: For the purpose of this discussion, we will use the following definition of *Smart Systems*, roughly based on IBM's Smart Planet Initiative: A smart system captures the four key features of human intelligence:

- Knowledge (K): familiarity and awareness or understanding of someone or something (e.g., healthcare)
- Detection (D): ability to discover, sense, or feel a situation such as problem or opportunity based on the knowledge (e.g., detect symptoms of an illness quickness quickly)
- Adjustment (A): ability to change accordingly, stop and choose a different strategy (e.g., prescribe a medication)
- Learn (L): the capability to gain more knowledge and to use the knowledge to do a better job in the future (e.g., learning through practice)

This definition works very well for smart systems such as smart cars (a car that has knowledge about the streets, can detect a pedestrian crossing the street, adjust by applying brakes, and learn to do it better in the next round). Let us use this definition to define the somewhat elusive concept of a *Smart Factory:* Smart Factories have the knowledge about the products being manufactured, the ability to detect any challenges (e.g., breakdowns of machinery), adjust accordingly and continuously learn through machine learning algorithms. We will use this simple definition to explain smart supply chains, smart inventory management, smart logistics and other smart aspects of manufacturing 4.0. Please note that the four parameters (KDAL) can be conveniently used as a *metric* to specify how smart a particular system is. For example, a very smart factory would have a very high level of knowledge about products and the processes, very powerful capabilities to detect and even predict problems, adjust quickly to find workarounds, and keep learning by fully utilizing the massive volume of data being accumulated by the IoTs, sensors and other cyber physical systems in the factory. This data can help management to identify opportunities and inform maintenance, performance and other decisions.

Table2 provides a quick overview of some cutting edge digital technologies (from 3D Printers to Autonomous Mobile Robots) that support the key Manufacturing 4.0 processes such as Production, Logistics, Warehousing and Distribution, and Supply Chain Management. This table effectively shows how the Manufacturing 4.0 Business Pattern, shown in Figure2, is supported through digital technologies such as the following:

- **3D Printing (Additive Manufacturing):** This technology has improved dramatically in the recent years and has progressed from primarily being used for toys and prototyping to actual production. Advances in the use of metal additive manufacturing have opened up many possibilities for production. 3D printers at present can produce light manufacturing products (e.g., toys) completely and spare parts for heavy manufacturing products (e.g., cars and trucks) by using metal additive manufacturing. 3D printers are also revolutionizing the global supply chains and logistics by enabling design of products in Canada and production ("printing") them in an island in the Pacific by using additive manufacturing.
- **Artificial Intelligence and Smart Factories:** AI is used heavily in Smart Factories that have the knowledge (K) about the products being manufactured, the ability to detect (D) any challenges (e.g., failures), adjust (A) accordingly and continuously learn (L) through machine learning algorithms. As mentioned previously, Smart Factories seamlessly connect individual production steps, from planning to product shipping. They also optimize logistics by using smart supply chains that can adjust when they detect new events such as shipment delays.
- **Big Data and Data Analytics:** Smart Factories need to have repositories of data and knowledge for intelligent decisions. Data analytics models generate knowledge (i.e., Descriptive model that capture the relationships between equipment failures and shipment dates, Predictive models that estimate the magnitude of shipment delays, and Prescriptive models which suggest how to minimize delays for given equipment). Thus the analytics models basically take the massive datasets (Big Data) being generated by IoTs and sensors and convert this data to knowledge. For example, based on past data on cycle times for production, smart factories can predict future production rates.
- **IoTs, Sensors and Cyber Physical Systems:** Internet of Things (IoT) is basically the connection of all devices to the internet and each other by heavily using sensors. Cyber Physical Systems go beyond devices and utilize integrations of computation, networking and large physical entities that could be bridges and buildings – they can thus form networks of buildings, airports and hospitals. Smart Factories need to have repositories of data and knowledge for intelligent decisions. IoTs and cyber physical system networks with sensors are instrumental in creating these repositories. So the Smart Factories and other AI applications sit on top of IoTs, sensors, and cyber physical systems.
- **Smart Mobile Apps, Automated Mobile Robots (AMRs), and Augmented Reality (AR):** Smart Mobile Apps integrate many of the aforementioned technologies, and invoke others remotely, for almost all of the manufacturing processes. Smart mobile apps are very useful in developing countries for smart factories because they can run on slow networks. Although robots have been used to move goods around warehouses for a while, more attention is now being paid to Autonomous Mobile Robots (AMRs) because they offer increased flexibility and efficiency. AMRs move

through plants with purpose, finding the best route to their final destination and collecting data along the way. AMRs, coupled with augmented reality (AR) have great deal of potential for smart factories of the future.

- **Cloud Computing for On-Demand Computing and Data Storage:** IoTs store large amounts of data on the cloud, so the insights of other organizations using the same equipment can result in collaborations between different organizations on the same cloud. In general, Smart Factories need a great deal of computing and data storage capabilities. Cloud Computing is an ideal on-demand computing and data storage solution for Smart Factories.
- **Trusted Systems and Blockchains**: Blockchain provides digital ledgers that cannot be tampered with. In many smart factories, there are many records of transactions between various devices without any supervision or controls. These records are possible areas of application for blockchain. Blockchains technology can be used as a trusted tracking system for transportation of food products, electronic devices, and medications (e.g., vaccination that must be kept at certain temperatures) while in transit. Blockchain ledgers created by using RFID can raise alarms about expiration dates for food pharmaceutical products. The food industry requires more and more security and transparency and full documentation for tracking purposes. Blockchain is used for tracking as well as the collection of human and product data.

Table2: Cutting Edge Digital Technologies that Support Manufacturing Economies – A Quick Overview

Technologies	Production (CAD/CAM, MRP)	Logistics (QA, PLM,PDM, Transportation)	Warehousing & Distribution (Inventory Mgmt)	Supply Chain Management
3D Printing (Additive Manufacturing)	3D printers can produce light manufacturing products (e.g., toys) completely and spare parts of heavy manufacturing products (e.g., cars)	3D printers can revolutionize the global supply chains and logistics by designing products in Germany and producing them in small islands in the Pacific	3D printing on demand can eliminate the centralized storage centers and the need for expensive distribution systems	Supply chains of 3D printing are much simpler and can enable partnerships between developed and developing countries
Artificial Intelligence (Smart Systems through Knowledge (K), Detection (D), Adjustment (A) and Learning (L) Capabilities)	Smart Factories have the knowledge about the products being manufactured, the ability to detect any challenges (e.g., breakdowns), adjust accordingly and continuously learn through machine learning algorithms. The connected machines, devices, and production systems are at the core of Smart Factories.	Smart Warehouses have the knowledge about the products and can detect and predict the demand for particular products. Based on this data, they can adjust the orders so that the in-demand items can be delivered to the local warehouses and learn about the logistics in advance, to lower transportation costs.	Physical warehouses can be replaced with Smart Warehouses that store information about all items. A Smart Advisor can help determine which parts are suitable for 3D printing and evaluate challenges of producing 3D versus other traditional solutions.	Smart Supply Chain Management systems with KDAL capabilities can detect when weather conditions, for example, can delay shipments and proactively adjust to that reality, modify manufacturing priorities, and learn for future adjustments.
Big Data and Data Analytics (Descriptive, Predictive, Prescriptive)	Smart Factories need to have repositories of data and knowledge for intelligent decisions. Data analytics models convert data to knowledge. For example, based on past data on cycle times for production, smart factories can predict future production rates.	Predictive Analytics can determine needed repairs ahead of time and initiate repairs. Also, based on past data on transportation times during different weather conditions, delivery schedules of transportation can be adjusted.	Smart Inventory Management can capture Big Data accumulated through sensors and IoTs about which items are moving faster. This can help predict demand and determine re-order points.	Smart Supply Chain Management systems can also use prescriptive analytics (i.e., optimization algorithms) to determine which medication suppliers can meet emergency demands (e.g., in pandemics).

IoTs, Sensors and Cyber Physical Systems	Smart Factories need to have repositories of data and knowledge for intelligent decisions. IoT and other cyber physical system networks with sensors are instrumental in creating these repositories. So the Smart Factories and other AI applications sit on top of IoTs, sensors & cyber physical systems.	Smart Factories monitor the logistics, especially transportation, activities by embedding sensors into the transportation machines and item packages which collect data about the transportation time, detect any problems and adjust accordingly.	Inventories of medications have complex requirements such as temperatures and expiration dates. Smart inventories of medications use RFIDs with expiration dates that automatically raises alarms when expired.	Smart sensors transform the physical supply chain world into a digital shadow of an item as it travels through different stages in the supply chain. This gives the knowledge to managers to detect, adjust and learn.
Smart Mobile Apps & Automated Mobile Robots (AMRs), Augmented reality (AR)	Smart mobile apps can be used in developing countries for smart factories. But AMRs, coupled with augmented reality have great deal of potential for smart factories of the future.	Some AMRs are designed to work safely around people and thus freeing workers from repetitive & dangerous transportation tasks, especially in remote areas.	AR glasses could be used to project useful data, such as layouts and assembly tips on the real part, thus facilitating faster and error free work procedures.	AMRs can be much more effective than the AGVs (Automated Guided Vehicles) for Supply Chains because AMRs have many additional features
Cloud Computing for On-Demand Computing and Data Storage	Smart Factories need a great deal of computing and data storage capabilities. Cloud Computing is an ideal On-Demand Computing and Data Storage solution for Smart Factories.	Besides data and computations, cloud provides diverse web services (e.g., Amazon Web Services) applications in business intelligence and quality assurance.	Cloud-based inventory & warehousing applications can provide visibility for all products in any stage of their life cycle in any country.	Cloud-based supply chain management can significantly cut down on lost products it can locate a shipment during any stage of transport in any country.
Trusted Systems and Blockchains	Blockchain provides digital ledgers that cannot be tampered with. Blockchain ledgers can be used as a trusted system for collection of human data as well as product data.	Blockchains technology can be used as a trusted tracking system for transportation of medications (e.g., vaccination at certain temperatures) while in transit.	Inventories of medications have complex temperatures and expiration date requirements. Blockchain ledgers created by RFID can raise alarms.	Trusted blockchain ledgers can be created in global supply chains to assure compliance with the pharmaceutical and food industry requirements.

5. Short Case Studies and Examples of Manufacturing 4.0

5.1: Manufacturing 4.0 in SIDS at a Glance

This topic is being discussed in literature at present, albeit not extensively. The four sources listed below make the following points:

- First, many developing countries have coexistence of Industry 1.0, 2.0, 3.0 and 4.0. This presents interesting challenges that require innovative ways of delivering their services.
- Second, the ‘lack of a digital strategy alongside resource scarcity’ emerges as the most prominent barrier in both developed and developing economies. For developing countries, improvements in standards and government regulation could facilitate the adoption of Industry 4.0. But for developed countries, technological infrastructure is needed to promote the adoption of these technologies.
- Third, most discussions on industry 4.0 in developing countries have been “incendiary” and triggered conflicts. But entrepreneurial firms operating in Africa and least developed countries have been making progress in B2B trucking and supply chain systems, healthcare, and other related areas.
- Fourth, many countries such as Ethiopia, India and Bangladesh are raising economic power, but have not yet integrated very much with the global economy and still have not achieved their potential in context of technology, globalization, and international competitiveness like developed countries. The main key strengths of these courtiers are their large domestic market, young and growing population, a strong private sector with experience in market

institutions, and a well developed legal and financial system. Despite their strengths, they are facing many challenges in the increasingly competitive and fast changing global economy.

- Fifth, many SIDS and LDCs are exploring the following opportunities by using 3D printing:
  - Recycling of plastic waste for producing sunglasses, plastic purses, purses and the like
  - Artifacts for tourism such as expensive looking jewelry and clothes
  - Wood product manufacturing because SIDS have abundance of woods
  - Spare parts for shipbuilding to support the shipping industries
  - Partnering with larger industries in developed countries by becoming local outlets

Suggested References:

- “The challenge of preparing developing countries for Industry 4.0”, UN Industrial Development Organization (UNIDO), Jul16, 2017, https://www.unido.org/news/challenge-preparing-developing-countries-industry-40
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5.2 Short Examples of Manufacturing 4.0 and Sources for Additional Information

- *Decision Support System (DSS) for Luxury Products*: Bottega Veneta, an Italian luxury goods house, improved the supply chain by using a uniform data model, used by all the actors involved in the production process to collect and represent the large amount of data involved in the production process. A DSS (Decision Support System) allows the production planner to focus on different scenarios to take better decisions.
- *Volkswagen Cloud*: Volkswagen is creating a “Volkswagen Automotive Cloud” that offers features such as smart home connectivity, a personal digital assistant, predictive maintenance service, and media streaming. Volkswagen aims to add over 5 million Volkswagen brand offerings per year with the help of this cloud service. This cloud is an effective approach for managing and transmitting large amounts of data to their vehicles. The cloud storage space enables automotive companies like Volkswagen to use extensive data analytics algorithms to convert data to knowledge and business intelligence.
- *Automated Mobile Robots (AMRs):* A DHL distribution center in the Netherlands is using Automated Mobile Robots (AMRs) to perform pick and place operations. These AMRs autonomously move across the facility alongside the workers, automatically learning and sharing the most efficient travel routes. Using these self-driving robots can help reduce order cycle time by up to 50% and provide up to twice the picking productivity gain, according to DHL.
- *Augmented Reality (AR):* AR glasses are just beginning to find commercial applications. General Electric is piloting the use of AR glasses. Before using these smart glasses, jet engine makers often had to stop what they were doing in order to check their manuals and ensure tasks were being performed correctly. This is an error prone process. However, with AR glasses, they can now receive digitized instructions in their field of view. The mechanics can also access training videos or use voice commands to contact experts for immediate assistance. During the pilot, GE reported 11% improvement in previously. Similar applications of AR glasses in surgery and other delicate procedures are under investigation.
- *Sensors*: Sensors help manufacturers to optimize their operations quickly and efficiently by knowing what needs attention. There are many examples. Here is one. By using the data from sensors in its equipment, an African gold mine identified a problem with the oxygen levels that they did not know about. Once fixed, they were able to increase their yield by 3.7%, which saved them $20 million annually.
- *3D Printing:* Fast Radius, a Chicago-based manufacturer, uses a platform to collect data and findings from every part design that is stored and manufactured in the Fast Radius virtual warehouse. The data helps teams to identify applications suitable for 3D printing and evaluate engineering and economic challenges of producing a component by using 3D printing. The company also created a virtual parts warehouse consisting of 3,000 items for a heavy equipment manufacturer. This eliminated the high costs of storing rarely ordered heavy parts.

Suggested References:

- "Industry 4.0: 7 Real-World Examples of Digital Manufacturing in Action", March 28, 2019. URL: https://amfg.ai/2019/03/28/industry-4-0-7-real-world-examples-of-digital-manufacturing-in-action/
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- Marr, B., "What is Industry 4.0?", Sep 2, 2018. URL: https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/?sh=760593539788
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6. Computer Aided Strategic Planning for Manufacturing Industries

Rapid deployment of manufacturing economies around the globe require a wide range of digital solutions that need to be customized for different geographical locations with different capabilities and need be produced quickly and at massive scales under different government policies and industry guidelines. It is virtually impossible to handcraft the needed solutions individually and manually for every location and user needs. We have developed a factory model that builds highly customized solutions rapidly very much like the auto factories that have built millions of highly customized cars that integrate multiple technologies to satisfy needed safety requirements. Specifically, we are using a computer aided planning, engineering and management approach that is based on a "factory" model and is especially useful for Small to Medium Businesses and Towns (SMBTs). Our *software factory is* illustrated in Exhibit1.

Our vision is to use the SPACE (Strategic Planning, Architecture, Controls & Education) toolset, introduced in Exhibit1, as a "Factory" to rapidly generate needed artifacts manufacturing and other economies. Specifically, we are requiring that the solution services *must* be: a) low cost (i.e., affordable by SMBTs) but high impact, b) location and topic specific, c) integrated with each other, and d) smart so that they can acquire new knowledge automatically for better performance in the future. As a test-case, we have used the SPACE factory to populate portions of a Smart Global Village (SGV) – a *sandbox* with more than 800 "smart hubs" for 135 countries and spanning 12 sectors including disaster resilience and management. *As discussed below, we are now including manufacturing economies as a new sector, especially for SIDS.*

Exhibit1: Example of a Software Factory

The SPACE (Strategic Planning, Architecture, Controls and Education) environment behaves as a software factory that quickly produces *Smart Collaborating Hubs (SCHs)* as shown in Figure 4. An SCH is a center of activity that contains highly specialized and smart artifacts such as an Administrative Portal, a Citizen App, Training Materials and relevant Policies on a particular topic. Most importantly, all SCHs have pre-fabricated capabilities for collaboration with each other. The main input of SPACE is a Patterns Repository that contains an extensive library of business and technology patterns that can be combined into complex "bundles" to represent smart community centers, towns, cities and commercial enterprises spanning multiple sectors.

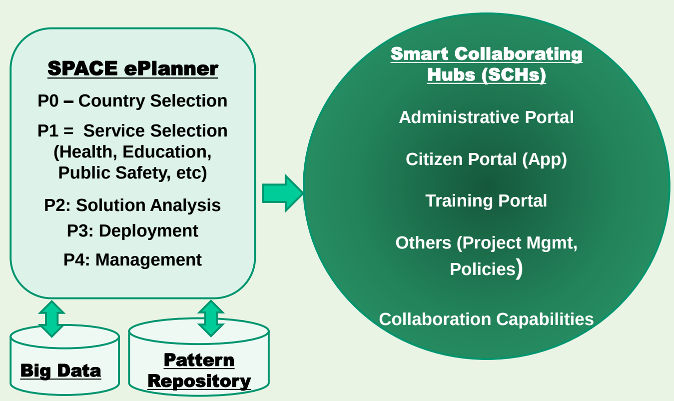

Figure 4: SPACE Factory that Generates Smart Hubs

Figure 5 shows our methodology that rapidly produces smart collaborating hubs by using the SPACE (Strategic Planning, Architecture, Controls and Education) environment. The integrated tools of the SPACE environment support the following phases of the Methodology:

- PHASE1: User decides what needs to be implemented where (e.g., an emarket in Jamaica) and invokes an appropriate advisor (e.g., the SDG Advisor to strengthen SDGs in an area) from our growing library of advisors. We are currently developing a Digital Transformation Advisor briefly described in Exhibit2, that will suggest the strategies to launch the most appropriate services in a particular location. This phase is essentially a "pre-processor" to PHASE2.
- PHASE2: The user invokes the SPACE ePlanner (the "factory") to generate a smart collaborating hub plus a strategic plan, feasibility study, funding proposal, an RFP, project management guideline and other artifacts needed to support the hub. For example, the ePlanner generates most of the artifacts needed to support a telemedicine or tourism hub.

- PHASE3: The artifacts generated by the ePlanner are analyzed/revised and a final smart hub is created. The final hub is "registered" in the Collaboration Network that interconnects all smart hubs (e.g., a community center in Solomons is registered for collaborations with any smart city, town or community on our network). Any "post-processing" (e.g., feeding the ePlanner artifact to a 3D printer) are also conducted in this phase.
  - Customize & Extend the Results as Needed
  - Initiate training and refinement of Hub
  - Preparation of the Final Hub
  - Funding/Entrepreneurship (Fintech**)**
- PHASE4: The results are finalized and hub administrators go through training for smooth operations. The focus of this phase is to determine Uses Cases that are of high impact but low value. Specific activities of this phase are:
  - Detailed Implementation Scenarios for different user groups
  - Computer Aided Resource Planning for different disaster scenarios
  - B2B Collaboration Scenarios between large number of hubs located in different parts of the world .
  - Management and Governance issues for workforce training

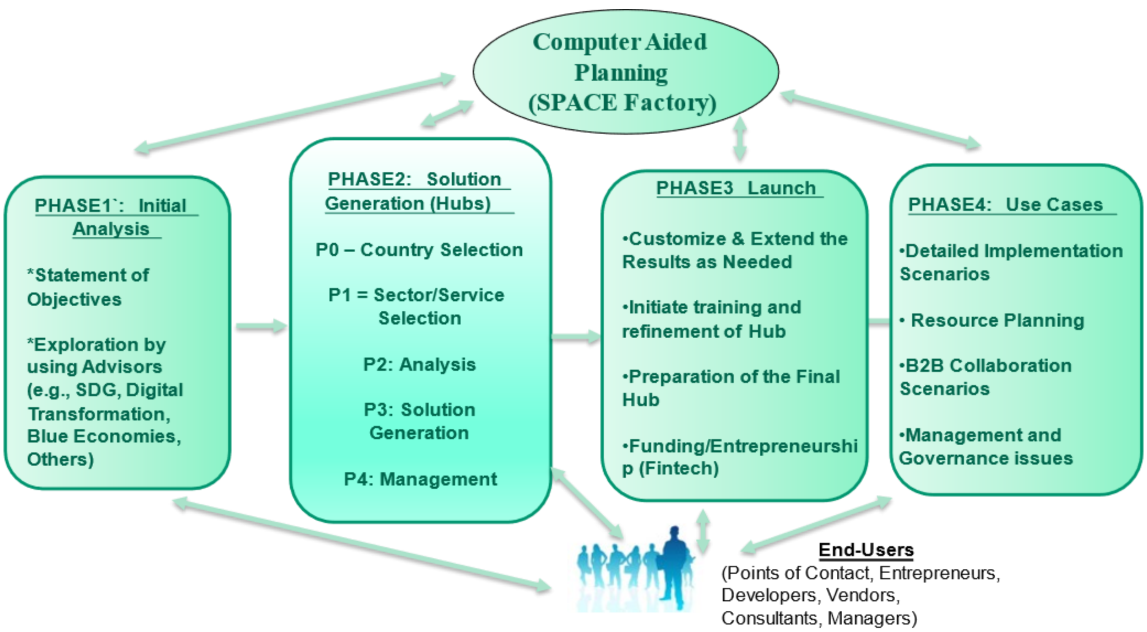

Figure 5: Computer Aided Planning, Engineering and Management Methodology based on SPACE Factory

Exhibit2: Overview of the Digital Transformation Advisor (DTA)

The main objective of this Advisor is to help the users decide which one of the manufacturing4.0 services should be launched first and which ones later or not at all (i.e., develop a Manufacturing4.0 Strategic Plan). The Advisor heavily relies on the Manufacturing Evolution Stage Model described in Section 3 and then helps the user determine what should be the next stage. The user first chooses a country (e.g., Jamaica), and then selects a sector. It then does Cost-Benefit analysis to determine which technologies available in Jamaica could reduce the costs and increase the benefits, etc. Once done, the Advisor could invoke the SPACE, or another Tool, for detailed planning and implementation of the chosen services. More information about this Advisor will be provided later.

7. Sample Results – A Smart Global Village and a Smart City & Communities (SCC) Lab

Since 2015, we have been using the SPACE Environment to support our work with the UN ICT4SIDS Partnership, NSF work on Smart and Connected Communities (SCCs), local and regional initiatives such as Digital Pakistan that is now evolving into Digital Asia, urbanization initiatives such as the Consortium for Urbanization, Digital Transformation initiatives spurred by COVID19, and now the Manufacturing Economies issues. In parallel, the SPACE Environment has been used to teach graduate level courses in Strategic Planning, Enterprise Architectures and Integration, and Smart Cities and Communities. As a result, large number of NGOs, government officials, industry personnel and graduate students have used SPACE. Instead of different toolsets for different audiences and problem domains, we have used SPACE as a single factory with different preprocessors and post processors for different audiences. This thinking is reflected in the Methodology presented in Figure4.

As a consequence of large number of experiments around the globe, SPACE has generated a Smart Global Village (SGV) -- a large sandbox (more than 800 hubs spanning more than 130 countries) for all SPACE users. Figure 5 shows the overall SGV. We have also used SPACE as a factory to generate the Smart City & Community (SCC) Lab that consists of a set of *Smart Collaborating Hubs (SCHs) for SCC communities.* Figure 6 shows the SCC Lab also. These hubs offer topic and location specific services and are also interconnected through a smart collaboration network with *some* Knowledge, Detection, Adjustment and Learning (KDAL) capabilities. The SGV and SCC Lab are being used extensively to develop very interesting and innovative collaboration scenarios for healthcare exchanges, entrepreneurship networks, emarkets and global supply chains. We are using a system of systems approach to gradually make the SGV and SCC Lab smarter: a) gradually make the individual portals in each hub smarter, b) make each hub smarter by improving the collaboration between portals in each hub, and c) make the overall SCC Lab smarter by making the collaboration *between the* hubs smarter through better user community involvement. Basically, smart cars gradually become more effective as better digitized road maps become available and smart cars and smart roads, with sensors, learn from each other and become much smarter over time.

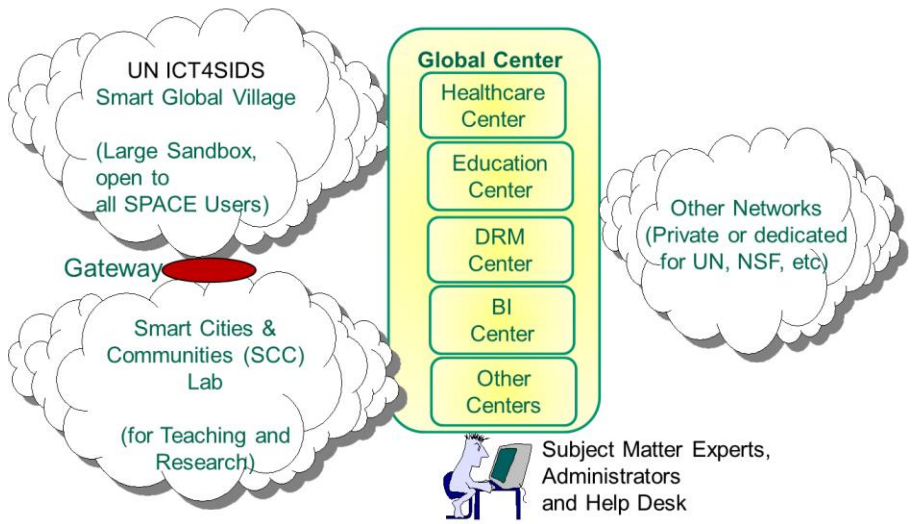

Figure 6: The Smart Global Village

8. Concluding Remarks

Large initiatives such as manufacturing 4.0 require a wide range of digital solutions that need to be customized for different geographical locations with different capabilities. These solutions need to be produced quickly and at massive scales to meet the specific demands of various populations and under different government policies. It is virtually impossible to handcraft the needed solutions individually and manually for every location and user needs. We have developed a factory model to rapidly build highly customized solutions very much like the auto factories that build millions of highly customized cars to satisfy needed safety requirements for different user populations. Our factory-based methodology has produced a Smart Global Village (SGV) that is growing rapidly.

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