New Era of Project Delivery – Project as Production System

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ABSTRACT

Project management can be viewed as having developed over 3 distinct time frames, or Eras, in response to the evolving nature and needs of projects over time. Viewing project management through the framework of the 3 Eras provides a number of useful insights described in this article. Conventional project management, as codified by the Project Management Institute, spans the first two Eras. It has two fundamental gaps, preventing the satisfactory management and execution of today's complex and dynamic capital projects. Understanding these gaps explains why some traditional responses to recover from cost and schedule overruns in projects do not work. We describe how Project Production Management (PPM) provides the two missing elements of conventional project management. We conclude with the perspective that PPM ushers in a new third era of project management to address today's complex major projects operating in dynamic environments.

Keywords*: Project Management; Project Production Management; Production System; Variability; Buffers*

INTRODUCTION

The engineering and construction industry is in crisis. The situation now affects shareholder value for asset owners, developers, operators, contractors, suppliers and society in general. It is of particular concern for energy, manufacturing and processing companies. As producers, these companies must continue to invest capital to bring new solutions to market, optimize production capacity and comply with regulatory requirements. Addressing less than desirable project outcomes has now become a priority for executives and corporate boards.

Capital project outcomes continue to frustrate business executives and their shareholders across a range of industries. A 2014 Ernst & Young survey[1] concluded that nearly 65% of major capital projects in the oil & gas industry suffered cost overruns, and over 75% suffered schedule overruns. Professor Paul Teicholz

1 "Spotlight on oil and gas megaprojects", Ernst & Young, 2014

of Stanford University has conducted research studies[2] comparing productivity in the manufacturing industry with productivity in the construction industry, concluding that the productivity in the construction industry has stagnated over the last half century, whereas manufacturing productivity has increased 150% over same period. Statista, an online statistics portal, presents a capital projects "hall of fame", seen in Figure 1, comparing recent over-budget construction projects across the world, starting with the Channel Tunnel. The top 12 projects have cost overruns ranging from 100% of planned budget to 300% of planned budget.

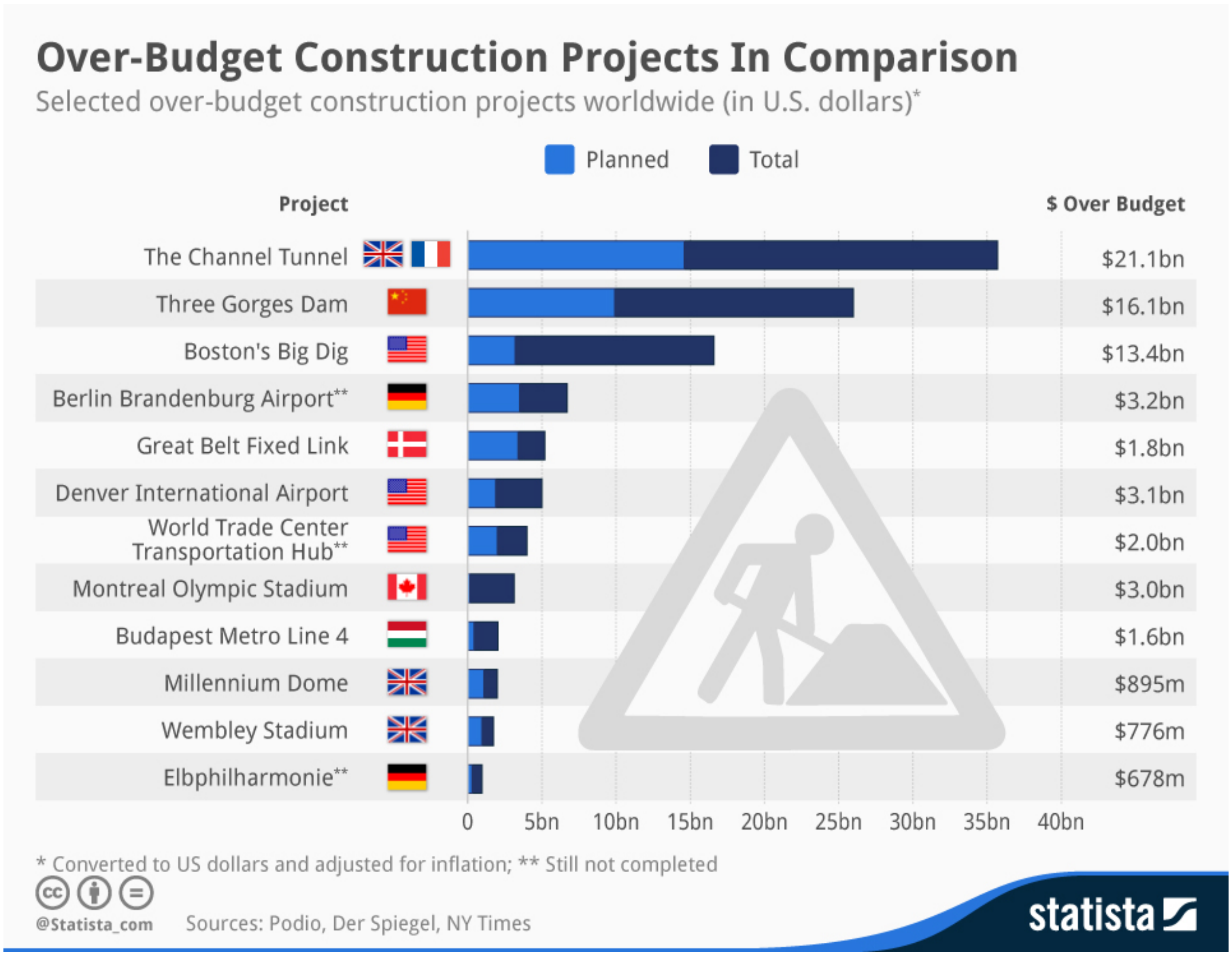

Figure 1: "Hall of fame" for major infrastructure projects with cost overruns

Recognizing the current critical state of the industry and associated impact on business and shareholder value, companies involved in the delivery of capital projects are implementing a host of solutions, including multi-party relational contracts, increased levels of project controls, methods to ensure supply of information and goods to the workface, and more. Despite these attempts however, performance continues to decline.

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2 "Trends in labor productivity in the construction industry", P. Teicholz, PPI Symposium, Dec 2015

Historical analysis of the evolution of project delivery methods sheds light on why project performance continues to degrade despite the proliferation of conventional project management practices. The subject of project management can be viewed as an evolution over three major eras, as illustrated in Figure 2.

ERA-1 PRODUCTIVITY 1900 - 1950	ERA-2 PREDICTABILITY 1950 –	ERA-3 PROFITABILITY 2000 –
SCIENTIFIC MANAGEMENT	PROJECT MANAGEMENT	PROJECT AS PRODUCTION SYSTEM
How to get more out of workers?	How to predict project outcomes through measurement and compliance?	How to deliver business objectives with minimal use of resources?

Figure 2: The 3 Eras of Project Delivery

Era 1 - Scientific Management
Era 2 - Project Management
Era 3 - The emerging construct of Projects as Production Systems

By viewing Era 1 + Era 2 as "conventional project management," the lens of the 3 Eras highlights a few gaps in conventional project management practices when applied to today's complex and dynamic projects. The first gap is that conventional project management does not include detailed project work execution - operations management - within its scope. The second gap of conventional project management is that it does not systematically account for the impact of variability and work-in-process (WIP, or inventory) during project execution. Understanding these gaps explains why some typical responses from conventional project management practitioners to cost and schedule overruns are ineffective, as described here.

The emerging Era 3, Projects as Production System construct, addresses the gaps of conventional project management. We conclude that implementing Project Production Management ushers in a new era of project delivery to produce major capital project outcomes superior to the recent past.

ERA 1 – SCIENTIFIC MANAGEMENT

Starting in the early 1900's, Frederick Taylor was in the vanguard of a movement preoccupied with organizing and managing the work of laborers in factories. The primary task Taylor focused on was "**how to get more out of workers**," with a view to improve overall productivity through understanding and organizing the tasks performed by workers. Through time-motion studies and other analyses, he tried to convert the jobs performed by individual factory workers into sequences of simplified tasks for which workers could be trained to execute as quickly as possible. Through this body of work, Taylor established many of the practices that are still in use today. These include the separation of planning the work from doing the work, the advent of functional departments, and the application of time-motion studies and activity sampling, amongst many other innovations.

In 1918, Daniel J. Hauer translated Taylor's concepts from the shop floor to the construction site in his book, *Modern Management Applied to Construction*. Henry Gantt, another disciple of Taylor, added planning and control tools, including the ubiquitous Gantt chart, to Taylor's management system. Together these men built the foundation upon which projects are delivered today. The use of centralized planning/project controls, the application of activity sampling to determine "time-on-tools," and the use of bar charts are just a few of their concepts that continue to be used in project management, stemming from Era 1.

Era 1 is best understood as the era focused on getting more out of craft workers through the brute force of Taylor's Scientific Management.

ERA 2 – PROJECT MANAGEMENT

If Era 1 management focused on "how to get more out of workers" and on labor productivity, then Era 2 management focused on "**how to get more predictable outcomes through measurement / compliance / controls**."

By the 1950's, it was clear that Era 1 practices were not enough to manage the projects of the time. Projects were increasing in size and complexity, and cost and schedule overruns were becoming increasingly unpredictable. Frustrated with the outcomes of mission critical defense projects, the U.S. Department of Defense under Secretary of Defense Donald McNamara launched US DoD 7000.2, C/SCSC. This initiative, along with the Navy's development of the Program Review and Evaluation Technique (PERT) and Remington Rand Univac's work with DuPont in the development of the critical path method (CPM) scheduling approach, all set the foundation for modern day project controls.

The development of these tools for forecasting only increased the separation of planning activities from work execution activities. As a result, during Era 2, project management moved further and further away from its roots in operations, increasing the intensity of its focus on planning and prediction. In their 1959 paper, "Critical-Path Planning and Scheduling,"[3] James E. Kelley and Morgan R. Walker introduced CPM and listed four tasks of project managers:

1. To form a basis for prediction and planning

2. To evaluate alternative plans for accomplishing the objective

3. To check progress against current plans and objectives, and

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3 James E. Kelley, Jr. and Morgan R. Walker, "Critical-Path Planning and Scheduling" 1959 *Proceedings of the Eastern Joint Computer Conference.* Retrieved from https://www.computer.org/csdl/proceedings/afips/1959/5055/00/50550160.pdf

4. To form a basis for obtaining the facts so that decisions can be made and the job can be done

Over time, these advanced forecasting tools became the basis of protecting / seeking claims for schedule acceleration and delay in planning functions. Arguments ensued over who owned the “float” within the schedule duration and how it should be allocated. These arguments manifested into strict specifications about how project schedules are to be created and updated, especially by governmental entities. To this day, it is not uncommon to have two or more schedules for a project: “one for the owner” and the other for managing the project.

ERA 1 + ERA 2 = CURRENT APPROACH

“Conventional project management,” which we define here as the combination of the Era 1 and Era 2 bodies of knowledge, has two fundamental insufficiencies to deliver today’s complex and dynamic projects. First, the focus on planning and forecasting and the exclusion of operations management from scope overlooks the need to organize detailed work activities within the project in order to control overall project performance. Second, there is little to no consideration of the impact of variability and inventory on overall project delivery. To not recognize variability and inventory is to not recognize the exponential compounding effect that variability and inventory have upon each other and on total project performance. We elaborate upon each of these insufficiencies below.

Conventional project management focuses on planning and reporting. The execution of a project—the hands-on work of operations management —was outside the purview of project management, a move that occurred during Era 2. Excluding operations management is still the case today. The current edition of the *Project Management Book of Knowledge* (5th edition), issued by the Project Management Institute (PMI), states in Section 1.5.1.1:

“Operations management is a subject area that is outside the scope of formal project management as described in this standard.

Operations management is an area of management concerned with the ongoing production of goods and/or services. It involves ensuring that business operations continue efficiently by using the optimum resources needed and meeting customer demands. It is concerned with managing processes that transform inputs (e.g. materials, components, energy and labor) into output (e.g. products, goods, and/or services).”

PMI clearly states that operations management is out of the scope of project management, as defined by PMI and the *Project Management Book of Knowledge*. PMI recognizes that operations management exists, but it positions that discipline as an engineering science that comes into play only after a capital project is complete and ready to begin operations. According to PMI, operations management is not something that can be effectively applied to the project delivery process. Actually, as we subsequently describe, the configuration of operations, especially to be robust to control the impact of variability and inventory, is a distinguishing feature of Project Production Management.

Why are variability and inventory so important? What are their effects on project performance? A few examples can illustrate how viewing the work to be performed in a project is no different from a production system.

First, let's consider a very simple production system: the assembly of burgers in a fast food restaurant. It is a production system because burgers are assembled from inventories of ingredients in response to orders placed by customers. There are various types of variability encountered in the production process, for instance:

- Variability in the times orders are received

- Variability in the type of order – for instance a cheese burger vs. a plain burger

- Variability in the cycle times in performing different steps

- Variability in availability of certain ingredients

- Variability in amount of staff throughout the day

All these variations present challenges for the restaurant in meeting its goal of satisfied paying customers at a target price. For instance, if the restaurant takes too long to assemble and deliver burgers because it doesn't have enough staff to assemble burgers (or shortage of ingredients), customers stop coming. If one person completes their tasks in the assembly of a burger much faster than the next person who takes over, then an inventory of unfinished burgers (work-in-process) builds up.

Variability can be beneficial or detrimental. New technology or new techniques for assembly are examples of beneficial variability, where re-sequencing food preparation tasks can potentially shorten cycle time without increasing tasks. Other types can be detrimental – for instance, having delays because one runs short of inventory or because equipment breaks down. It is frequently possible to take steps to reduce detrimental variability in operations. For example, to ensure one doesn't have unanticipated delays, implementing automated re-stocking of inventory once it reaches a minimum level, or frequent inspection and maintenance of equipment, are standard ways of ensuring detrimental variability is kept to a minimum.

Uncontrolled variability will give rise to uncontrolled inventory / increased cycle time, loss of capacity or some combination thereof. While it is frequently possible to take steps to reduce detrimental variability, it is rarely possible to wholly eliminate it. One can manage residual detrimental variability by placing buffers in the assembly process - having the appropriate combination of inventory (ingredients), capacity (staff) and time. For instance, in order to have the fastest delivery times, one can have an inventory of pre-prepared burgers ready to go in response to orders as they are placed. Or one can have plenty of staff, and plenty of ingredients to ensure burgers are prepared as fast as possible in response to orders – not quite as fast as pre-assembled burgers, but fast nonetheless. Or one can have much longer times to deliver burgers, by having a minimal staff and minimal stock of ingredients. Different combinations of inventory, capacity and time have different costs and financial impact on the economics, not to mention the time of delivery.

A second example to show how variability can be managed through an appropriate combination of inventory, capacity and time is by comparing oil changes done for Formula 1 with a retail automotive tire repair chain. In Formula 1, the extreme variability of arrival times – the uncertainty of when a car comes in within a 4-hour period for a tire change – is handled by having a massive capacity of technicians, equipment and an inventory of supplies to ensure the shortest possible time spent in executing a tire change. The utilization of capacity is extremely low, however, the execution cycle time is extremely fast. In contrast, a retail tire repair chain targets an acceptable waiting time to manage the economics of having capacity that's working at close to full utilization. As a result, execution cycle time goes up in response to working at close to full capacity.

The same principles of variability and inventory compounding each other's effects in project performance are at play in construction projects and oil & gas capital projects, just on a much bigger scale. In a construction project, there is variability in execution times of the individual work steps to be performed. There will be variation in arrival times of supplies to the construction site. There may be variation in the availability of trades and construction equipment required to execute work. This, and myriad other types of variability, can give rise to unwanted or unplanned inventory – work-in-process – as individual work stages are completed, but then must wait for the next stage of work to start.

As with the two examples cited earlier, variability can be managed by a judicious combination of inventory, capacity and time to place buffers along appropriate places in the project's execution workflow in order to optimize the throughput through the project.

While our discussion has been qualitative, there are systematic and scientific ways of analyzing the behavior of processes in the presence of variability, and a science to design actions to mitigate detrimental variability, as well as a science to design the optimal allocation of buffers to manage residual detrimental variability. This is part of the foundation of Project Production Management and is further elaborated in articles by Spearman & Pound and by Choo later in this journal. The systematic accounting for variability with actions to reduce and to buffer is one way in which PPM is distinguished from conventional project management.

The absence of scientific design in project execution has had a profoundly negative impact on capital project performance in the construction and oil & gas industries. A classic practice in oil & gas is to amass a lot of inventory in the belief that having plenty of inventory on hand will assure continuous smooth execution with minimal delays. But inventory, besides being very expensive to have extra on hand, is subject to its own variability (spoilage, obsolescence), and is not always the most effective buffer against the types of variability that are actually encountered in oil & gas projects. Because variability in the project work continues to cause unplanned outcomes, the results are large costs from setting up the wrong type of buffer, project delays, poor quality and excess work-in-process. The financial and schedule overruns in recent years have been spectacularly bad, as exemplified by the exhibit in Figure 1, and cited in the oil & gas megaproject study by Ernst & Young.

While capital projects are failing to hit their targets, the connection between project misses and the two insufficiencies of conventional project management is not obvious to many. This may be a function of the power of the conventional project management paradigm and its supporting infrastructure. Regardless of why the connection is not being made, it has given rise to a number of ineffective responses that require greater investment by oil and gas executives without eliminating cost overruns and scheduling delays.

These widely-adopted responses include:

- **Project controls:** Project controls are project management practices on steroids. They attempt to solve the capital project problem by driving project management down to lower levels of a project's organizational chart. This means more reporting on what work has gotten done and how much it has cost, and more forecasting of the work that needs to get done and how much will it cost. More reporting and forecasting of time and cost—but, as in project management, the execution of the project remains outside the realm of project controls.

- **Contracts:** Contracts are an attempt to offload the risk of capital project misses. They encompass a variety of models, all of which attempt to reduce or transfer risk and achieve project targets by using incentives and/or penalties to modify behavior. Contracts cannot, of course, address the execution of work in and of themselves. At best, they are legal constructs that shift costs, without addressing the root causes. At worse, as research on using money to change behavior has shown, a contract approach to capital project success is both expensive and ineffective—often encouraging people to focus on the ends instead of the means, and to try to game the system.

- **Modularization and offsite assembly:** Modularization and offsite assembly respond to the capital project problem by shifting the work—ideally, to somewhere where assembly costs are lower and conditions are easier to control than the often remote and dangerous project locations. Unfortunately, these responses introduce new problems. First, they add complexity to the project's supply chain, which makes it increasingly difficult to plan and execute the project. Second, although assembly costs may be lower offsite than onsite, the cost savings tend to be illusionary because modularization and offsite assembly come with less-recognized WIP costs—such as those associated with longer lead times, transport, handling, and storage. Beyond these issues, the need for these components to be integrated at the site also brings a host of challenges.

- **Workface planning:** Workface planning attempts to reduce the capital project problem to a labor problem. To boost time on tools, its adherents break down tasks into work packages. Multiple packages, which might encompass 500 to 2000 hours of work and involve several trades, are delivered at the workface to enhance productivity by helping workers ensure that they have the information, materials, and tools needed to complete a specified task before they try to execute it. In essence, workface planning is a hybrid extension of project management and modularization, with work being planned and assembled weeks in advance that may or may not be possible to execute at its scheduled time.

However, the four responses described above share the same flaws found in conventional project management itself, being that:

1. None of them attempt to directly manage the execution of work

2. None of them recognize, account for, or attempt to manage variability and WIP

As a result, they ultimately add cost and complexity to the project, without solving the core problem that is endemic throughout the engineering and construction industry.

The Construction Industry Institute (CII) and Construction Owners Association of America (COAA)'s Advanced Work Packaging (AWP) approach is a good example of the Era 1 combined with Era 2 construct. AWP endeavors to increase "time-on-tools" by ensuring all necessary information, materials and construction equipment are available for the craft person when needed. However, it ignores the more important task at hand, which is effectively completing work in the right quantity, at the preferred quality and the desired time.

The implications of variability and excessive work-in-process should not be overlooked. Since conventional Project Management does not recognize variability and WIP, inventory is often used to shield downstream work enabling increased capacity utilization.

At the root of the issue is the cost and time required to amass, handle, hold and preserve inventory, not to mention the risk of obsolescence, theft and damage. This cost is not only related to the financial investment but also to the unnecessary use of cash. Often called pre-productive capital, WIP is the equivalent of cash that is not earning a return on investment because the project is not complete and/or due to lost opportunity cost.

Project managers and business leaders are often called upon to develop cost and schedule recovery plans. These efforts have limited impact due to the amount of WIP in the system. Frederick Gluck and Richard Foster pointed out that the ability to influence decreases with time.[4] We propose that this decrease is directly related to the amount of WIP in the system, as illustrated in Figure 3.

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4 Managing Technological Change: A Box of Cigars for Brad. Gluck, Frederick W. and Foster, Richard N. *Harvard Business Review*, 1975.

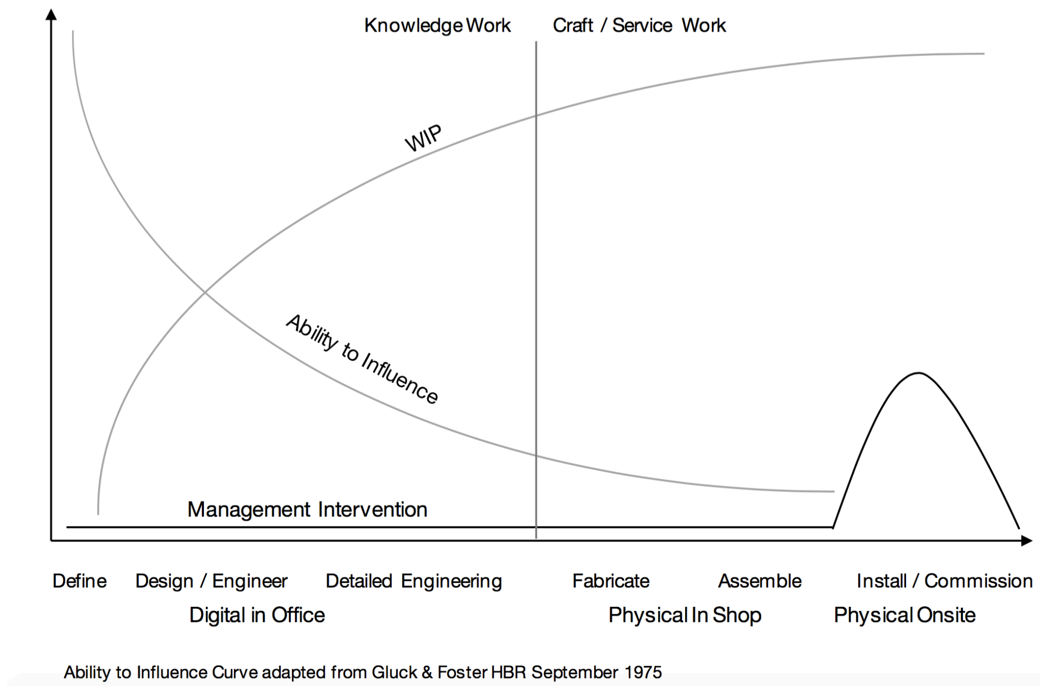

Figure 3: WIP reduces ability to influence

ERA 3 – PROJECT AS PRODUCTION SYSTEM

Beginning in the early 1990's at the Stanford Center for Integrated Facility Engineering (CIFE), Lauri Koskela, PhD, a visiting researcher from Finland, asked, "can and how does the new production paradigm apply to the delivery of projects?"

Guided by reports coming from the automotive and other manufacturing sectors, researchers at Stanford and U.C. Berkeley, including Glenn Ballard PhD, Martin Fischer PhD, Greg Howell P.E, Iris Tommelein PhD and later James Choo PhD, began developing a production-focused approach to project delivery. These efforts identified key factors missing in the constructs of Era 1 and Era 2, including sizing and locating of buffers, sources and implications of variability as well as the lack of effective production control. At the same time, Pacific Contracting of San Francisco and later BAA and its supplier network, began experimenting with the application of this new paradigm. One such example was the successful delivery of the construction phase of Heathrow Terminal 5.

Looking back at Henry Ford's system of Mass Production and Frank Woollard's Flow Production followed by Toyota's Production System, the key strategies of all these manufacturing systems include maintaining a flow of production from the beginning to the end of the process or the value stream by reducing variability and effectively controlling the amount of work-in-process.

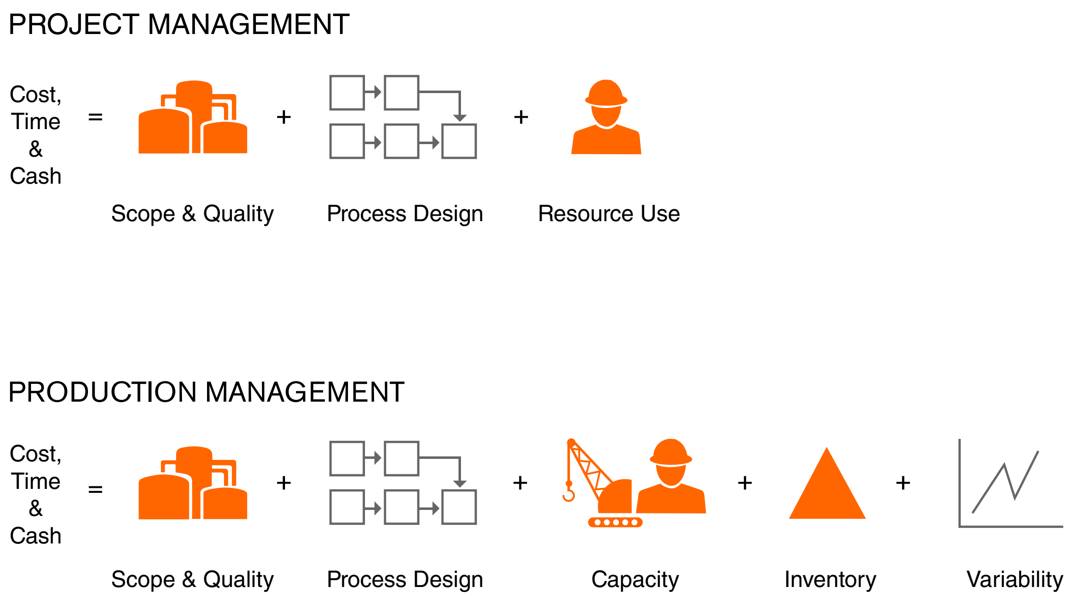

Figure 4: Contrasting Era 1 + Era 2 Conventional Project Management with Era 3 Project as Production System

The figure above illustrates the contrast between conventional project management – Era 1 + Era 2 – with Era 3 - Project Production Management.

Conventional project management is a tradeoff between cost, time and scope, using the levers of scope or quality, process design and capacity. Those using the forecasting/planning tools of conventional project management typically make statistical assumptions about how long project work execution should take, and what it should cost, without a detailed analysis of how the work should be configured or executed. This typically happens because they are not directly responsible for it, or lack the subject matter expertise to organize the work, even if they bear responsibility for it. Process design is performed by the planning functions using tools such as work-breakdown-structures, rather than by those doing the work.

As for setting capacity, project managers trained in conventional project management set capacity within the overall constraints of cost, and by comparing what past projects have used for capacity. There is generally little to no consideration of the strategic allocation of capacity across different parts of the project as a buffer to optimize execution of work. Conventional project management generally seeks to maximize the utilization of the most expensive capacity within the project, in a belief that maximizing capacity utilization optimizes overall project execution performance in terms of cost and time to execute – Taylor's construct for Scientific Management.

Project Production Management seeks to optimize cost, time and scope with the levers of process design, capacity, inventory and variability.

PPM approaches process design very differently from conventional project management because it seeks to design processes accounting for the impact of variability through the strategic placement of buffers within the process. Moreover, the science of operations management dictates that buffers can be some combination of inventory, capacity and time – not simply capacity. PPM systematically takes into account all these considerations to optimize project delivery.

Four theoretical operations management results, outlined in the basic text by Philip M. Morse[5] and recapped by Wallace J. Hopp and Mark L. Spearman,[6] form the basis of the systematic analysis of a project to understand the limits on performance at any point in the project and the overall limits:

1. In 1954, Morse proposed and in 1961 Little validated the queuing equation, relating work-in-process (WIP, or inventory) that arises from the execution of a task to the cycle time to execute the task, and the throughput (number of times per unit time) of completing the task.
   That equation is: WIP = Throughput x Cycle Time

2. The cycle time formula denotes all the component times that contribute to the overall cycle time in executing a work task within a project.

3. As work tasks accumulate or queue to be completed at a point in a project, Sir John Kingman, a British mathematician, set forth an equation, known as the VUT equation. This equation approximates the mean waiting time in a queue using variability, capacity utilization and service rate.

4. Variability at any point in a project will be buffered by a combination of inventory (WIP), capacity and cycle time.

These results are instrumental in incorporating knowledge about capacity and variability in a project to design both the project work (process design) and set limits on capacity and inventory to optimize project execution throughput. This is a fundamental difference from conventional project management.

CONCLUSION

Viewing project management through the lens of the 3 Eras provides a foundation upon which to understand its evolution and where we are today. Conventional project management can be viewed as the culmination of Era 1 and Era 2. Project Production Management (PPM) overcomes two fundamental limitations of the conventional project management approach and ushers in a third Era of project management necessary to address the challenges of today's complex and dynamic capital projects. Now that the underlying physics of project delivery can be understood through the application of operations management / science, it is time to apply the necessary principles to today's large capital projects.

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5 Queues, Inventories and Maintenance: The Analysis of Operational Systems with Variable Demand and Supply, P. M. Morse, John Wiley & Sons, 1962.

6 Factory Physics, W. J. Hopp and M. L Spearman, 3rd Edition, Waveland Pr. 2011.