MIT Sloan School of Management

MIT Sloan School Working Paper 5380-18

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April 2018

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April 2018

Version 1.0

1.0 Introduction

If you work in a contemporary organization, you probably feel like you have both too much to do and not enough time in which to get it done. You have too many items on your "to do" list, but seem to spend more time prioritizing than checking them off; you attend too many meetings, but never seem to reach any decisions; and, above all, the more emails you answer, the more messages you find in your inbox. And this situation probably afflicts not just you, but your entire company. Deliverables are late, projects are behind, and the whole organization constantly scrambles to meet its objectives. Under this kind of pressure, "process" usually goes out the window and everyone tries to get their work done any way they can.

Though working this way is not a lot of fun, many leaders believe that their organizations thrive under such pressure. They reward managers who deliver under duress and work to develop a culture in which having the biggest "to do" list, working the longest hours, and being the most willing to depart from standard processes to get things done is the path to the top. But, as popular as this mode might be, it is also deeply pathological.

The costs of having too much to do are well documented and research suggests that taking on more work eventually leads to a *reduction* in productivity. People who work too much are less creative, less productive, more prone to mental and physical illness, and more likely to leave your organization and work elsewhere.[1] Project teams facing overly aggressive schedules and inadequate resources are more likely to be late *and* miss their cost and functionality targets.[2] Overfilled R&D portfolios yield products that miss their market windows and are uncompetitive.[3] Worse, taking on too much work with too few people has been implicated in many major industrial accidents and disasters, including the demise of the Columbia space

[1] Carmichael, "The Research Is Clear"; Kodz et al., *Breaking the Long Hours Culture.*
[2] Lyneis, Cooper, and Els, "Strategic Management of Complex Projects."
[3] Repenning, Gonçalves, and Black, "Past the Tipping Point"; Repenning, "Understanding Fire Fighting in New Product Development."

shuttle, the explosion at BP's Texas City Refinery, and the recent spate of collisions that have killed 17 sailors in the US Navy.[4]

Though overload and its associated cost are all too common, one management function has learned to avoid them. Prior to the 1980s, US manufacturers often tried to maximize performance by focusing on the productivity of the individual parts that comprised the manufacturing system. Each machine and operator would be given aggressive targets for her portion of the process under the theory that if everybody was busy, the plant would produce maximum throughput. Visits to Japanese manufacturers and books like *The Goal*[5] revealed that the "keep everybody busy" theory was flawed; maximizing the productivity of components did not necessarily maximize the productivity of the *system.* Today, factories are run differently. Managers are acutely aware of which operations are critical to the overall performance and allocate their time and attention accordingly. Thanks to mastering overload, manufacturing and assembly plants today are both more efficient and more flexible than they were in the 1980s.

In contrast, the "keep everybody busy" theory remains alive and well in knowledge work. Though there are fewer careful studies, evidence suggests that in many processes (ranging from serving bank customers to performing complex surgeries to developing cutting edge new products), many organizations overload their employees in the hope that keeping everybody busy will maximize the performance of the system.[6] Despite the ubiquity of this practice, there is little reason to believe it actually works.

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[4] Columbia Accident Investigation Board, "NASA - Report of Columbia Accident Investigation Board"; The B.P. U.S. Refineries Independent Safety Review Panel, "The Report of the BP U.S. Refineries Independent Safety Review Panel"; U.S. Navy, "Collision Report for USS Fitzgerald and USS John S. McCain Collisions."

[5] Goldratt and Cox, *The Goal*.

[6] Mangi and Repenning, "Dynamic Work Design Decreases Post-Procedural Length of Stay and Enhances Bed Availability.; Oliva and Sterman, "Cutting Corners and Working Overtime."

In this paper we introduce a simple system for managing knowledge work that builds on two ideas, *Pull* and *Visual Management*. Pull is a simple technique for managing the flow of physical work that eliminates the problems associated with the "keep everybody busy" approach and improves resource allocation; Visual Management enables techniques normally associated with managing physical work (like Pull) to be used for knowledge work. Combining Pull and Visual Management can dramatically improve the effectiveness of many knowledge work processes. To introduce our approach, we describe two recent interventions in the genomics platform at the Broad Institute, the industry leader in genetic sequencing. The first highlights the benefits of using Pull by describing an intervention focused on improving the flow of physical work. The second intervention shows how, when combined with Visual Management, Pull can also be used to avoid overload and, thereby, dramatically speed the pace of knowledge work.

2. The Genomics Platform at the Broad Institute

DNA is quite literally the "source code" of life, and the ability to read an individual's DNA sequence is opening a new era in medicine and enabling new, more effective treatment of a variety diseases. After almost ten years of effort and $2.7 billion,[7] the first draft of the human genome was completed in 2001, and in 2004, thanks to a generous gift from Eli and Edyth Broad, that human genome project became the Broad Institute, one of the largest experiments in the Life Sciences. The Institute's mission is to transform medicine through systematically understanding the genetic underpinnings of disease. The unique organizational experiment catalyzed rapid progress in genomics, and today the Broad plays a central role in unraveling the mysteries held within each cell, including its circuitry, genetic makeup, and response to perturbations.

[7] Lander et al., "Initial Sequencing and Analysis of the Human Genome."

Since its founding, the Broad's organization structure has evolved into two distinct components, a set of research programs and a set of technology platforms. The research programs design studies for which genetic information might provide a window into the origins of diseases like cancer and diabetes. The technology platforms, specifically the genomics platform, supports the research programs by analyzing the samples generated by the studies (typically blood or tissue) and identifying the DNA sequences contained therein.

Reading a DNA sequence requires several steps: The sample is first prepared through a variety of chemical manipulations; the prepared sample is then placed on a sophisticated instrument that uses lasers to identify the DNA sequence; and, finally, the resulting data are aggregated, analyzed, and returned to the researcher for downstream analysis and biological insight. Since the first genome was sequenced, the cost of doing so has dropped over 100,000-fold and what once took years and billions of dollars can now be done in a matter of days for a thousand dollars. To support the growing demand for processing, the genomics platform has built a significant operations infrastructure and can now process over a million samples annually. Today, Broad's genomics platform leads the industry, with an enviable ability to deliver industry-leading analysis, cutting edge technology, and continued cycle time and cost reductions, and, in doing so, are making a material contribution to the health and well-being of society.

Such a combination of operational and technological prowess is difficult to build in any organization, but given Broad's history and context, it is particularly impressive. Broad started as a distributed, research-focused organization staffed by chemists, biologists and applied mathematicians, most of whom had advanced degrees. In its early days, the genomics platform resembled the other research labs at Broad. Work was done in small batches, often following informal or even improvised processes. Given the highly educated and capable people that Broad tended to hire, there was never a shortage of new ideas; almost everybody in the platform was working on new technology to improve the sequencing process. This loosely organized configuration of dedicated staff produced rapid advances in sequencing technology and Broad established itself as a leading provider. But, as often happens with successful organizations, growth revealed the limits of their existing approach. By 2012, cycle time for processing samples had grown to over 120 days and Broad's position as the industry leader in sequencing technology was at risk. Though industry demand for sample analysis was growing, Broad's demand was declining as researchers began sending samples to other labs. Addressing these challenges required first implementing Pull to manage the flow of physical samples, and then using Visual Management to create a similar system for managing the flow of new technology that supported the platform.

3. Push vs Pull in the Lab

Broad's declining ability to handle the demand for its services was rooted in the use of a *push* system to manage the flow of samples through the lab. The essence of the push approach is that each person in a given process works as quickly as she can and "pushes" her completed task to the next person in the system, whether or not that person is ready for a new piece of work. At Broad this meant that when a sample arrived it would be immediately pushed into the process where it would wait in front of the first preparatory step (see Figure 1). When that step was completed it would be moved to the next step, where it would again wait until it was processed and so on until it reached the sequencing machines that would read the DNA.

The collection of samples that sat between each process step constituted work-in-process inventory, or WIP. When used properly WIP can improve overall throughput by decoupling the different steps—even if the person upstream from you is stuck on a particularly hard task, the WIP inventory between the tasks allows you to keep working. Scholars in operations management have developed sophisticated models for figuring out exactly how much WIP should be placed in between each operation in a manufacturing process.[8]

Unfortunately, practice doesn't always follow theory. As Broad continued to "push" samples into the system, the piles of WIP inventory continued to grow, far exceeding any optimum level. The piles had grown so big that that when somebody needed a specific sample, it could take two days to find it. Managing the consequent congestion and confusion occupied an increasing fraction of the leadership team's time, and distracted them from doing the research needed to maintain the technological edge that they had worked so hard to develop. Worse, though academic theory suggests that WIP helps buffer against variability in individual tasks and thus improves throughput, utilization of the sequencing machines continued to fall. The sequencing instruments represented that platform's single biggest capital expense and, due to rapid technology changes, often had a useful life of less than two years. Being cost competitive required fully leveraging this investment. The team felt like they were working harder every day to push samples through the process day and yet the performance just seemed to be getting worse. What was happening?

[8] Spearman, Hopp, and Woodruff, "A Hierarchical Control Architecture for Constant Work-in-Process (CONWIP) Production Systems"; Hopp and Spearman, *Factory Physics*.

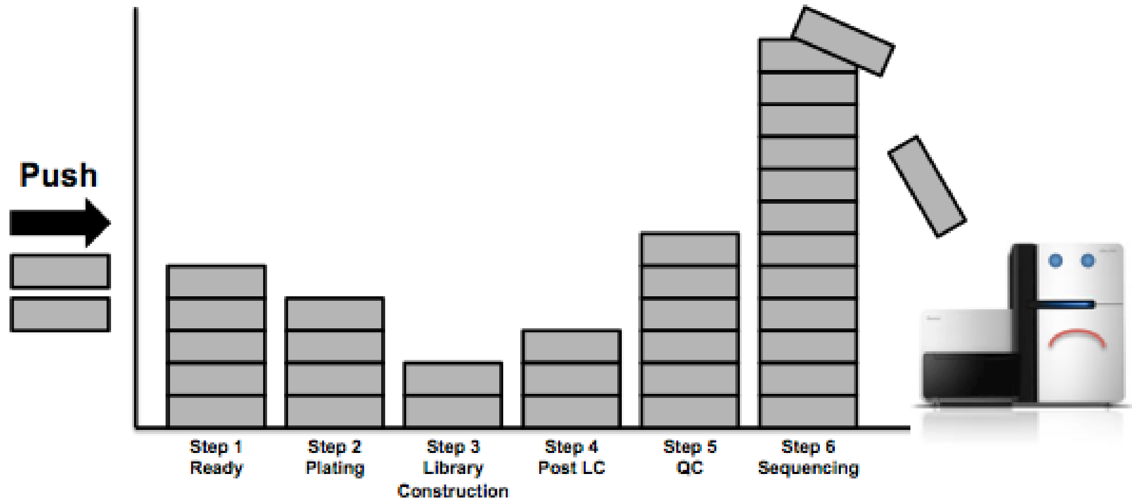

Figure 1. Push System for Feeding the Gene Sequencing Machines

In practice, push systems often suffer from three related problems. First, they are slow. When WIP accumulates far beyond any "optimal" level, it takes a long time for each sample to get through every pile and be completed. The more WIP there is, the longer a given task will take. By 2012 Broad was trying to keep track of thousands of in-progress samples, and average cycle times grew beyond 120 days.

Second, when WIP accumulates at each step, the person executing a particular operation often faces more work than he or she can complete in a given shift. When there is too much to do, there is a strong tendency to engage in *local reprioritization*, meaning that each person in the process looks at the pile she is facing, determines which items are the most important, and then works on those tasks first. Prior to implementing Pull, the operations teams started each day by prioritizing their piles: Is there a particularly important set of samples that needs to go first; should the sample on the top of the WIP pile be next or should you respond to the angry researcher who just called to complain about not receiving her data? When each person (or team) in the process chain prioritizes her work differently--the task you think is the most important may not be the one that others rank most highly-- local reprioritization creates variability. If a task happens to be prioritized by everyone, it gets done quickly. But, that means another task has been moved to the bottom of several "to do" lists and it might take weeks or months to get done. As the in-progress samples accumulated at Broad, not only did the average cycle time grow, but the process became increasingly unpredictable. Some samples would be completed relatively quickly while others could take six months or more.

The tendency of push systems to produce long and unpredictable cycle time produces the third and biggest problem, the tendency to *expedite*. When a really important piece of work comes along managers are often unwilling to push it into the process and risk having it get stuck in a WIP pile. So, being proactive, they find a way to work around the system and insure that their task gets prioritized at every step. In factories, this is called expediting. Prior to the lean revolution, it was not unusual for manufacturing and assembly plants to have an army of staff who did nothing but hand-carry specific jobs through the production line to make sure they got done. But expediting is like a narcotic; if you are not careful, the more you use it, the more you need. When a piece of work is expedited, it means that all the other tasks in the WIP piles are deprioritized and will take longer to complete. Those tasks will too eventually be late and also require expediting, thus creating a vicious cycle of expanding piles of WIP, growing cycle times, and ever-more chaos.

At Broad, the production team would start each morning by developing a schedule for that day's work in the hope of processing the most important samples. But, this schedule rarely lasted more than a few hours before new demands and shifting priorities— whether it was an angry email from a researcher or the announcement of a new grant— would cause them to return to the lab and begin re-arranging the piles in the hope of meeting their new targets. They even had a set of samples that they called F.O.E.'s, which stood for "friend of Eric," Eric in this case being Eric Lander, Broad's founding director. When the director inquires about a particular set of samples, those samples get prioritized.

But well intended efforts to reprioritize and expedite, while effective in the short run, created an almost constant need for "firefighting." Samples that needed processing were distributed throughout the lab, and there was no means of organizing them. When a technician wanted to start preparing a sample for sequencing, the first thing she had to do was find it, but, more often than not, halfway through her search, her attention would be directed to another set of samples that suddenly had become a higher priority. The operations team spent its day responding to complaints and then trying to expedite accordingly, leading to an increasingly inefficient allocation of resources. Despite working ever longer hours, the lab was falling ever further behind. Morale was low and arguments erupted daily as team leaders tried to figure out why yet another sample was about to miss its promised delivery date.

Pull

To get Broad's operations out of constant overload and the consequent firefighting, the team switched from a push system to one based on the concept of *Pull*. The key to understanding the difference between push and Pull is to see that WIP inventory is always a double-edge sword. It helps buffer the inevitable variability between different operations, but in doing so it also hides information that operators and supervisors could use to manage and improve the work *system*. In a push system with lots of WIP, an operator can focus on her individual task with little regard for what is happening around her. But, while this decoupling enhances individual productivity, for all the reasons discussed above, it limits the overall performance of the work process. The essence of a Pull system is to set clear limits (both upper and lower) on WIP accumulation and then, if the system hits one of those limits, use that information as a signal of an underlying problem. Managers can then trade off short-term productivity and the long-run learning that comes with fixing problems by adjusting the WIP limits—tighter limits lead to better information and more learning; a broader span leads to fewer hiccups and more short-run throughput.

At Broad, implementing Pull began with reconfiguring the inventory holding areas to limit the number of samples between each operation. A simple system of green, yellow, and red boxes provided technicians with clear signals about the state of their operation relative to the overall production system (see Figure 3). If a tech's downstream box was empty, then she should process samples. Once the yellow box was full she was near the end of the day's work and a full red box signaled that it was time to stop. If a technician was done with her work for the day, she could quickly assess the overall state of the system by looking at other boxes and identify a colleague who might be behind and need some help. By providing clear produce/stop signals, a Pull system promotes effective line balancing

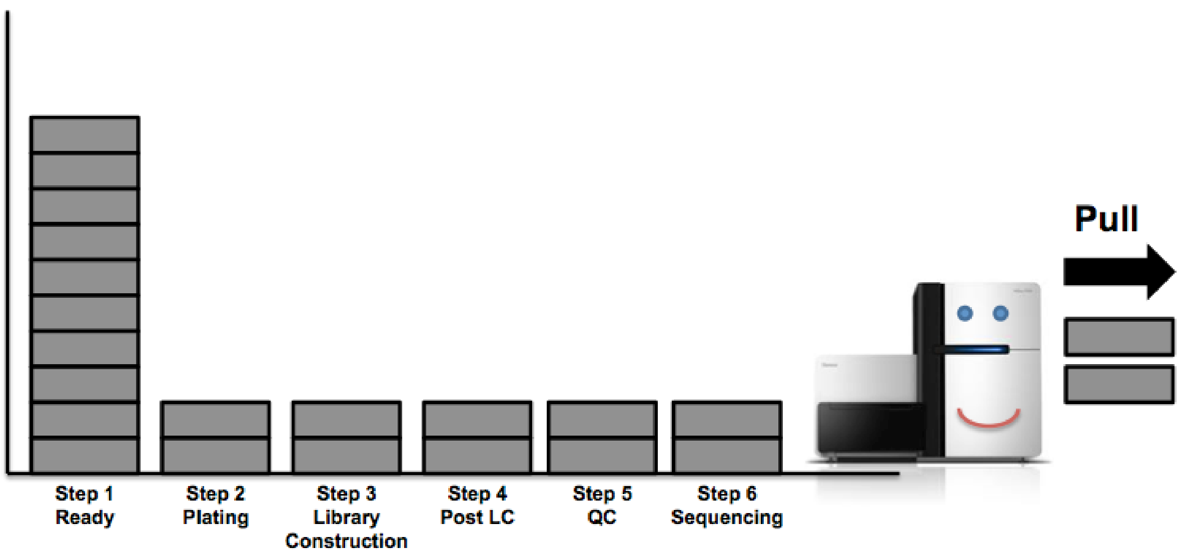

Figure 2: Pull System for Managing Samples

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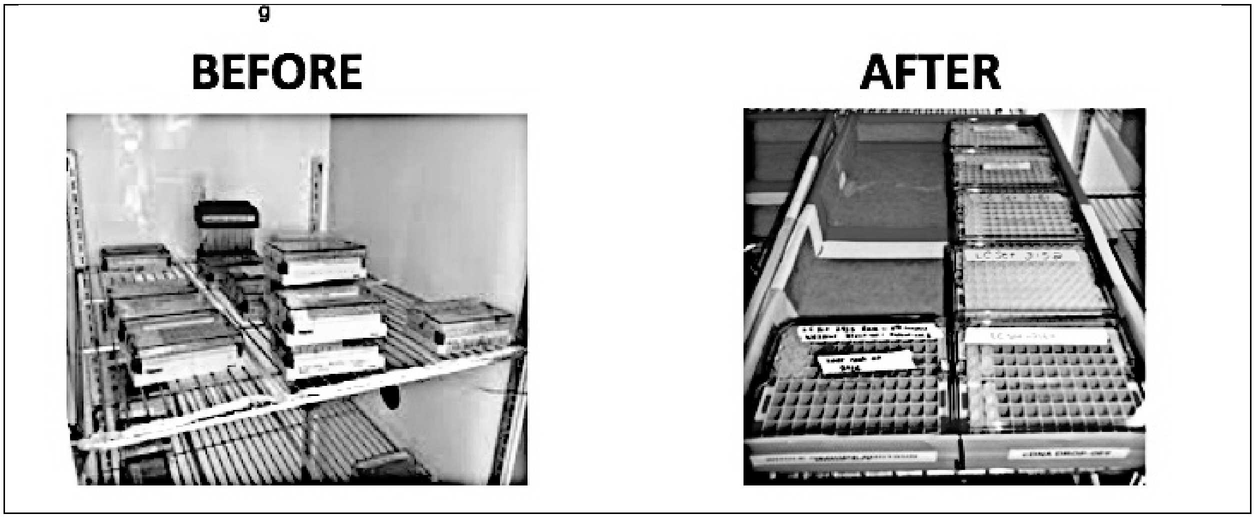

Figure 3. Sample Waiting Areas Before and After Implementing Pull. In the push system on the left, samples were allowed to accumulate. In the new Pull system WIP is restricted, thus providing clear signals to both technicians and managers.

Pull systems also provide a clear set of “vital signs” to managers. Whereas the WIP in a push system hides process bottlenecks and unreliable equipment and procedures, such improvement opportunities are much easier to see in a Pull environment. At Broad, a quick walk through the production system reveals which parts of the operation are moving and which are stuck. A perpetually full Pull box means either the downstream task is moving too slowly or the upstream one is moving too quickly. An empty Pull box at the end of the day means that something is wrong with the operation that feeds it. With this transparency, the operations team was quickly able to identify and fix a variety of process bottlenecks and other problems that had previously been obscured the large number of samples that were in process.

The major impediment to implementing a Pull system is resisting the temptation to expedite. Once both operators and managers get clear signals concerning the true health of the process, they can rapidly address bottlenecks and other problems that restrict throughput. Similarly, limiting WIP results in a process cycle time that is both faster and more predictable. That said, the system of clear signals can easily be corrupted by well-intentioned efforts to rush a particular job through the process. In a well-functioning Pull system, jobs can be re-prioritized before they enter the process (see Figure 2) but once they enter they need to proceed to completion.

Broad's operations team made a concerted effort to wean themselves off expediting. With time, they developed a common language to hold each other accountable for sticking with the process. In the morning production meeting it was not unusual to hear team members call each other "pushers," a light-hearted reminder that they were falling back into the vicious cycle of expediting. Even the center director agreed to refrain from re-prioritizing mid process. He was welcome to reorder the samples sitting in front of the process as often as he pleased, but once it entered the lab, it should be allowed to proceed without intervention.

Implementing Pull produced significant gains. Utilization of the sequencing machines rose almost immediately (see Figure 3) and eventually more than doubled; today it rarely falls below 90% and often exceeds 95%. Process cycle time eventually fell by more than 85% and the variance declined dramatically. Creating a faster, more predictable and transparent process reversed the vicious circle of expediting and created a virtuous cycle of stability and growing competitive advantage. With the improved predictability, the lab received fewer queries from researchers wondering where their data were. The staff once dedicated to expediting could now focus on fixing the fundamental problems that prevented the process from functioning as desired (a process that was greatly enabled by the transparency that also comes with Pull). Today, in part due to the release of the resources formerly dedicated to shepherding samples, the platform has pioneered a variety of industry leading services.

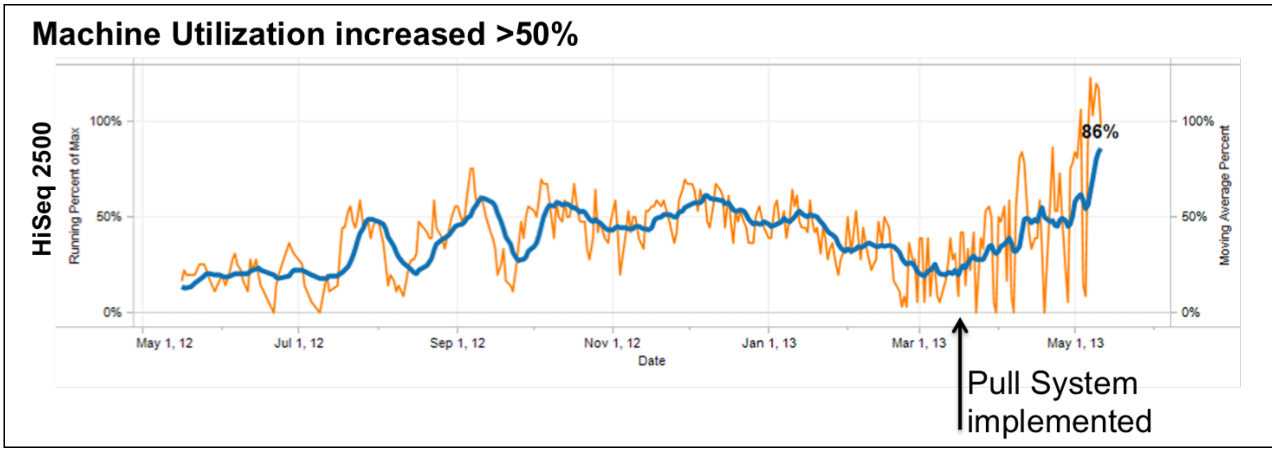

Figure 4. Results of Implementing Pull

4.0 Creating Pull for Knowledge Work

The improvements Broad made in its operations would be impressive in any industry. That said, it was a relatively modest leap from a traditional manufacturing and assembly environment to implementing Pull in the samples lab. The next intervention, however, was far more novel. Genetics is arguably the fastest changing industry in the world. The cost of sequencing has fallen over 100,000 fold since the Human Genome Project, far exceeding Moore's famous law suggesting that the price of manufacturing semiconductors falls by half every two years. Broad researchers produced many of these innovations and have collaborated with equipment manufacturers on several others. Management scholars have historically argued that innovation and efficiency are strict trade-offs; those processes that are highly efficient are slow to change, while rapid adaptability comes at the expense of cost leadership. Though it may not have entirely eliminated this trade-off, by adapting the Pull approach to managing technology development, Broad transformed itself into a highly efficient processor while simultaneously leading its industry in generating new technology.

Push in Knowledge Work

While Pull systems are widely used to manage factories, knowledge work processes are almost exclusively managed via push and, in our experience, are even *more* prone to the costs of overload. How many times have you sent a short email to a friend with a subject line like "quick thought" or "new idea?" More generally, if your organization is staffed by talented, capable employees, they will produce a constant inflow of new ideas that immediately get "pushed" into the organization. Worse, in knowledge work it is difficult to even count the amount of work in process. It resides in email in-boxes, project files, and individual "to do" lists. Given the propensity for pushing new ideas into an organization, it is not surprising that studies of new product development organizations indicate that such systems often have three to five times as many projects in progress as they have capacity to complete.[9] Broad's R&D processes were certainly another case in point. In 2012, they had many more ideas under consideration than they could investigate fully and many more projects underway than their overloaded operations team could ever implement.

The push approach to managing technology development and implementation created a set of failure modes similar to those experienced in the lab. At any given moment, there were dozens of projects underway and, consequently, projects often took a long time to get finished. The development teams, accustomed to exercising considerable autonomy, would engage in local reprioritization and regularly switch their focus from one idea to another, both reducing productivity and creating variability.[10] And, just as happened in the lab, facing a technology development process that was slow and unpredictable, leadership routinely resorted to expediting. When something *really* needed to get done, often due to a customer requirement or a change in a vendor's technology, the development teams would drop everything and fight the new "fire" until it was completed. Expediting had *become* the development process and the genomics platform was losing the technology leadership position it had worked so hard to develop.

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[9] Wheelwright, *Revolutionizing Product Development*; Oosterwal, *The Lean Machine*; Repenning, Gonçalves, and Black, "Past the Tipping Point."
[10] Wheelwright, *Revolutionizing Product Development*.

Implementing a Pull system had reduced overload and improved resource allocation in the lab, could something similar be done to manage the portfolio of technology development projects?

Using Visual Management to Create Pull

The trick to adapting the Pull concept to generating and managing knowledge is to give work a physical "face." In some contexts, managers have successfully used visualization for decades. The data needed for a pending merger or acquisition are often captured in a "war room." Similarly, when facing an accident or other unforeseen event, companies in high hazard industries often dedicate a room to "incident command," capturing all the information needed to manage an unfolding and fluid situation. Paradoxically, though "war room" style representations are often used quite effectively to manage one-time events, visualization is less popular in "peacetime." There are, however, several reasons to believe that this approach would be equally if not more effective for day-to-day work.

Human beings are visual creatures, and a growing collection of evidence suggests that our physical environment exerts a strong influence on the ways our cognitive systems perceive and process information.[11] In many cases, things we can see, touch and taste influence our thinking in ways that aggregate data or abstract concepts do not. It probably shouldn't surprise us that the concept of Pull was first developed in the context of physical work. WIP inventory is easy to see and its excess accumulation generates an intuitive sense of trouble. Similarly, when a production line in a factory stops, it generates a clear signal that something has gone wrong and people naturally converge to help. In contrast, those who oversee knowledge work rarely know how many projects they have currently in progress and have little information about whether or not those projects are progressing. Unlike an assembly line, when work on a key component of an

[11] Wilson, "Six Views of Embodied Cognition."

R&D projects stops (perhaps because the person doing it got stuck), it doesn’t generate a clear signal to the entire organization. The essence of Visual Management is to give knowledge work a physical manifestation so that it is easier to see when it is moving and when it is stuck.

To reduce over-commitment and begin “pulling” projects through the development process, Broad’s leadership team started by listing all of the projects currently underway. Using some unused wall space, they drew a simple schematic of their development “funnel,” creating a separate box for each of its major stages (feasibility, design and validation). Each of the projects underway was then transferred to a Post-It note and placed on the funnel diagram in the box corresponding to the development phase that it was in.

This simple exercise created the first visual representation of their development portfolio and led to two insights. First, the lack of common prioritization was now obvious. Nobody on the leadership team was aware of every project or there was little consensus about which among them was most important. Many of the projects in the funnel overlapped and/or competed with others. Second, there was simply too much work in the system. Comparing the number of projects in process to the recent delivery history suggested that they had at least twice as much work as they could complete in the best of circumstances. Much like the piles of samples in the lab, *seeing* each project as a Post-It note revealed the consequences of continuing to push new ideas into the development process.

To continue the exercise, the team began meeting in front of the funnel board weekly. A set of Post-It notes were developed to represent each project and contained three elements: 1) an activity related to the project (e.g., developing a testing protocol); 2) the name of the person doing activity; and 3) a target completion date. During the weekly meeting the owner of each project would report on those activities on the board for which she was responsible (names being listed on the Post Its). The conversation around each activity focused on two key elements.

First, was the activity completed on time? If not, a Post-It with a contrasting color (usually bright pink) was placed on top of the original entry to signal that something was not going according to plan. Similar to how a stopped production line draws attention in a factory, once a "stuck" activity was identified, the leadership team could discuss ways to get it moving, whether it be adding resources or removing an organizational road block. It was not unusual for problems to be solved in the weekly "board" meeting, thus quickly getting projects back on track. Second, once all the activities for a particular phase were completed, the team would discuss whether or not the project was sufficiently compelling that it should move to the next phase. If the answer was "yes" then new Post-Its, representing the next set of key activities, were created and placed on the board.

Consistent with the initial observation that they had too much work in progress, in the early meetings the entire board rapidly went "pink," meaning that most activities were behind schedule. Over the course of the first year the team took on the painful task of cutting the number of projects in progress by more than fifty percent. Canceling low priority activities produced significant reductions in the time required to complete those projects that survived and increased the overall throughput of the system.

Though pairing down the portfolio was necessary, it was unlikely to be sufficient to produce sustained improvement. Like any organization staffed with smart capable people, the Genomics platform staff produced more good ideas than they had the resources to execute. Without rules for managing of the portfolio, the overload was almost certain to return and painful cuts would again be required.

To create a more dynamic approach to managing the funnel (and thus avoid the need for periodic and painful "purges") the team made three adjustments to their weekly meeting and supporting visual board (see Figure 5). First, a "hopper" was added in front of the funnel. The hopper contained all of the proposed projects that had yet to be started and, therefore, had not entered the development funnel. To facilitate prioritizing those ideas, the hopper was organized as a two-by-two matrix in which each project was ranked by both its potential impact and the effort required to complete it. Ideas could be added to the hopper at any time (simply be creating a Post It) and each suggestion was discussed and ranked each week. Second, a column called "agreed and ready" was added in between the hopper and the first stage of the development funnel. When a new idea in the hopper was deemed worthy of development it would go into the "agreed and ready" area. The "agreed and ready" column is akin to the pile of samples sitting in front of the production process in the lab. The team would review it weekly and adjust the priorities as needed. Third, to facilitate Pull, the team would review the amount of work in the various stages of the funnel and only pull from the "agreed and ready" column when they judged that they had enough space to start a new project.

To assesses whether or not they had space for a new project, the team modified the Pull approach used for samples. In the lab, samples can easily be reduced to a common unit of work and therefore it is relatively straightforward to size the Pull boxes. In contrast, R&D projects come in a variety of shapes and sizes and it's difficult to reduce them to a common resource unit. To confront this problem Broad's board does not directly match projects to available resources, but instead relies on weekly check-ins, facilitated by the visual system, to make subjective assessments of the amount of work they can handle. Doing so creates a more *dynamic,* flexible system for managing the portfolio that allows them to capitalize on the deep experience and expertise of their team members. Each activity supporting a given project is given a completion date based on its owner's assessment of how long it would it take in normal circumstances, meaning in a *properly loaded development system*. The relevant contributors are then asked to assess whether or not, given their current loading, they think they can meet that date. If the answer is "no," then there is too much work in that part of the development system. Similarly, a lot of pink Post-its (meaning dates have been missed), indicates that the pipeline is congested.

New projects can't go in until an existing project goes out (either because it is completed or canceled). Development teams still occasionally miss their delivery dates, but this approach provides a simple and intuitive approach to allocating scarce development resources. In a similar vein, with the visual board, the leadership can easily spot bottlenecks and/or individual performance management issues. If certain portions of the funnel are moving more slowly than the others, then either the resources need to be rebalanced or the relevant staff need to engage with their work differently.

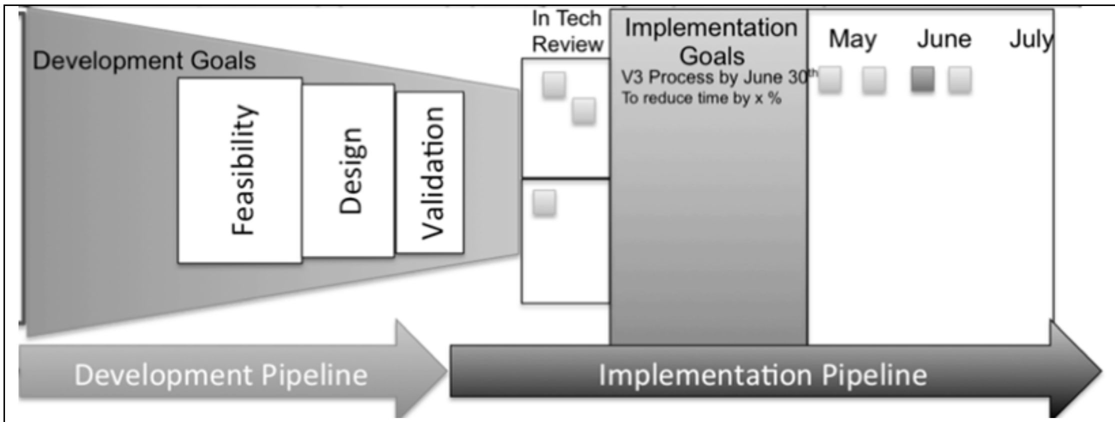

Figure 5. Overview of Visual Management Board

Creating a Pull system for knowledge work has produced significant gains. The velocity of the technology development process has increased several-fold and the technology platform has returned to its industry-leading position. The team reports deeper engagement in their work and far more success with cross-functional collaboration. Whereas previously the team struggled with the turf battles that often ensue when a collection of different functions, all with their own goals and projects, try to coordinate, they are now far more integrated. The quantitative results also bear out the qualitative assessment.

Thanks to its improved ability to develop and introduce new technology, Broad is now capable of analyzing many samples in less than a few days and, due to efficiency improvements, they have dropped their prices by more than 90 percent since 2012. Shorter cycle times and lower prices mean that researchers studying everything from cancer to Ebola can run more experiments and get the results back faster, thus quite literally speeding the pace of science. During the course of developing this system, the team dutifully kept every Post-It that came off the board when it was completed and placed it on a large spike next to the board. After four years of running the system, the team held a small celebration and counted all of the completed Post-Its. In the space of four years, the team had executed over 4,000 separate development activities, representing about one every two weeks for each member of the extended leadership team.

5.0 CONCLUSION

As we have begun to teach this material, by far the most common question goes something like this: "Sure, this works in your examples (we typically discuss manufacturing, genomic sequencing, and drilling oil wells), but will it work in *my* organization?" We always give the same reply: "The stuff we teach only works in organizations that have people in them." Toyota and other Asian manufacturers catalyzed a revolution in manufacturing, and western companies spent the better part of two decades mastering quality management and lean production (an effort that continues to this day). But, while the companies using lean methods have developed significant capability in manufacturing and supply chain operations, they have missed a larger message. The assumption underlying the understanding of lean methods is that they represent a better way to organize manufacturing activity. The message underlying our quip is that many of the tools and practices associated with quality management and lean approaches work, not because they are better ways of organizing manufacturing activity, but because they are better ways of organizing *human* activity.

Transferring these ideas from physical to knowledge work is, however, not trivial. Upon seeing this material in one of our classes at MIT, an exasperated student blurted out "I see why this works, but it just feels so…. well…. 1970s." He went on to speculate that there must be a more contemporary way to develop the system; Post-Its just seemed too low tech and "retro." There are good digital solutions for creating a visual management system but using them comes with risk. The magic of Broad's system does not lie in the Post-Its, but in the quality of the conversations that the Post-Its catalyze. In a truly lean, Toyota-style production system, the physical work signals the need for interaction and problem solving. Effectively organizing work off the factory floor requires catalyzing similar conversations, but digital systems, by isolating us from our work and from each other, risk creating ineffective work. Recognizing innate human strengths developed through evolution, the next generation of digital systems might focus on creating effective, real-time interaction rather than trying to substitute for them. If the experience at the Broad and other firms is any guide, those firms that master this challenge will generate a significant advantage over their competitors.

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