From Continuous Improvement to Centralized Information: The Life and Times of a Systems Thinking Intervention

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Abstract

This multi-method retrospective case study examines the implementation of a systems thinking intervention – The Manufacturing Game® – as part of a comprehensive approach to "Proactive Manufacturing" and workforce involvement in continuous improvement at an American oil refinery. Notable gains in local reliability metrics such as equipment failure rate were achieved as a result of these efforts, which contributed to impressive gains in financial, safety, and environmental performance. At the same time, the overall contribution of the program to the refinery's performance is ambiguous, confounded by simultaneous investments in the physical capacity and technical capabilities of the plant, along with increases in the crude-gasoline price spread that all together generated significant value. This ambiguity created interpretive flexibility for employees of the plant, who were able to both interpret and shape the continuous improvement activities based on prior political divisions, mental models, and interpretive biases. To make sense of these emergent and unintended consequences, a speculative model of relational conflict that undermines workforce participation in continuous improvement is proposed. [1]

Keywords: Continuous improvement, workforce involvement, The Manufacturing Game, systems thinking, organizational learning, organizational change, qualitative research.

Introduction

The translation of system dynamics models into board games has been a mainstay of system dynamics theory and research, beginning with the Beer Distribution Game

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(Sterman, 2000; Sterman, 1989). Among those to make an appearance at the System Dynamics Conference (e.g. Ledet, Monus, Cardella, & Burgess, 2005) is The Manufacturing Game® (hereafter referred to as TMG or the Game). TMG focuses on the relationship between equipment defects, maintenance activities, and operational reliability and performance in a continuous manufacturing facility. Workshops employing the Game have been conducted in a number of industries, with the majority being in the oil and gas, chemical, and pharmaceutical industries (Ledet, 2007). The Game provides an example of system dynamics being used to construct a *social technology* (Jay, In Press) – a replicated, iteratively developed methodology for planned organizational change.

This study examines the actual effects of this technology's implementation in an oil refinery, where the Game was used as part of a multi-year program of change labeled as Proactive Manufacturing. Through our analysis, we seek to inform the underlying theory of the Game and Proactive Manufacturing and their method of implementation in organizations. We believe that our findings are generalizable to other programs and technologies of organizational change, particularly those focused on workforce involvement in continuous improvement.

Our research questions are simple, building off the basic claims of The Manufacturing Game® seminars and design intent of Proactive Manufacturing as a social technology. First, how successful were these efforts at their immediate goal, which is the improvement of plant reliability through workforce involvement in cross-functional teams? Second, what was the impact of any changes in reliability on overall financial, safety, and environmental performance of the plant? Third, how can the answers to these questions inform the underlying system model, the design of Proactive Manufacturing as a whole, and continuous improvement activities more generally?

Before we answer these questions, we will give more detail about the program, the site of implementation, and our research methodology. Then we will present our findings: that the program was successful in improving aspects of plant reliability and likely contributed to the refinery's significant performance gains. We also find, however, that political conflicts inside the refinery that pre-dated the program – left unaddressed – continued to influence perceptions and undermined workforce engagement, thus limiting the potential impact of Proactive Manufacturing. We will attempt to identify the causes of these dynamics and use our research to augment some core assumptions of Proactive Manufacturing and similar social technologies.

The Manufacturing Game

The Manufacturing Game® (TMG) was originally developed at Du Pont Corporation and was built from a system dynamics model of chemical plant performance. Carroll, Sterman, and Markus (1998) document the history of the Game, which emerged from a benchmarking study of maintenance costs among Du Pont's plants. One of the critical features of the Game's history was that the system dynamics team originally tried to convey insights from the model to chemical plant personnel through causal loop diagrams and hands-on interaction with the Powersim-based computer model. These modalities were not effective in stimulating interest or understanding, which led the team to design a

board game and learning laboratory inspired by the Beer Distribution Game (Carroll et al., 1998).

There are at least two lessons of the Game that were intended by its designers (Ledet & Ledet, 2002). The first is similar to that of Repenning & Sterman's (2002) work on capability traps – that without investment in plant capability and a willingness to endure a "worse before better" transition, it is nearly impossible to escape a reactive mode of system behavior that further erodes capability. In the context of continuous processing, this means being willing to stop the production process and forego revenues while maintenance personnel work on the equipment to eliminate existing defects. The reward for these investments is higher reliability, revenue, and safety and environmental performance in the long run (sufficient accumulation of defects results in safety and environmental incidents).

The second intended lesson is about the importance of cross-functional collaboration. In order for the benefits of proactive maintenance to be realized, there must be coordinated effort among the three roles in the Game – operations services that manages the parts shop, maintenance planners who schedule and execute maintenance activities, and operational managers responsible for meeting product demand and profitability goals. These players must manage resources together to support preventative maintenance activities. They can also allocate people from all departments to cross-functional teams in order to conduct improvement activities and attain even higher performance. Improvement activities serve to reduce the inflow of new defects, for example by working with suppliers to reduce defect rates in new equipment arriving at the parts shop.

The system dynamics model used to develop the Game is rather complex and is in fact proprietary to Ledet's organization. For the purposes of this study, however, the core of the model can be depicted as a simple co-flow.

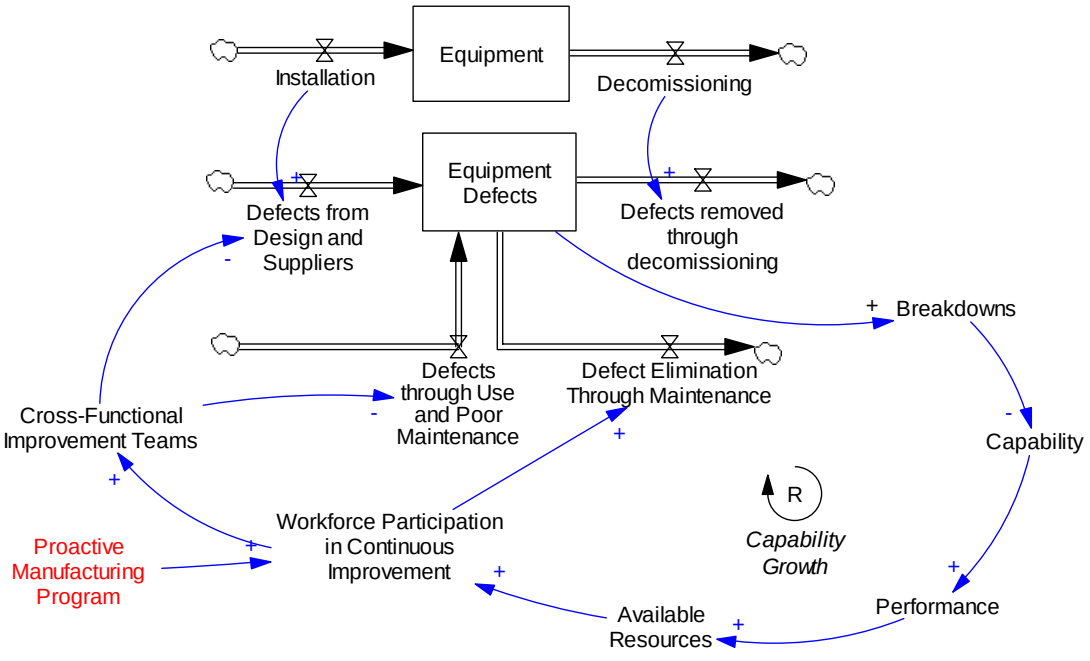


Figure 1 - Core model of The Manufacturing Game®

Here, equipment defects are seen as a property of equipment in the facility. Some arrive with the equipment in the form of design flaws or poor quality from suppliers. Other defects arise in the course of use or through improper or unskilled maintenance procedures. Defect elimination activities can focus on preventative maintenance that removes existing defects, or they can work proactively to slow the inflow of new defects (e.g. through re-design, training of technicians, changing suppliers, etc.). If successful, these defect elimination efforts result in fewer equipment breakdowns, improving the capability and performance of the organization. These performance gains can generate a self-reinforcing Capability Growth if the new resources are re-invested in further defect elimination. The Manufacturing Game® gives players an opportunity to allocate people among preventative maintenance and defect elimination activities and experience the resulting improvements.

Proactive Manufacturing

Implementation of The Manufacturing Game® by Ledet and colleagues is not, however, restricted to game play. As described in several publications about the Game's use at BP's Lima, Ohio refinery (Griffith, Kuenzil, & Monus, 1999; Houshower, 1999; Ledet et al., 2005), the Game has been incorporated into a system of activities designed to reinforce and enact the insights of the game into an organization. Together these are better conceptualized as a program or technology known as Proactive Manufacturing, which has been compared to Total Productive Maintenance (Nakajima, 1988) by proponents (Griffith et al., 1999). At Lima, the approach included the following activities:

- Two-Day workshops in which The Manufacturing Game® was played by every employee in the plant.
- Action teams, formed during the second day of the workshop, in which people work together across functional lines to eliminate a defect in equipment, procedures, or practices.
- A Continuous Improvement Forum (or "CI Forum"), meeting at regular intervals and open to all plant personnel, in which people could present progress and challenges in their defect elimination efforts. The CI Forum is also used to deliver leadership and soft skills training to develop the capabilities of those involved.
- A set of cultural artifacts to reinforce the principles of the game, including slogans such as "Don't Just Fix It, Improve It" and "Don't Let the Bugs Bite" – including cartoon images emblazoned on posters, banners, hard hat stickers, and embroidered patches for shirts and coveralls.

This approach was carried on to the Redberg Refinery[2] described in the present study, where it was augmented with one additional element: the creation of Natural Work Teams at each of the processing units in the plant. The purpose of these teams was to serve as a unit-level analogue of the CI Forum. A coaching and training program

[2] The organization's identity and its members have been disguised for this study

developed "first level learning leaders" for personnel at the manager, supervisor or hourly levels to help facilitate the learning processes of these Natural Work Teams.

The intention of the consultants and plant managers involved with the Proactive Manufacturing program at Redberg was to enhance the reliability of the plant through engaging the workforce in defect elimination. Through these efforts, they hoped to improve profitability, workplace safety, and environmental compliance of the plant in a sustainable manner. They employed several threads of innovative organizational theory and practice along the way:

- Practice fields and reinforcement of learning through action (Kim, 1989; Kim, 1995; Roth & Senge, 1996)
- Team-based organization and workforce participation in continuous improvement, from studies of Japanese management practices (Womack, Jones, & Roos, 1991)
- Insights about organizational culture and the importance of artifacts (the bug imagery) and regular rhythms of events (the CI Forum) in embedding new dimensions of organizational culture (Schein, 2004).

As we will see, however, in the complex social system of the refinery, these intentions interacted with the history and social structure of the plant in unforeseen ways. Through a detailed case history of Redberg Refinery, we hope to illuminate challenges that this and other similar methodologies must confront.

Methods

In the tradition of Eisenhardt (1989), this multi-method case study is designed for developing social theory and posing critical research questions. Strictly speaking, the findings can not be generalized beyond the refinery under study, nor to an understanding of the impact of other systems thinking methodologies, such as group model building. We do pose questions, however, that may be relevant and worthwhile to consider in a variety of other contexts.

Site – Redberg Refinery

Redberg Refinery is a mid-size oil refinery, processing over 300,000 barrels of oil per day and producing jet fuel, diesel fuel, and gasoline for a variety of markets. The plant employs around 800 people full time, 600 of whom are hourly workers organized by four different unions. A few hundred contractors also work at the plant on any given day, working on new construction or non-routine maintenance.

Over the past twenty years, the refinery has undergone several changes in ownership, each of which has brought in a new plant manager. These changes were significant for the refinery workforce, bringing with them changes in policies, compensation, management philosophy, and job security. It was one of these plant managers, Eli Larson[3], who implemented the Proactive Manufacturing program, having worked with it

[3] This and all names in the document (other than Winston Ledet) are pseudonyms.

in his previous position at another refinery. Eli retired when the Redberg refinery was purchased in 2005, bringing in a new plant manager from elsewhere in the new owner's corporation. The data collection period for this study was January-March, 2007, roughly a year and a half after this transition.

For most of its history, Redberg synthesized its products from the industry standard West Texas Intermediate (WTI) crude oil. This changed, however, when the refinery's owners negotiated a contract for heavy, sour crude oil from a foreign supplier at a guaranteed spread below WTI's market price. Because this more difficult raw material requires special equipment to process, the company secured financing for a significant $850 million capital expansion at the plant. As refinery capacity shortages nationwide increased the market price of finished products, this guaranteed price spread was exceeded and became an even greater profit margin. Proactive Manufacturing was initiated during the capital expansion as a way of improving the reliability of existing equipment and thereby optimizing the return on investment in new equipment. The combination of technical capabilities from the plant expansion, contract for the sour crude, market conditions, and reliability improvements worked synergistically to improve the plant's financial performance by an order of magnitude.

The downside of this synergy, however, is that the concurrence of management changes and capital expansions confounds the effects of the organizational practices implemented during that time. While multiple changes are a limitation for pure evaluation research, they are also what make the present study more interesting. We found that people at the refinery have as tough a time understanding what causes performance improvements as we did. This uncertain causality has kept the sensemaking process active, and has allowed divergent perspectives to endure about the value of Proactive Manufacturing relative to other changes in the plant. We interviewed people at multiple organizational levels, several years after Proactive Manufacturing was the focus for learning, improvement and change, and found that these perspectives not only shaped people's feelings about the past but also explained their actions in the present. These perceptions provided a window into the underlying political divisions of the plant and some of the challenges that Proactive Manufacturing, or any continuous improvement efforts, would have faced.

Interviews

The primary source of data for the study was a series of 66 interviews with 48 people conducted by the two authors between December, 2006 and March, 2007. All but four of the interviews were conducted face to face during visits to the Redberg refinery. Most were conducted as one-on-one interviews behind closed doors, but there were five group interviews with up to four people at once in a meeting room or operations control room.

Sampling of interview subjects began with Winston Ledet and former plant manager Eli Larson, and then continued through a snowball process that was coordinated by the manager of maintenance for the plant. Characteristics of interviewees are depicted in the table below.

Table 1 - Number of interview subjects by job category and functional department

Function	Hourly	1st Line Supervisor	2nd Line Supervisor	Manager	Staff	N/A	Grand Total
Clerical		1					2
Engineering		1		1			2
Finance				1			1
HR				1			1
HSE				1	1		2
IT					1		1
Maintenance	3	7	5	1			16
Management				2			2
Operations	9	2	1	1			13
Services				1	3		3
Training					3		3
Consultant						1	1
External	1						1
Grand Total	13	11	6	9	8	1	48

As a result of partnering with the maintenance manager as the primary contact inside the plant, the sample of interviewees is by no means representative of the organizational structure of the plant. It is heavily weighted towards salaried managers, supervisors, and staff (n=34) with hourly workers making up a small part of the sample (n=13), particularly given that of the roughly 800 employees on payroll, close to 600 of them are hourly. The sample is also heavily weighted towards the Maintenance function (n=16), whereas Operations is a far larger organization within the refinery.

With these limitations in mind, we did attempt to speak with structurally significant members of the under-represented groups – we talked to the heads of the three largest unions of the plant, including the committee chair of the local United Steel Workers union that represents 500 of the plant's hourly employees in operations and maintenance. For the purposes of this research, which is to identify the political divisions and narratives surrounding the Proactive Manufacturing program, this sample was adequate to capture the local complexity.

Interviews lasted anywhere from 30-120 minutes, although most were 60 minutes long. They were recorded on digital audio files that were compared to handwritten field notes and transcribed for key quotes. Interviews consisted of three phases. In the first phase the informant was asked for a brief career history, and we recorded the sequence of jobs they had filled both prior to and since arriving at the refinery. In the second phase we presented our informants with a timeline of events at the plant, divided into two columns: one column for business events and results (e.g. the capital expansions and changes in

ownership) and another column for improvement programs, including Proactive Manufacturing. After presenting them with the timeline, we asked them to tell us stories about events they found significant in the plant's history or about those they were directly involved in. If we had omitted any events they thought significant, we encouraged them to tell us, and we progressively edited the timeline with each interview. The third phase of an interview involved asking specific questions, or clarification of what the respondent said that might have differed from what we heard from others.

Observations

In addition to formal interviews, one of the authors conducted approximately eight hours of ethnographic observations in control rooms, in morning meetings of maintenance managers, at supervisors' morning handoff meetings from the night shift, at a maintenance planning meeting for a section of the plant, and at a root cause analysis meeting for an equipment failure. During these observations, he took hand-written field notes which he transcribed with additional observations and reflections each night, along with notes and reflections from interviews. The other author was involved in a consulting, training, and facilitation role for the first level learning leaders and with the plant management team from 1998 to 2002. Records from that clinical engagement served as a documentary data source to supplement his recollections.

Documentary sources

To supplement the interviews and observations, we collected a great deal of archival and documentary material from the plant. This material included:

- Record keeping about The Manufacturing Game®, action teams, CI Forum, and Natural Work Teams, including attendance
- Documentation of CI Forums, including video recordings of three sessions and PowerPoint slides from almost everyone of the meetings
- Historical interviews of Redberg's managers: One set were interviews with plant management team members was conducted in 2000 by the consultant introducing The Manufacturing Game®. Another set of interviews and notes were conducted by the second author of this paper and provided as feedback in facilitating a series of quarterly leadership team learning meetings from 2000 to 2002.
- Financial records, including variable costs for oil and energy purchase and operational fixed costs including expenditures on labor and maintenance. These records only date back to 1995; before that the records are the property of a company with whom we did not have a research agreement
- Safety and environmental records, including OSHA and EPA recordables for the years before, during, and after the Proactive Manufacturing Program
- Feed Rate and Reliability records for each of the major processing units in the plant, from the period of 1991-2007

Analysis

Analysis of the data was primarily qualitative, using the method of grounded theory (Glaser & Strauss, 1967). Transcriptions of fieldnotes and interviews, along with other archival documents, were imported into a database and analyzed using the *Atlas.ti* qualitative data analysis software. Elements of these texts were coded by the first author and reviewed by the second author using concepts emergent from the data and from the academic literature on organizational learning and change. Some concepts were linked and grouped into themes in order to build the theoretical insights described in this paper. Specialized queries and searches allowed some hypothesis testing and verification, along with gathering of quotes cited as evidence below.

Where appropriate with the quantitative time series data, simple regression analyses were conducted to detect linear and quadratic trends over time.

It is worth noting that clear analysis of the interview data in this case is by no means straight forward. Perceptions of the value, the meaning, even the sequence of events involved in Proactive Manufacturing differ sharply depending on whom we asked in the refinery. Some were clearly advocates of the program, saw it as an approach and philosophy of work, and believed it had been critical to the operational and financial success of the plant. Others thought the program was a fine idea but irrelevant and poorly implemented, paling in comparison to the capital expansions occurring in parallel or the changes in management before and after the program. Still others, particularly in the hourly ranks, were opponents of the program, who thought of it as an attempt by management to get them to work harder, and that the net impact on the plant has been deleterious.

For many of the respondents, however, their views were mixed. Often they would talk about the value of the program and its early successes, and point to ways that current practice reflects the ideals they learned. Then they would add additional stories about failures to invest in necessary maintenance improvements or about subsequent management behaviors and programs that undermined the spirit of cross-functional collaboration. Given this complex picture, it would be more accurate to organize the data in terms of *narratives* rather than opinions or attitudes (Czarniawska-Joerges, 1997; Ewick & Silbey, 1995). Instead of forcing the data to fit into an assumption that people hold unitary views, a narrative mode allows us to describe the raw material and process of sensemaking (Weick, 1995).

Results

Timeline of events

The most basic result of the research, which we developed iteratively in conducting our interviews, was the development of a timeline of the Redberg Refinery's history. While our informants described a variety of events, a few were repeatedly cited as critical to the plant's culture and performance and the careers of the people who work there. They also provide an important backdrop and context for the implementation of Proactive Manufacturing, which helped generate its successes and challenges.

Table 2 - Timeline of events at Redberg Refinery

Year	Management regime	Event
Late 1980's	OldCo	TQM implementation – early attempt at workforce involvement in continuous improvement
1992	OldCo	OldCo reduces dual train refinery to single train refinery, massively cutting personnel from 3000 to 800 and decomissioning equipment to shave operating costs in preparation for sale
1995	SmallCo – Sam Taylor	SmallCo purchases Redberg for $89 Million
1995-1998		Efforts by new managers to reach out to hourly workers lead to conflict with supervisors. Early investments in reliability improvements
1998		Announcement of deal for heavy, sour crude and Heavy Oil Upgrade Project (HOUP)
1998	SmallCo – Eli Larson	Arrival of Eli Larson as plant manager
1999		Manufacturing Game and action teams begin "Boris the Bug" imagery and slogans posted
2000		Continuous Improvement Forum established
2000		HOUP construction begins, financed by $650M in loans.
2001	SmallRefCo – Eli Larson	SmallCo sells off retail, becomes refining-only company SmallRefCo
2001		Natural Work Teams established, Productive Conversations coaching commences
2002		HOUP construction finished; heavy, sour crude processing begins
2002		IPO of SmallRefCo – hourly workers excluded
2002		25% reduction in salaried workforce for cost control
2003		Lubrication program begins – offshoot of Natural Work Team
2005	MidCo	MidCo purchases SmallRefCo for $8 Billion. Nearly half of the company's capacity is in Redberg and more than half of total margin, placing its evaluation at close to $4 Billion. Eli Larson retires.
2007		Research for this paper conducted

In this timeline, the grayed cells highlight the implementation of elements of Proactive Manufacturing. A few things are critical to note about events before, during, and after the implementation of this program.

- Before Eli Larson's arrival, the plant management team led by Sam Taylor implemented two key policies that would impact later events: beginning to invest in maintenance and reliability improvements; and reaching out to hourly workers through a Union Management Team and open-door policy. The former is critical in people's sensemaking about plant performance; the latter shaped the political landscape into which Proactive manufacturing arrived.
- Simultaneous with Proactive Manufacturing, as discussed earlier, the Heavy Oil Upgrade Project significantly changed the supply and product mix. This substantially boosted the financial performance of the refinery. With increases in the market price of fuels, these organizational, technological, and strategic improvements increased the annual profit margin of the refinery by 3,150% between 1999 and 2006.
- These capital investments created a temporary situation of limited cash and extensive debt. In this context, Proactive Manufacturing came with substantial cost and risk – the initiators of Proactive Manufacturing repeatedly emphasized that the program was initiated by Redberg itself, without the backing of SmallCo's senior management team. It also required an investment of more than $1 Million in consulting fees, licensing, and personnel time away from regular work. The successes achieved were therefore highly significant to leaders and advocates of the program.
- After Proactive Manufacturing efforts began, two events occurred that affected morale, sensemaking, and participation in continuous improvement activities: an IPO of the company that brought financial gains to managers while excluding hourly workers; and a reduction in salaried workforce that eliminated numerous staff and supervisory positions.

With this context in mind, we can begin to analyze the effects of Proactive Manufacturing on equipment reliability, the influence on overall plant performance, and the political dynamics arising in the course of its implementation.

Impact on reliability efforts and outcomes

To the extent that the program was successful in improving reliability of the equipment, we would expect to see improvements in mechanical availability, as well as qualitative evidence that the program left its mark. While not perfectly conclusive, the available data are indicative of a successful program that paid for itself many times over.

Action teams and maintenance efforts

Action teams formed after The Manufacturing Game® workshops are the route of most direct influence for such improvements. On the second day of the Game workshop, participants are asked to form small teams composed of people from multiple levels and functions of the plant. These teams were assigned problems to solve in the plant, framed as defects or "bugs" in the plant. If the team knew of a more pressing issue to tackle then

it was their prerogative, but the majority seem to have taken on the project assigned. A spreadsheet used to track action team status from 1999-2000 includes 88 action teams formed around pre-existing issues and 27 "proactive" teams who developed their own project. Success stories about these teams abound, and managers credit these teams with financial benefits that paid for the Proactive Manufacturing program several times over.

> *At the close of the second day, at the end of the day, we say "we've got these projects and think you would work good on this team." They split up into teams to work on these projects. Some of those projects have actually been successful, they were successful and we still talk about some of them today. One of them was one at 43 they had a seal that kept going out on a certain pump… Well, [engineer] started asking questions about this pump and why, you know, the next thing that come up was, "why do we run that pump?" We run it because of this. Next thing that come up was, "Fix it? We can shut the whole system down." We didn't really need it. They were just kinda runnin' this system. And they shut it down and saved so many dollars because they didn't have to fix the problem, 1. And 2, it was a bunch of hardware you didn't have to upkeep. It was a major accomplishment.*
>
> *We had refractory [insulation] in the regenerator at the FCC to keep the metal from burning up… Refractory would fall out of the overhead of that regenerator and then you had to shut the cat cracker down because you had an unexpected fall down. Well, when the Manufacturing Game came in, that just happened to happen sometime during that time frame. Here was a chance to put their money where their mouth was. They decided that they were going to do it right [the management team]. They said it might take us a few more days to stay down, and may cost us some extra dollars, but they had proven to those who worked in that area that they really meant what they were saying… They didn't just patch it, they cleaned it up and put it in right the way it should be. It cost several thousand dollars to do that, but the end result is they didn't have a fall down again. Matter of fact, I don't know that to this day, it has fallen down since.*
>
> *There was a team put together to do one thing, but they said we've got a problem over here. One of them was at the old coker. They had a problem with the air system – it was always dirty. Water and stuff in it. Their team came up with a design to dry the air out, have cleaner air for their tuggers – they use air tuggers in the drilling process… And we published that for many years, for a long time, and presented it at the Manufacturing Game.*
>
> *I was on the one that won the President's Award. We had a lot of leaks in the sewer out here, and we were trying to identify where these streams were coming from. There is a company that came in and helped us do a fingerprinting process. They run tests on samples and they could tell exactly what stream was going into the sewers and we could backtrack and fix the problem. We saved several million dollars that year. Everybody knew that, you know, at the waste water plant we were killing bugs out there [specialized algae and bacteria used to clean waste water]. We were killing off the bugs, and it can be pretty expensive. And then we get cited also along with that. So we knew we had to address it.*

They were not big things – they were small things. Nothing wrong with that. Enough small improvements make a big change in the bottom line. One thing is that they fixed the blowers at 1241. The blowers, that's something that brought in combustion air for the regeneration process. They were falling down all the time. Every time one of them would fall down, they would cut throughput for the units [which cost $80K/day]. They put together a team of operations, maintenance, everybody. One thing that's nice, you do have cross-functional teams. They looked at equipment and found it was an alignment problem between the driver and the blower… They went from 6 months or less on a run to 2 or 3 years without falling down… Savings were $700K/year. See that is significant with the operators too because they don't have the blowers falling down at 2 in the morning when it's 30 degrees outside.

It's only mechanical about 20% of the time. That's where Eli Larson, why we have so much faith in this thing, even though you spend half a million dollars [for the program], that sounds like a lot of money. No matter what plant you go into, they are wasting money hand over fist… it's easy to find something that will pay for that investment. We found something within the first few months that paid for that three times over. It had to do with a flaring process we were doing here. We were importing gas from [supplier]. The procedure simply called for us to import it at a certain rate, which was more than we could handle. All we had to do was slow that down. Because we were bringing it in at such a high rate that we ended up flaring a lot of it. Simply by changing the procedure and getting with the supplier to say, hey, we need to take this at a little bit slower rate. They said, OK, and it was no big deal. All of a sudden we stopped flaring about a million dollars worth of gas a year… They worked all that out, and found out hey, this is a procedural thing. You know how much that costs? It costs ZERO.

We got together as a group of admins and stenos. We said what are you doing, how are you ordering, where are you getting this from? How can we make this a group effort where we get the most for our bucks? Best quality at best price. That fell into food service as well as office supplies… After we looked at, OK, this is what we are doing, this is what is resulting, how can we make this work to where we can get the most for our buck? We got a team together and evaluated the office supply situation, compared different office vendors, supply vendors and looked at maybe a new contract would be good if we could get corporate wide. That's what we did. SmallRefCo-wide contract for office supplies. It worked out to where we saved at least $50,000 over a period of time for that year, because of using a source that was common to everybody as opposed to a source here or there.

In these stories, we have numerous examples of Proactive Manufacturing directly affecting behavior and plant performance. While detailed impact analyses of these teams were not always conducted, they were repeatedly cited by informants as having led to improvements in reliability and reductions in operating costs. Informants also emphasized that these early action teams set an example that is now followed as part of the regular, everyday activity at the plant – cross-functional teams for defect elimination are now commonplace.

As further evidence of the plant's commitment to reliability improvements, we can see a surge in maintenance expenditures from 1999-2001, the period during which Proactive Manufacturing was initiated. These costs then decreased from 2001 to 2003, which may be evidence of the "worse before better" transition (Repenning et al., 2002) predicted by The Manufacturing Game®. Once preventative and proactive maintenance begin to improve reliability, the costs due to unplanned maintenance may have decreased.

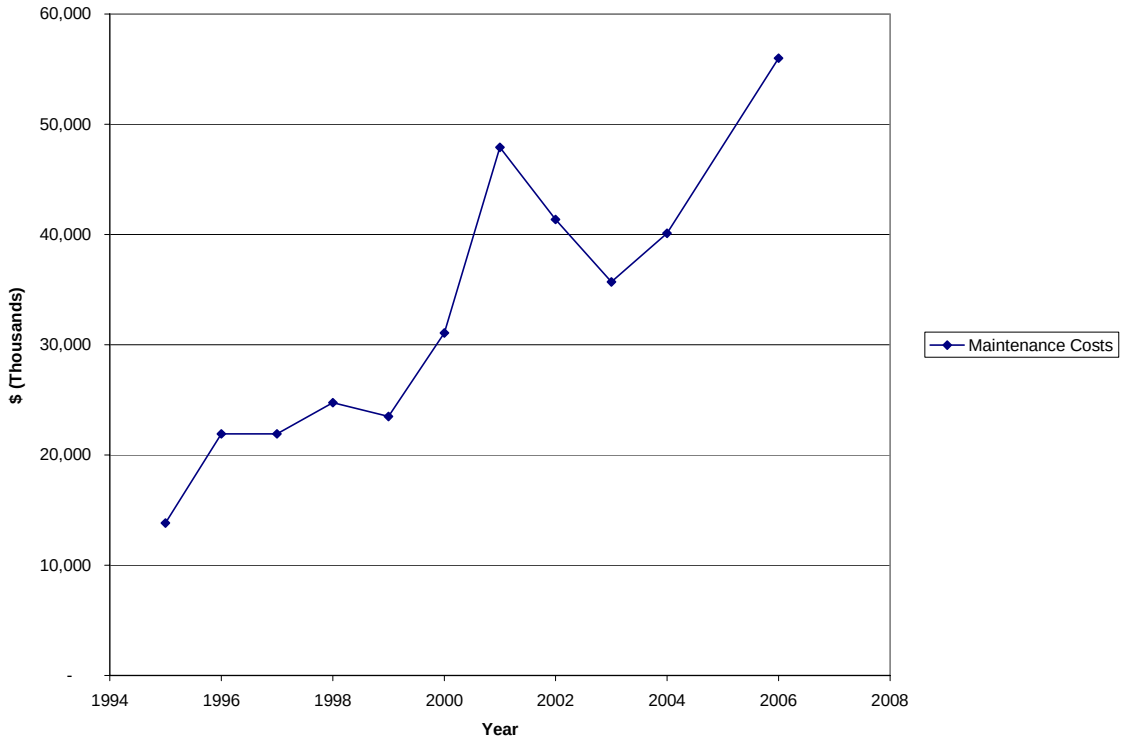


Figure 2 - Maintenance costs at Redberg Refinery, 1995-2006

Following this period, maintenance costs then began increasing again from 2003-2006. There are three possible reasons for this increase: it may be indicative of further preventative and proactive maintenance investment; it may be a result of the organization backsliding into reactive maintenance; or it may simply reflect the costs associated with integrating and maintaining new equipment brought online with the Heavy Oil Upgrade Project in 2002. This is an example of how plant-level indicators are difficult to interpret during the post-1999 period because of the simultaneity of multiple processes in the plant. To get a clearer picture, it is critical to examine more of the quantitative and qualitative data.

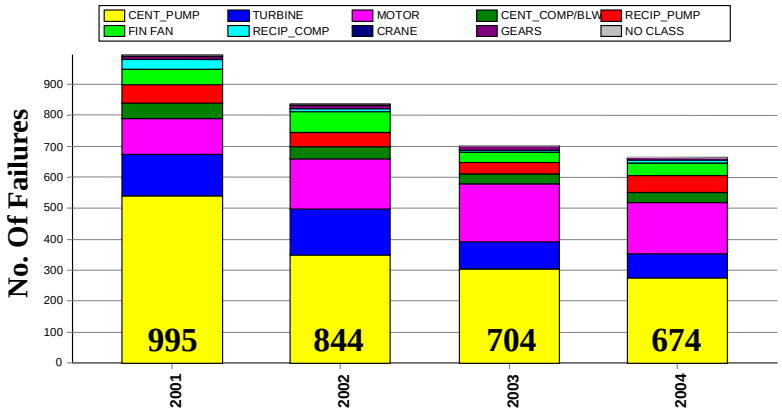
Rotating equipment reliability

At the most micro level of rotating equipment (pumps, motors, compressors, etc), internal data show significant improvements in reliability following Proactive Manufacturing. Figure 3 below, extracted from a Computerized Maintenance Management System (CMMS), shows a steady decrease in failure rates from 2001 to 2004. Ideally we would observe data of this type from before 2001 in order to see the longer term trend, but there are two notable features of this data display. First, the reason the graph begins in 2001 is

that this is the year when the CMMS was implemented, which itself was a part of reliability investments at the plant. Second, 2001 is a year after The Manufacturing Game® was completed and the CI Forum began. This evidence is suggestive (but my no means conclusive) that Proactive Manufacturing efforts contributed to reliability improvements.

Figure 3 - Internally circulated data on Failure Rate

Rotating Equipment Failure Count by Equipment Types for 2001, 2002, 2003, 2004



Lubrication Program

One compelling manifestation of this change in culture has been the development of additional, more focused improvement programs by participants in Proactive Manufacturing. In the context of a Natural Work Team, one hourly operator with a passion for machines became curious about high rates of motor breakdown and its relationship to lubrication practices. The company funded him to attend a conference on lubrication, and then helped him attend a four-day course to be certified in lubrication science and technology. He used this education to begin asking questions about lubrication use at Redberg. His inquiry, in partnership with a maintenance technician in a refinery laboratory, discovered mismatches between lubrication and metallurgy and problems with contaminated lubricants related to operations practices. Beginning with experiments in his own area of the refinery, he discovered the increase in MTBF and decrease in maintenance costs associated with proper lubrication.

This local inquiry then led to a systematic overhaul of lubrication procedures and a round of training for operators and maintenance personnel about the science of lubrication, which seems to have increased MTBF on critical equipment. Advocates of continuous improvement efforts know about the lubrication program and cite it as the cutting edge of the program. And it is an example of the success that comes from connecting a philosophical approach to cultural artifacts and a willingness to invest in following through.

Along with the Natural Work Teams, came the bug thing – don't just fix it. Something like this allowed me to stand up and say, "hey, guys you're preaching this, but all we did was repair this machine again. We didn't find out what's happening to it. We're just fixing it all the time." After I had a little education, knew what I was talking about… Well, it kinda put the company on the spot. We're going to preach this, then we gotta practice it. More than once [I pointed to the bug]. No doubt, it gets people's attention. And it did. With everybody involved, and different ideas, between machinists, like I said, as a group making decisions, instead of just one person… Started using 1 micron oil everywhere in the plant… delivered straight from the truck – that's a standard. There's not many suppliers who can do it for you…

We started our own training program out here in 2005… We trained, we brought all the operators and all the machinists to the training course… It took about a year to get everybody through it. And it's not easy – you got… you walk in and try to make a lot of changes to people my age in this kind of service and they're going hell, we've been doing it this way for 30 years, what's the matter? You still gotta get the operators to focus. I mean… keepin' things clean would be the biggest thing. Not checking a lot of things they could be checking.

From the perspective of the Proactive Manufacturing program architects, this story is exemplary. It is not, however, without its challenges. The lubrication program requires cooperation among operations and maintenance, both of whom must utilize the right lubricants and monitor their effects.

At the management level, the relationship between operations and maintenance that the Proactive Manufacturing program tried to institute appears to be well modeled. At the union level, however, cross-functional collaboration is not as simple. Operators and many maintenance crafts people are organized by the United Steel Workers. This is by far the largest union, representing 500 hourly workers. Electricians (who do instrumentation) are organized by the IBEW, Machinists by the IAMAW, and clerks by a division of the USW, all of which add up to fewer than 100 people. Structurally this disparity in size poses a problem. Conflicts over turf can be poignant, and can impede cross functional efforts like the Lubrication Program. After the more positive part of the head operator's story, we heard the following:

This has been my struggle. Lubrication belongs to machinists. I have been allowed to practice this in my area… It's kind of like I was invading their territory. I had one of them almost choke me for it. The only reason I've been allowed to practice is that their work has gotten so busy in repairs that their preventive maintenance work is not getting done. Some of them are glad - I didn't want to mess with those filters anyway. Someone like them sees… I get my hand slapped. So it's really been a struggle with two different unions involved.

The limitation of our retrospective methodology is that it is unclear whether these and other conflicts existed before the inception of the program, undermining cross-functional work throughout its history, or if this is a more recent phenomenon. Regardless, while the Lubrication program has on the whole successful, it highlighted the importance of political dynamics, which we will discuss in more depth in a later section.

South side green-field culture

Changes at Redberg associated with Proactive Manufacturing are particularly noticeable on the south side of the plant where capital expansions associated with the Heavy Oil Upgrade Project occurred. To facilitate financial management of the loans needed to build the new equipment, that part of the plant started as a separate subsidiary company at the start, and workers were employees of that subsidiary. Although personnel and managers were drawn from the existing organization to work on the new equipment, the south side has the quality of a partially "green field" area. A single control room filled with dozens of computer screens controls multiple processing units; this affords different operational procedures than the older sections of the plant where small, unit-specific control rooms are the norm. Other innovations, for example the installation of a simulator for training of operators, helped create the idea that the south side would be a site of innovation and high performance. The manager in charge of setting up south side operations was also a particularly strong advocate for Proactive Manufacturing, carefully chose the workers for the new plant, and sought to infuse the new culture with this philosophy.

In our interviews with south side supervisors and hourly workers, we noticed a level of both consensus and enthusiasm that differed from the other section of the plant. One head operator put it as follows.

> *[On the south side] management and operations actually work together. They don't fight each other as much. It's not an us-against-them thing most of the time. I'm sure on the other side of the yard you hear that a lot… Philosophy is different from what I was used to on the other side of the yard. This was the first time I heard proactive. I didn't have a clue what it was. They actually try to be proactive here. Try to do routine preventative maintenance stuff. Actually do it, not just have it on paper. Try to head something off before there's a problem. Most of the time. It's totally different from the north side… First day I was over here, [manager] said this is how it's going to be, and it actually has been. Before people wouldn't talk to somebody that high. They never came around. Now you see them all the time. You can talk to these people just like you and I are sitting here talking. To me there's not that much animosity between the jobs… It was the purpose at the time, because if that project didn't go through, the whole plant would have been sunk.*

This quote indicates both the increased capability of the south side and the way that capability derived from being a site of novelty and innovation. Another head operator and the maintenance and operations supervisors were all highly optimistic about the culture and performance of their units. Some of the common worker-supervisor conflict and discontent we documented (described below) did not seem as active among south side personnel.

We also received reports from an outsider in the engineering team that meetings and cross-functional coordination practices were particularly effective. This led the first

author to observe two meetings – one planning meeting focused on maintenance activities, and one root cause analysis team inquiring into the repeated failure of a ventilation door on one of the units. Both meetings convened supervisors and hourly personnel from maintenance and operations as well as some engineering staff. Both were conducted with a high level of energy and precision as compared to the plant-wide morning handoff meetings we observed. And both meetings involved moments where the principles of The Manufacturing Game® were clearly and assertively brought into play.

At one point in the planning meeting, an operations supervisor named Max Neville paused the group to emphasize the importance of coordinating schedules among operators and maintenance to facilitate preventative maintenance activities. Then, a moment later, when a maintenance supervisor described a successful repair completion, Max again paused the conversation to emphasize the cost savings involved in that activity. This use of "teachable moments" to encourage a proactive and collaborative approach characterized Max's participation in the Root Cause Analysis meeting as well. When it seemed that the group was converging on a quick-fix solution to the failed ventilation door, Max emphasized the importance to endure extra down-time and operational cost to "fix it right the first time," using almost verbatim one of the slogans from Proactive Manufacturing that hangs on walls throughout the refinery.

These observations highlighted both the embedding of Proactive Manufacturing philosophy into the culture and practice of the refinery and the need to continually maintain it. Max's assertions of proactive approach are pedagogical – an attempt to change or maintain proactive principles. Later in an interview he emphasized the importance of ongoing work to stay in a proactive mode. A strong advocate of the Natural Work Teams (NWT) approach and host to what seems to be the longest running NWT, Max recounted his recent need to re-emphasize principles of disciplined operation with the team because safety incidents had begun to occur under his watch.

More generally, our interaction with Max also highlighted the importance of supervisors in maintaining shifts in organizational culture. Although his recent NWT meeting got labeled as the "ass-eatin' meetin'," it was clear that Max maintains a style of empowering management compatible with a workforce engagement approach.

> *If you tell people what to do, and give them the tools, most of the time they will produce it for you… that's why I'm talking to you relaxed because I know they're on the job. I have time to look down the road a bit.*

He encourages Natural Work Teams to form action teams to work on specific improvement efforts, for example on tolerance alarms or maintenance procedures. But these projects don't occur until a worker volunteers and educates themselves to become a "guru" in that area.

The difficulties that Max does face highlight the importance of the distinctive south-side culture. When he has had workers transfer from the older section of the plant into his unit, they have had trouble adapting to an atmosphere where they are expected to take charge and engage in continuous improvement. Four of the six workers who transferred there from a utility plant ended up returning to their old unit after the "ass eatin'

meetin'." Although the two that remained fit in better with the south side culture, one of Max's head operators expressed similar concerns.

> *It's slowly changing back the other way… That sense of being needed or whatever, don't know if that makes sense. It has gotten to the point where okay, you're established, we got what we wanted, now we're going to go back the other way. More friction, us against them. It's headed that way… Just a feeling. A sense… [When things were starting up] everyone was on the same page, we was all together, one big happy family. Now we're getting' new people over here, they didn't go through that. Sometimes the buy-in and stuff is not what it should be, in both directions. Both being management and labor or whatever.*

As we will discuss further below, the new intended behaviors and social structures of Proactive Manufacturing and continuous improvement are always subject to buffeting and retrenchment into pre-existing ways of operating.

General positive accounts

Beyond the specific stories and localized efforts, we heard general accounts that were consonant with the intended outcomes of Proactive Manufacturing and describe changes in the organizational culture.

> *One major thing I think Proactive Manufacturing did, and the idea of a cross-functional team did… prior to that, there was finger-pointing. There was the tendency to lay blame [among operations, maintenance, and engineering]. Lots of finger pointing and wanting to assign accountability to another organization. The one thing that Proactive Manufacturing has done by developing the cross-functional team approach… when we got an issue to be resolved, there is engineering, there is operations, there's maintenance, there may be enviornmental health and safety… whoever the right folks are, they get together and talk about it, and they solve the problem. And many times it goes undocumented…*
>
> *When you make the transition out of the finger pointing mode, and people work together on some of these things, when something doesn't go right, then if it's an operations issue then operations is much more willing to put their hand up and say "this is our fault. We let that bearing run dry. Or we let that pump run dry." Rather than try to cover it up and try to bring the maintenance guys or engineering guys to try to solve a problem that didn't exist in the first place.*
>
> *-Member of Management Team*

> *We ran this refinery for years as reactive. Every time something broke, run out there and fix it. We try to be very very proactive… Let me put it this way – we have to be, to survive, to be proactive. I have 8 guys, and several thousand pieces of rotating equipment. You do the math. There is no way you can repair all this if it's falling down all the time with 8 guys. We have to work smarter. The repairs we make have to last longer. The troubleshooting has to be better. The material we go to has to last longer. The conversations you have with operators – what*

actually is running in this? With the engineers – are we seeing H_2S in this? What is the limit on the amine here? We have to have better conversations, we have to talk better, we have to be more clear so that we can provide better equipment so we get longer runs on our equipment.

But the thing about Proactive Manufacturing, what that does is give you the big picture on how one piece of the puzzle affects everything else. That's what Proactive Manufacturing is about – it's seeing the big picture. You have to start there. You can't have people in their own little world, just working on this here. They have to understand this pump affects this unit, this unit affects this unit, this unit affects the other side of the refinery, which affects the whole refinery. Proactive manufacutring is to put in the minds of the people an understanding of how what we do – what every individual person does – how important it is to the whole organization.

-South Side Maintenance Supervisor

It seems to me that things have taken time but things have changed. It has taken a long time but has had some effect. They stayed with the program so long that it's now part of the culture. But there are still those who don't buy in… They don't believe in it… Some of them, they are just old school, old paradigms, where it's "once again, here's another program." Apathetic look – like "that won't do nothing for us." But if you look at it in long run, I think it really has improved things… The improvement in the attention to the equipment, and the seriousness of keeping equipment in good shape.

-Hourly Operator

For the maintenance managers, Proactive Manufacturing has been a powerful influence. As Carroll, Sterman, and Markus (1998) point out, maintenance is not part of the "image" of a plant, usually being considered a service or cost center. The Manufacturing Game® attempts to shift that discourse and thereby legitimate the role that maintenance plays in plant performance. Proactive Manufacturing is, for them, an ideology and a way of life – in essence, the right way to do the job. Their narrative of success is woven with a narrative of the "good old days" and of a lost hero in the form of the plant manager Eli Larson. In a group interview with the second-line maintenance supervisors:

S – Eli Larson brought Proactive Manufacturing, Productive Conversations. People thought it was flavor of the month. But driven by plant manager who walked the talk. Operations and maintenance was us and them. We got more trust and respect - issues easy to solve. Eli set expectations, you knew where you stood.
W - Eli preached it every day - talked about it every day. Pounded in idea of reliability. Insisted that we fix things right - long term solutions. Eli knew everyone.
S - Knew weaknesses and strengths. Empowered you to do work. Best manager I've ever seen.

Other directors in the management team – engineering, health/safety/environment – take the stance of favorable bystanders who reaped ancillary benefits from the program.

> *The action teams that were spawned out of the Proactive Manufacturing workshop concepts, and the notion of employee involvement and getting employees directed towards solving problems was a way to real solutions… I love that concept. That was something that OldCo really tried to get going through a quality movement in the late 1980's with some limited success. It really took off here, and helped in the environmental area because a lot of the problems – equipment reliability problems – one of the consequences of those problems are environmental emissions or excursions.* ***So people working on those problems were solving my problems.*** *And also there were several teams… in fact I counted at one time there were at least 23 teams – Proactive Manufacturing teams – that were working on solutions to environmental problems.*
>
> *[I ask him to compare TQM and Proactive Manufacturing]*
>
> *I would have to say… I would have to give the edge slightly to the Proactive Manufacturing movement here. I think it was more effective. I think it won over more people than the quality movement. I think people attended a lot of the quality meetings and training classes because they were obligated to do it but in my recollection there wasn't that level of volunteerism and commitment to the movement that we had in Proactive Manufacturing. PM had the edge. I also have to say that Eli as a leader of it, and face and spokesman for it… he was much more effective than his counterparts in the quality movement… He was determined to win over the hearts and minds… he was really committed and really believed in it, and he was determined to persuade as many people as he could at Port Arthur that it was really the way to success and sustained success, through reliability. Reliability in our equipment, our procedures, and even our people. We had to eliminate breakdowns and failures, and wherever we did that, success would follow in all these other areas. It was a very compelling argument.*
>
> *-EHS Manager*

The current plant manager, who assumed his position when Redberg was acquired in 2005, is intrigued by what occurred, and is interested in the findings and recommendations in our case study as part of his thinking for how to go forward.

Other supporters include supervisors and superintendents from both maintenance and operations. Typical benefits cited include:

- Improvement of Mean Time Between Failure and other measures of reliability
- Erosion of "us and them" between maintenance and operations
- Fixing it right the first time – going an extra step in maintenance activities, realizing that doing so leads to reduced workload in the long run – "If you can get to a place where mechanics can do preventive maintenance and not fight fires all the time."
- Ease of pulling together teams to work on necessary repairs and improvements

Plant-level performance

As we can see from these responses, Proactive Manufacturing seems to have had a powerful effect on aspects of plant reliability and on the organizational culture surrounding maintenance and reliability improvements. The contrary views highlight some challenges the program has faced, and the need for ongoing reinforcement of the ideas, but the picture is on the whole positive.

When we examine the unit-level and plant-level reliability data, that picture is somewhat less clear as we will see below. To the extent that the program was successful in improving reliability of the equipment, we would expect to see improvements in mechanical availability and uptime, with concomitant increases in profitability. We might also expect to see a decrease in safety and environmental incident rates due to equipment failures. While substantial performance gains are evident, their timing relative to the simultaneous influence of the Heavy Oil Upgrade Project (HOUP) and Proactive Manufacturing make causality difficult to determine. What we found was that this ambiguity kept sensemaking active and allowed for multiple interpretations both for us as researchers and more importantly for people working in the refinery.

Plant-level up-time and reliability

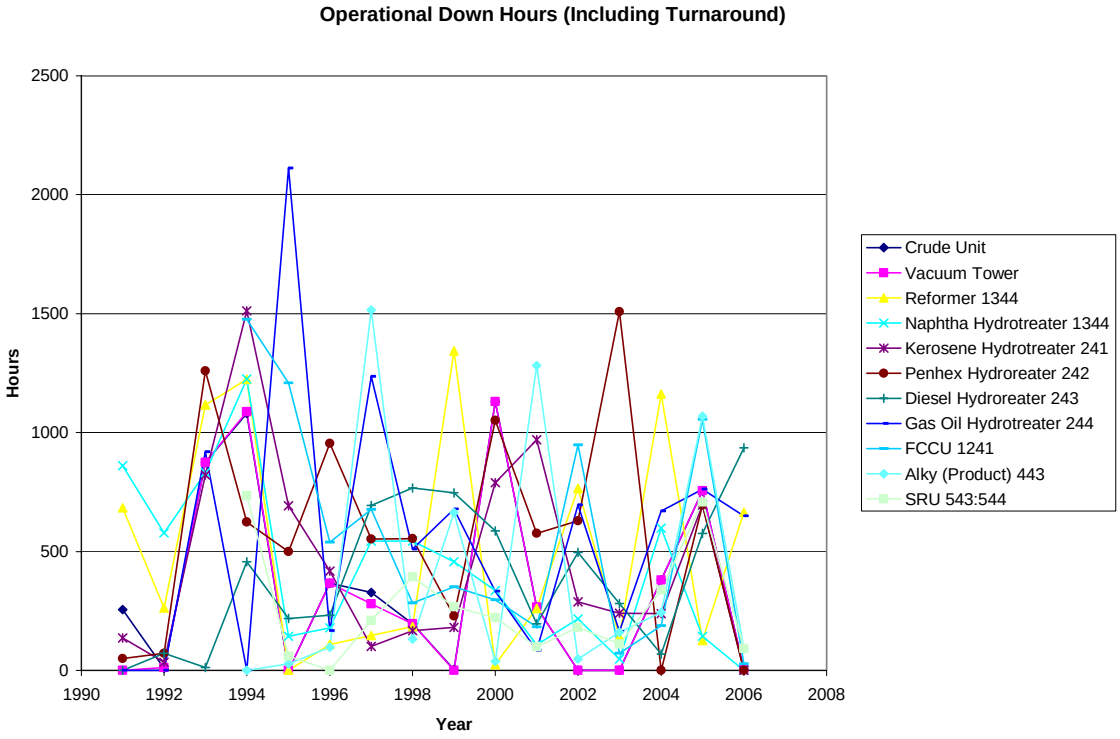
Reliability of the plant is measured by counting the number of hours during which processing units are taken offline, and comparing it to the ideal case of full operation – 24 hours per day, 365 days per year. The difficulty in accounting for these "down hours" is that there are several reasons why a unit might be taken offline:

1. Unplanned maintenance, as during an equipment failure
2. Planned maintenance or regulator inspections, including turnarounds that occur at regular intervals
3. Economic down time, in which one unit is slowed or shut down because its product is less profitable than others' in the plant
4. Shutdown of equipment upstream or downstream of the unit that require the unit's shutdown in order to halt the flow of product

In order to examine the impacts of a reliability program, it is best to look at *operational availability*, which is based on categories 1 and 2. Category 3 is omitted in order to exclude the influence of external price fluctuations that yield economic downtime. Category 4 is omitted in order to avoid double-counting outages due to mechanical failure (although doing so creates a conservative measure of the impact of operational down time).

The graphs below present operational downtime data for 11 of the plant's 19 units. These 11 were selected because reliability data was available for the period 1994-2006, with some data extending back to 1991. A simple graph is presented as Figure 4.

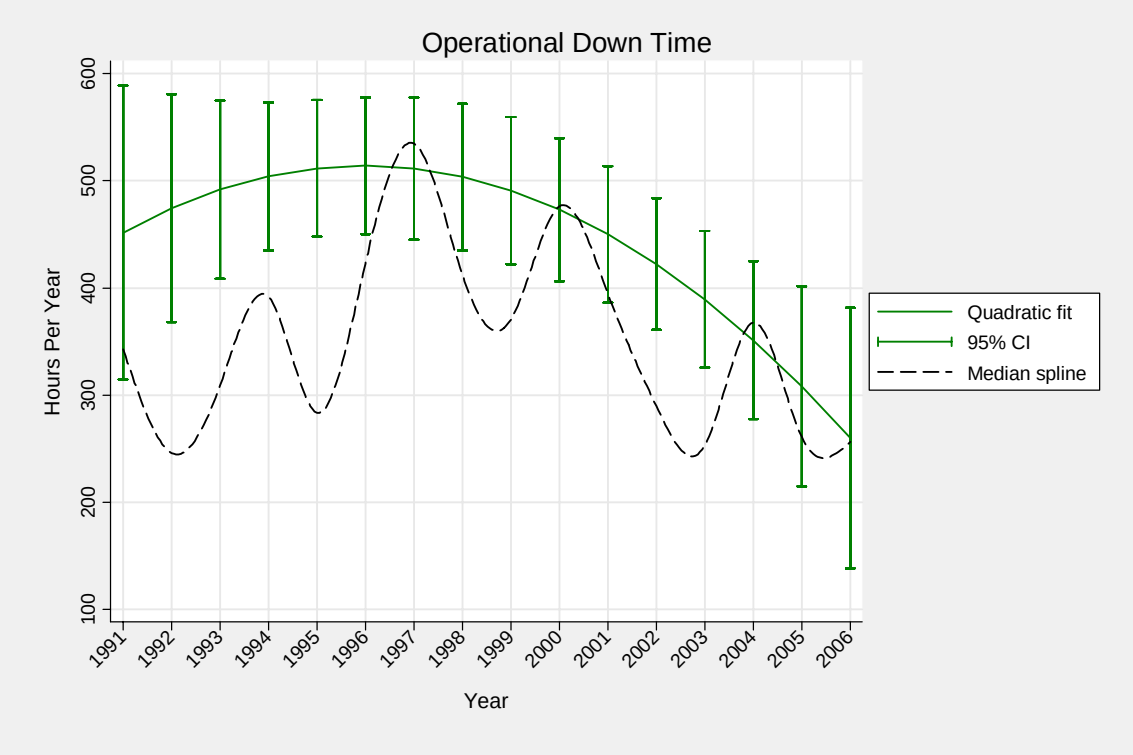
Figure 4 - Operational Down Hours for selected units



The challenge of making sense of this graph puts readers in the shoes of people inside the plant. First, no time series graph of this sort had been produced as part of the archival materials we saw. Plant level data about reliability, combining data from multiple units around the refinery, is available primarily to personnel in the operations services group. Quantitative data is not, of course, the only raw material for sensemaking – direct experience of working as an operator or maintenance technician certainly grants a sense of trends over time, and discontent with poor availability of equipment can get conveyed through stories and other kinds of talk. But a systematic analysis of trends over time, let alone their connection with interventions like Proactive Manufacturing, is beyond the likely scope of such conversations. Reliability data, whether presented quantitatively or through conversation, must make sense of complex stochastic processes involved in the failure of equipment and the need for maintenance. These ongoing change processes *in the equipment itself* create ambiguity about the influence of systematic, deliberate intervention.

For the purposes of our analysis here, however, we were more precise with the data available. Following the recommendation of the plant's reliability engineer, this somewhat chaotic data can be smoothed out by normalizing the effect of planned turnarounds. For each of the units, the number of down hours due to turnaround was summed and averaged over the period of observation, yielding a measure of Adjusted Operational Down Hours. This measure can serve as a dependent variable in regression analysis, with measurement year as a predictor, in order to analyze trends in operational downtime.

Figure 5 - Operational Down Time, analyzed across 11 refining units.
Planned turnarounds have been normalized across the observation period.



Here in Figure 5 we can see that there is a general downward trend in operational down hours in the plant, and thus an improvement in operational reliability. The polynomial regression has a somewhat better fit than a linear regression, however (Linear: F=6.75, p=.01, R2adj=.0335; Polynomial: F=5.38, p=.006, R2adj=.0501). This indicates an increase in operational down hours, peaking in 1996, followed by a decline. This is not the pattern one would expect if Proactive Manufacturing (which began in earnest in 1999) had been the most significant influence on reliability. Instead we see improvement beginning in 1995, which is consistent with the idea that pre-Proactive Manufacturing efforts to improve reliability may have had an important influence.

Still, the data does not contradict the idea that Proactive Manufacturing helped. The median spline in Figure 5 shows rough behavior over time for operational downtime at the refinery. In particular, from 1999 to 2003 we can see a pattern that could be interpreted as a "worse before better" transition – an increase in operational down hours for proactive maintenance in 2000 followed by an improvement in plant reliability over the subsequent three years. Following this same logic, however, we could say that there is a larger worse-before-better pattern coinciding with the overall tenure of SmallCo from 1995 to 2005, beginning before Proactive Manufacturing.

Health, Safety, and Environmental Results

As the refinery's manager of health, safety, and environment (HSE) indicated, many of the Proactive Manufacturing efforts were focused on safety and environmental problems

in the plant. If successful, the program should have had an effect on the plant's performance in these domains.

In the safety realm, data is readily available in the plant due to reporting requirements by the United States Occupational Health and Safety Administration (OSHA). Job-related injuries, whether by falling off a ladder, being burned by hydroflouric acid, or getting a paper cut in an office, must be recorded and reported to OSHA. The refinery had records dating back to 1993. As a benchmark for these data we used the petroleum refining industry average (USDOL-BLS, 2007). Trends in the refinery and industry data are plotted in Figure 6.

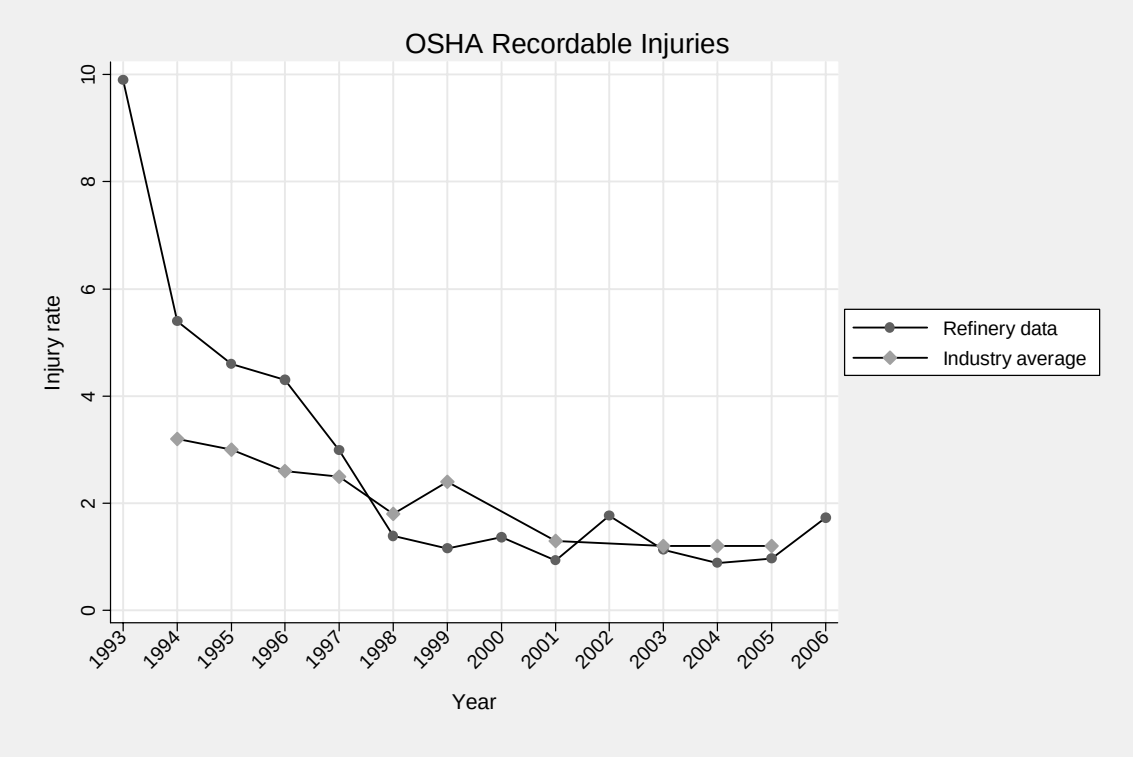


Figure 6 - Safety performance: OSHA Recordable injuries per 100 full-time equivalent workers. Petroleum refining industry average included as benchmark

Here we can see a general downward trend in the injury rate, with the most significant improvements occurring between 1993 and 1998. These improvements moved Redberg's injury rate from high above to somewhat below the industry average. Since then, the refinery has won more than thirty industry awards for safety performance, and achieved milestones such as 1 million man-hours without a serious injury (i.e. one resulting in lost work time). These performance gains were likely due to targeted behavior change programs initiated by the HSE department, including significant rewards for safety performance. One such program included a pickup truck raffled to one of the workers, contingent on the plant's meeting its safety goals.

Notably, however, these improvements occurred before the implementation of Proactive Manufacturing. If we examine the period after 1998, when Eli Larson arrived and initiated the program, we see a pattern of bumpy but flat performance in the OSHA recordable rate. A linear regression on the post-1998 data reveals no significant change

over time (t=.25; p=.814). This pattern implies that either Proactive Manufacturing had no effect on this metric, or that its effect was eclipsed by simultaneous increases in recordable injuries, such as might occur in the south side construction activities.

On the environmental side, we can examine the two most common types of environmental pollution – oil spills and airborne emissions in excess of the refinery's permits, both of which are tracked and reported to the US Environmental Protection Agency. Unfortunately the same industry-level data were not available from the EPA for comparison, so we simply include the trends in reportable spills and emissions in Figure 7 below.

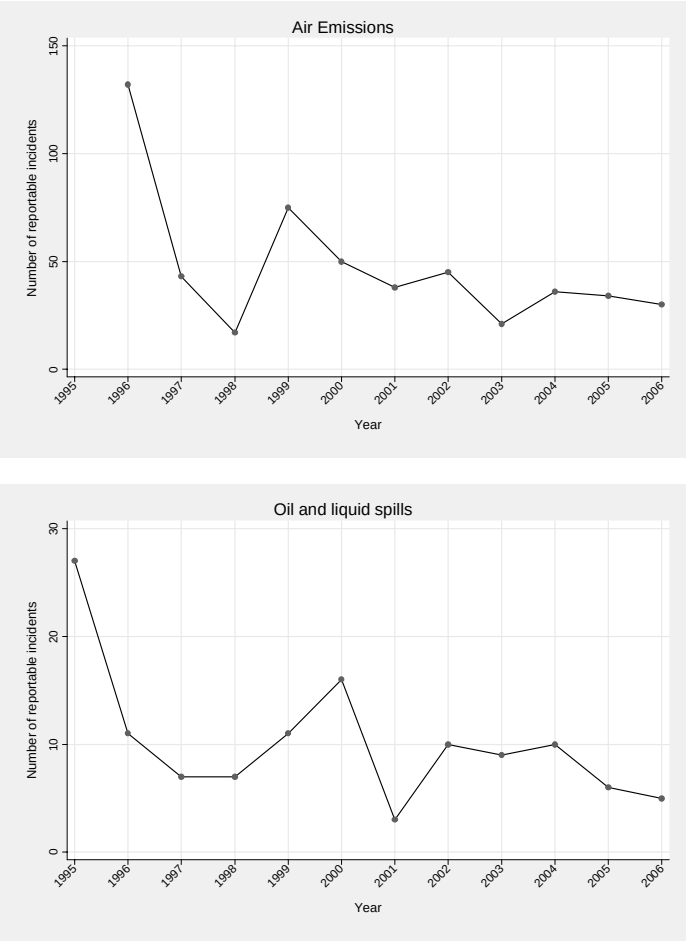


Figure 7 – Environmental performance: Reportable air emissions and liquid spills, for years with available data

In the case of these environmental excursions, we see a similar improvement in plant performance over time, at least for the period with available data (1995-2006). Much of the improvement in environmental performance, however, occurred prior to 1998 and the initiation of Proactive Manufacturing. In fact both graphs show *increases* in the number of environmental excursions around that time, with improvements that follow.

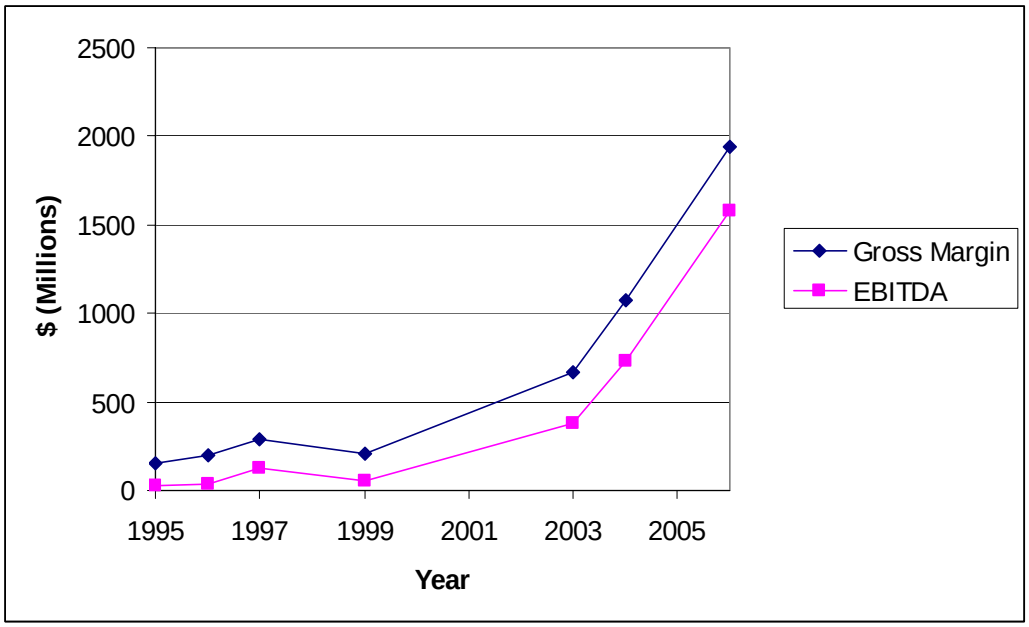
We can examine whether Proactive Manufacturing coincided with improvements in these metrics by examining data from 1999 onwards, when the program was in effect. For liquid spills, there is no significant improvement during the 1999-2006 period (t=-1.48,

p=.19). For air emissions, there is small but significant improvement over time (t=-2.87, p=.028). These latter improvements may be due to the Proactive Manufacturing efforts, but as with the safety data, any effects are confounded by simultaneous programs that took environmental performance as their primary focus. In 2000, for example, an environmental awards program was instituted that offers a cash bonus to all workers in the plant if environmental targets are met. The sharp decline in liquid spills following the initiation of that program may be indicative of its success, as well as longer term changes. But such causation is impossible to infer from data available either to us as researchers or to the plant personnel.

Financial Performance

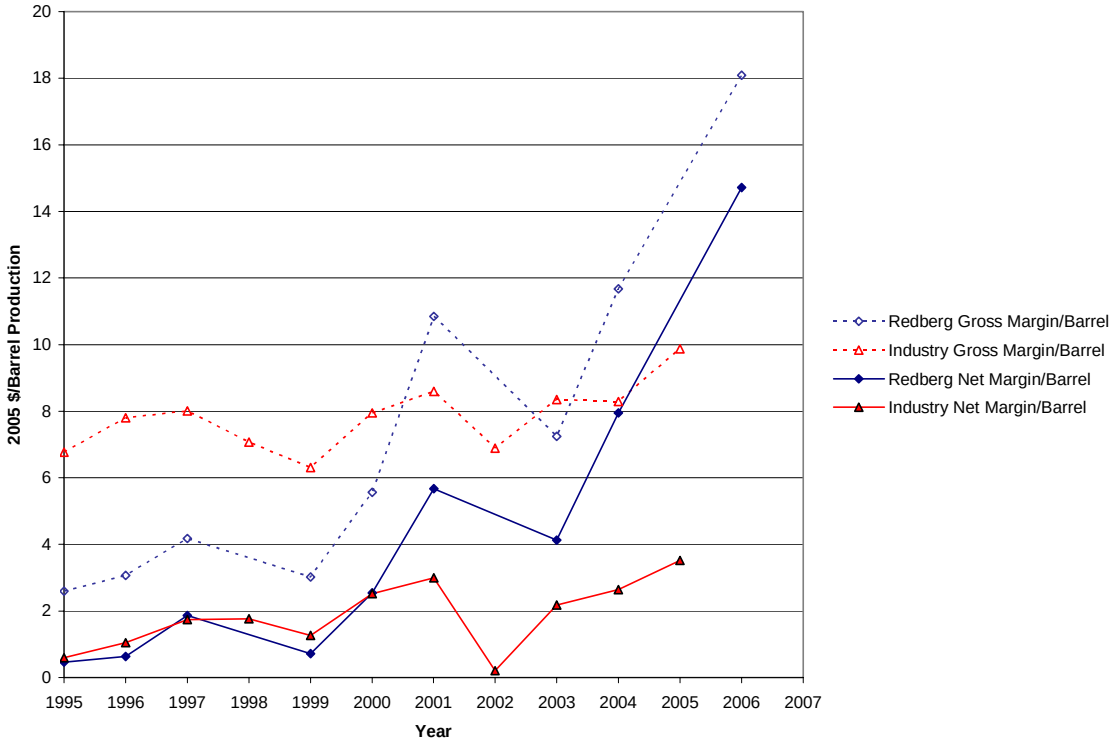
Archival sources from the plant show that during the period under study, Redberg Refinery enjoyed substantial gains in financial performance. The following graph of the plant's gross margin and EBITDA depicts this trend.

Figure 8 - Financial performance of Redberg refinery



From refinery earnings in 1999 of $50 million, we see an increase by a factor of 31.5 to $1,580 million in 2006. By using measures of gross margin and net margin per barrel of production, we can compare these performance measures to those of the refining industry as a whole. Doing so allows us to account for the effects of fluctuations in crude oil and refinery product prices. Industrial comparisons for financial data are taken from the U.S. government's Financial Reporting System Survey (USDOE-EIA, 2007). Here we can see that the refinery began to exceed industry performance in 2001, and has continued a trend of increasingly outperforming the industry.

Figure 9 - Redberg financial performance compared to industry average data from USDOE. Gross and Net Margin measured in US$/Bbl of refinery production



Much of the performance gain visible in these graphs appears due to strategic business decisions made by SmallCo. When SmallCo purchased the refinery, they did so in partnership with a private equity group who invested upwards of $850 million in alterations to the plant. The financiers did so because SmallCo had brokered a ten-year deal with an foreign oil company, allowing Redberg to purchase heavy, sour crude oil for an attractive price spread below the market rate for the more standard West Texas Intermediate crude oil. The investments in the plant were necessary to process this new supply – a decoker and hydrotreater to handle the heavy molecules and an extensive sulfur processing facility to handle the "sour" sulfur content. The contractual price guarantee was needed to ensure that the substantial capital improvement loans could be repaid.

These expansions all occurred on the south side of the plant, divided by a road from most of the older equipment. To assist monitoring and operation of this new equipment, a state of the art centralized control room was built – two rooms full of computer screens, complete with simulation capability for training new operators. Collectively, these expansions were known as the Heavy Oil Upgrade Project or HOUP.

People in the plant are unanimous that the guaranteed margin associated with the heavy sour crude deal was a boon to the plant's financial success. The financial data for the plant show a significant improvement in 2000 associated with this change. The later refining market conditions made this investment even more profitable than had been originally forecasted.

Some informants, particularly in the operations services group, also emphasize the importance of the plant's flexibility in offering a dynamic product mix to the market. This flexibility of production if afforded by three elements of plant capability: the ability to handle multiple kinds of crude oil, including heavy sour crudes; sophisticated monitoring and control systems allowing fast changes in operational plans; and cross-functional skill and collaboration necessary to handle changes in supply and product mix.

Given the significant increases in financial performance, members of the refinery and consultants rightly regard Redberg to be a breakthrough success story. When we asked why some of the consulting activities around Proactive Manufacturing had been discontinued, one manager said, "what do we need consultants for, to help us count our money?"

Interpretative Flexibility

The trouble, as mentioned above, is that the simultaneity of multiple change processes produces interpretative flexibility about the *cause* of Redberg's success, whether in the financial, safety, or environmental realm. Faced with ambiguous internal data, employees and managers face the same challenges we do as researchers. Is the plant successful because of Proactive Manufacturing and a highly committed workforce, because of the technical capabilities enabled by capital expansions, or because of business environment changes and improved market prices? Teasing apart these three effects would require a prodigious accounting analysis that the plant's financial team has not conducted. Differentiating the effects of Proactive Manufacturing from those of focused safety and environmental programs on HSE performance would be even more difficult. Making sense of the plant's history therefore falls to the individuals and political factions involved.

For the designers of Proactive Manufacturing, the intent was to create deliberate synergy.

> *The investments that had been made over the last four years or so was just a very bare maintenance but probably not even called a sustaining maintenance level. So some of the facilities had regressed and degraded, and reliability, you know, wasn't good. A lot of room for improvement. And of course then when I got there, it was very obvious to me anyway that we had a huge project that could be very very economically viable and yet it was all dependent upon good safe and highly reliable operation of the old plant. It was all fully integrated together – you could not run one without the other. So then that's when we decided to take the same approach – pretty much the same – as was done at Heartland, in terms of using the Manufacturing Game, bringing in all the people, putting them through the two day workshops, making them become familiar with the theory behind it. Forming action teams to go off and make improvements. And starting a CI Forum… with pretty much the same representation as at Heartland.*
>
> *Eli Larson, former plant manager*

For some people within the plant, however, their own sensemaking has led them to a more binary conclusion.

I can tell you right now, Sam Taylor was probably the biggest factor in getting the [heavy sour crude] deal and making Redberg what it is today… Between Taylor and the deal and the plans for the decoker and then [SmallCo CEO] going on through with it and everything else, by the time Eli Larson came in here, he was just basically a figure head. Everything had been set up as far as moving forward. He came in as a plant manager, nothing else. His deal was the Proactive Manufacturing and the CI Forum – that was his big push for anything, so… And really what put us in the place of where we are now is Taylor, the CEO, and, you know, the money… they were fixin to spend a billion dollars on this place and it wasn't worth at the time… in fact they were still tied up in debt with OldCo. So it was a good PR program, it was a good group that went out there and did the financing. Like I said, Larson came in… his part in it was a whole lot less than the rest of them, almost non-existent… He stayed for, you know, quite awhile and ended up smelling like a rose. He is one of those guys who landed in the right spot at the right time.

This quote comes from an hourly maintenance worker who is the head of a union in Redberg, and presents a contrary view – that success derived from strategic changes and capital expansions, and Proactive Manufacturing was irrelevant. This quote indicates how political contests within the refinery – such as those between union, supervisors and management – can shape the data people look for and the conclusions they draw. Given the interpretive flexibility of the data available, there is no objective arbiter among these perspectives, which have real consequences in the way events play out as will emerge below. People held closely to their perspectives and accumulated supportive experiences, thereby reducing any need for, or influence of, data that would confirm or refute their personally held views, or of those views of the people with whom they identified themselves.

Conflict and Controversy

In the course of our interviews, a number of people expressed negative views of the program and the plant as a whole. Although their causal reasoning differs, there are two things that most of these attributions and narratives hold as their focus. The first is the degree to which a "proactive" approach to maintenance and equipment repair has actually been implemented at the plant, as part of Proactive Manufacturing or otherwise. The second is the failure of the program, particularly the Continuous Improvement Forum, to gain significant participation from the hourly workforce. This non-participation, and the change in CI Forum over time, illuminates dynamics worth considering in the implementation of similar programs in other contexts.

Perceived limitations to Proactive Manufacturing

Most of those who described limits to the Proactive Manufacturing approach said that the plant had failed to implement one of the key lessons of The Manufacturing Game®: that you have to spend money on maintenance to get out of a reactive mode. Some attributed this to the fact that SmallCo, the owner of the plant when the program was implemented, was short on funds and was unable to invest in plant upkeep. Others felt that managers simply hadn't learned the lessons of the Game. Nearly every operator we spoke to, and

several supervisors, could name a few pieces of equipment that had been awaiting repairs for what they thought was an excessive period of time.

> *SmallRefCo was tight on cash and lots of stuff wasn't implemented because they didn't have means. They fell by wayside. For example, there is one thing where we could switch a turbine drive with a motor drive to get better steam balance on one of the units. We could use less 15 lb steam. Typically we vent and lose energy. They knew about that for years but never did it because of money. Even now hasn't been done.*
>
> *-Maintenance planner*

> *Across the street they always had two big huge wet gas compressors. You'd run one one month and then you'd go over there, and the other one would be slow rollin' and you'd switch over and run it, and do any maintenance you had to do on that other one. Sometime about 5-6 years ago, they took this equipment and they just decided that, well, we'll repair it and we won't run it. So what it did is it set over there and it had some problems with it… the refinery fuel with H_2S in it, it's got corrosives in it, well, it eat up the shaft in there. So they had to pull the shaft out and replace it, and worked on it. But I'll bet you that dang compressor hasn't run in over three years. Runnin' wet gas through it. And you would never see that before, you'd always see them maintain the equipment and swap from one to the other. Now basically you've got one compressor over there and if it goes out, you're going to the flare. And you don't have a backup to do it. So it's gonna be a loss of product, it's gonna be a loss of, you know, I guess you could say an environmental excursion. It's gonna be all kinds of stuff because it wasn't deemed necessary to maintain the equipment… The guys over here would speak up about it. They would say, "this is a situation where you don't want to get into." And they'd hear, "well, you know, we're not gonna spend the money, or you know it costs too much," and I think that's kind of like that BP [Texas City refinery disaster] deal – you get to the point where these guys in those downtimes look for so many different ways to cut cost, that you know it's to the detriment of the people, the jobs, and the actual bottom line of the corporation. It's an immediate impact. I guess from workin' out here through OldCo, SmallCo, SmallRefCo, NewCo… that it's a short term fix for a lot of things. They don't do a long term… because I guess you could say maybe they won't be around. Why worry about it if we're not gonna be around?*
>
> *-Maintenance Worker*

Others acknowledged investments in reliability, but emphasized that these had occurred during Sam Taylor's management tenure in the early days of SmallCo's regime. Given the curve in reliability data that begins declining in the mid-1990's, this is a plausible interpretation, one that downplays the role of the action team projects described above.

The critical thing we noticed, however, is that these views were much more likely to be expressed by informants who had other concerns related to political conflicts within the plant. Given ambiguity in the data, people interpreted the success or failure of the program through the lens they wore. To understand the sources of these political

conflicts, it is necessary to look at other stories told about the history of the plant that emphasize separation between management, supervisory, and hourly worker levels.

Policies differentially affecting hourly workers, supervisors, and managers

While some degree of conflict among hourly workers, supervisors, and managers is expected in any manufacturing facility, particular events in Redberg's history helped shape the norms and interpretive schemes that interact with those of Proactive Manufacturing. One of the most salient processes that people discussed was the change in management when SmallCo first purchased Redberg Refinery in 1995. The new plant manager Sam Taylor and his management team, along with the investments in the HOUP, established a relationship with the union leadership in the plant that had not existed under OldCo. A Union-Management team was formed, which was designed to address consistent grievances that union membership had and to engage hourly workers' help in improving the plant.

As part of these activities, union leaders were given an opportunity to *name supervisors that they wanted fired* because of conflict with hourly workers. One story about this process, told in hushed tones, was that the HR manager and union leader would sit in a room and invite one supervisor after another, at which time the HR manager would ask, "Should we keep him?" Along with the firings, the plant management instituted an "open door policy" allowing workers to come to managers with complaints about their supervisors; managers responded by overturning some of the supervisors' decisions. One story to emerge along these lines was about an overtime lunch policy, in which a supervisor tried to follow a plant policy about the provision of lunch for workers on overtime.

> *I didn't feel that SmallCo held honesty and integrity very high on their priority list… They would try to promote an initiative behind closed doors but when we tried to manage it in the plant, we got no support…. Things as simple as an overtime lunch – this is a small example but indicative of the philosophy. We met with all the supervisors and they said, you will administer the overtime lunch policy. If you work overtime, from the graveyard over to today, it's an unexpected overtime so you are allowed to order breakfast. In some cases you can order breakfast and lunch. Supervisors were trying to administer that policy. It wasn't long before one of the hourly workers called the managers and said, "I think I deserve a lunch." The operator thought it was unfair. We administered the policy as it was written. Instead of getting two overtime lunches he got one. Or might have been the dollar amount. But the plant manager overrode and completely redid, and I guess gave in to the guy.* ***We felt like he cut that supervisor off at the knees.*** *Eliminated any authority or credibility that supervision had in the plant. From that point forward it became common practice – word gets around – that any time an hourly worker didn't like something, they went around the supervisor and the area supervisor directly to the plant manager. In all the years I've been in the plant, the SmallCo senior management was the weakest we've ever had. Weak in leadership. I think we developed some bad habits. We developed some philosophies that we're having to change now and that we started to change when Eli Larson came on board.*

-Member of plant management team

While these moves intended to show management's seriousness in engaging the hourly workforce, the unintended consequence was to alienate and frighten supervisors. The phrase "cut off at the knees" emerged in several interviews with people who had been supervisors in this time period. In response, the supervisors banded together to organize a facilitated session in which the "97 Issues of the Supervisors" were elicited. These 97 Issues served similar function to union grievances, most of which asked for clarification about compensation and policies for supervisors and their workers.

It was in this context that Eli Larson arrived and brought Proactive Manufacturing. On the one hand, the intention of the program was to unite people across levels and functions in the organization, through mechanisms like action teams. On the other hand, the program itself became an object of interpretation within the political landscape of the plant. The same supervisor who had helped organize the 97 Issues and "almost got myself fired" showed great passion and interest for Proactive Manufacturing and was promoted to operations manager in part for this reason. Because the earlier moves had made the distinction between supervisors and hourly workers particularly salient and contentious, these later moves made Proactive Manufacturing vulnerable to appearing as a management endeavor (and CI Forum as a "management meeting") instead of something more integrative.

In addition to these events, several other actions on the part of SmallCo's senior executives (above the plant management level) served to reward some people while alienating others. All of these occurred after Proactive Manufacturing had begun, and shaped the way management and management initiatives were perceived. These include:

- Personnel cuts: Due to shrinking margins and cost pressures prior to the company's IPO, a 25% reduction in salaried workforce occurred in 2002, known internally as "Black Monday." Hourly workers were protected by their unions but supervisors and staff were not.
- Changes in gainsharing plans from a constant 8% up and down the organization to a stratified plan where hourly workers stayed at 8% maximum while supervisors could get 25%, superintendents 50%, and the plant manager 125%.
- The CEO retiring with a $93 Million pay out, at roughly the same time that this stratified policy occurred.
- Exclusion of hourly workers and supervisors from participating in the company's IPO, after the expectation had been set that participation would be possible
- Changes in benefits programs that went around standard union negotiation processes, an action perceived as using loopholes in union contracts to impose managers' agenda

Although the personnel cuts directly affected the Proactive Manufacturing activities by removing advocates and organizers, the other events do not directly affect the continuous improvement process. All of them, however, were cited by multiple personnel as relevant to the credibility of worker involvement efforts, and as grounds for non-participation on the part of union committee members and their hourly constituents.

Much of the research on high performance work practices, high-involvement employment practices, lean manufacturing, and similar "post-bureaucratic" organization styles (Macduffie, 1995) emphasizes the importance of coherent logic with consistent practice "bundles." In Japanese or Japanese-influenced manufacturing plants, this logic involves the kind of employee involvement in improvement efforts that we see at Redberg Refinery, along with human resource management practices that ensure job security: long term employment; training for new and continuing workers; job rotation; and pay based on skills, training, and company performance. Vallas (2003), drawing on Barley and Kunda (2001), emphasizes that these practices constitute normative control, providing a moral grounding for the exercise of managerial power. These moves, while not carried out by the immediate implementors of Proactive Manufacturing, nonetheless affected the way it unfolded. The easiest way to see a decline in confidence, particularly among hourly employees, is by looking at the Continuous Improvement Forum, or CI Forum.

CI Forum – From Continuous Improvement to Centralized Information

Although the original activities required the participation of everyone in the plant, the ongoing CI Forum is a voluntary activity, offering a free lunch for those attending. Its purpose is to sustain an ongoing focus on continuous improvement activities, to share successes and progress with plant personnel, and to handle issues and challenges arising in the course of defect elimination efforts. While some hourly workers continue to attend CI Forum, the number appears to hover around 1-2 out of the 800 in the plant. Of the 40-50 who do attend regularly, the vast majority are supervisors and staff. These results parallel those by Vallas (2003), who found similarly narrow participation in continuous improvement activities at a paper mill. There are a number of causes that people cite, which we outline below.

The simplest cause for worker non-participation, and one of the most frequently cited, is that it can be difficult for hourly workers to leave their regular posts. The CI Forum happens the third Wednesday of every month, at lunch time; for people on a day-job rhythm, this can work. For hourly workers on 4*12 hour shifts each week, it means staying significantly late or arriving significantly early at the plant. The choice of meeting time is, of course, a political question – when asked whether the time might make it difficult for hourly workers to attend, the organizer responded "maybe if we played with the time we might get more hourly folks," but there is little active engagement with this question that we could see.

The more provocative explanations focused on the policies described above as creating divisions between managers, supervisors, and hourly workers. The fact that CI Forums are now attended by far more supervisors than hourly workers may be a symptom of this division. One trainer, who had an earlier career as a well-respected supervisor, said it succinctly: "It's a management meeting." One of the union leaders, whose opinions and actions are no doubt influential for other workers, told the following story.

> *One of the things they always did, whether it was contractors or company personnel, they always provided you the resources in the area you were doing the shutdown. Because what happens is your manpower is multiplied in that area… So the facilities here such as water and sewer and all that is not adequate to take*

care of it. So ever since I've been here… they moved, you know, John-on-the-spots in, wash stations in, and more water, all that kind of stuff. Well, after SmallRefCo got started with the CI Forum, I was working on a shutdown over on the next unit… and they didn't have water. So, you know, one of the questions I had was I talked to the unit supervisor and said, "We need some drinkin water stations over there." And they said, "They can come over here and drink water." And I said, "Well that's counterproductive, because they're not working over here, they're working over there." He said he wasn't gonna do it. So I called HR department and said hey, we got some problems here. If we're going to be this… get into this… CI Forum, with all this change and all this innovation… we can't even do what we've maintained in the past! I need some Gatorade or something over here. I had to go pick up a case of Gatorade to bring over there. I tell you what it was the biggest rigamarole you ever did see just to get water over to the people who were working. After that is when I dropped out of the CI Forum. I said, if y'all can't make any more sense about providing for your working people than you are, then there is no sense in me going to the CI Forum because y'all aren't really concerned about what happens to the working people. So, that was the last time I went to the CI Forum.

In a similar story, one hourly operator, Carl, who had been heavily involved in CI Forum, was concerned about an issue in his part of the plant that affected operators' quality of life in working there. Carl tried to bring up the issue repeatedly, which generated friction with his supervisor. The supervisor asked him to "shut up about it" and then Carl abruptly stopped receiving emails related to the Forum. It is difficult to uncover exactly what happened, but it appeared that the supervisor told the organizer that Carl wanted to be removed from the list. Following this incident, Carl never returned to CI Forum or participated in any of the activities.

Carl's exclusion is an interesting case for three reasons. First, because he was highly active in the Proactive Manufacturing efforts prior to this incident, he is a good case for analyzing strong reasons for non-participation. Second, his complaints were perceived irrelevant by supervisors, highlighting the fact that hourly workers and supervisors have different issues they consider important. Third, the supervisor's stance towards Carl and deliberate exclusion may have been a result of the early supervisor-hourly conflicts, a way of re-asserting supervisory authority (although this is speculation). The net effect is to both exclude an hourly worker and exclude a voice willing to raise negative issues. The accumulation of such events would tend to make CI Forum both a management meeting and meeting more focused on success than challenges.

Elaborating on this idea of CI Forum as a pat-on-the-back management meeting, one of the hourly workers put it more colorfully:

I was asked to go maybe 5-6 years ago and I went and it was like a big giant suck ass session. Some people just couldn't control theirselves because the plant manager was there. I'm like… you can't tell the man the truth when he's sitting there, then what's the point? … You know what I mean when I say kissing up to the boss. These are supervisors or other salaried type people and their whole agenda was to get in with the plant manager and get higher up. Kind of destroyed whatever they were trying to do for maintenance. [The maintenance director]

asked me why I didn't go to more CI Forums and I said I couldn't take all the sucking ass and he said I can understand that, it's pretty bad. So even upper management knows it.

Colorful language aside, there are several features of the CI Forum as practiced that may bias it towards an exercise in ingratiation. First, attendance is recorded and monitored, and at one point there was a KPI for supervisors about their own attendance and the attendance of their hourly people. This was a controversial move – some advocates of the forum felt it critical to keep it voluntary. Monitoring and rewarding CI Forum attendance may select for those supervisors most interested in ingratiating themselves with the plant management.

Second, while the intention of CI Forum may have originally been to discuss issues arising in the course of doing continuous improvement, the emphasis has been on describing success stories. While this function of "celebrating" achievements may provide an incentive, it also sets the tone of not raising issues perceived as negative, and even suppressing them.

Third, over the course of the CI Forum's evolution, it seems to have become increasingly focused on information provided by the plant's management team. One of the original purposes of the Continuous Improvement Forum was to make improvement visible to the supervisors and workforce by presenting data about plant performance. This tradition was set by plant manager Eli Larson, who was the first to make some of the financial numbers transparent, along with measures of equipment failure rates and reliability. As the CI Forum has evolved, the tradition has been to have each of the management team members present the data they know best: the financial manager presents revenues, costs, and margins; the HSE manager reports incident rates; the operations services manager presents rate and reliability; and so on. And, in fact, the people who do attend CI Forum, including hourly workers, describe this as the most valuable part of attending, because it gives them an indication of what is going on in the rest of the plant.

The trouble is that, as a result, CI Forum has therefore become a predominately one-way communication device. Most of the time is taken up by these presentations. As one supervisor put it:

I'll be honest with you, I have mixed feelings [about CI Forum]. Sometimes it's like a show. It's entertainment…

Sometimes I just don't want to go. I don't want to go there because I don't think I'm getting a lot out of it. There are some things, like we might go over refinery metrics or refinery profitability, but we spend way the heck too much time talking about it. We need to show the data and get on with the show. We drag it out… and with all due respect to the directors [names some], a lot of them like to the talk. They get up there and they ramble, and I'm thinking "get to the point." So something that in my book should take 5 minutes takes 30. But on the other hand, it's communication, and a lot of people out here will say they don't know what's going on because they don't get communicated to. The good thing is, you're going to get communicated to over there! And you'll have an opportunity to communicate some of your thoughts.

This aspect of CI Forum was brought into relief most powerfully in another conversation that the first author had with two operators – Frank, who is a relatively new hire, and George, who has been at the plant for thirty years. We were sitting in a control room, discussing the history of the plant. I brought up CI Forum. George was vaguely aware of its existence, and asked what "CI" stands for. Frank, who has eagerly gone to CI Forum several times because he is interested in hearing how the plant is doing, said "I'm pretty sure it stands for 'Centralized Information Forum.'" I was about to correct him and let him know that it stands for "Continuous Improvement Forum" until I realized that his *interpretation* of CI Forum was reasonably in line with how the forum had evolved within the culture and context of the plant.

When we examine the graph below of attendance records at CI Forum, we can see a fairly steady pattern of attendance, with a gradual increase in 2004 that peaks in 2005. This period coincides with the IPO of the parent company of the refinery, and the record peak coincides with the decision to sell the refinery and change plant managers. This behavior is consistent with the idea that CI Forum is a venue for "centralized information" about goings on in the company.

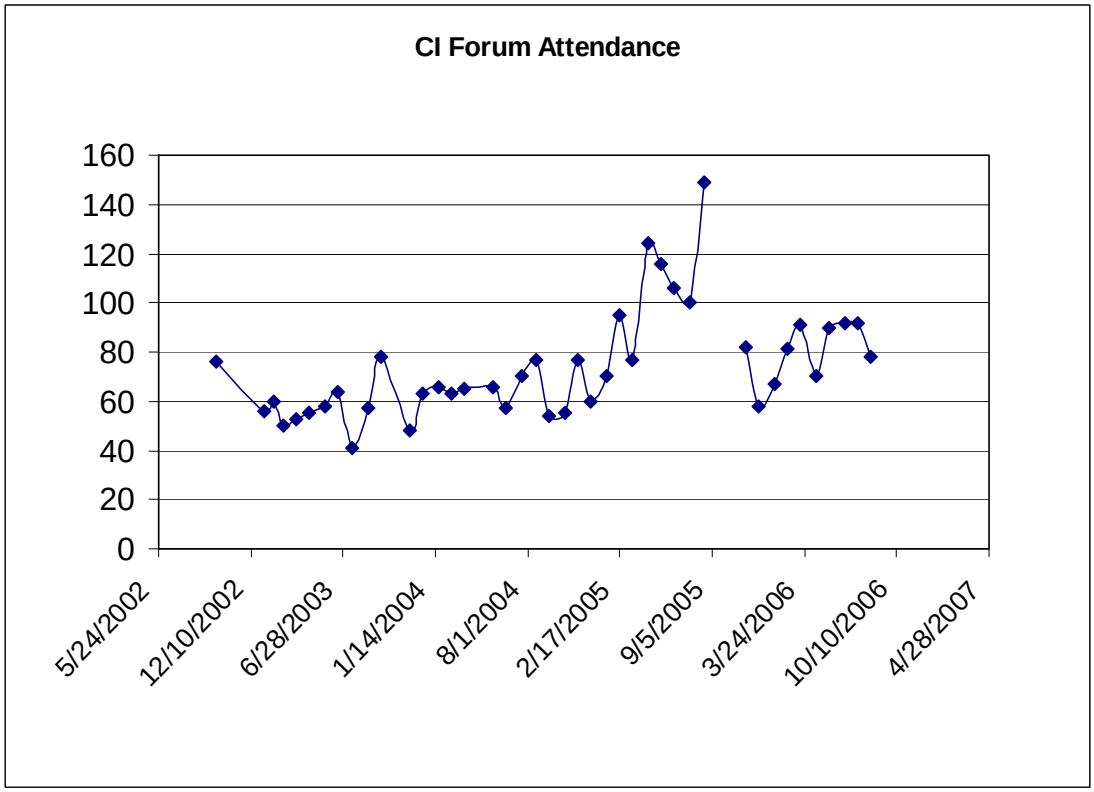


Figure 10 - CI Forum attendance, 12/2002 through 10/2006
Note: CI Forum not held in September-October, 2005

CI Forum is not the only continuous improvement activity, and in fact is designed to support the cross-functional teamwork happening out in the plant every day. Because it is designed to be a cross-level and cross-functional governance body, however, it serves as a microcosm for the plant as a whole. While Proactive Manufacturing was largely successful in fostering continuous improvement, the evolution of Continuous

Improvement into Centralized Information shows that some of its momentum has decayed over time. In the discussion below we will more explicitly theorize about this process.

Discussion

The purpose of this study was to examine the implementation of Proactive Manufacturing at the Redberg oil refinery, and evaluate its effects on reliability and overall plant performance. We hope to use the results to inform three things: the model underlying The Manufacturing Game®, which was developed using system dynamics; its method of implementation as part of a program of change; and attempts at workforce involvement in continuous improvement more generally. Rather than using system dynamics as a *method*, we have instead stepped back and treat the whole systems thinking intervention described above as a *phenomenon*, and examined it from a sociological perspective using the tools of grounded theory.

Our findings are that this program of change has had an important positive influence on the refinery, including measurable improvements in reliability and the development of a culture of proactive maintenance and defect elimination. Proactive Manufacturing has helped contribute to the refinery's industry-leading performance gains, particularly in tandem with a competitively priced heavy sour crude oil supply and significant investments in the plant's physical infrastructure. Nevertheless, this simultaneous investment in organizational and technical improvements creates ambiguity about the causes for the plant's success. This ambiguity demands an ongoing sensemaking process among the plant's personnel, from which multiple interpretations have emerged. Given a history of some conflict among managers, supervisors, and hourly unionized workers, these interpretations fall out along political lines – many hourly workers question the value and sincerity of management's attempts at workforce engagement. These divergent perspectives have led to a pattern of non-participation by hourly workers in the Continuous Improvement Forum, which has contributed to its evolution into something more like a "Centralized Information Forum." While this does not completely undermine continuous improvement efforts – they are alive and well in parts of the plant, particularly in the newer south side complex – it does indicate a challenge faced by continuous improvement as an organizational strategy.

Dynamics of implementation at Redberg

To illustrate the dynamics we observed, we can return to the original system dynamics model underlying The Manufacturing Game® and the Proactive Manufacturing Program, depicted above in Figure 1. In the model, one of the highest leverage points for plant performance is workforce participation in defect elimination efforts. Proactive work on defect elimination avoids the expensive and chaotic trap of reactive maintenance and unplanned repairs. By reducing such breakdowns, the plant can free up resources for further investment and stimulate a reinforcing dynamic of Capability Growth. At Redberg, implementation of this strategy occurred in parallel with capital investments and new supplier relationships designed to create a "world class facility."

At the risk of over-simplifying, we can therefore compress Figure 1, and depict the intended rationality of the managers of Redberg Refinery in the following causal loop

(Figure 11). Investment in workforce engagement was intended to bring about Capability Growth through continuous improvement at the front lines of the organization. Simultaneous investments in Plant Expansion would further augment performance and perhaps realize a synergistic effect. For the most part, this strategy seems to have been successful – the refinery has enjoyed significant improvements in equipment reliability and plant performance, making it the flagship refinery for both SmallCo and its acquirer, NewCo.

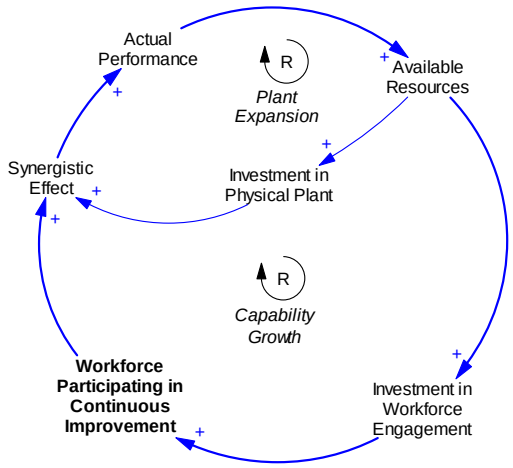


Figure 11 - Intended Rationality of Proactive Manufacturing

It is critical to recognize, however, that the policies depicted here were carried out in two distinct management epochs at Redberg in very different way. Effects accumulated from the first epoch – under SmallCo's first plant manager, Sam Taylor – set the context for those of Eli Larson and the Proactive Manufacturing Program. Some of these effects drove the Capability Growth reinforcing loop, as indicated by improvements in plant reliability beginning in 1996. Some effects instead created limits to growth – balancing dynamics that would later compromise workforce participation in continuous improvement activities.

For example, as discussed above, Taylor's approach to workforce engagement was through an open-door policy with hourly workers. This had the unfortunate consequence of undermining supervisor authority and spurring worker-supervisor conflict. We believe this shaped the way workers perceived the next wave of engagement efforts by supervisors as part of Proactive Manufacturing, a dynamic depicted as the Conflict balancing loop in Figure 12.

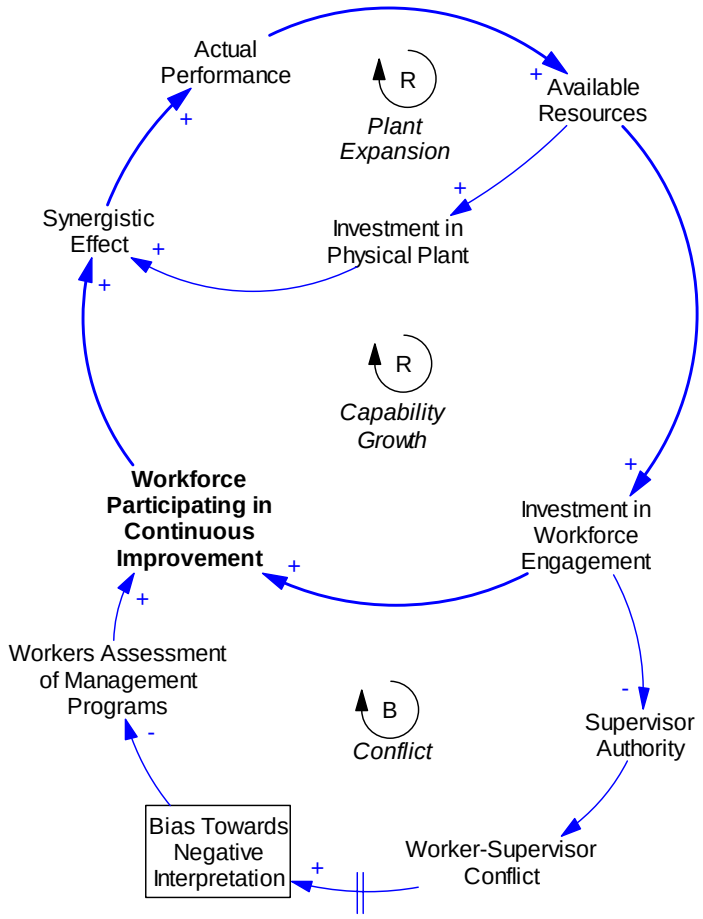


Figure 12 - Side effects of first-wave workforce engagement efforts

As time progressed, and the plant began to reap the benefits of these investments in capability, events transpired that further undermined workers' trust in management-led initiatives. These included changes in compensation practices that favored supervisors and management, as well as actions perceived as unilateral on the part of management, such as changes in benefits programs. Some of these decisions emerged from corporate headquarters, and the plant management team saw them as beyond their control. Nevertheless, in combination with an espoused philosophy of valuing and engaging the workforce, these decisions made management vulnerable to attributions of hypocrisy. This dynamic is depicted as the Distrust balancing loop in Figure 13.

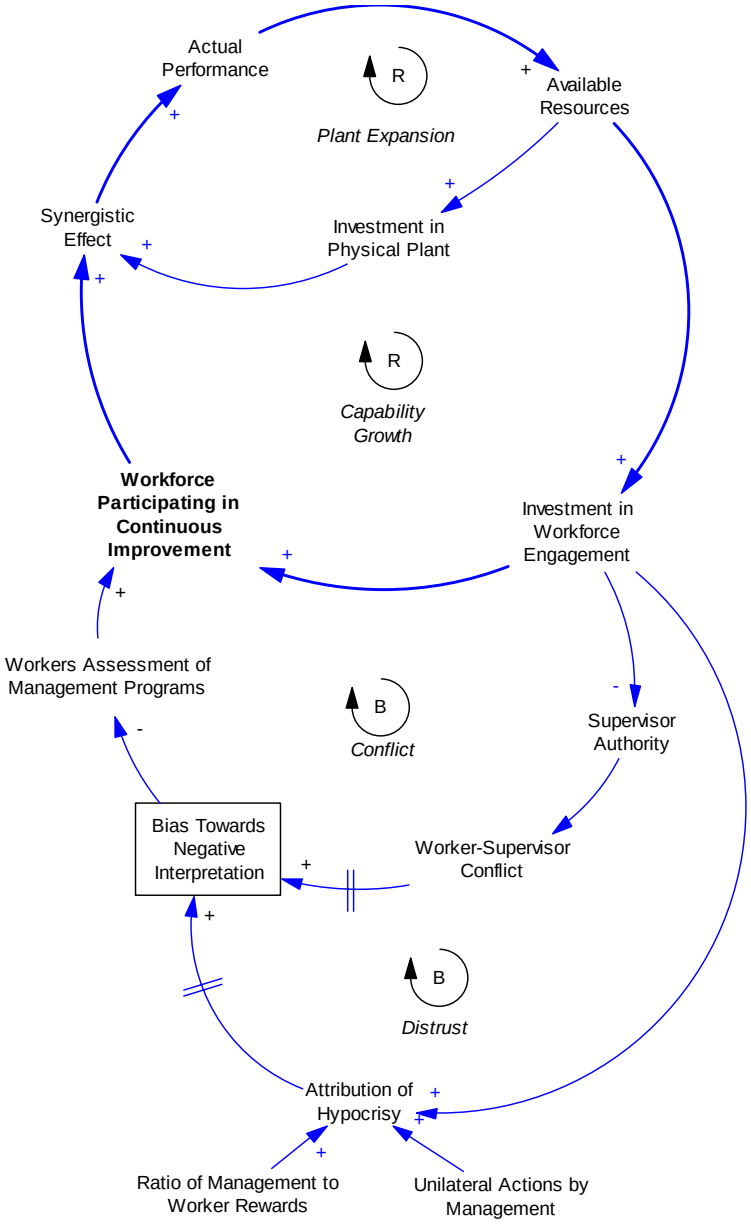


Figure 13 - Effects of policies differentially affecting supervisors and workers

The final dynamic that seems to have operated at Redberg is the interpretative flexibility discussed throughout this paper. Although the Conflict and Distrust dynamics may have fostered a feeling of alienation and a Bias Towards Negative Interpretation on the part of workers, such a bias should not necessarily lead to negative assessments of management programs. In the presence of clear and unambiguous data about the effectiveness of such programs in sustaining plant success, such biases might be weakened. In the Redberg context, however, the simultaneity of investments in the physical plant and workforce engagement created exactly the opposite condition. Causal ambiguity about Redberg's success increased the importance of workers' negative bias as they assessed management attempts at engagement, particularly the CI Forum. This dynamic is depicted as the Interpretative Flexibility balancing loop in Figure 14, which serves to amplify the effects of the other balancing loops in limiting workforce engagement.

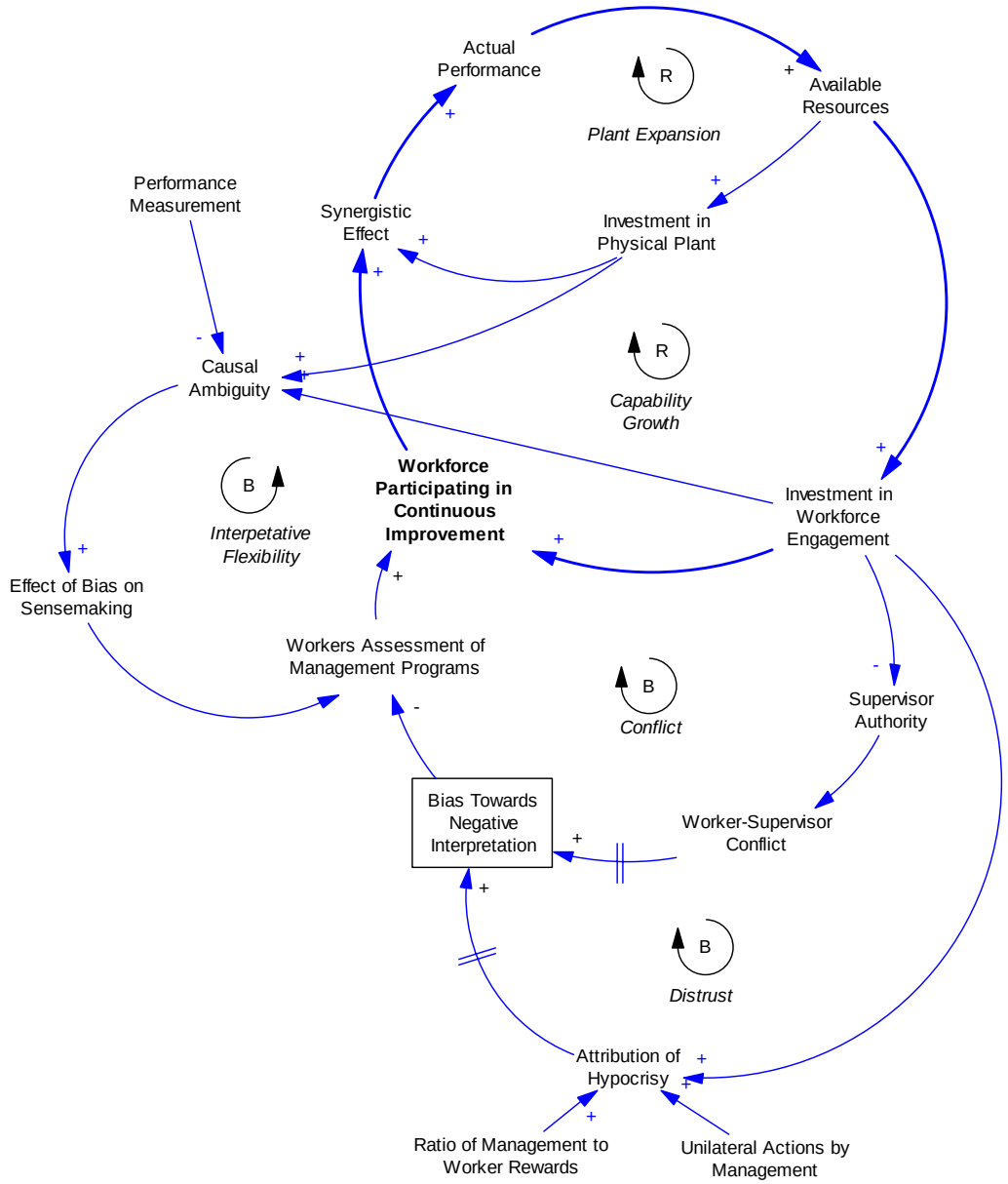


Figure 14 - Interpretative flexibility as side-effect of synergy strategy

Although these diagrams emphasize the negative side of the story, it is important to recognize that the dynamic here is not one of declining performance – Redberg has been a high performing organization during the period of study, and Proactive Manufacturing was, on the whole, successful. We simply posit that the growth in that performance may have been partially limited by an underlying dynamic of worker-management conflict and distrust. That dynamic has a stronger effect in a context of a synergistic business strategy that produces causal ambiguity and interpretative flexibility. These dynamics have eroded workforce participation in continuous improvement, and have helped transform the "CI" Forum from Continuous Improvement to Centralized Information.

Implications for The Manufacturing Game and defect elimination

While these findings speak to the *particular implementation* of The Manufacturing Game® and the larger Proactive Manufacturing program at Redberg, how might they inform the underlying model and approach?

In its simplest form, the original system dynamics model at Du Pont was based on a co-flow with two stocks - the equipment in the plant, and the defects in the equipment (See Figure 1). One critical insight from this framing is that defects start accumulating from the very point of manufacture at the supplier level, so defect elimination must be a proactive and continuous process. It is, however, very high leverage, because it frees up resources and yields increasing returns. The Manufacturing Game® attempts to create an embodied experience of these dynamics, with defects accumulating as chips that overflow and produce a shutdown and/or safety/environmental incident. The cultural credo created around TMG at Redberg reinforced this point - "Don't Just Fix It, Improve It," the imagery of "Boris the Bug" and "Fix it right, Don't let the bug bite."

In its enactment in action teams, the notion of a "defect" was extended to include not just physical defects (e.g. bad welding) and defects in the interconnections between physical items (e.g. mismatch between metallurgy and process), but in more abstract processes. If we look at the "Action team status" spreadsheet used at Redberg, we can see items like "refinery KPI's," "Utilities maintenance planning," even "Improving communications." The official definition of a defect among facilitators of The Manufacturing Game® is “any deviation from perfection.” Although some defect elimination activities are more abstract than others, they all provide a concrete point of focus for a group of people (ideally cross-functional and cross-sectional) to work on.

The trouble, as our study illustrates, is that people come into these cross-boundary contexts (the Game, the action teams, the CI Forum) with an already-accumulated stock of experiences, narratives, and perceptual lenses through which they view the others in that context and the very context itself. Like equipment coming in the door from suppliers with defects in tow, the relationships – out of which collaborative efforts are composed – come with their own historical baggage. Depending on the nature of this history, it might help or impede collaboration, or affect it in complex ways.

In the causal loop diagrams above, the unintended consequences of managerial action resulted in the accumulation of a stock we labeled as “Bias Towards Negative Interpretation.” While in this case, the stock referred to workers’ negative interpretation of management programs, it is an example of the more general phenomenon of relational conflict shaping perception and action. We can stylize this idea through a notion of “relational defects” in order to create a rhetorical parallel to the idea of defects in equipment. We might depict it as an additional co-flow like the one below.

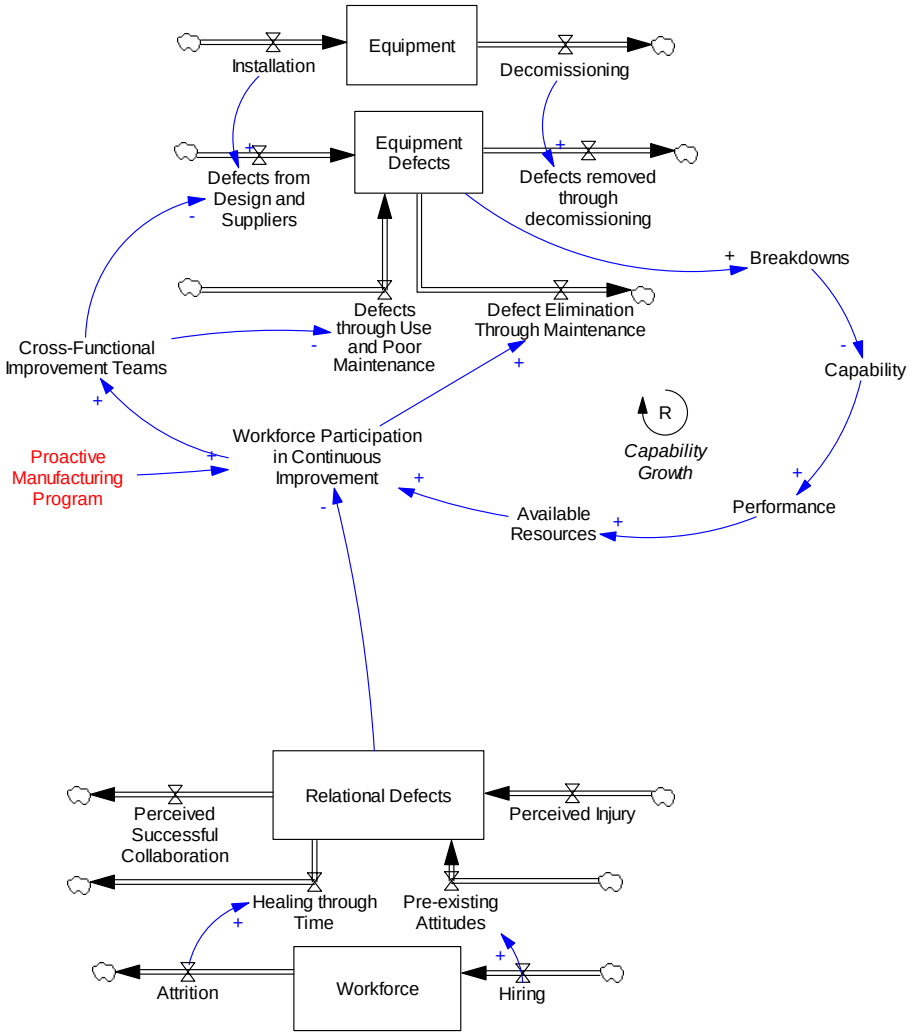


Figure 15 – Speculative Model - Defects in Equipment and Relationships

This framing allows us to think about a dynamic view of relational conflict that undermines collaboration and continuous improvement activities. In so doing, we illuminate a critical fact – that the *time scales* upon which these processes are working are quite different. Defect elimination in equipment occurs on the timescale of weeks to months. A Proactive Manufacturing program takes on the order of 3-5 years to settle into a stable rhythm and interpretation within the organization. But relational conflicts and the generation of stable interpretive frames and narratives happens on the timescale of decades. We can see this quite clearly in the data from Redberg Refinery, because the rise and fall of entire programs is taken as data in the formation of narratives and attitudes about trust.

These layers are not, of course, separate, and there important feedback loops. As we indicate through stories about action teams and cross-functional collaboration on the south side of the plant, collaborative efforts can actually serve to improve morale and foster further collaboration. This dynamic is depicted as the "Healing Through Collaboration" loop below. High performance of the organization can also be used as

evidence for successful collaboration, as it seems to be for many of the supervisors involved in Proactive Manufacturing. This is the "Success Stories" reinforcing loop. The underlying idea here is that successful collaboration is an important driver of trust, an idea supported by research in the social exchange theory tradition (Lawler & Yoon, 1996; Molm, Takahashi, & Peterson, 2000).

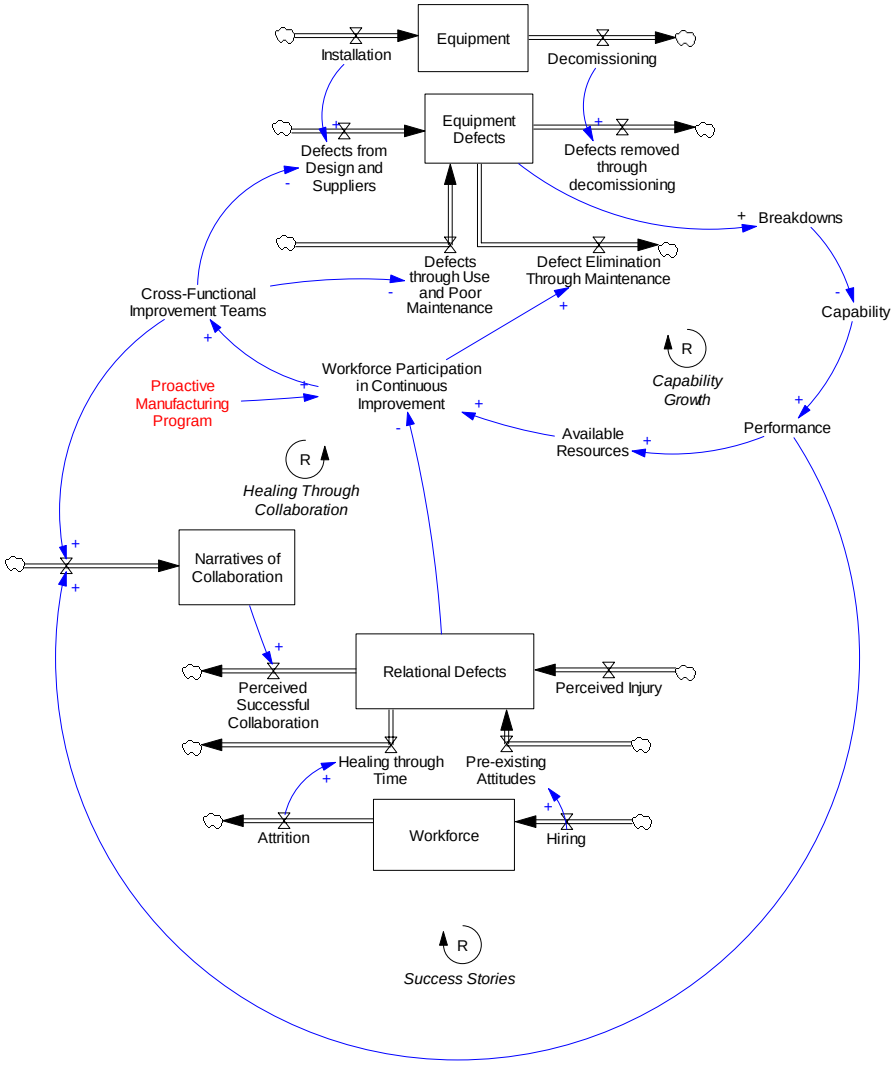


Figure 16 - Collaborative, cross-functional activity can gradually heal relational defects

At the same time, Narratives of Fragmentation also exist – stories and attributions that depict the organization as a site of conflict and performance as benefiting some people over others. Such narratives originate or are fueled by certain kinds of events, for example decisions that produce or highlight inequality among groups. These narratives create perceptions of injury or injustice among groups, which we see as an inflow to relational defects.

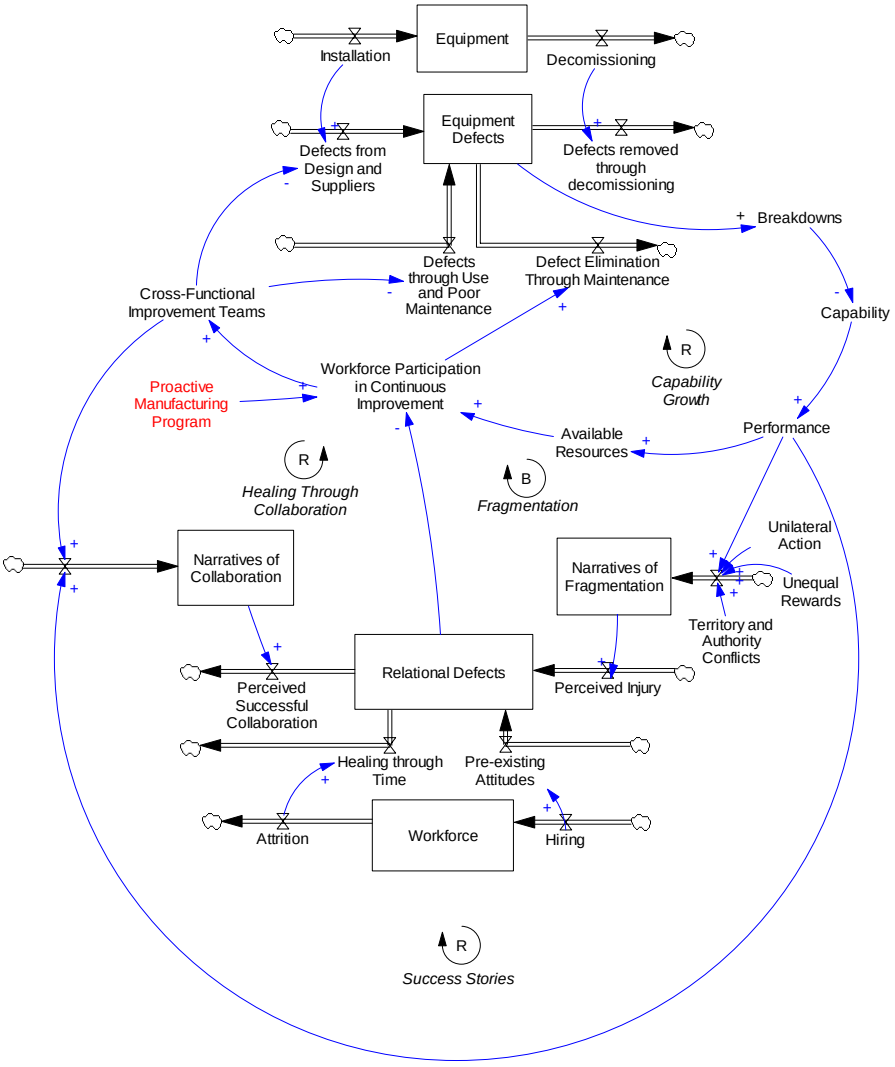


Figure 17 - Performance can also perpetuate relational conflicts when rewards are shared unequally

The implication here is that any program or social technology that seeks to reorganize work arrives in an already generated relational landscape. That landscape will influence both how the new actors and activities are seen and how they play out. Defects in relationships must at least be approached in parallel if not before any other defects in equipment or processes. While collaboration can heal relationships, it can also perpetuate fragmentation when rewards are shared unequally. Furthermore, the expectation must be that such processes will take the same order of magnitude of time as it took to accumulate the relational stocks.

Again, while the worker-supervisor relationships were salient in the Redberg context, relationships as framed in this conceptual model exist across multiple boundaries in the organization. In particular, there are functional lines (operations, maintenance, engineering, HSE, finance), employment tiers (corporate, plant management, supervisors, hourly workers, contractors), and interactions between the two (e.g. between IBEW vs. USW unions). "Defects" can accumulate in any "tie" between people in these groups.

Clinical choices

From a practical or clinical perspective, the question thus becomes one of "how to eliminate defects in relationships between human actors so as to produce integrative action?"

We don't have any answers or even hypotheses here. What we do have is an analogy (John Carroll, personal communication) between the inter-group conflicts at Redberg Refinery and individual therapy. In the individual therapy realm there exists a dichotomy between Freudian psychoanalytic approaches and cognitive-behavioral therapies. Psychoanalysis focuses on history of relationships back to childhood, and say that you can't move forward without addressing and re-narrating them. Cognitive Behavioral approaches say that it might even be counterproductive to unearth the past and mentally reinforce trauma, so the important thing is to focus on moving from the present forward through new behaviors.

Although this study does not resolve or necessarily even inform this question, it does pose it quite nicely in the organizational realm.

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