Analyzing the Conflict between Production and Manufacturing Engineering: A System Dynamics Model

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Abstract

Based on an in-depth field study in an electronics plant in Singapore, this paper examines the dynamic interaction between two of the key functions, Production (P) and Manufacturing Engineering (ME). P and ME are responsible for process execution and process development respectively, and for process smoothness jointly; their relationship is asymmetrical if judged from organizational and structural aspects. The paper reveals the causes and effects of three types of short-sighted functional behavior – burden-shifting, resource-fighting, and corner-cutting. The resulting P-ME conflict and some practical approaches for conflict resolution are reported and analyzed in a qualitative system dynamics model. Although this research is based on a single firm, the findings have implications for many contemporary plants where the proliferation of new processes puts stress on the P-ME interface. Future researchers can use more samples to test and theorize the findings of this research.

Keywords

conflict, case study, causal loop diagram, manufacturing engineering, production, process development, process execution, short-sighted behavior

1. INTRODUCTION

Production (P) is a practical implementation function responsible for generating throughput by utilizing the production process, and Manufacturing Engineering (ME) is a technical function, responsible for designing new production processes and solving difficult process problems. Process development translates a product design into the technical knowledge, organisational capabilities, and operating processes needed to create the product and the output is a new or improved production process (Pisano, 1996, p33).

As ME focuses on changing the production line through new or improved processes, P focuses on production output. They both share responsibility of process smoothness and may fight for some shared process resources. Furthermore, difficulties for process development are exacerbated by its position between product design and process execution. The resultant ‘squeeze’ results in very short process development cycle times, made worse by the proliferation of new products. Hence, the causes for departmental tensions (and potential conflicts) as summarized by Rahim (2001, pp170-175) – system differentiation, task interdependence, dependence on scare resources, jurisdictional ambiguity, and line-staff relationship and asymmetrical interdependence – indeed exist for the interface between P and ME.

High tensions are often accompanied with some short-sighted behaviors by one or both parties (Dalton, 1959; Walson & Dutton, 1969; Repenning & Sterman, 2000, 2001 and 2002; Delbridge, 2000). This paper explores the technical and operational issues related to some typical short-sighted behaviors in the interaction between P and ME, and the resulting conflicts. Research methodology and research context including the focused plant and its process and organization are introduced in Section 2. Based on the discussion on organizational sources in Section 3, some typical types of short-sighted behaviors are explored in Section 4. The result conflict is modeled and analyzed in the language of qualitative system dynamics – causal loop diagram – in Section 5. Finally, managerial implications and future research direction are given.

2. RESEARCH METHODOLOGY AND CONTEXT

The research is based on an in-depth case study and relies on theoretical sampling rather than statistical sampling (Glaser and Strauss 1967; Eisenhardt 1989). A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context (Yin, 1994) and it is especially useful for the exploratory investigation of complex phenomena in their natural setting, with a resultant good understanding of the context (Meredith, 1998). Repenning and Sterman (2002) gives a good example of analysing an integrated organizational and operational issue using case data and qualitative system dynamics model, and thus provides a suitable method and procedure for this research to follow. The research site is an American electronics plant located in Singapore (renamed AES for anonymity). AES specializes in Printed Circuit Board Assembly (PCBA). The researcher conducted about 200-hour formal/informal interviews with relevant people and made more than 400-hour passive observations. Besides the research’s strong engineering background helped understand the details of the manufacturing process and technologies in the particular case. (Prior to this project, the researcher had been an engineer in a factory environment for several years.) The unit of analysis is group behavior rather than individual behavior. The data collected from process engineering manager, test engineering manager, process engineers, and test engineers represent ME, and the data from production manager, production superintendent, production supervisors and some line leaders represent P.

AES was established in Singapore in the mid 1980s as the manufacturing base of an American company, whose head office (HO) and product design center remained in the United States. The practice of decoupling product design and process development is common in industries such as automobile assembly (Fujimoto, 1993), as well as the PCBA industry, where both mechanical drawings and electronic specifications can be transferred. Like most PCBA plants, AES has the following functions on site: P, ME, quality control/assurance, warehousing/shipping, purchasing, planning, accounting and human resources. Since its inception, AES was recognized by its customers as producing sophisticated products with a high degree of quality and responsiveness. The product proliferation triggered by Japanese appliances companies resulted in increased variety and complexity in the manufacturing process and increased frequencies and speeds in process changeovers. The demanding market required AES to concurrently raise the bar in all operational dimensions and in turn potentially caused increased tensions between P and ME.

The PCBA process is as follows: material preparation > re-flow for surface-mounted devices > automatic insertion for through-hole components > manual insertion for special components > wave-soldering > manual touch up > In-circuit Test > final assembly > functional testing > outgoing quality checks > finished goods audit. Some products require two different functional tests (before and after final assembly) and some products require a burn-in test. There are two types of elements in the process flow – standard and product-specific. In the front-line (down to ICT), the hardware is standard and is available on the commercial market, but the software and jigs vary from product to product. In the back-line, both hardware and software are product-specific, as the assembly patterns and the electronic features are highly variable. Product-specific elements are custom-built by ME. Introduction of a new process is complicated because of the high number of product-specific elements required.

Among the 250 people in P, there were three four-year university degree holders – one manager, one assistant manager, and one supervisor. Twelve others had three-year polytechnic diplomas, whereas the rest – mostly production operators – had generally started work immediately after high school. All ME members of AES, thirty-four in total, had diplomas, undergraduate degrees or masters of electronic (or mechanical) engineering. ME in AES was split into two groups – test engineering and process engineering. Test engineering handled testing processes, while process engineering handled the else. ME engineers were expected to work late to solve major process problems whenever they occurred.

3. THE STRUCTURAL FACTORS FOR POTENTIAL CONFLICTS

The overlapped responsibilities and the asymmetrical relationship between P and ME are structural factors that may result in departmental tensions and short-sighted behaviors.

3.1 The Overlapped Responsibilities

The strategy and set-up of functions within AES suggest that P and ME valued different things. P valued stability, because change inconvenienced them and had an impact on their production goals. The throughput number was P’s key measure of performance. This is underlined by the most common question directed to the production manager during production meetings, which was, “Can you ship this today?” In contrast, ME valued change (new set-ups or improvements), because that is what they were charged with. ME had two major responsibilities – process development and process improvement. A frequent question directed to the ME manager during production meetings was, “Why can’t we automate it?”

At the same time, ME was, like P, responsible for the process smoothness of existing lines. ME members in AES were involved in both process development projects, as well as daily process problem-solving. The rationale behind this practice was: 1) no process was stable immediately after development, so the developer had to stay involved, and 2) the experience gained from line support could help “design for manufacturing” in future projects. So there was some overlap between P’s and ME’s objectives.

Process smoothness was a critical measure of line control and shows the degree of variation when materials flow through the process. Reject piling, job rushing, line slowing, machine break-downs, and extra work-in-process are signs of poor process smoothness. A common question to both P and ME staff at production meetings was, “Is the setting correct? Are we doing it properly? Why is it still unstable?” Conceptually speaking, process smoothness is a process state in which process variations are all within control limits. Safayeni and Purdy (1991) use the concept of process smoothness with a similar meaning in a case study conducted in a PCBA plant and conclude that, in order to implement JIT successfully, plant management needs to develop some new variety-handling mechanisms to replace inventories for “absorbing” process variations. While both P and ME had some responsibility to keep the process smooth, the general rule in AES was that P handled technically simple tasks, whereas ME handled technically difficult tasks. Technically difficult tasks referred to the diagnosis of hard process faults or product rejects and the handling of complicated process changeovers. Normally, P was accountable for mistakes in operations, while ME was responsible for improperly developed hardware, software or physical fixtures.

Process smoothness problems in the plant were sometimes easily solved, but at other times major effort was required over a long period of time. Sometimes this major effort resulted in the automation of a previously manual operation. Here is an example: The product Luna (a control board for a commercial washing machine) had a large Vacuum Fluorescent Display (VFD) panel mounted. When it was first produced, continuous rejects from customers became a major headache. The functional test included the testing of a long series of rapid flashing lights, which was too hard for a test operator to capture. The cost of quality was high enough for plant management to invest in a test development project developing a “vision” tester, which made use of digital camera and a signal processing system. Ashby’s Law of Requisite Variety (1956) states that to control a complex system, the controlling system must generate at least as much variety as the system being controlled. In this case, process variety is absorbed in the process developed by ME, or, the duty of handling process variety is shifted from P to ME.

3.2 The Asymmetrical Relationship

Three empirical evidences observed in AES demonstrated the asymmetrical relationship between P and ME in terms of political power and control over resources. They are throughput as a precedent performance measure over others, line-staff perception and the short-term view, and P’s control of shared process resources.

3.2.1 Throughput as a precedent performance measure over others

In AES, on-time delivery was the top priority of manufacturing because the throughput number was the most tangible manufacturing outcome. Whenever there was a problem in throughput, managerial attention and resource allocation favored P. The plant focused all available resources – manpower and machine time – to get the required number out the door. As a result, process development projects were moved to the back of the queue. As Repenning and Sterman (2001) find, in many manufacturing operations, long-term activities (e.g. working smarter by process improvement) usually yield to short-term activities (e.g. working harder by process execution).

3.2.2 Line-staff perception and the short-term view

With throughput as the main production goal, manufacturing management generally regard P as a primary activity (a line function), with ME as a secondary activity (a support or staff function). In his case study, Dalton (1959) reported that one major issue in the plant was that, while the staff group had to understand the problems of the line groups and get along with the line people in order to promote their ideas, none of these were reciprocal requirements imposed on the line groups. In the case of P and ME, this would mean that the success of ME depended on the acceptance of their ideas by P, but not vice versa. Although this line-staff mentality has changed over the years (Jaikumar, 1986), the traditional line-staff mentality of P taking precedence over ME appeared in AES on a regular basis, whenever throughput pressure was on. A common request in production meetings whenever throughput was in trouble was, “Can someone in ME help fix the problem?”

3.2.2 P’s control of shared process resources

Due to the nature of process execution, P usually had control over the use of process resources such as machines and testers. Because such process resources were also necessary for ME to do experiments and debugging for their process development function, ME’s performance relied heavily on P’s willingness to release enough resources.

4. SHORT-SIGHTED BEHAVIORS AND THEIR IMPACTS

From the previous section and two derived empirical findings, it is apparent that P and ME are interdependent, with both differences and commonalities. While ME strives to come up with complex technical ideas in its process development and improvement role, it then has to rely on P to develop, experiment and improve the process, as P has control of process resources. Likewise, although P is in charge of throughput, it has to rely on ME to solve difficult process problems. P and ME are also linked because together they are responsible for process smoothness, and because they share the same process resources. These shared yet competing elements led to tensions in the P-ME relationship. In fact, P and ME had almost all the typical sources of conflict – system differentiation, task interdependence, dependence on scare resources, jurisdictional ambiguity, and line-staff relationship and asymmetrical interdependence as summarized by Rahim (2001, pp170-175).

Signs of conflict between the two functions were readily apparent at AES. People from P and ME argued regularly at the weekly quality meetings and P and ME managers tried to push problems on to each other in the daily production meeting. In one particularly vicious incident, a production supervisor abused an ME engineer in front of many production operators for not showing the "right attitude" in recovering a workstation breakdown which shut down the line for a few hours. As one production supervisor said in an informal meeting:

> We know they [ME engineers] are unhappy. However, we are not loading them more. We just push for more and better engineering support, especially in set-ups. A few years ago, when we only ran eleven high-volume models with stable flows, we seldom called on engineering for help. But now it is different. We have more than fifty models, too many set-ups, too many problems, it's too complex…. They can't just hide in the lab.

The conflicts developed between P and ME at AES were accompanied with short-sighted behaviors by both parties. These are summarized in Table 1 below, and explained in detail after.

Table 1. Conflict Types and Short-sighted Behaviors

Conflict Level	*Types of Conflicts*	*P's Short-sighted Behaviors*	*ME's Short-sighted Behaviors*
1	Burden-shifting	Pushing technically simple problems to ME	Unwillingness to resolve technically difficult problems
2	Fighting for Resources	Unwillingness to release process resources	Utilizing unnecessary process resources
3	Corner-cutting	Ad-hoc changes of process parameters	Playing safe in setting process parameters

4.1 "Burden shifting" Behavior

At AES, both P and ME practiced burden-shifting behavior. Burden-shifting refers to pushing responsibility onto another group, or pulling in extra resources from another group, while that other group has to carry an extra load in order to attain a common goal. In AES, ME handled technically difficult tasks, whereas P handled technically simple tasks, for the same goal – process smoothness. But there was often no clear line between "technically difficult" and "technically simple" tasks. In AES, task ambiguity was seen in many activities such as process changeovers and set-ups, handling newly developed processes, handling unforeseen process variations and repairing defective products. From P's point of view, any unstable operations are technically difficult and ME should get involved in process improvement.

One ME engineer claimed:

> In normal situations, we all know how to cooperate. The problem is that when the production is under pressure, we engineering people are forced to do all kinds of

> jobs, set-ups, repairs, and solve many funny [unexpected and unusual] problems. If we are loaded up with both simple and difficult jobs, who is going to do the development job?

The same situation viewed from one P supervisor's perspective:

> The problem is more than just clarifying simple and difficult problems in set-ups or troubleshooting. You might say: I have a written procedure for the job, so the job is simple and production just needs to follow the procedure. When you set up a complex machine, if everything is normal, it is fine; but if it is not normal, then there are too many possible causes, which is not simple at all. … It is beyond [what] our operators can handle.

Process changeovers were especially complicated during the introduction period of a newly developed process. In several instances at AES, P staff tried to switch some new processes, but made things worse. As one quality supervisor said in a quality meeting:

> We have many procedures for process execution, but not enough procedures for changing processes. We need the procedures for changeovers that can be used to guide our operators step by step in a simple manner, but engineering says it is not as easy as we think.

A process engineer responded:

> Not all the changeover steps and procedures can be documented. There are fifty models, and at least twenty processes [process steps] for each model. There are too many transit states for the possible changeovers between any two models. We have to spend a lot more time to help set-ups. We have much less time for design.

Repairing defective products is another area that showed task ambiguity. Delbridge (2000) reports "a debate over who did what rework" (p60) between "finals" and "panel shop" in a PCBA process. ("Finals" in Delbridge's case is equivalent to "final assembly" in AES, and "panel shop" is equivalent to "insertion and soldering".) In AES, the general rule was that ICT repair was an assignment of P, and FT repair was an assignment of ME. The faults on the rejected boards from in-circuit test (ICT) were simple and clearly indicated. Assigning the ICT rework to P was also a way to make P responsible for, and quickly act on obvious process problems that were reflected in the ICT rejects. Diagnosing the rejected boards from functional testers (FT) and finished goods audit (FGA) stations was hard because sound knowledge of electronic functionality was required. However, in the fieldwork, it was noticed that P frequently sent some ICT rejects to ME by declaring them "hard rejects". According to a ME engineer, it was reasonable if P occasionally seek technical help from ME, but it was "bad" if P took it for granted and even pushed away simple ICT rejects.

In most cases, the burden-shifting behavior at AES tended to go in one direction, from P to ME. That is, P found it easier to claim ignorance about the technical aspects of an activity than ME was able to claim that the activity was simple. ME often had no choice but to allocate more resources for daily process problems to help maintain the shared performance measure of process smoothness. This left ME with fewer resources for process development and postponed ME's development projects.

Occasionally, ME staff refused to do technically difficult jobs when they were busy on development projects, and claimed that P operators “could easily learn how to do it”. But this burden shifting strategy was ineffective, because if P made a mistake and could not do the job, the problems again became ME’s responsibility. Thus burden-shifting behaviors continued in mostly one direction, from P to ME, because, while ME could do P’s job, P could not do ME’s job.

The above discussion gives rise to the following empirical finding:
Empirical Finding 1: Because of imbalance in functional capability, the different and common responsibilities and the asymmetrical political power, there is a tendency for P and ME to conduct “burden-shifting” behaviors for ambiguous tasks and most such behaviors are conducted by P.

4.2 “Fighting for Resources” Behavior

A second short-sighted behavior that was common at the P-ME interface in AES was fighting for resources. P and ME shared process resources such as machines and machine time. While P used the resources for process execution, it received technical support from ME, and in return provided the access to the same resources for process development. However, as the PBCA market changed and the plant entered what was termed earlier the “changeover game”, P became less flexible about sharing resources for process development. As one production supervisor said:

> What I see is that my people need to do more switchovers. We run too many models each month…. More switchovers mean more time wasted and more mistakes. More mistakes mean more reworks and re-runs. But I still have to meet the [throughput] target. My operators need to run faster …. The boss won’t invest in new machines and testers, because the boss wants high utilization. Who knows whether the high demand will last. … The issue [shortage of process resources] has become more serious.

The view described above highlights the chain of reaction that was driven by the marketplace: more models and smaller batches, more frequent process changeovers, more time “wasted” in process changeovers, fewer process resources available, less productive production time, the need to run faster and longer to meet throughput targets, more mistakes in process execution (more process problems and defective products), and rework that takes up more human and process time. All in all, there was more pressure on production.

A more detailed look at the issues adds the following factors that increased uncertainty in utilizing process resources:

(1) Available process resources changed constantly due to changes in production planning and implementation.
(2) Execution time on a newly developed process was often longer than what would become the status quo, and was difficult to estimate.
(3) The amount of process resource needed by ME for experiments and debugs was not fixed and was hard to predict.

These uncertainties, coupled with the greater production pressure, necessitated ongoing negotiations between P and ME for the allocation of process resources.

As Walson and Dutton (1969) observe, when two units depend upon a common pool of scarce organizational resources, the competition for resources tends to decrease inter-unit problem-solving and coordination. The process engineering manager said:

> My engineers have been tied up with so many new models. But before the production run, they are not given enough machine time to carry out experiments. My engineers told me the machine time given [by P] …and used for process development is much less, not to mention that we are handling more models with more model parameters to set.

When process resources became scarce, P tended to ignore ME's requests. Because P precedes ME in controlling the process resources, ME had little comeback on the issue and became very frustrated. To counteract the problem, ME played a "shortage game" when it negotiated with P, using ME's greater power in technological judgment to request more than it needed.

The shortage of machine time available to set process parameters adversely affected the quality of developing new processes; which, in turn, gave rise to extra process problems, defective products, and the uneconomical use of machines in process execution. As a result, there was an increasing pressure on the process resources and increasing tendency to take short-sighted behaviors in order to claim more of the scarce resources between them.

Empirical Finding 2:
2.1 When there is a shortage in resources, because of P's having more control over resources and resource utilization uncertainties, there is a tendency towards P being unwilling to release process resources to ME;
2.2 Because of Empirical Finding 2.1 and ME's control in technical judgment, there is a tendency for ME to request more than it needs.

4.3 "Corner-Cutting" Behavior

A third type of short-sighted behavior that takes place on factory floors is cutting corners. This type of behavior has been well documented by a number of authors (Dalton, 1959; Lu et al, 1999; Repenning and Sterman, 2000 and 2001; Delbridge, 2000; Oliva & Sterman, 2001). (Oliva & Sterman (2001) provide some evidence of corner cutting in service operations.) Repenning and Sterman (2000) explain this behavior as a result of increased production pressure and control. Workers caught between high throughput goals and the need to comply with stricter rules cut corners and play games with numbers in order to appear to meet all their objectives. They keep these ways of cheating the system secret from management. When management notices poorer quality or that the numbers don't match the actual output and put tighter controls around the 'lazy' workers, the resulting defensive behavior triggers more corner-cutting, such as an unwillingness to do preventive maintenance or the keeping of secret inventories. Repenning and Sterman (2001) sum up that increased throughput is associated with a departure from standard routines and processes, cutting corners, and a reduction in the time spent on learning and improvement. Dalton (1959) comments that line personnel justify cutting corners with the rationale that they can be more effective by flexible reinterpretation of control and incentive schemes, and by ignoring many discipline and safety issues. Delbridge (2000) observes, "To meet the efficiency figures she [a team leader] must constantly look to increase the linespeed and keep people operating as fast as they are able. Consequently she is regularly scrutinising the line, looking for opportunities to increase the speed of the line so that she can keep on schedule and make her targets." (P55-56)

In line with the literature, there was evidence of corner-cutting at AES, especially during times of radical targets – for instance, in a period when AES struggled to halve its total manufacturing cycle time:

> (1) In a weekly quality meeting, a process engineer accused a production supervisor of increasing the speed of the wave-soldering machine regardless of the technical specifications.
>
> (2) In another weekly quality meeting, a test engineer pointed out that a test operator skipped some testing steps clearly specified in the functional test procedure.
>
> (3) On one occasion, the managing director of AES walked around the factory floor and told the production manager to speed up the line. He implied that his "years of experience" gave him a "gut feel" for what speed range was appropriate for the particular model.

On the surface, these corner-cutting behaviors were mostly observed on the production line. However, in response to criticism, the P superintendent had this to say:

> In many cases, the engineers just set a very slow speed to play safe. Some new engineers just copy the old procedures. If you don't believe me, you should look at the wave-soldering speeds in the manual book – Jupiter is the same as Orion. How can that be? Orion is much simpler than Jupiter. Furthermore, the speed should be adjusted over time. We have been running Orion for three years. Now that we know this model so well, we can run it faster.

The response from the ME manager was:

> It sounds like my engineers have not studied the wave-soldering properly. I have to say something for them. If they are not given enough time [to develop a new process], how can we expect them to find out the optimal setting for wave-soldering? You have your targets to meet and we have ours, but if you cut our machine time, we will certainly miss our targets. That is one of the reasons our engineers set a safe speed. But you cannot use this as an excuse to set any speed you like. You can adjust the number of workers [attached to the line], but the machine speed must follow the procedure. That is the spec.

Despite the ME manager's justification, ME staff did cut corners. Sometimes the process developed by ME was too "safe" in terms of process parameters, as a quick way of getting the new development job completed, but which undermined the optimization of process settings. Engineers blamed this response on resource shortages because of P's "burden-shifting" behaviors – loading ME with more problem-solving jobs or, P's "unwillingness to release resources to ME", as well as other engineering resource shortages. As a result, ME's quick-fix corner-cutting gave P an excuse to cut corners in response, by ignoring the specification and speeding up machines to whatever speed they felt was appropriate. Some experienced P staff believed that experience was a better predictor than the scientific experiment done by engineers, which is just one-sided argument in the famous debate about whether production is a science or an art. Although this argument was sometimes true, this attitude did nothing but increase the corner-cutting behaviors undertaken by both parties.

A detailed examination at AES revealed that corner-cutting activities brought serious consequences, such as the faster deterioration of process equipment, unusually complicated defective products, and more human mistakes in the manual processes when machines such as wave soldering, were sped up too much. On the surface, P was hit harder by the cycle of corner-cutting that went on at AES: there were more rejects and process breakdowns reported in the daily production meetings. However, because difficult problems were ME's responsibility and P has more control in the short-term issues, ME generally found that it was charged with solving the problems that came out of corner-cutting. Furthermore, through burden shifting by P, even simpler problems caused by corner-cutting might be given to ME to solve. Thus, corner-cutting behaviors actually hit ME harder than P. Empirical Finding 3 summarizes the above discussion and shows how behaviors from the two functions reinforce each other.

Empirical Finding 3:
3.1 Under high throughput pressure, there is a tendency for P to cut corners.
3.2 When there is a shortage of resources due to Empirical Finding 1 (burden shifting) and Empirical Finding 2 (resources fighting), there is a tendency for ME to cut corners.
3.3 Corner-cutting activities hit ME harder because handling the resulting process problems can become ME's responsibility due to the responsibilities of and asymmetrical relationship between ME and P, and Empirical Finding 1 ((burden shifting).

5. MODELING AND DISCUSSION

5.1 Modeling the P-ME Conflict

A causal loop diagram (Figure 1) is used to model the dynamics of the P-ME conflicts at AES that result from the short-sighted behavior described in the previous sections. Causal loop diagrams are useful for integrating different types of variables into one system (Sterman, 2000). Repenning and Sterman (2000 and 2001) use the causal loop diagram as a tool to analyze some physical and behavioral factors related to process improvement.

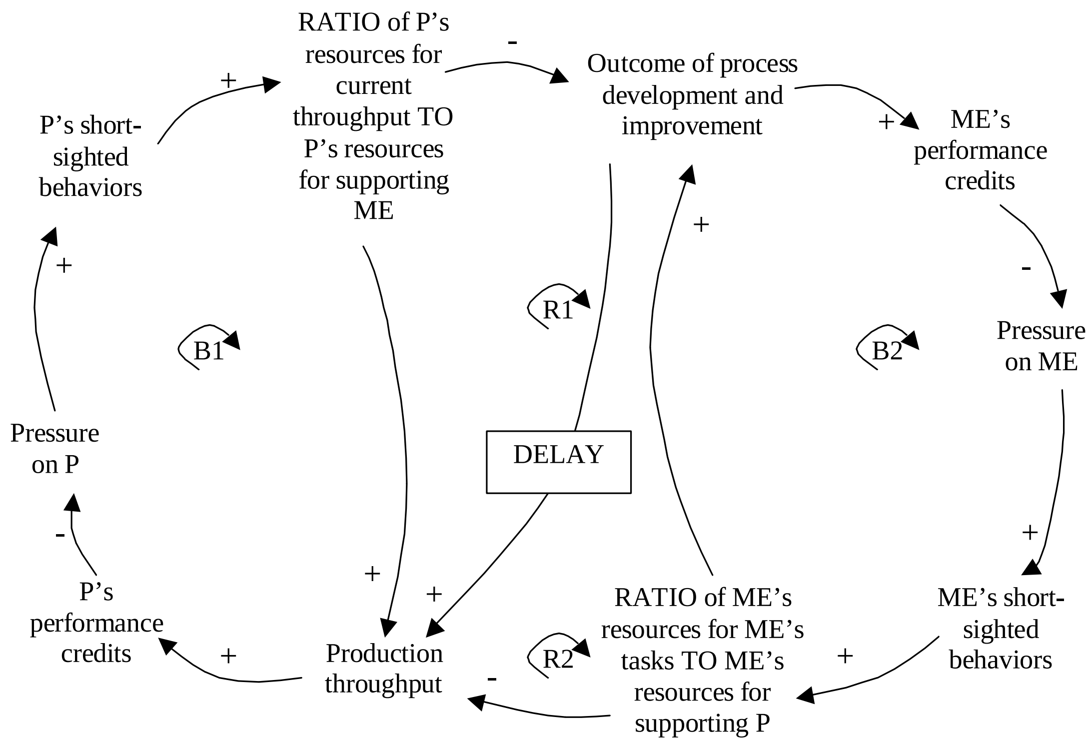

Figure 1. The Conflict Model

Notes: A positive link in the loop means that if the cause increases, the effect increases above what it would otherwise have been; a negative link means that if the cause decreases, the effect decreases below what it would otherwise have been (Sterman, 2000, p139).

There are four loops in Figure 1. Loop 1 (B1, a balancing loop, labeled as "P's Short-term") encompasses 5 variables. The throughput gap and resultant pressure trigger P's short-sighted behaviors which relatively increase the resources allocated to boost the current throughput number but reduce the resources allocated to support ME's necessary development/improvement (or, an increase of the ratio). This is a quick and short-term solution to gain more performance credits for P.

Loop 2 (B2, a balancing loop, labeled as "ME's Short-term") encompasses 5 variables. The outcome gap of ME and resultant pressure trigger ME's short-sighted behaviors which increase the ratio of the resources allocated to ME's own tasks *to* the resources allocated to line support to P. This can increase short term performance credits for ME.

Loop 3 (R1, a reinforcing loop, labeled as "Long-term Side-effect") has 6 variables and a delay element. The reduced allocation of resources of P to support ME harms the "outcome of process development and improvement", which, after a delay, comes back to negatively affect process execution and throughput. This is very likely to result in more pressure on P and more P's short-shorted behaviors.

Loop 4 (R2, a reinforcing loop, labeled as "Vicious Circle"), including all the variables in the diagram, goes along the rim clockwise. The situation becomes worse and worse since ME's short-sighted behaviors and P's short-sighted behaviors harm the performance of the other party and thus cause more short-sighted behaviors.

Loops 3 and 4 are reinforcing and "vicious" in nature because they start from the "negative" variables (short-sighted behaviors) and then, after a loop back, reinforce the variables. Sterman (1989) explains it as such: Qualitative behavior is a function of the feedback structure in which it is embedded; people tend to make decisions for local optimization, and a delay in the feedback loop may further blind people's global mind. An interesting note here is that, the existence of Loop 4 relies on the existence of both ME's and P's short-sighted behaviors, but the existence of Loop3 relies only on the existence of P's short-sighted behaviors. That is to say, "P's short-sighted behavior" is a stronger enabling (or disabling) factor, which is in line with the asymmetrical P-ME relationship discussed above.

5.2 Conflict Resolution

Senge (1990) states that systemic structures influence patterns of behavior, and patterns of behavior influence individual events. A systemic structure refers to the interrelationships between key variables as described in the responsibilities of and relationships between ME and P. The behaviors that result are the short-sighted behaviors of Empirical Findings 1, 2 and 3, and the events that they impact are individual production runs and development projects.

Therefore, it is not the individual managers, operators or engineers who cause the conflict, but the underlying mix of ambiguous goals and political asymmetry built into the structure at AES. P and ME people who argue on the factory floor commonly go out drinking together afterwards. Thus it seems that, to mitigate short-sighted behaviors and conflicts, management needs to alter the systemic structure rather than teach individual people how to get along. This view is supported by other researchers (Walson and Dutton, 1969; Pondy, 1967). However, in reality, given AES's successful operations strategy, which is based on different goals for P (low cost, conformance quality) and ME (flexibility and high quality), it is unlikely that changes can be made at the structural level. Then what can the organization do instead? This paper does not set out to develop methods about conflict resolution as there is plenty of existing literature already that does this. However, it is valuable to show how AES did manage its conflict, because the plant had been quite successful in its overall performance.

Conflict management was indeed part and parcel of AES's ongoing managerial responsibility. A significant portion of daily production meetings, weekly quality meetings, and monthly management meetings was used for conflict resolution in a general sense. The QA/QC manager, the plant manager, the MD formed a triad of "arbitrators", even if they didn't realize it.

The QA/QC manager was an excellent facilitator with a good sense of humor. He had both quality engineering and personnel management experience, and tended to find the root causes of process variations and carefully distribute the responsibilities across different functions. As a good friend of both P and ME managers, he was a popular "buffer" between P and ME. He chaired the quality meetings and became an effective arbitrator in many occasions.

The plant manager, a brilliant engineering graduate from the top local university and a recent MBA holder, had been assigned to various positions (quality, materials, and planning) before becoming the plant manager at a young age. He looked at issues mainly from a planning and coordinating viewpoint and always reminded everybody in daily production meetings that "we are all in the same boat." He continually focused on what was good for the plant as a whole, rather than P or ME's potentially entrenched positions.

The MD, a charismatic figure with a good engineering background, spent a great deal of time walking around the factory floor. He made hard decisions and earned respect even while he wasn't always liked. But without him, it was likely that AES would not have been successful in a competitive industry. When the plant manager could not get the ME manager and the P manager to agree, the MD would step in and provide a "technical" solution. He knew how to push for improvement in both process development and process execution and hence could convince both sides.

This three-level arbitration, formed by quality manager, plant manager and MD, was very effective at conflict resolution and played a key role in keeping AES focused on its operations strategy.

As well as the managerial approach to conflict resolution, another effective approach in AES was continuous improvement in the speed and quality of process activities. If the cycle time of process execution and process development could be reduced, or, the reliability could be increased, more process resources could be freed up, with less conflict as a result. In essence the vicious cycle (as depicted in Figure 1) can be broken. Some comments from the production manager illustrate this point:

> We still give the same amount of machine time to process [engineering] and test [engineering], but when we run more models, the machine time allocated for each model is much less. This is why they [ME] complain. In fact, we in production are facing the same problem. When we have to switch from one product to another, we have less time left for the real productive work. I have been thinking about this for some time… what to do about it. If we have to run with a shorter manufacturing cycle, then process [engineering] and test [engineering] also have to do something. I think everybody has to cut the cycle time, not only production.

In fact, AES initiated projects for cycle time reduction on several occasions, aimed at reducing manufacturing lead time, process development cycle time, and process execution cycle time. One finding from these projects was that cycle time reduction in process execution relied heavily on the quality of process development. If, during the process development stage, proper automation technologies were substituted for unstable and complex production jobs, both the throughput and quality of process execution were dramatically improved. This suggests that if ME was given more process resources for the development job, both process development and process execution would benefit. However, the production manager was right that ME also needed to try to save process resources in the environment known as the ‘changeover game’, just as P needed to.

Technological advancement can also help alleviate the conflict. One example was that the new ICT (In-circuit tester) installed in AES had a special function which enabled both “front office” and “back-office”. In the front office production testing was carried out while concurrently in the back office ME personnel could debug some portions of the ICT testing program and collect and analyze real-time testing data. Although this multi-task technology was mainly used for software sharing rather than hardware sharing, it somehow separated sharing resources and thus slightly altered the structural factor that caused the conflict.

The ways of conflict resolution discussed above can be summarized in three variables: management intervention (arbitration), ME’s capability (quality and time improvement in process development, and ME’s technological advancement) and P’s capability (quality and time improvement in process execution, and P’s technological advancement). Managerial intervention is a quicker and short-term solution, whereas capability increasing as a fundamental solution requires long-term investment. These options are added to the basic conflict model (see Figure 2), whereby each party increases its capability when they face the performance shortfall and pressure for improvement (in two balancing loops, B3 and B4), as well as gets their short-sighted behaviors controlled by management intervention.

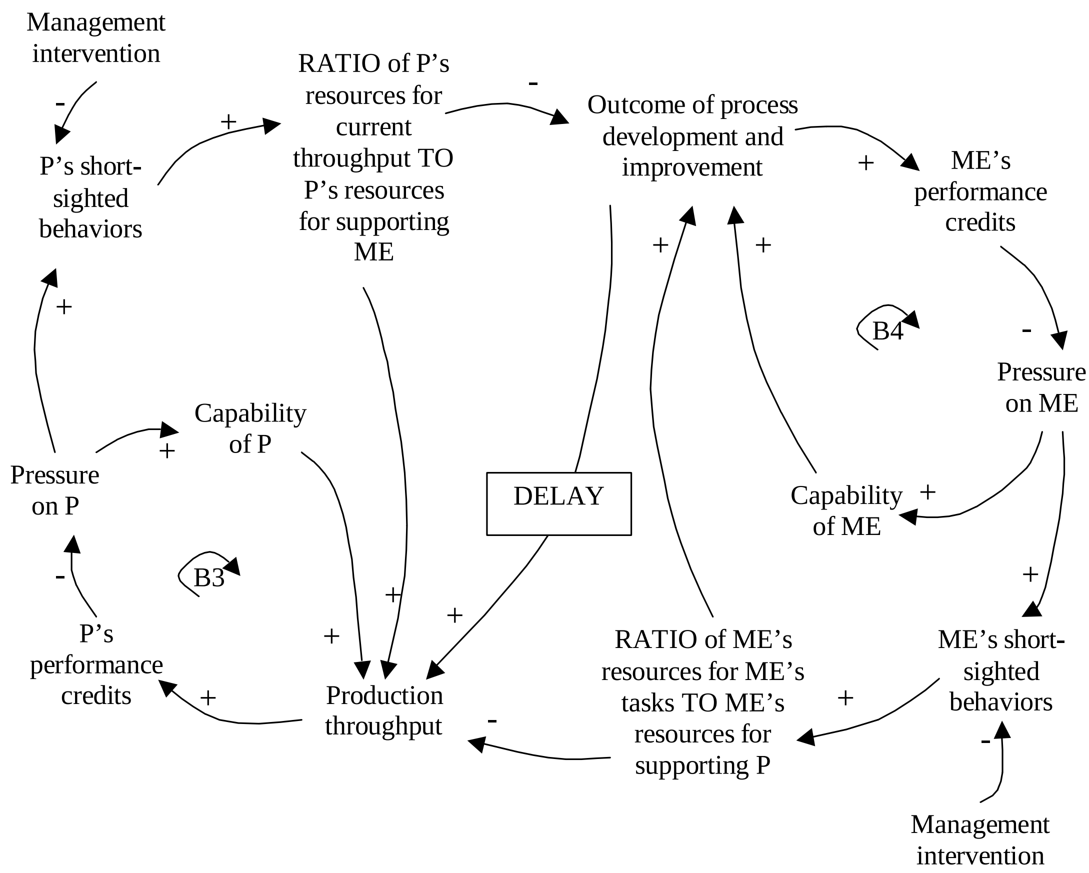

Figure 2. The Conflict Model: Cause and Resolution

6. MANAGERIAL IMPLICATIONS AND CONCLUSION

The findings of this case study indicate that the mixed operations strategy at the AES plant level, used to meet both cost and flexibility requirements, increased the tensions between P and ME. These tensions were exacerbated by structural factors related to ambiguous responsibilities and asymmetric political power. The operations strategy, like the structural factors, was hard to alter. Problems continue to appear on factory floors as process development is squeezed between product development and process execution. Thus it seems that the conflict between P and ME is likely to remain, and should be regarded as a necessary “evil” for the plant to sustain its competitiveness. This research explores and analyzes the conflict-related functional behaviors, process activities and operational dynamics in a specific plant where P and ME are clearly separated functions, and summarizes them in Empirical Findings 1, 2 and 3 as well as a causal loop diagram as a qualitative system dynamics model. The case study also shows several approaches for conflict resolution, such as managerial intervention, capability building, and technology advancement, which enriches the causal loop diagram.

Conflict resolution would be easier if long-term solutions (process development) were considered equivalent to short-term solutions (increasing throughput) in order to break the vicious conflict circle. The lesson for management is a need to recognize ME as a primary function equivalent to P, and treat it accordingly when requesting resources. Giving ME an equal bargaining voice might encourage the ME function to produce better long-term solutions that would provide success for the entire product realization process. As Pisano and Wheelwright highlight, "Although every organization should find ways to avoid unnecessary complexity, those with strong process-development and manufacturing capabilities will have more freedom in developing products than those forced to stick with simple-to-manufacturing designs (1995, p97)". In this sense, this research contributes to a better understanding of the role and function of process development by examining the interaction between process development and process execution.

Demanding customers mean that the operations strategy being both efficient and flexible becomes a key competitive advantage. At the same time, process development has increasingly become a key element of operations strategy (Hayes et al., 2004). Therefore, the empirical findings developed from the case study may be transferable to many other contemporary manufacturing operations with two key and distinctive functions – P and ME – working together for process and operational improvement.

This research has a non-traditional research approach which relies on un-intrusive observation methodologies. The specific interaction between P and ME is rather hidden because these roles are often consigned or executed within the manufacturing operation. P-ME interactions therefore likely remain obscured in the absence of insider studies (the author who observed first-hand data) that bring to light the intra-operation dynamics. Although this research is exploratory in nature, and the empirical findings it has developed are well grounded and can be used as guides for construct generation and theoretical development in further studies with data from more sources. There is also a need to further analyze the ME function in relation to other functional areas that it intersects with such as product design, planning/scheduling, and external engineering supply. As a tentative constraint, the analysis of this paper is more focused on the technical and operational aspect of a functional P-ME conflict. Although some social theoretical framework about conflict is quoted, the conflict is not defined and discussed as a social construct. Maybe this is because this research was initially set up as a project in operations management rather than in organizational behavior.

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