Work Force Development for Manufacturing in the 21st Century

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Introduction:

Manufacturing is seen as the next big savior of the industrial world to address the ills of the 20th century (i.e.) high unemployment and stagnant wages for the working class. Rapid economic growth of the emerging nations such as China and India by the end of the 20th century is credited to their growing manufacturing base. The same is also seen as the source of shifting employment away from developed nations and the higher unemployment and stagnant wages in these countries. Yet, we now see emergence of industrial growth in parts of the globe, perhaps at the expense of growth in China in the manufacturing sector. Programs for Next Generation Manufacturing in USA promoted by the U.S. President Mr. Obama and his administration as well as the Make in India campaign by the Prime Minister Modi and his government in India, would seem to suggest that manufacturing of the future will be the source of employment with well-paying jobs in the 21st century, just as it has been the case in most of the 20th century.

In a recent study** it is reported that

- *India's manufacturing sector could grow six fold by 2025, to $1 trillion, while creating up to 90 million domestic jobs*.
- *For an average company, the potential productivity improvements represent about 7% increase returns on sales.*
- India's manufacturers must also improve the productivity of their capital, in some cases by 50 percent or more.
- While such improvements are challenging, they are possible if companies set bold targets and adopt an "owner–entrepreneur" mind-set.

**https://www.mckinseyquarterly.com/Operations/Performance/Fulfilling_the_promise_of_Indias_manufacturing_sector_2943#top

These opportunities are very attractive. They set clear targets to aim for as the outcomes of the "Make in India" campaign. But, in our view, the exact nature of the work force skills and sustained development of such skills will be a critical issue for any level of competitiveness in the manufacturing sector. Hence, in this paper we address the following questions: What is manufacturing? What are the core capabilities of any manufacturing company or industry? What are the work force skills required to be relevant for 21st century manufacturing? What are the strategies to develop such work force skills required to exploit the core capabilities of manufacturing companies, looking into the future?

What is Manufacturing?

Manufacturing is often associated with a factory or the production floor. The collection of machinery and equipment with things being made conjure up the image of any manufacturing floor. The vision of the manufacturing plant with hundreds of workers doing their work in a well-organized and synchronized manner is now being replaced with the robots doing most of the work, with few people working at locations interspersed across the factory floor. Engineers and operations managers represent this organized execution of manufacturing activity through schematics called "Process flow diagrams". While these images of the production floor and the schematics to represent them are rampant, there is no clear consensus on "What is manufacturing?" Let us try and answer this simple question from different points of view.

Let us take a larger perspective or holistic view of manufacturing. We shall describe this later as the system thinking. When we look beyond the nuts and bolts or the micro-details, it is easy to recognize manufacturing as an organized effort using a collection of processes. These processes can be divided between Physical Processes and Service Processes as illustrated in Figure 1.

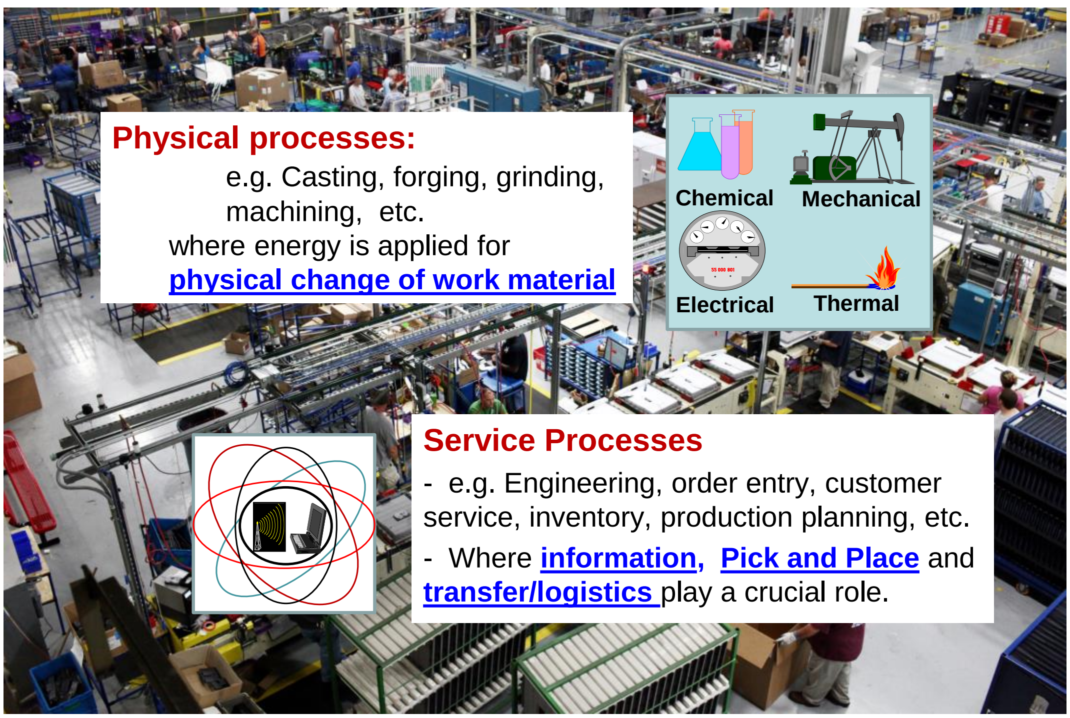


Figure 1. Manufacturing: An organized collection of Physical and Service Processes.

Physical processes *are those that radically change or alter the inputs into finished goods.*
Service processes *on the other hand enable these physical processes to be carried out as an organized and coordinated set of events leading to the desired*

outcome through production planning and control, supply chain, movement of goods and information, etc.

In fact the Service processes are ubiquitous. They are seen from the very early stages of manufacturing where the raw materials and all other necessary supplies are procured, where information is gathered and organized leading to decisions on what to manufacture, product mix, when, how, etc. These service processes may be best described as Information Processes. These information processes were also described in the past as White Collar jobs. Digital Technology enabled solutions (through computers, communication devices, networks, data base, ERP, etc.) have radically transformed these information processes at the shop floor as well as all related activities pertaining to manufactured goods from conception to their delivery for end users.

The service processes are also required within every physical process such as loading and unloading of parts, setting up of the machines, CNC programs that control machine movements in the required timing, sequence, nature and duration, etc. It may even be useful to define these service processes as pick and place or transfer activities. These groups of processes are always a blend of information activities as well as physical effort. As an example the operator of a manual lathe or grinding machine will load and unload the parts (pick and place). He/she will also effect the machine motions necessary through the physical operation of the knobs and controls in the machine. Through these actions the operator transfers the information in the part drawing or blue print into machine motions necessary to achieve the desired component.

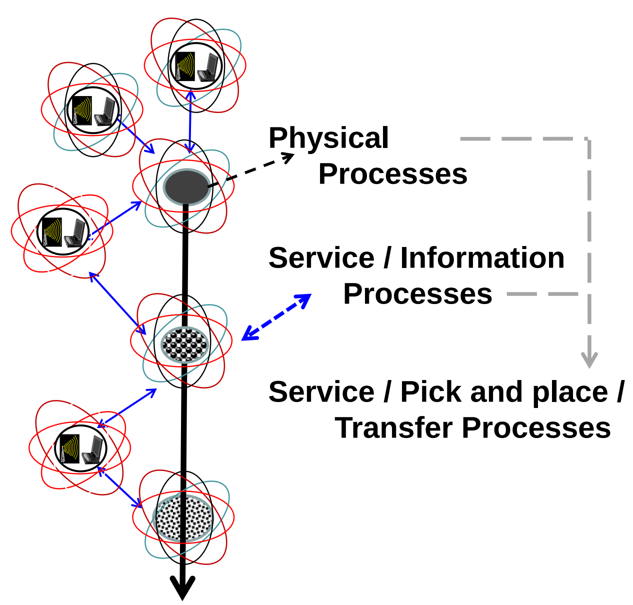


Figure 2. Manufacturing: A collection of Physical and Service processes.

The physical process such as forming, forging, molding, welding, cutting, machining, grinding, plating, coating, etc. are all shrouded by the information processes as well as by the pick and place / transfer events or processes. With the evolution in Programmable Automation much of these pick and place / transfer processes are also changing rapidly. The manual operator being replaced by Computer Numerical Control (CNC) is well established in the past few decades. Much of the human labor used in the manufacturing floor in the past has been due to the flexibility or adaptability of the human resource in the assigned tasks. Thanks to advancements in the speed of computing, lower cost of computing and the speed and flexibility of controllers Programmable Automation is emerging as the next wave of technology for many aspects of manufacturing. Hence “Manufacturing” can be seen as:

> *A collection of (a) physical processes enabled by a host of (b) information processes and aided by a collection of (c) pick and place and transfer processes, which at the moment are a combination of physical events and information events.*

This description of manufacturing is illustrated as noted in Figure 2.

Core Capabilities of any manufacturing company:

System thinking is also described as looking at the big picture, recognizing the pattern rather than being fixated on the pixels on the screen. From this perspective we can look at Manufacturing also in terms of the outcomes. Every manufacturing activity is focused on only three outcomes. They are (a) Product, (b) Processes that enable the product and (c) USE or processes in which the product is used. http://stimsinstitute.com/2012/08/19/vision/

Manufacturing operations do not exist in isolation or in a vacuum. They are part of a sequence of operations starting from product design and development. The manufactured goods are made available to the users through the sales and marketing functions of the company. Sales and marketing functions also serve as the eyes and ears of the company providing new insights for future products and the processes required for them. This alternative view of the manufacturing is illustrated in Figure 3.

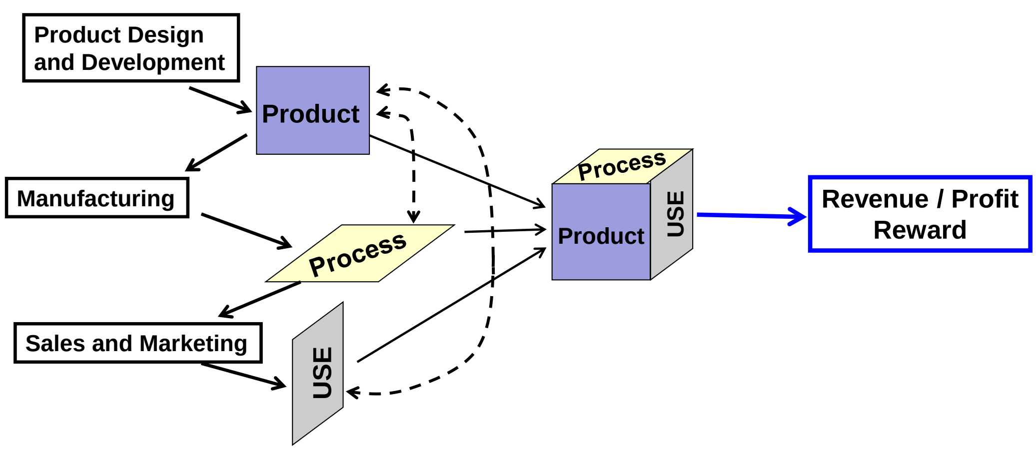


Figure 3. Manufacturing – A collection of inter-related core capabilities.

Product is the source of revenue, for any manufacturing company. In the automotive industry, manufacturers of automobiles are recognized as the OEMs. All the parts suppliers to the OEM are recognized as Tier 1, their suppliers are recognized as tier 2, and tier 3 respectively and the supplier of raw materials to these companies are recognized as tier 4. Machine tool manufacturers that make the machines that make every other manufacturing are also recognized as OEMs! Tooling suppliers who supply their products purchased by every level mentioned above are strangely classified as Tier 3 or Tier 4 suppliers! These classifications have evolved based on the flow of information processes pertaining to purchasing and their details and the amount of business involved. But such classifications become irrelevant when our emphasis is based on physical processes and their integration. But for each of these manufacturers at every level, PRODUCT is their source of revenue. Thus product determines the very reason or purpose of existence of any manufacturer. Hence it is easy to recognize the product as the core capability of any manufacturer.

We have already discussed in detail that manufacturing operations are rich and intense with the deployment of **processes** resulting in the products. We have already described the three families of processes deployed in all manufacturing operations as illustrated in figure 2.
Only through the value delivered by the **USE or Application** of the product, the revenue and profit for the manufacturer is realized. With the above in mind, "manufacturing" may be defined as:

> *The repetitive use of processes, to achieve or USE the "Product"*
> *at the required quantity, place and time to meet the end user needs.*

The value perceived by the user determines the quality requirements and hence the acceptable price and in turn the revenue and profit realized through any manufacturing activity. This cascading role of the three core capabilities of every manufacturer (i.e.) Product, Process, Application/USE is schematically illustrated in Figure 4. Thus we find two parallel chains operating across all manufacturing companies (i.e.) Supply Chain which deals with the information processes that interconnect the various tiers of manufacturers and Functional Value Chain, where the physical processes and their exploitation play a silent but foundational role across the manufacturers. In this description of manufacturing, we find that the role of physical processes and their knowledge and the capabilities enabled through them as a critical need. The application/USE as seen by the supplier of the product is also a "Process" in the eyes of the user. Since the products are enables by processes and the USE is also a process in a manner of speaking, we are left with "Process and its knowledge and the capability to manipulate any process" may be the primary core capability or skill set of any manufacturing professional! The role of human labor and their employment is not explicit in this description of manufacturing. It is important for policy makers to make note of this subtle but significant point.

If we agree to the premise that the goal of any manufacturing is to deploy "Processes" repetitively, then we have two options: (a) Steady improvement in the processes already deployed; this is achieved through the well-known approaches for Statistical Process Control and continuous improvement through Lean, Value stream mapping, etc. In these approaches standardization of known processes and de-skilling are the primary goals. The result is a constant reduction in the explicit knowledge and skill required relative to the Physical Processes. Over time, they have become the black boxes surrounded by a myriad of service processes, which are generic and practiced in all companies and industries. (b) Introduction of a stream of new solutions resulting in New Products, New Processes and New Applications/ USE. These new solutions are the result of intense knowledge of the core capabilities unique to the manufacturing company.

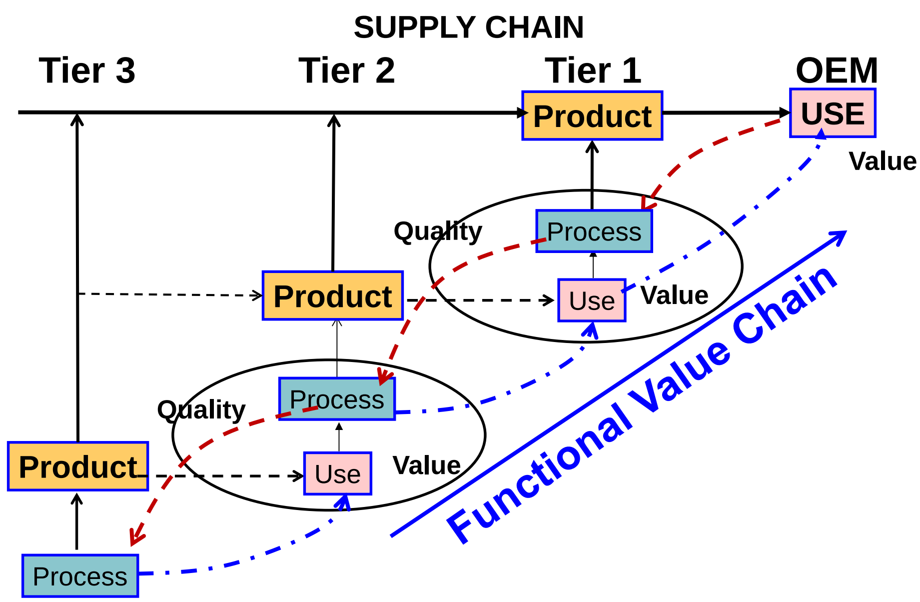


Figure 4. Manufacturing: An economic activity enabled by three core capabilities (i.e.) PRODUCT, PROCESS and Application / USE.

These two approaches for innovation in manufacturing are like two vectors pulling apart from each other as illustrated in Figure 5. This is described as the Binary Economy.
http://stimsinstitute.com/2013/07/17/learn-to-swim-against-the-tide-of-binary-economy/
The Binary Economy has indeed created a new situation, where the "middle" of any kind – in terms of product / Process / USE knowledge – is no longer sustainable. Strategies for continuous improvement to meet the price and delivery requirements are no longer satisfactory. "*Six Sigma, Kaizen, Lean, and other variations on continuous improvement can be hazardous to your organization's health. While it may be heresy to say this, recent evidence from Japan and elsewhere suggests that it's time to question these methods*"**.
**http://blogs.hbr.org/ashkenas/2012/05/its-time-to-rethink-continuous.html

The minimum required for survival of many manufacturing companies seems to be a strategy for constant price reduction year after year. This is typically of the order of 10 to 15% for most auto parts suppliers. According to a recent report, new and customized process solutions that anticipate the needs of the customers have proven to be successful for many manufacturers. http://stimsinstitute.com/2014/10/22/future-of-manufacturing-and-core-capability-development/

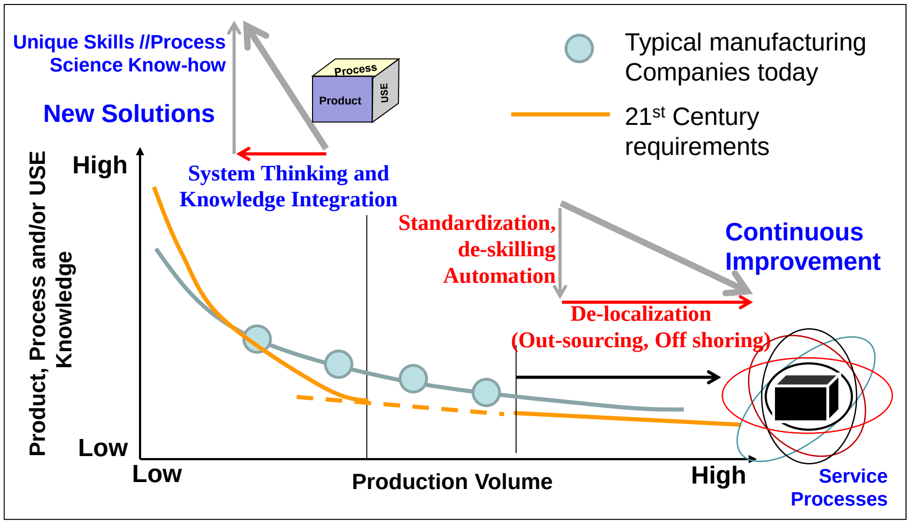


Figure 5. Binary Economy: New Solutions Vs. Continuous Improvement

Looking further into the future, it is our view that radical departures from competitors through break through new solutions in terms of Product, Process and USE and their deployment in large quantities will be the only sustainable strategy for survival and growth for many manufacturing companies and industries. The recent success of Apple Co. which appears unique and special today is likely to be the norm for most manufacturing companies of the future.

Work force skill required for future manufacturing:

If new solutions are the pathways for the future in manufacturing, it begs answer to the basic question: What is a solution? We define every solution as a system that transforms chosen inputs into outputs. Every process deployed in all manufacturing activities is a system that involves a “transformation”. All physical processes deploy laws of nature as the transformation phenomena. Often the transformations occur for short periods of time, of the order of seconds and sometimes as short as milliseconds. Hence, it is natural to ignore them in the clamor of many events associated with manufacturing with long time horizon such as supply chain events, inventory control, production planning, etc. It is the knowledge of the “transformation” behind these processes that are at the heart of all manufacturing operations. By ignoring them, the manufacturers are at peril like a health fitness program that ignores the heart and its function! Conversely we can define any new solution as the knowledge of the “transformation” behind the physical processes and the use of such knowledge to achieve outcomes that add value or meet anticipated needs of the users. This description of the solution as a system, comprising of Knowledge of the transformation and its deployment are illustrated in figure 6. With the above in mind, one could conclude that the future manufacturing professionals require intense knowledge of the "Transformation" and creative ways to deploy such knowledge together with all associated service processes.

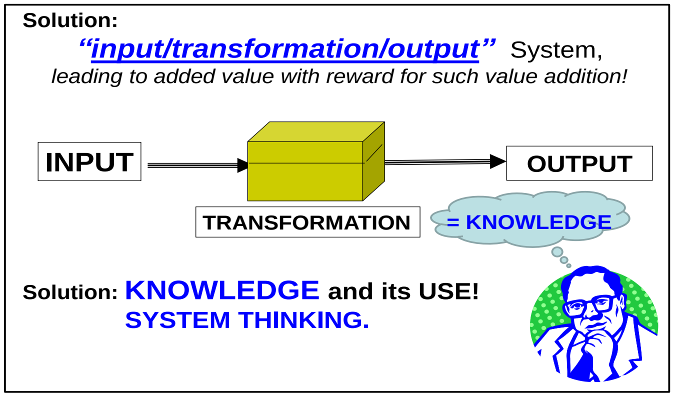


Figure 6. What is a solution? It is a process that can be described as "Input/transformation/output" system.

System Thinking:

If manufacturing consists of a collection of processes and if every process is a system, then it becomes evident that it is essential to treat all manufacturing activities as interconnected network of systems. The number of such systems involved and their interconnectivity create a level of complexity far beyond the comprehension for most workers. This leads to reliance on well-established standards, practices and procedures. In due course, rules of thumb dominate the land scape, while the basis for such rules are often forgotten or not understood at all.

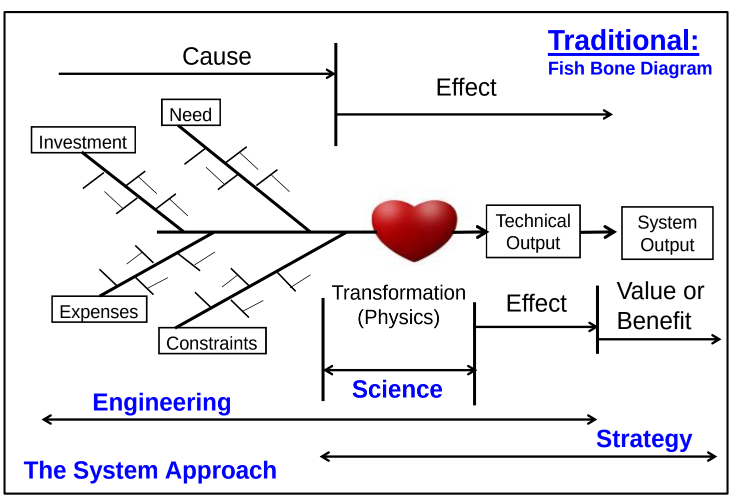


Figure 7. The System Approach for Industrial Processes

Attempts to model manufacturing processes using computers often mask the complexities and the transients unique to the "transformation". In due course, we treat the physical process – an engineering event driven by laws of nature – as statistical events. As a result we have fish bone diagrams (after asking the "Why?" five times) that outlines the cause and the effect, without addressing the physical phenomena or the transformation.

Instead, we recommend an approach where the inputs for any manufacturing process are divided between four well defined categories. These inputs simultaneously excite the transformation leading to the outputs. These outputs are also divided between the "What?" or the technical outputs and the "Why/" or the value/benefits described as the system outputs. Then we can infer that quantitative or intuitive knowledge of the transformation as the "science"; application of such knowledge to achieve the desired end result as "Engineering". The comprehension of the distinction between the technical and system outputs is the "strategic intent" and the executing the system in an organized integration of inputs leading to the outputs is the "Operations" aspect in the "management" of the process. Thus every process is a system where the science, engineering and management aspects are integrated. We identify this manner of addressing the process as the System Approach as is illustrated in figure 7and the methodology behind it as System Thinking.
https://stimsinstitute.files.wordpress.com/2012/08/the-system-approach-2014.pdf

http://stimsinstitute.com/2013/10/04/every-one-of-us-needs-a-strong-dose-of-system-thinking-do-you-agree/

Process Science:

Every industrial process that enables the core outputs of any manufacturing company – product, process and USE – can be described as a system illustrated in figure 8. In fact every manufacturing unit can also be represented as a system, with a much similar frame work as illustrated in Figure 8. Here, the knowledge of the transformation of all the physical processes is identified as Process Science. Experts or specialists in process science will be the back bone of the manufacturing workforce of the future.

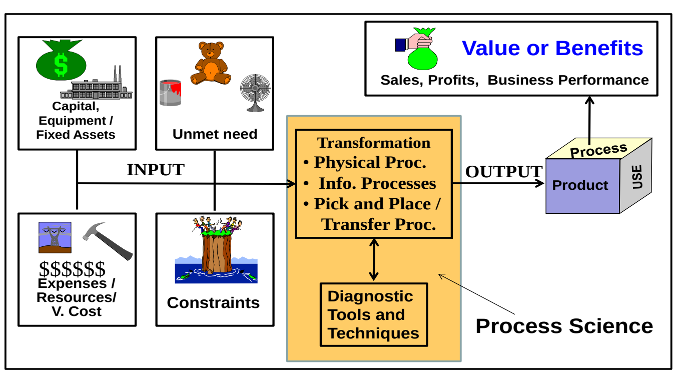


Figure 8. Manufacturing unit viewed as a system;
Process Science – the heartbeat of any manufacturing unit.

Referring to figure 2, one can observe that while the manufacturing enterprise is indeed a complex organization, the core capability of all such enterprises are enabled by a well-defined set of physical processes. Each of these physical processes is enabled by identifiable physical events (involving energy transfer) that can be measured. The signals that reflect such processes enable us to infer what is really happening at the interface. These un-seen events – the microscopic interactions - lead to the transformation of inputs into outputs. While measurement and monitoring of process signals is almost imperative in continuous processes – such as chemical manufacturing processes – they are not as robust or relied upon in discrete components manufacturing processes such as machining, grinding, welding, forging, forming, …etc. In our view such collection of process signals – the vital signs of the process – and their exploitation will be the core capability of future manufacturing professionals. Enabled with such capability they will have a wide ranging impact in manufacturing processes as illustrated in Figure 9. The process science starts with collecting the process signals. This leads to the basic steps such as process diagnostics and problem solving.

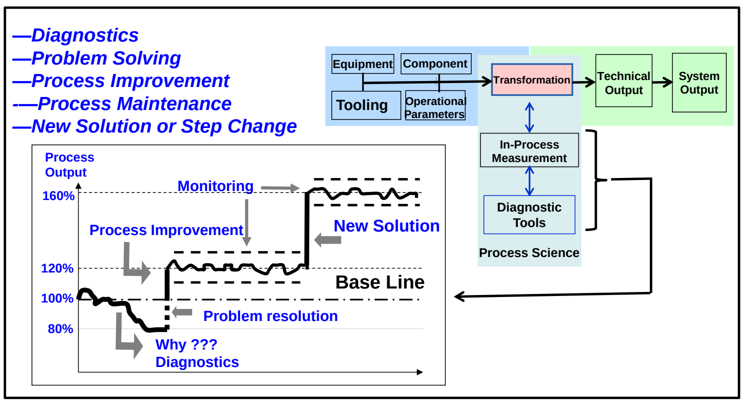


Figure 9. The role of Process science and its progressive impact on manufacturing process innovation.

The trial and error solutions which are common today in the manufacturing floor – often termed as firefighting - need to be replaced by clear cause and effect relations validated by process signals. Today IT applications are seen as plug and play solutions and readily applicable across a wide range of

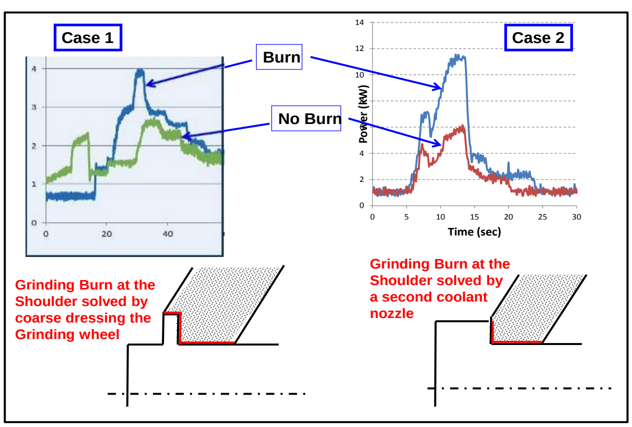
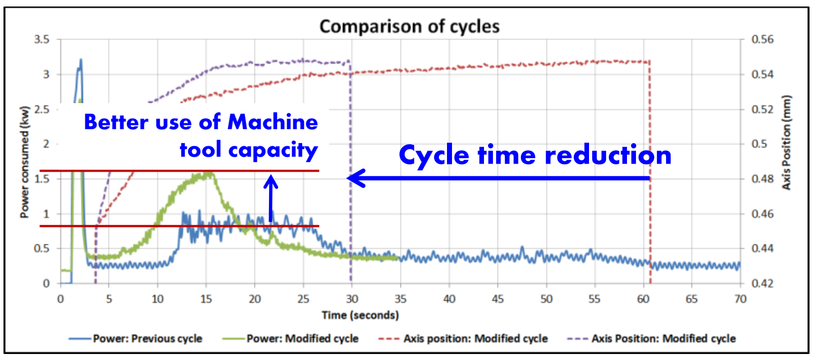


Figure 10. Process signals as aid to apply process science in manufacturing operations.

installations. The same approach can be adapted if manufacturing problems are solved using process signals and the knowledge enabled through them. We find that the process signal would be the same when it represents the same basic phenomena – process physics. This enables manufacturing professionals to integrate knowledge across many industries and applications. As an example, Figure 10 illustrates process signals collected under two totally different situations – different parts, being ground on different machines and at different plants. Yet, the process problem – burn observed on shoulder grinding – gives similar process signals. Also the solution – when the burn is eliminated – also gives similar signals! But, the actual solution – the engineering – in each case was different. This is not much different from observing lightning in the sky or an electric spark in a light switch. In both cases the phenomena – process science - is due to electric discharge! Manufacturing professionals of the future will need this competence to observe the process phenomena, use process signals to identify the science behind it and find solutions (engineering) in a seamless manner. This capability to identify the scientific crux of the problem (Zoom in) and apply this knowledge to provide support for a wider range of manufacturing operations (Zoom out) is an essential element of system thinking advocated earlier.



Cycle time reduction in bottle neck operation resulted in 40% increase in production line through put.

Figure 11 Strategy (management) in combination with process science and engineering.

Management skills (i.e.) strategic thinking and operational excellence are also required as integral part of the work force skills of manufacturing professionals of the future. No amount of skills in science and engineering are adequate unless they show up as bottom line results of value to the investors. Their views are reflected through the CEO or GM of the manufacturing unit. Figure 11 shows the use of process signals to identify the details of a CNC grinding process and the opportunities for cycle time reduction and better use of the machine capacity. But, this exercise was carried out after substantial discussions with the plant management to identify this process step as the bottle neck for the entire production line. Hence any improvements in this operation will have a direct impact on line through put and hence an improvement in the top and bottom line of this manufacturing unit. Indeed, in this case the line through put was increased by 40% without any need for additional investments whatsoever. This is an example of the breakthrough – step change - solutions that will be expected as a routine output of manufacturing professionals of the future. But, in order to sustain such improvements the process has to be managed as a whole – as a system. Constant tweaking or small changes in the system which disturbs the equilibrium of the process cannot be tolerated, if maximum impact is the desired outcome. This will require manufacturing professionals who are simultaneously good at process science as well as process economics, with expertise to integrate knowledge from all available sources.

It is important to recognize that diagnostics, problem solving and process improvements are the necessary steps leading to step change or break through innovation. This view is distinct and counter to the notion that break-through innovations are serendipity or happen as chance events. In fact every flash of new idea is a response to a sustained effort to solve the known problems and needs. But, greater emphasis on science – the why? - leads to questions of "Why not?, which in our view is the seed for break through innovation, particularly for manufacturing process solutions.

Labor Vs. Skill requirements for 21st Century manufacturing:

Manufacturing Processes	**Traditional Sources of Knowledge**	**New Knowledge Required**	**Traditional Worker Skills**	**New Worker Skills Required**
Physical Processes	Engineers and shop floor workers with technical training, trade skills and academic education.	• Process Science • Diagnostics • Data and Analysis • Sector specific know-how	Engineers with years of experience located close to the shop floor operations	• System Thinkers • Solution Providers • Reliant on Process Science • Reliant on sensors, signals and their use.
Information Processes	Collection of tasks that evolved through the years	• IT • Data Base • Big data • Analytics	**White Collar Workers** with standard plug and play IT solutions	• System Thinkers • Solution Providers • Customized IT solutions
Pick and Place / Transfer Processes	Industrial work force through many years of training and hands on experience.	• CNC • Robotics • AGV • Drones	• **Blue collar workers** • Standard work and tasks • Physical effort and de-skilled operations.	• System Thinkers • Solution Providers • Comfortable in virtual control environment

Table 1. Knowledge and skills required for the 21st century manufacturing work force.

We can summarize our discussions thus far as noted Table 1. Here we have identified the three different processes that constitute any manufacturing operation: Physical Processes, Information processes and Pick and Place or transfer processes. In each category we identify the traditional sources of knowledge. For example much of the knowledge of the physical processes today comes from the manufacturing engineers (process engineers, quality engineers, maintenance engineers, etc.) and factory workers. They are generally engineering graduates or trade school educated. Through standardization and de-skilling much of this work force has been depleted in most companies. Workers with the process knowledge in USA were used to set up the outsourced plants in China and other countries through multi-national companies. Later the same workers have been right sized or down sized (in other words laid off!) on their return. Also the economics of the past which allowed for many of these workers as specialists with unique know how in narrow aspects of individual processes specific to each plant is no longer acceptable. Hence the education and skill of the future manufacturing work force requires new knowledge and new skill sets as outlined in table 1.

We have identified “sector specific know-how” as an aspect of new knowledge of physical processes required for the professionals. As an example “Tribology” the science of friction and wear between sliding surfaces is commonly encountered in countless number of manufacturing processes. Yet, the application regimes and process constraints (boundary conditions) of this science are unique to each manufacturing process (such as grinding, forming/forging, lapping, etc.). Such sector specific education or knowledge will be required of manufacturing professionals of the future. To this end there are very few educational opportunities available across the globe. Such education will also require collaboration through industry organizations, leadership from industry leaders and experts with sector specific knowhow. An excellent example of this can be seen at: http://stimsinstitute.com/2014/12/12/sector-specific-education-offered-successfully-for-third-year-in-a-row/

Summary:

It will require substantial explanation to cover the details of new knowledge required and the related skill sets in each of the three process categories outlined in table 1. But it is important to recognize that manufacturing professionals of the 21^{st} century will require ability for aggregation of knowledge and related skills in all three process categories. In addition they should be capable of configuring the scope of the need – the system – and delivering comprehensive solutions (Figure 6) to meet such needs. Such comprehensive education and work force development will require collaboration across industry leaders – such as the CEOs attending this forum – leadership from specific companies (such as MGTL), industry organizations such as IMTMA, academic institutions such as IIT – Madras and the initiatives such as the NGPG research project and Center of Excellence for Machine Tools and Production Technology supported by the DST, G.O.I. and resources such as the STIMS Institute with global expertise engaged in fostering such collaboration and the necessary eco-system. Development of such eco-system is often referred to as the “Fraun-Hoffer model” , which has evolved in Germany over the years. This evolution of eco-system for manufacturing skills and work force development inside of India over the past few years is illustrated in Figure 12. This effort has to continue and in a sustained manner. In due course such collaboration has to translate into unique manufacturing process solutions and platforms, which draw upon the resources from across the globe, but also deliver solutions of impact for users across the globe. This model for manufacturing process platform evolution by systematically integrating the core outputs of all players is schematically illustrated in Figure 13.

Today, there is rampant complaint that bright students do not pursue careers in manufacturing. It might be better to state that today's manufacturing in India, particularly in the most visible sectors such automobiles and their parts manufacturing, merely copy or replicates solutions already perfected elsewhere and made available to Indian manufactures through joint ventures and technical collaboration agreement. In such climate there is little demand for creativity. Such replication efforts also support only low wage jobs as illustrated earlier in Figure 5. To counter this trend, MGTL – with guidance from STIMS Institute - has recently started an internship program to recruit highly talented graduates and train them in system

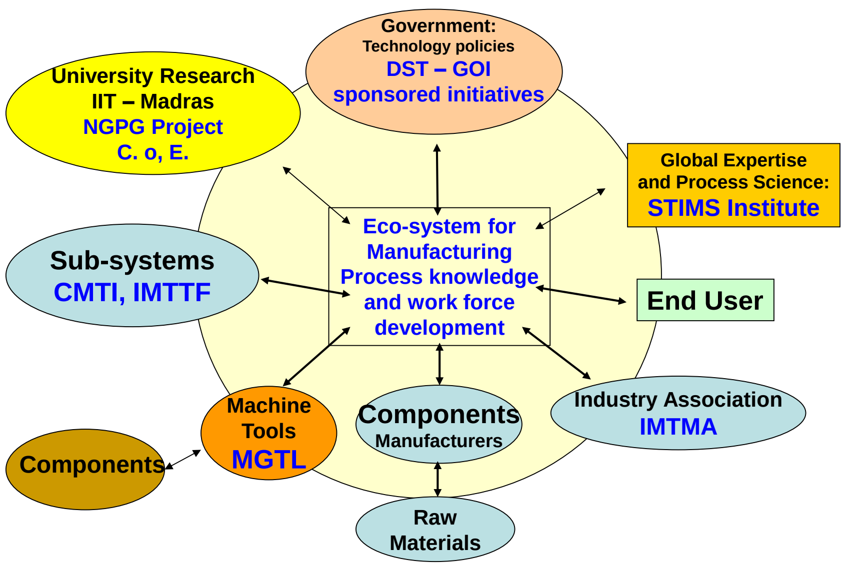


Figure 12. Example of evolving eco-system inside of India for manufacturing process knowledge.
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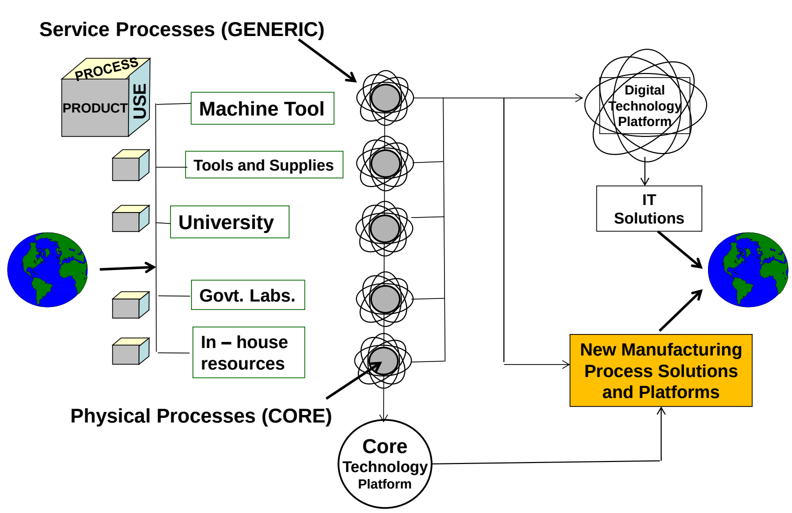

Figure 13. Integration of core technology across companies
can lead to new Manufacturing Solutions and Platforms.

thinking and transformational skills. As part of the internship program, these professionals engage in a set of projects of commercial impact for MGTL as well as foster relations through academic research projects and the eco-system development efforts. As an example, the details of work by the first intern can be seen at: http://www.mbrijbhushan.com/ As a next step to promote system thinking and new solution development, MGTL and STIMS Institute have collaborated to launch a new initiative: GPS (Grinding Process Solutions). Please see Figure 14 for details. The concept is to foster inter-industry collaboration and knowledge integration with an emphasis on Process Science, Diagnostics, data driven solutions through System Thinking and Transformational skills. These models and collaboration opportunities are available for the CEOs and their companies to adapt and simulate in their organizations.

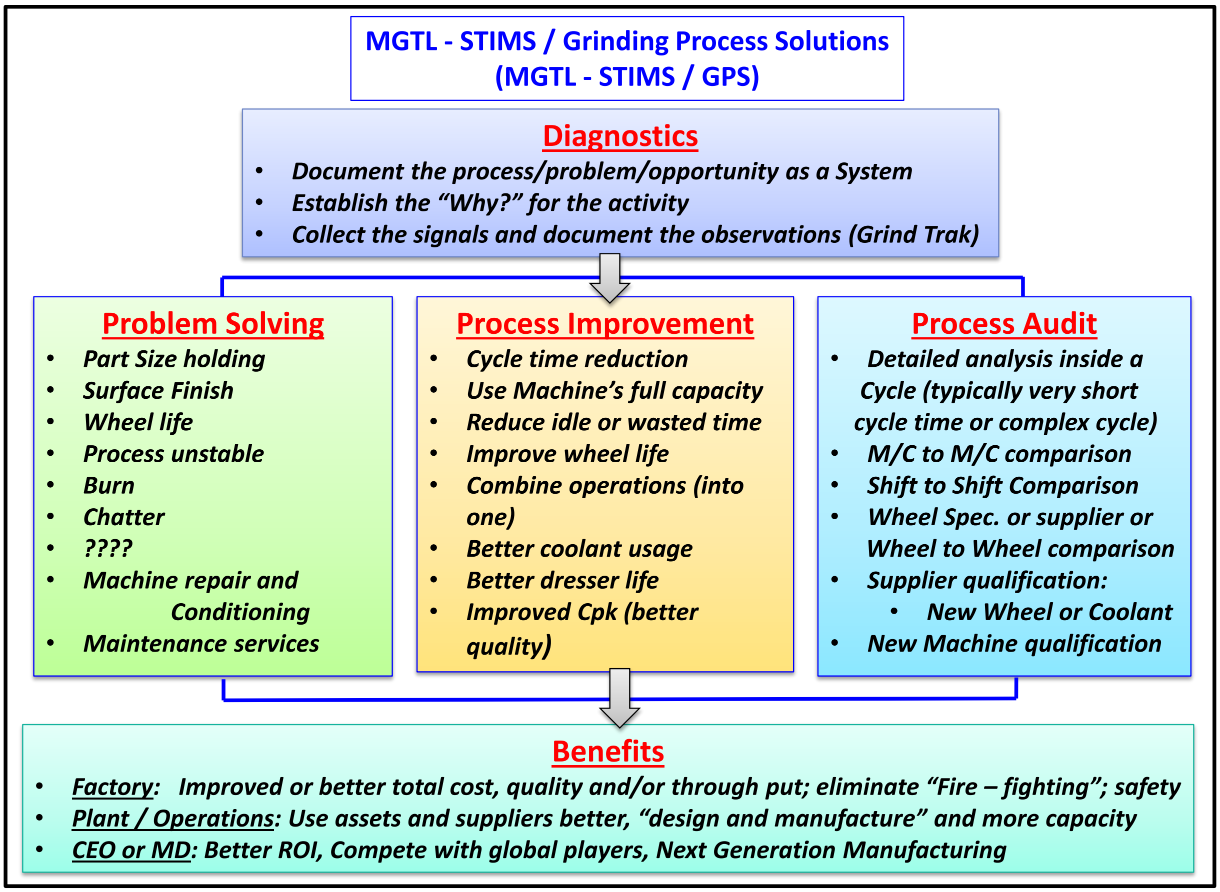

Figure 14. GPS – Grinding Process Solutions.