The Efficiency Trap and the Role of Learning by Doing in Process Improvement Dynamics

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Abstract
The paper develops a system dynamics model of process improvement when the same workers do both production and improvement work. The productivity of improvement work grows with worker experience. Results show managerial policies emphasizing efficiency are unlikely to yield lasting benefits, while policies that foster learning yield sustained superior performance.

Keywords: process improvement, learning, system dynnamics

Introduction
A wide range of approaches to process improvement aimed at improving cost, cycle times, quality, flexibility, or throughput call on front-line employees to engage not only in the production and delivery of the goods and services that a firm sells but also in activities to build the organization's capabilities by improving core business processes. Because the same personnel do both the primary production activity and the implementation of improvements, managers must make decisions about the allocation of resources to these activities. 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. Despite the widespread occurrence of this resource-constrained problem in practice, the problem has received limited attention from scholars of process improvement.

Previous Literature
The more general resource allocation decision has attracted a considerable amount of scholarly attention, especially in the literature on quality improvement. One view aspires to achieve zero defects, implying that more improvement is always better (Crosby, 1979;

Deming, 1982). Another view examines economic trade-offs to determine the optimal level of investment in process (or quality) improvement (Carrillo and Gaimon, 2000; Fine, 1986; Li and Rajagopalan, 1998), implicitly assuming that resources are available to scale up to optimal levels. However, other studies take a closer-in look at process improvement and find that resources are shared between production and improvement activities, characterized as first-order improvements (working harder) and second-order improvements (working smarter) (Repenning and Sterman, 2002). Morrison (2012) takes a more micro view and formalizes the critical interactions between first- and second-order improvement (Morrison, 2012). Under conditions of constrained resources, the interconnection between these useful activities is inescapable. Allocating available resources to production and improvement, not choosing the overall level of resources, characterizes the challenge facing managers implementing 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 output and investing resources in process improvement to increase throughput. The model incorporates learning: 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 in a system facing the dual pressure to produce output and to build capability.

A Model of Production and Process Improvement

Consider a stylized firm that manufactures widgets, aims to maximize the rate of production, has an option to do process improvement, and has a fixed quantity of labor to allocate between producing widgets and doing 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 for the improvement projects, but they may choose to rely on old habits that are potentially more productive in the short-run. The manager allocates 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 master the new methods if they gain experience through their project work, a form of learning by doing.

Figure 1 shows the stock and flow and feedback structure of the model. A full description of the model and complete listing of model equations is available from the author in a technical appendix.

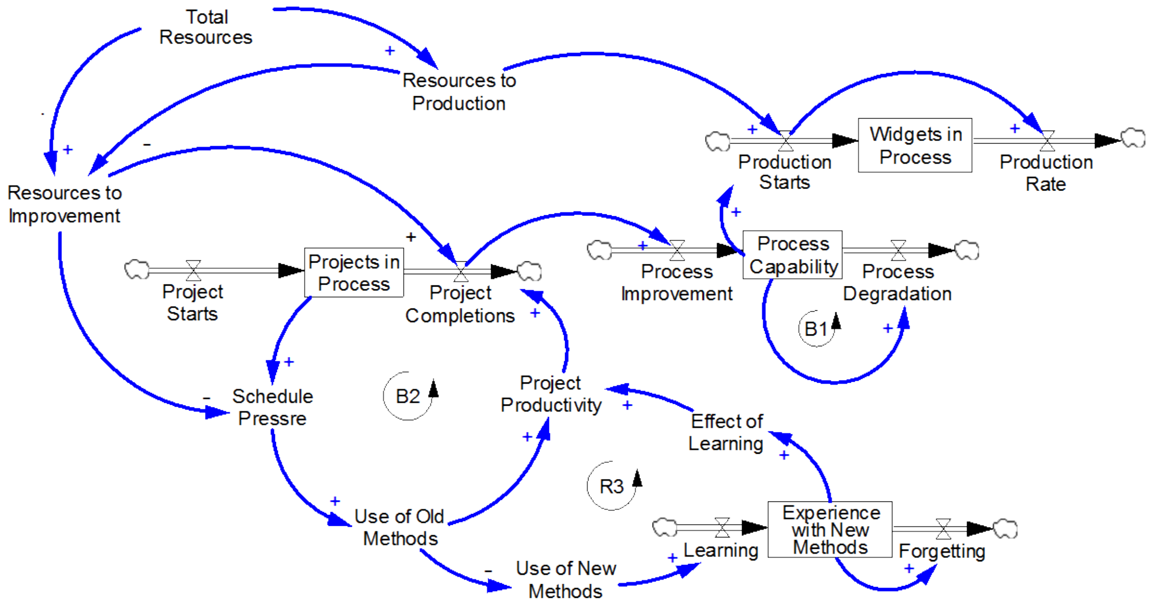

Figure 1: A model of the work of production and process improvement

Model Behavior and Policy Analysis

This section reports simulation analyses that investigate the dynamic behavior of the stylized production system. Space does not permit display of graphical output, but key features are described in this section. Table 1 summarizes a series of simulations the test the system's response to managerial policies characterized by two choices: the allocation of resources and the targeted rate of process improvement. The allocation of resources between production and improvement is implemented by changes in the quantity of resources allocated to production. The remainder of the available resources is allocated to improvement activities. The second managerial choice is the policy rule for the project start rate, for which we test three policies. One policy option, labeled here "constant starts," is to hold the project start rate constant at its initial value. 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 "efficiency orientation," adjusts the rate of project starts to the feasible rate of project completions estimated from the quantity and productivity of resources to improvement. This policy assigns project work consistent with the goal to keep the improvement resources fully productive with ideas for implementation. 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, this is the minimum rate of project completions that this will forestall a decline in process capability.

Table 1 reports Cumulative Production, the sum of the production rate over the 100 simulated weeks, for simulations in which a change in indicated resources allocated to production and a policy for project starts (constant starts, efficiency orientation, or learning orientation) are introduced at week 10. A base run (Scenario 1) in which resources are kept at their initial values is used for comparison. When the resources to production are increased by 10% beginning in week 10 for a period of 20 weeks

(Scenario 2), this causes a reduction in resources to improvement for the same period. For a short period, the extra production resources produce more widgets, but the shift causes a decrease in improvement projects completed. Consequently, process improvement declines below the rate required to maintain 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 reverts to its original mix the production rate falls sharply, because the extra resources to production are taken away but process capability has deteriorated. The increase in improvement activity eventually exceeds process degradation and thus restores process capability. Three other scenarios (3, 4, and 5) include an increase in resources to production. The dynamics are substantially the same: increasing resources to production starves the essential improvement activity, so these results are hardly surprising. The last 13 simulations shift resources in the other direction: by decreasing the allocation to production, the resources to improvement are increased. When this shift is accompanied by constant starts or an efficiency orientation policy, there is no overall improvement in cumulative production. The dynamics of the production rate, most salient to the manager, exhibit a classic pattern of worse before better, but (as can be seen in the simulation output, not shown here) there has been no fundamental change in the method of doing improvement.

The simulations with the learning orientation (Scenarios 8, 14, 16 and 18) display a fundamentally different pattern of behavior. The system makes 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 (as seen in the Fraction of Time to New Method output graphs) 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.

Why is there such a dramatic difference? When the extra resources to improvement are shifted under the efficiency orientation, project starts are increased, forcing workers 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. 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. They accumulate experience with the new method 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

Table 1: Summary of Simulation Results

Scenario		**Resource Allocation Policy**		**Improvement Policy**	**Cumulative Production**
		Fractional Change in Resources to Production	**Duration of Change in Resources (weeks)**		
1	Base Run	0	0	Constant starts	27.64
2	Increase Prod'n Res	+10%	20	Constant starts	27.60
3		+100%	20	Constant starts	18.31
4		+10	20	Efficiency orientation	27.01
5		+10	20	Learning orientation	26.30
6	Increase Imprvmnt Res	-10%	100	Constant starts	25.55
7		-10%	100	Efficiency orientation	26.73
8		**-10%**	**100**	**Learning orientation**	**51.39**
9		-10%	20	Constant starts	26.93
10		-10%	20	Efficiency orientation	27.32
11		-10%	20	Learning orientation	27.16
12		-10%	50	Constant starts	26.51
13		-10%	50	Efficiency orientation	27.15
14		**-10%**	**50**	**Learning orientation**	**51.38**
15		-20%	20	Efficiency orientation	27.31
16		**-20%**	**20**	**Learning orientation**	**63.73**
17		-30%	10	Learning orientation	27.31
18		**-50%**	**10**	**Learning orientation**	**70.69**

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.

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.

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. 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. 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). Explanations range from superficial implementation (Anderson, Rungtusanatham, and Schroeder, 1994) and mismatched cultures (Detert, Schroeder, and Muriel, 2000) to excessive bureaucracy (Hackman and Wegeman, 1995), excessive rhetoric, and insufficient substance (Zbaracki, 1998), but the phenomenon is at best poorly understood (Pfeffer and Sutton, 2000). 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 and focus on efficiency 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. Understanding the links between primary production capability and learning-oriented activities that build capability to sustain ongoing improvement holds great promise to inform theory and practice of process improvement.

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