Managing the Dynamics of Process Improvement:

Production, Improvement, and Learning

ABSTRACT

This paper considers the problem of managing process improvement when resources are constrained. The paper constructs a system dynamics model that formalizes the critical interaction between using resources to produce primary output and investing resources in process improvement as means to increase throughput. The model incorporates learning so that the productivity of doing improvement activities grows as workers accumulate experience with new methods. The model enables a rigorous examination into how the feedback structure of process improvement presents challenges to people in a system facing the dual pressure to produce output and to build capability. Simulation analysis highlights the dynamics of the tradeoff between production and improvement and demonstrates the existence of a tipping point that distinguishes enduring high levels of production from modest or no improvement. Results show the superior performance of counter-intuitive policy orientations that favor learning.

Managing the Dynamics of Process Improvement:
Production, Improvement, and Learning

To succeed in the face of competitive markets and increasingly demanding customers, organizations must strive to improve the performance of their fundamental business processes (Dean and Bowen 1994). Managers have available a wide range of approaches to process improvement, such as total quality management, business process reengineering, statistical quality control, lean manufacturing, six sigma, and so on (Monden 1983; Womack, Jones et al. 1990; Hammer and Champy 1993; Cole and Scott 2000; Rigby 2001). Process improvement initiatives may be focused on reducing cost, reducing cycle times, improving quality, enhancing flexibility, or boosting throughput. The widespread availability of such approaches to performance improvement notwithstanding, there is considerable disagreement as to whether these programs are helpful in improving organizational performance (Ittner 1994; Ittner and Larker 1997; Staw and Epstein 2000; Hendricks and Singhal 2001).

In practice, managers facing the need to improve (or perhaps even maintain) their firm's productive capability must make decisions about the allocation of resources to these activities. This resource allocation decision has attracted a considerable amount of scholarly attention, especially in the stream of literature on quality improvement. For example, one view holds that organizations should continually aspire to achieve zero defects, implying that more improvement is always better (Crosby 1979; Deming 1982). A different view holds that quality improvement practices have positive returns, but only up to a point, so managers should choose quality levels based on economic trade-offs

(Juran 1979). Researchers in this stream have studied and modeled costs and tradeoffs in order to determine the optimal level of, or optimal policies for, investment in process (or quality) improvement (Fine 1986; Li and Rajagopalan 1998; Carrillo and Gaimon 2000). In either case, framing the question as the choice of the level of investment implicitly assumes that resources are available to scale up to optimal levels and perhaps that resources can be reduced when excessive. This firm-level view of the question is helpful to set long-run strategies. However, a closer-in look at managing process improvement suggests that resources are shared between production and improvement activities (Repenning and Sterman 2002). Indeed, the engagement of front-line workers in the activities of improving the work processes is a distinctive element of many process improvement programs, most notably the approach used in the Toyota Production System (Spear and Bowen 1999). Allocating available resources to production and improvement, not choosing the overall level of resources, characterizes the typical challenge of managers implementing process improvement.

An emerging stream of literature examining the phenomenon of problematic process improvement has explicitly considered feedback explanations. In this literature, one class of explanations points to factors in the organizational context that undermine the sustainability of the improvement activity. Sterman, Repenning and Kofman (1997) (Sterman, Repenning et al. 1997) highlight the impending fear of losing jobs as improvements yielding greater productivity imply a need for fewer employees. Keating and Oliva (2000) point to the challenges of simultaneously undertaking multiple improvement projects (Keating and Oliva 2000). Repenning (2002) shows the dynamic effects of waning employee commitment to process improvement (Repenning 2002). Repenning and Sterman (2002) develop a causal loop model of the dynamics of process improvement that distinguishes first-order improvements (working harder) and second-order improvements (working smarter) (Repenning and Sterman 2002). This paper contributes to a second class of feedback explanations regarding problematic process development that takes a more micro view and identifies critical interactions in the work of process improvement itself. The explanation for problematic behavior is rooted in understanding the links between activities to build primary production capability and learning-oriented activities that build capability to sustain ongoing capability building. Under conditions of constrained resources, the interconnection between these useful activities is inescapable.

This paper considers the problem of managing process improvement when resources are constrained. Specifically, we consider the case in which total resources available for use in production and improvement are held constant. Resources may be constrained for a variety of reasons, such as shortages in local labor markets, budget restrictions imposed by enterprise management, and differences in realized versus forecast market demand. Although these practical constraints can often be overcome in the long-run, we believe such resource constraints accurately characterize the problem from the perspective of a mid-level supervisor or a front-line worker. Despite the widespread occurrence of this resource-constrained problem in practice, the problem has received limited attention from scholars of process improvement.

The purpose of this paper is to examine the dynamics of process improvement when resources are constrained. Specifically, the paper constructs a dynamic mathematical model that formalizes the critical interaction between using resources to produce primary output and investing resources in process improvement as means to increase throughput. The model incorporates learning so that the productivity of doing improvement activities grows as workers accumulate experience with new methods. The model enables a rigorous examination into how the feedback structure of process improvement presents challenges to people in a system facing the dual pressure to produce output and to build capability.

The paper is organized as follows. The next section begins with a brief description of the stylized setting for the production system and then presents the model first using causal loop diagrams to show the feedback structure and then describing the underlying mathematical formulations. The following section uses simulation analysis to explore various polices for managing production and process improvement. Finally, the concluding section discusses the findings and some implications for theory and practice.

A MODEL OF PRODUCTION AND PROCESS IMPROVEMENT

Consider a stylized firm that manufactures widgets. The firm aims to maximize the rate of production given a production process with certain capability, an option to undertake process improvement to increase the capability of the process, and a fixed quantity of labor available to allocate between two activities: producing widgets and conducting process improvement work. Workers build process capability by completing process improvement projects, which are started according to goals set by the manager. Workers are encouraged to use new, promising methods to conduct the improvement projects, but they may choose to rely on old habits (i.e, shortcuts) that are potentially more productive in the short-run. The manager must choose how to allocate resources between production and improvement activities. The workers adjust their work practices in response to the pressures that arise from their production and improvement goals. They also can learn and eventually master the new methods if they gain experience through their project work, a form of learning by doing.

The remainder of this section presents the stock and flow and feedback structure of this system. Selected equations are presented for clarity, and the entire model is documented and available in the technical appendix. Time subscripts are omitted for simplicity. The basic "physics" of this production system are depicted in Figure 1. Production (Q) is modeled as a third-order delay of production starts (S), capacitated by the resourced production rate. Production starts are set equal to the rate at which production can be completed, which is determined by the resources to production (R_p) and the process capability (C). The process capability is increased by process improvements (I) and decreased by process degradation (D). Process degradation models the limited useful life of the maintenance and improvement activities as well as turbulence and continuing change in the standards for success in the marketplace.

$$Q = \min(\mathrm{DELAY3}(S, \tau_p), R_p{*}C)$$

$$S = R_p{*}C$$

$$dC/dt = I - D$$

$D = C/\tau_d$

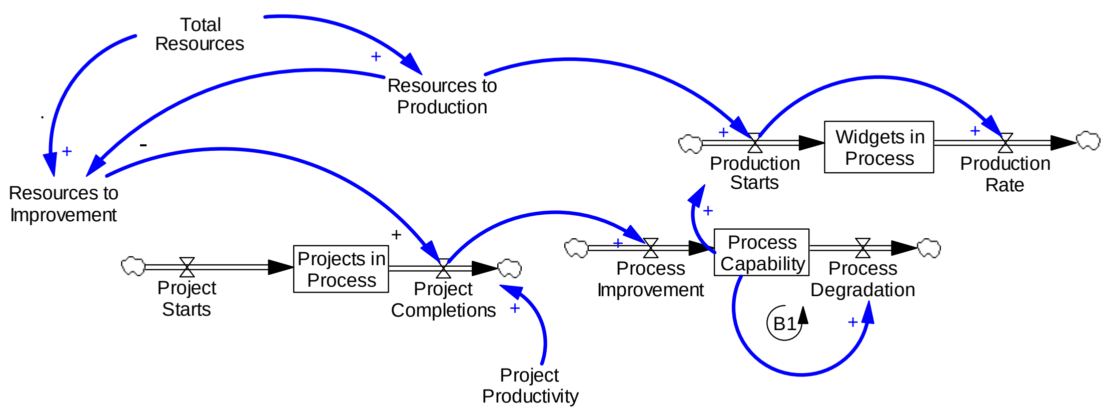


Figure 1: Physics of Production and Process Improvement

Process improvements are done by the workforce. Process improvements are determined by the project completion rate (B) and the improvement value (ν) of each project toward building process capability. The model makes the *a fortiori* assumption that all projects are beneficial (or at least that on average they are), assuming a constant contribution value for each project completed. The project completion rate is determined by the resources to improvement (R_i) and the productivity of improvement activities (P_i), unless the improvement resources are starved for work. The maximum feasible completion rate of projects is based on the amount of project work in process (W) and the minimum completion time (τ_{min}). The project work in process is increased by the project start rate and decreased by project completions. Total resources (R_{tot}) are split between resources to production and resources to improvement; alternatively, the resources to improvement are the total resources less the resources allocated to production.

$$I = \nu * B$$

$$B = \min(R_i * P_i, W/\tau_{min})$$

$$dW/dt = Z - B$$

$$R_i^* = R_{tot} - R_p$$

$$dR_i/dt = (R_i^* - R_i)/\tau_r$$

Production workers are assumed to be relatively unskilled in the use of the new improvement techniques that will be introduced as a means to enhance capability. Thus, the initial productivity with the prescribed method is low, but the workers have an alternative. They may do their improvement work using the methods with which they are already familiar, methods that are at least initially more productive. The productivity of improvement activities is then the weighted average of the productivity of work with new methods (P_n) and the productivity of work with the old methods (P_o), weighted according to the amount of time spent doing work with the new (T_n) and old methods (T_o). As workers use the new methods, they accumulate experience with the new methods (E). Experience is increased by learning (L), but is also decreased by forgetting (F). Accumulated experience increases productivity with new methods, following standard learning curve formulations (Argote 1999). Learning is determined by the rate of project completions and the average fraction of project work time doing the new methods. Forgetting is modeled at a constant fractional rate, as in standard treatments of learning curves (Argote 1999).

$$P_i = (P_n * T_n + P_o * T_o)/(T_n + T_o)$$

$$P_n = P_{n0} * (E/E_0)^{\wedge\rho}$$

$$dE/dt = L - F$$

$$L = B*A$$

$$A = X/W$$

$$dX/dt = Z*K - B*A$$

$$K = T_n / (T_n + T_o)$$

$$F = E/ \tau_f$$

The first policy or decision rule that needs to be represented is how the workers split the time they spend on improvement activities between the new and old methods. The model represents this as an endogenous decision rule by which the workers adjust to the pressures they face to get their improvement work done. Industrious and conscientious workers face two constraints. The first is an output objective, to get the assigned work done at the indicated completion rate, (B^*), given the work to do and the expected completion time (τ_e). The second is a resource constraint, to use only the total amount of time allocated to improvement (R_i).

$$B^* = W/ \tau_e$$

(1) $P_n^* T_n + P_o^* T_o = B^*$

(2) $R_i = T_n + T_o$

The solution to these two simultaneous equations yields an expression for the allocation of time:

$$T_o^* = (B^* - R_i *P_n) / (P_o - P_n)$$

The model also assumes, contrary to fact, that the allocation decision is made with full knowledge of the state of the system, including instantaneous and completely accurate knowledge of the indicated completion rate, the productivity of time using the old and new methods, and the current allocation to improvement. The reason for this assumption is to eliminate any flaws in perception, information processing, or allocation decision making as possible causes of the pathologies that will be observed in model behavior.

There are no “mistakes” in decision making, although the policies that govern the ongoing allocation decisions may be flawed.

The workers adjust their work methods towards this indicated allocation of time. Note that this allocation of time means the workers spend as much of their improvement time as possible doing the work with the new methods consistent with the need to get their improvement work done at the indicated rate. The adjustment process closes a balancing loop, B2, in Figure 2. But, a consequence of increasing the reliance on old methods is a reduction in the amount of learning and thus accumulation of experience with new methods that would increase improvement activity, as shown in reinforcing loop R3.

$$dT_o/dt = (T_o^* - T_o)/\ \tau_W$$

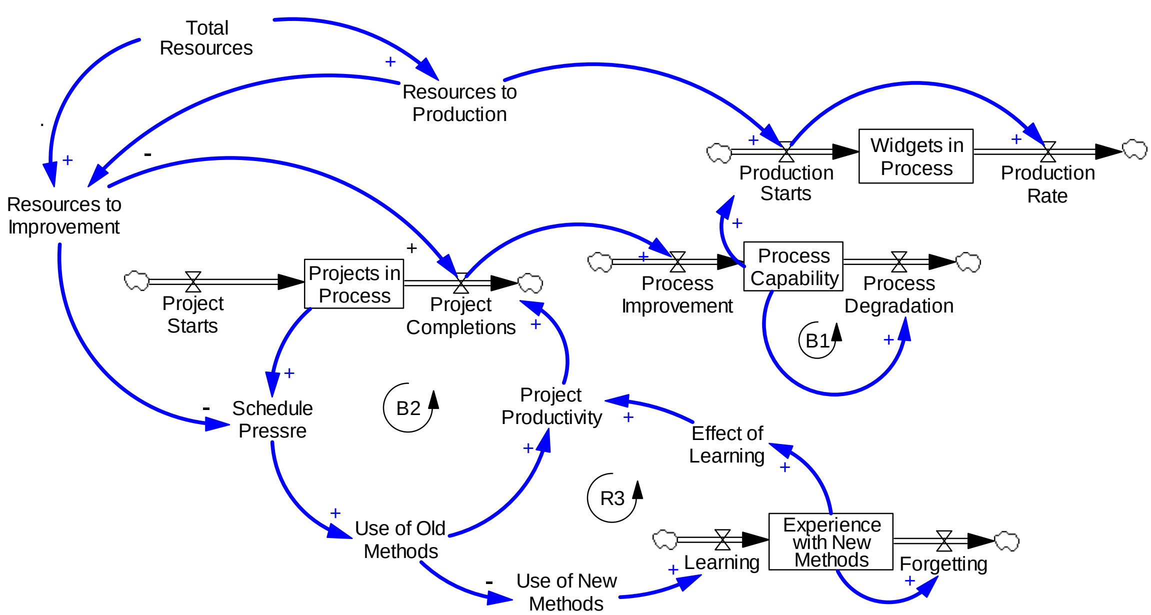


Figure 2: Learning and Adjusting to Pressures in the Work of Process Improvement

Two more policy rules are needed to complete the description of this system, both representing managerial policies. The following section uses simulation analysis to explore the influence of these two policies on the system's behavior. The first policy is the allocation of resources between production and improvement. Variations in this policy are implemented using exogenous changes as described in the next section. The second policy is the determination of the project start rate. The next section models several policy options for managing project starts.

All model parameters, initial values, and fully documented equations are presented in the technical appendix. The model is initialized to start in equilibrium conditions. The starting equilibrium means that the production rate equals production starts, that process improvement is occurring at exactly the rate necessary to offset process degradation, that learning is occurring as exactly the rate necessary to offset forgetting, that project completions are occurring at the indicated rate, and that allocation of worker improvement time between the old and new method is at the desired allocation.

MODEL BEHAVIOR AND POLICY ANALYSIS

This section presents the results of simulation analysis to investigate the dynamic behavior of the stylized production system under various policy scenarios. Changes in the allocation of resources between production and improvement are implemented by changes in the quantity of resources allocated to production. The remainder of the available resources is allocated to improvement activities. The key choice represented in this rule is the allocation of the workers' time among two activities: production, which is a type of first-order improvement, and problem correction, which is a type of second-order improvement (Repenning and Sterman 2002). The decision rule implied here is that the production activities take a higher priority than the improvement activities, consistent with the field study data in Repenning and Sterman (2002). For example, a respondent describing a pilot improvement project said, "People had to do their normal work *(production activity)* as well as keep track of the work plan *(improvement activity)*. There just weren't enough hours in the day, and the work *(production activity)* wasn't going to wait." (Repenning and Sterman 2002 p 273. Comments in italics added.)

The second managerial policy that varies in the tests below is the rule for the project start rate (Z). One policy option, labeled here "constant starts," is to hold the project start rate constant at its initial value ($Z = Z_0$). This policy does not increase the rate of introducing new project work even when more improvement resources are available, so it might be considered a naïve policy. A second policy option, labeled here "productivity orientation," is to adjust the rate of project starts based on the feasible rate of project completions estimated from the level and productivity of resources assigned to improvement projects. This policy might represent the mental model of a manager who assigns project work consistent with his beliefs about the resources required to accomplish the given amount of work and who seeks to keep the improvement resources fully productive with ideas for implementation. The feasible rate of project completions (B^d) is determined by the resources allocated to improvement (R_i) and the current productivity of improvement activities (P_i). The manager uses the standard stock adjustment policy based on the target rate of completions to bring the stock of projects in process to a target value (W*). The productivity orientation policy begins with the same project start rate as in the constant starts policy but adjusts the project start rate as resources are increased or decreased or productivity rises or falls. The policy takes the following form:

$$Z = \max(0, B + (W^* - W)/ \tau_a)$$

$$W^* = B^d * \tau_e$$

$$B^d = P_i * R_i$$

The third policy option, labeled here "learning orientation," sets the project start rate to achieve the rate of process improvement indicated to offset the current rate of process degradation. Because of the basic stock and flow dynamics of process capability, any rate of project completions lower than this will result in a decline in process capability. The policy takes the following form:

$$Z = D/\nu$$

The results that follow are based on a set of simulations that explore the dynamics of this system by varying the policies for allocation of resources and for starting improvement projects. Table 1 summarizes the results of the simulations. All simulations begin in equilibrium conditions and run for 100 weeks. An exogenous input at week10 changes the indicated resources allocated to production by the listed percentage for the time period corresponding to the duration listed. The policy for the project start rate is set to one of the three policies: constant starts, productivity orientation, or learning orientation.

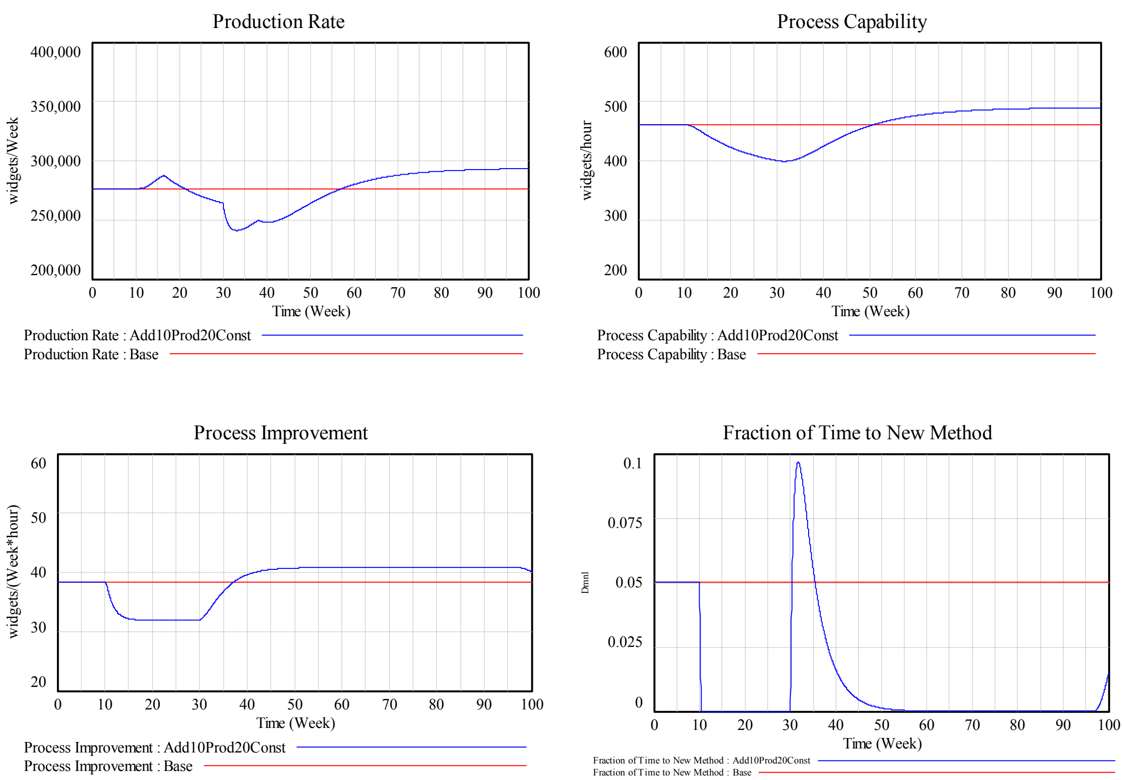
For comparison of the various scenarios, Table 1 also reports the Cumulative Production, defined as the sum of the production rate over the 100 simulated weeks. The "Base Run" scenario makes no exogenous changes, so the system continues in equilibrium. The remainder of this section shows the results of some of the simulations summarized in Table 1 to highlight the system dynamics.

Table 1: Summary of Simulation Results

Scenario		Resource Allocation Policy: Fractional Change in Resources to Production	Resource Allocation Policy: Duration of Change in Resources (weeks)	Improvement Policy	Cumulative Production	Shown in:
1	Base Run	0	0	Constant starts	27.64	Fig. 3
2	Increase Prod'n Res	+10%	20	Constant starts	27.60	Fig. 3
3		+100%	20	Constant starts	18.31	Not shown
4		+10	20	Productivity orientation	27.01	Not shown
5		+10	20	Learning orientation	26.30	Not shown
6	Increase Imprvmnt Res	-10%	100	Constant starts	25.55	Fig. 4
7		-10%	100	Productivity orientation	26.73	Fig. 5
8		**-10%**	**100**	**Learning orientation**	**51.39**	**Fig. 6**
9		-10%	20	Constant starts	26.93	Not shown
10		-10%	20	Productivity orientation	27.32	Not shown
11		-10%	20	Learning orientation	27.16	Not shown
12		-10%	50	Constant starts	26.51	Not shown
13		-10%	50	Productivity orientation	27.15	Not shown
14		**-10%**	**50**	**Learning orientation**	**51.38**	**Not shown**
15		-20%	20	Productivity orientation	27.31	Not shown
16		**-20%**	**20**	**Learning orientation**	**63.73**	**Not shown**
17		-30%	10	Learning orientation	27.31	Not shown
18		**-50%**	**10**	**Learning orientation**	**70.69**	**Not shown**

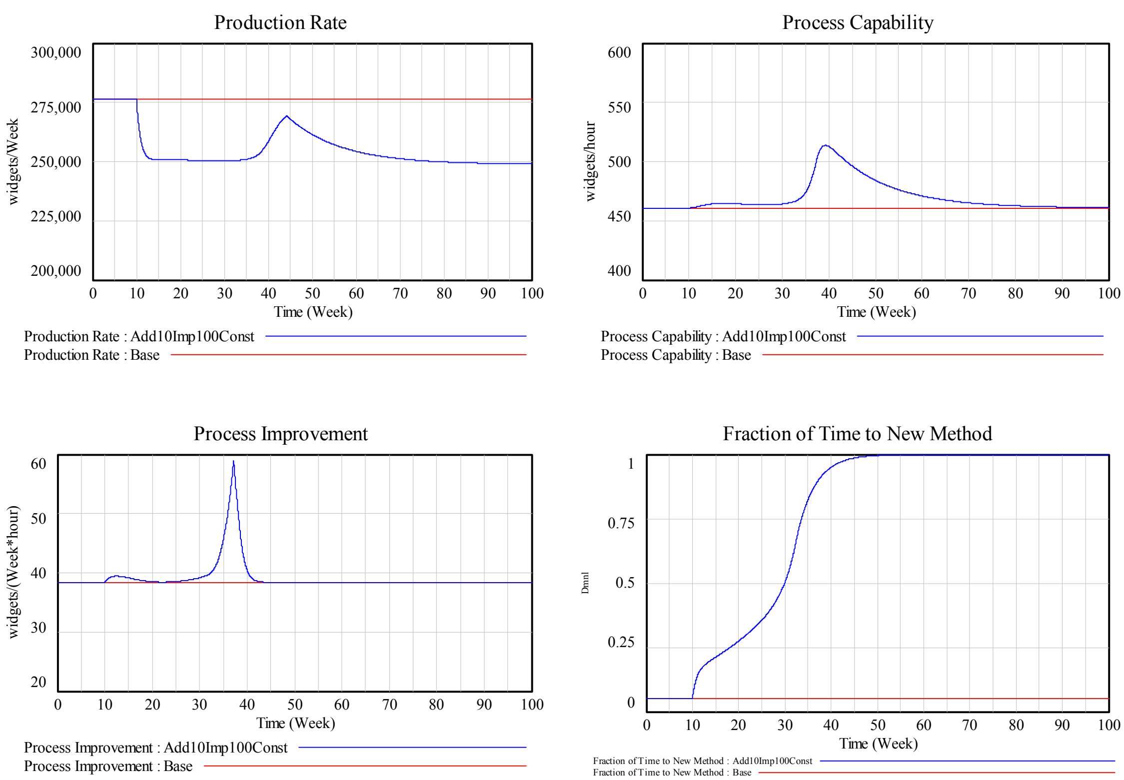
The first tests are to establish basic behavior patterns of the system. Figure 3 shows the Base Run (Scenario 1) and the results when the resources to production are increased by 10% for a period of 20 weeks (Scenario 2). Increasing resources to production reduces the resources to improvement for the same period. For a short period, the extra production resources produce more widgets, but the shift of resources away from the improvement activities causes a decrease in improvement projects completed. Consequently, process improvement declines below the rate required to maintain the status quo process capability. Process capability deteriorates, and by week 22 the production rate drops below its initial rate – despite the additional production resources. At week 30 when the resource allocation shifts back to its original mix the production rate falls sharply, because the extra resources to production are taken away but process capability has deteriorated. The shift of resources at time 30 begins an increase in improvement activity that eventually exceeds process degradation and thus restores process capability. An interesting feature of this outcome is that by the end of the simulation, process capability and consequently the production rate climb to above their original levels. The reason is illuminating. During the period when resources were shifted to production, the improvement resources faced increased pressure to complete projects and responded by completely eliminating the use of the new (less productive) methods. They abandoned the new techniques of the improvement program. By doing so, they boosted the productivity of time spent on improvement by a small amount. At the end of the simulation, although the resource mix has returned to its original allocation, process capability is maintained at a higher level because the improvement project completion rate is higher. The initial mix of improvement activity, which includes a small (5% of time in these simulations) amount of time with the new method, offered some slack that has been squeezed out in the scenario of Figure 3. Table 1 shows three other scenarios (3, 4, and 5) in which resources to production are increased. The dynamics are not substantially different from this scenario, so those simulations are not shown here.

Figure 3: Response to Increasing Resources to Production



Increasing resources to production starves the essential improvement activity in this system, so the results of the previous scenario are hardly surprising. The next simulations shift resources in the other direction: by decreasing the allocation to production, the resources to improvement are increased. Figure 4 shows the Base Run and the results when the resources to production are decreased by 10% permanently while the project start rate is held constant (Scenario 6). The production rate decreases at first because resources are shifted away from production. Eventually, the improvements implemented by the additional improvement resources cause an increase in process capability and also a boost in the production rate. However, this performance improvement is only temporary. The flow of process improvement returns to its original rates, because the improvement resources are starved for work once they have worked through the backlog of projects. Process capability eventually erodes to its original level, and the production rate falls once again. The graph for fraction of time to new method shows that the new method becomes the dominant approach. With little pressure from work to do, the improvement resources have comfortably allocated their time to learning the new method. But, despite their mastery of the new improvement methods, their proficiency does not translate into useful output, because they are starved for improvement work.

Figure 4: Response to Increasing Resources to Improvement with Constant Project Starts



The next simulation attempts to solve the work-starvation problem of the previous runs by adjusting the project start rate based on the resources available for improvements. Figure 5 shows the Base Run and the results when the resources to production are decreased by 10% permanently and the project start rate follows the productivity orientation described above (Scenario 7). As before, the production rate decreases at first because resources are shifted away from production. But now, the additional improvement resources have a continuing flow of new work to do, so process improvement increases permanently, building process capability to a higher level and sustaining the system at a modestly higher level of performance. The dynamics of the production rate, most salient to the manager, exhibit a classic pattern of worse before better. Due to the inter-temporal tradeoff, the cumulative production (26.72 mn) is only marginally better than that of the base run (27.64 mn) by the end of the simulation, and with considerations of the time value of output, not included here, may indicate that this improvement scenario is less desirable than the status quo. Note that the Fraction of Time to New Method had returned to its original value. This scenario shows some benefits of shifting resources to improvement activities, but there has been no fundamental change in the method of doing improvement.

Figure 5: Response to Increasing Resources to Improvement with Productivity-oriented Project Starts

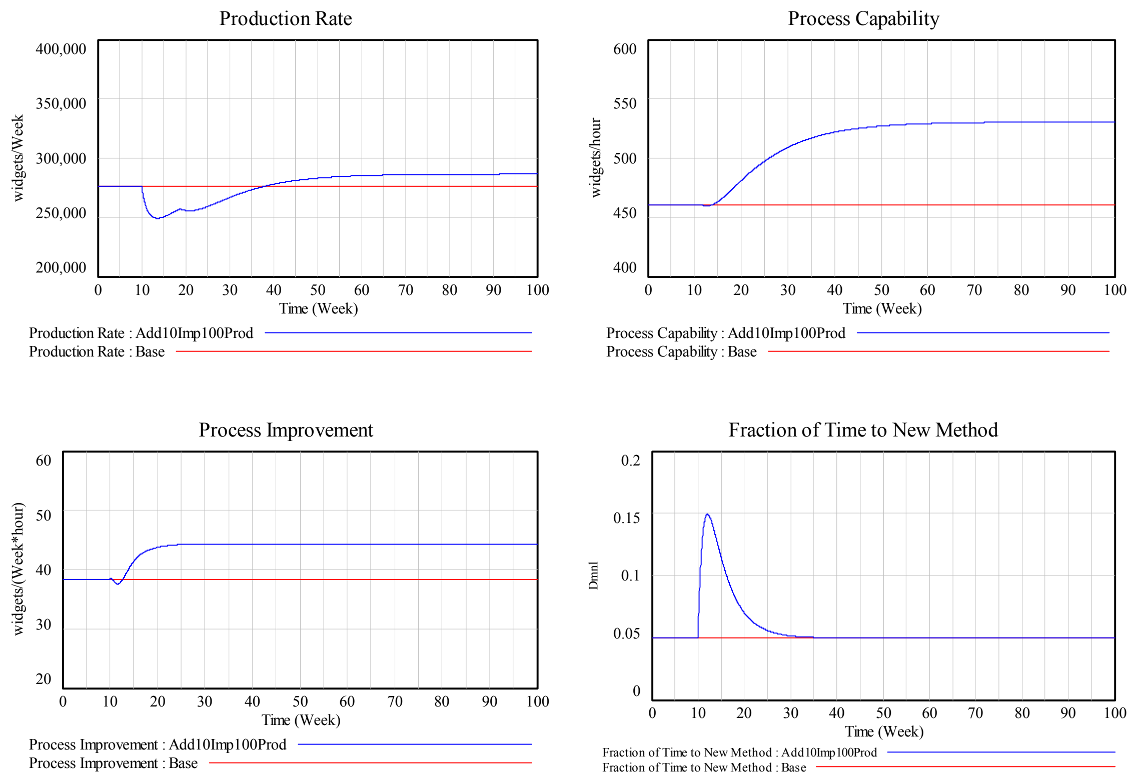


Figure 6 show the two simulations from Figure 5 (Scenarios 1 and 7) and adds one more simulation in which the only difference is the policy for project starts. In the new scenario (Scenario 8, shown in the green line) project starts are based on the learning orientation described above. Now, the system has made an enduring transition to a significantly higher level of performance. The production rate is permanently higher, supported by a high process capability maintained by ongoing process improvement at a much higher rate. The workers have fully adopted the new methods for improvement activity (see Fraction of Time to New Method) yielding higher productivity in their project work and enabling them to sustain the higher rate of process improvement required to maintain a higher process capability.

Figure 6: Response to Increasing Resources to Improvement with Learning-oriented Project Starts

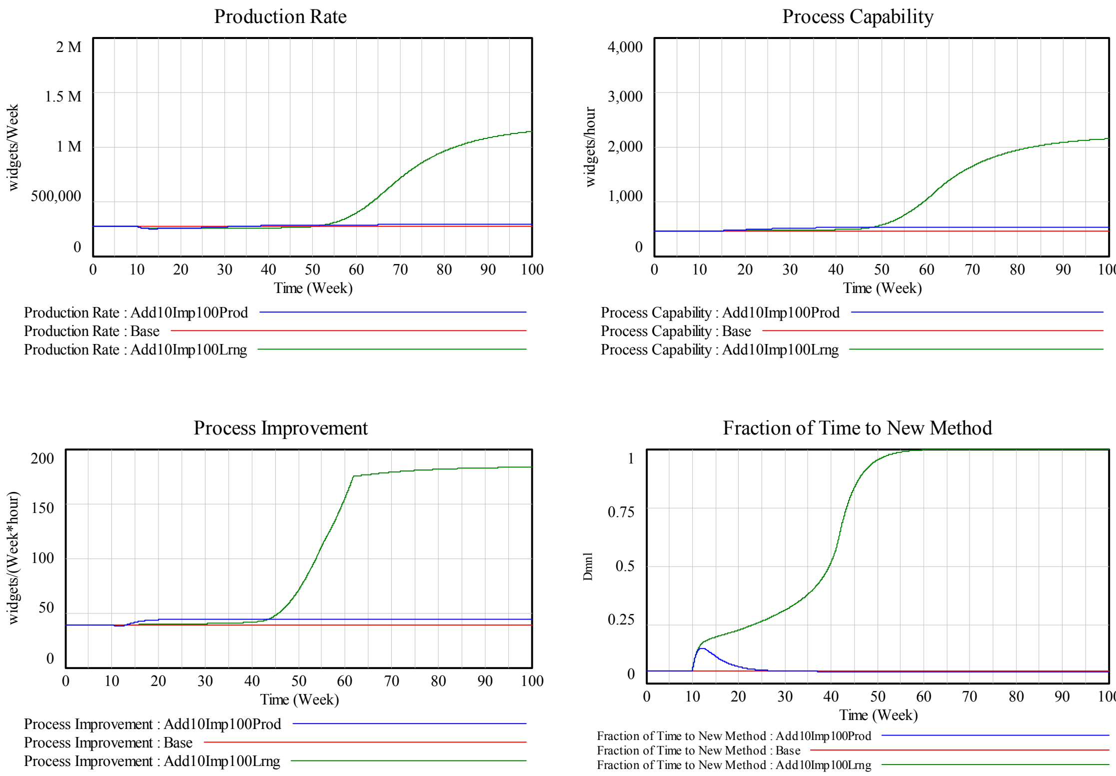
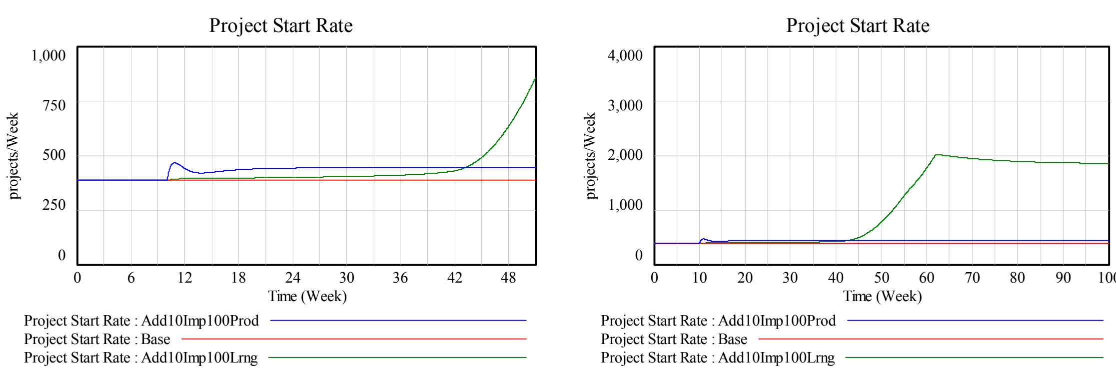


Figure 7 offers some insight into why there is such a dramatic difference. The left panel shows the project start rates for the first 50 weeks to allow for a closer look. The right panel shows the same for the entire simulation. When the extra resources to improvement are shifted in week 10, under the productivity orientation, project starts are immediately increased. The improvement workers face pressure to get their improvement work done, so they continue to rely on the old, proven methods for doing things. The result of this well-intended response from the improvement workers is that they do indeed get the work done, contributing more process improvement and building process capability, as shown in Figure 5. But, because they are pressured to get their projects done, they allocate very little of their time to learning the new methods. Conversely, under the learning orientation, the project start rate increases only modestly at first – and in particular less so than the amount by which the improvement resources increased. The effect is to encourage the improvement workers to use the new method, and they do just that as can be seen from the Fraction to Time New Method in Figure 6. They accumulate experience with the new method (filling the stock of experience in Figure 2), boosting their productivity and engaging the reinforcing learning by doing loop. The better they get at using the new methods, the less costly in terms of productivity it is to use the new methods, the greater proportion of their work they do with the new methods, and the more they learn and further increase their proficiency. The stock of experience fills enough to cross a tipping point, after which the new method becomes preferred, and the reinforcing loop propels the system to its new and more desirable state. The less aggressive project start rate policy has encouraged learning, and the system has transitioned to an enduring state of superior performance.

Figure 7: Comparison of Project Start Rate Policies



Recognizing that the stock of experience characterizes a tipping point is an important insight that has policy implications. The key to the successful transition to an enduringly superior process capability is to cross this tipping point. Once the workers have made this transition, the “extra” resources that were beneficially allocated to improvement in order to facilitate learning can now be more usefully applied to primary production activities. Fewer resources are required to sustain the process at higher levels of capability because the resources working on improvement activity are now far more productive, reaping the benefits of the accumulated experience. A policy that allocates resources to improvement first and until the system crosses the tipping point and then transfers resources back to production will yield even better quantitative results, as measured by cumulative production. Table 1 shows several scenarios (Scenarios 9 - 18) in which the policy invests in improvement activity early and then shifts the resources back to production. In Scenarios 14, 16, and 18, the system crosses the tipping point, because the early investment in improvement has been not just enough to do improvement but enough to foster learning sufficient to build the experience needed to sustain improvement productivity at high levels. The results of these three scenarios show performance even better than that in Scenario 8, as measured by cumulative production.

Taken together, the various simulations reported in Table 1 highlight several important features of the feedback structure of process improvement. First, this is indeed a policy resistant system. Despite the wide range of policy attempts in these simulations, including some extreme tests, the effect on overall performance for most of these is rather minimal. There are several balancing loops in this system that act in ways that provide strong policy resistance. Second, a small number of these policies, all using the learning orientation for project starts, achieve and sustain superior performance. The key in all of these scenarios is that the workers have had the opportunity to focus time on improvement activities using the new methods, building experience with the new methods, and thus increasing their productivity doing improvement. The learning orientation, with a slower project start rate, has put a bit less pressure on the improvement resources, and the result is an allocation of time that builds experience to such a level that the system passes a tipping point before the extra resources are reallocated back to production. Third, although there is no exogenous growth goal in the scenarios that achieve this superior performance, process capability and the production rate do indeed grow. This occurs because the reinforcing "learning by doing" loop propels the system to higher and higher levels of performance.

DISCUSSION

This paper examined the problem of allocating a fixed quantity of resources between the activity of producing output and the activity of conducting process improvement work in order to maximize the performance. We then used simulation analysis to highlight the dynamics of the tradeoff between production and improvement and demonstrated the existence of a tipping point that distinguishes enduring high levels of production from outcomes with modest or no improvement.

The simulations revealed that slowing down the rate of starting improvement projects leads to better performance. This somewhat surprising result highlights two important features of the dynamics of this system. At least in part because the workers are assumed to adjust their allocation to yield to the pressure to achieve the desired project completion rate, the consequence of overstretching resources will be seen in the long-run in the steady-state mix of work practices in process improvement. Second, important and interesting dynamics in this system are found in the stock and flow structure of the stock of Experience with the New Methods. This observation suggests what may be an important re-conceptualization of the managerial objective. Rather than focusing on achieving the highest possible output or rate of process improvement, managers should focus on building experience to get past the tipping point. Such a re-conceptualization underscores the need for further study of the qualitative and perhaps even more importantly quantitative characteristics of the increase and decrease of process capability and the rates of learning and forgetting of new methods. Another important implication for practicing managers is to develop and monitor signals or specific metrics that can bring better visibility of the state and rate of change of the important stock of experience.

These results also provide some insight into the study of implementation failure (Klein and Sorra 1996). Scholars of this problem note that the track record of process improvement initiatives is an inconsistent one. On the one hand, there is ample evidence that these initiatives are sometimes successful in yielding improvements in organizational performance. But, on the other hand, many efforts fail to yield the desired benefit, often exhibiting a pattern of short-lived improvement followed by a decline in performance to levels at or below those before the improvement initiative began. The reasons that many organizations face difficulties in implementing what they know to be good ideas remain at best poorly understood. Explanations range from superficial implementation (Anderson, Rungtusanatham et al. 1994) and mismatched cultures (Detert, Schroeder et al. 2000) to excessive bureaucracy (Hackman and Wegeman 1995), excessive rhetoric, and insufficient substance (Zbaracki 1998). The results shown here suggest that critical interactions within the work of process improvement, rooted in the need to gain experience with new methods through learning by doing, are key to another explanation. Managerial policies that overemphasize accomplishing the primary work of improvement at the expense of learning new methods may unwittingly squeeze out the possibility of successfully transitioning past the critical tipping point in learning-based process improvement.

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