Dynamic Benchmarking:
Experiencing the Best Practices of Others in Your Plant

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Overview

Benchmarking for Reliability Performance Improvement

Starting in the late 1980s and continuing today, benchmarking has been one of the key tools for evaluating and improving reliability performance. Most benchmarks used today, however, are a snapshot - giving a good view of what your operation looks like today and what it could look like given best practices. They provide little insight into the cause and effect relationship inherent in performance improvement.

Conventional benchmarks also suffer from an apples-to-oranges problem: managers always question if the comparison plants are adequately similar to their own plants. In addition, today's benchmarks don't provide any what-if capability and many fail to capture the key benefits of greater reliability – reducing costs related to lost opportunity and waste. Most conventional benchmarks give an image of performance at a moment in time but they don't show how it happened.

One of the earliest comprehensive benchmarks came out of DuPont in the late 1980's. A multi-year study of over 140 plants at numerous companies worldwide produced a detailed, dynamic model of plant operations and reliability to better understand how the "best of the best" companies achieved their performance and the true cause-and-effect relationships.

That model also led to an important insight: eliminating the source(s) of defects is a much higher leverage point than taking out defects more efficiently. This insight, along with tools to implement defect elimination, has led to dramatic improvements at DuPont and many other organizations. The model itself, however, was never used directly as an analytical tool until now.

The Manufacturing Game® was created based on the insights from the DuPont model. During the course of the last ten years, we refined the model further with our clients as well as outside experts. The result is a comprehensive, dynamic model of reliability that provides a tool for looking at the consequences of decisions and policies.

Our model is a system dynamics model, with over 500 variables and more than 1,000 interconnections. Sound complex? It is, but this level of detail is still a simplification of interactions at a real plant.

Our model is not meant to predict discreet events at particular points in time, but rather mimics real site performance over the course of months or quarters. It also details maintenance and reliability practices and contains a strong operations component, while most of the outputs are production-based and financial in nature.

Following is a review of the best practice data imbedded in our dynamic benchmarking model that illustrates different approaches to reliability and their relative value. We'll also examine some typical pitfalls that doom many reliability initiatives.

The Three Elements of the Dynamic Benchmark Model

Three key components make up our model of dynamic benchmarking. The first is the ***data input*** – the plant data much like any benchmark would have, including work order mix, production, waste, staffing and systems. The second element, missing from most conventional benchmarks, is *performance differences in* ***practices***. These performance differences come from data from best practice plants and from experts in the field. The final element is *management* ***policies***: overtime caps, desired improvements in maintenance systems, headcount and priorities of various types of work. Changes in these policies allow for "what-if" scenarios, a core factor of our dynamic benchmarking model.

<table>
<tr><th colspan="2">Inputs to the Model</th></tr>
<tr>
<td>Plant-Specific Data:

Maintenance manpower
Operations manpower
Number of work orders in system and completion rates
Percent of planned vs. unplanned vs. PM work
Effectiveness of CMMS systems
Effectiveness of Inspections
Effectiveness of operator rounds and troubleshooting
Defect volume and sources
Stores levels and turns
Spare parts service level
Stores cost
Equipment by type and area
Linkage between production and downtime
Material margin
Energy cost per unit production
Maintenance and manufacturing costs
Cost of capital
Replacement value of assets
HSE performance
</td>
<td>Best Practices

Productivities of planned and unplanned work
Impact of defect elimination activities under different circumstances
Planner productivity
Ideal inspector productivity
Ideal operator rounds effectiveness
Potential defect rates
Operator productivity
Stores requirements based on the nature of the operation

Plant-Specific Policies

Planning and takedown policies
Planner time allocation
Operator time allocation
Mechanic time allocation
Inspections
</td>
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</table>

The advantage to this type of benchmark is that the impact of various practices and strategies can be easily examined. Plug in a couple more planners and more jobs get planned, productivity goes up, storeroom stock outs go down and maintenance costs are lowered. Additionally, this type of benchmarking eliminates the apples-to-oranges problem, as plants are looking at their own results with best practices. Dynamic benchmarking provides "the movie" instead of the snapshot of conventional benchmarks. The user can see both potential performance and what practices are required to get there.

<table>
<tr><th>Model Outputs:</th><th>Uses of the Model:</th></tr>
<tr><td>

Cost of Unreliability
Return on Investment
Costs:

Energy
Maintenance (Parts and Labor)
Waste
Other Manufacturing

Production
HSE Performance

</td><td>

Identify volume and type of defect elimination required to achieve goals
Create a coordinated strategy for improving planned and scheduled work
Set interim goals to gauge success along the way
Set realistic targets for production and financial improvement
Build a shared vision of the path forward
Test proposed outside and corporate initiatives for effectiveness

</td></tr>
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Contrasting the Benchmark Models

As outlined below, the difference between standard correlation benchmarking and our model of dynamic benchmarking is the representation of cause and effect relationships.

Where a correlation benchmark captures data from multiple sites and quantifies a plant's performance on a relative basis, our dynamic benchmark model uses estimates of best practices captured from multiple sites to *gauge the impact* of those practices. Our model depicts how those practices actually function, and incorporates local plant data and policies. Therefore, the output from dynamic benchmarking is specific for the plant modeled, yet still reflects the impact of best practices.

To the best of our knowledge, this modeling effort is unique. A review of current literature and internal corporate documents found several examples of simulation models that could be used to analyze the impact of alternative assumptions for mean time between failure and mean time to repair. We found no other models that focus on the dynamic causal relationships that *generate* these variables. To capture how these relationships are generated, you have to include the actions and behaviors of the people in the organization as well as the equipment they work with. To do this, you cannot rely on corelational models. People are much more complex than that.

Contrast

Correlational Benchmark:
Captures data from multiple sites and quantifies their performance on a relative basis. Correlates practices to different levels of success.

Dynamic Benchmark:
Uses estimates of best practices captured from multiple sites to gauge the impact of those practices. Model represents how those practices actually function and loads local plant data and policies. The output is specific for the plant modeled but reflects the impact of best practices.

Use of Model	Correlational Benchmark	Dynamic (Causal) Benchmark	Example
Help for strategy and goal setting	Shows only end states	Shows the path to get there	How many planners should I have to achieve world class results?
Focus on the key drivers	Correlation does not indicate causality. Most drivers are not captured in model.	Causality and drivers explicitly modeled.	World class producers have 20% lower costs. To achieve world class performance should we simply cut budgets by 20%?
Ability to deal with defect elimination concepts	Outside the scope of the model	The heart of the model	Which sources of defects are our biggest issues and how should we go after them?
Identify bottlenecks in the system	Variables are assumed to be independent	Models the actual dependencies between variables	Planning resources are sufficient but CMMS system does not allow for capture and use of data.
Quantify opportunity for improvement	Always has some “apples to oranges” issues	Models your plant with best practices	A plant that is two years newer and closer to feedstock is world class in performance. Is its better relative performance due to location and age or practices?
Gauge improvement based on actions taken	Typically compares the current state of the operation with the past and other facilities.	Specific actions have specific expected results that can be compared.	Did the actions that we took based on the last benchmark yield the expected results?

Building Ownership is the Key

The major finding from this renewed modeling effort is that the key factor in achieving the performance of the best practice companies is the level of ownership felt by the employees. All of the technical tools to increase reliability alone are not sufficient to improve the performance of the plant. It is the use of these tools by the employees that achieves the results. If no one has the will to use the tools on a daily basis, the reliability will go down.

In a case study, we found that the highest leverage activities were:

- A Large Number of Cross Functional on the Job Action Teams to Eliminate Defects (the best performance came when the number of teams equaled the number of employees divided by 5 for each of the first 3 years)
- Root Cause Analysis
- Management Support for Root Cause Analysis (provide the time and a small amount of money (less than $5,000) for each action team to find root causes)

- Good Systems in the Last Stages (CMMS, Operator Rounds System, Management of Change, etc. -- These are more effective after the defect elimination culture has been created.)

Some of the traditional approaches like Preventive Maintenance and Predictive Maintenance were found to be somewhat effective but much lower leverage than creating a workforce that feels empowered to eliminate defects. Many of the techniques in these traditional approaches are effective only when the work habits of the employees are tuned to eliminate defects. This was made clear to us as we tried to use standard statistical analysis at DuPont. We recognized that all of these tools assume, as pointed out by W. Edwards Deming, that your work systems are uniform and under control. We have found that the defect elimination culture creates that type of control in the minds of the employees if they take a systems approach. The use of cross-functional teams in conjunction with The Manufacturing Game® seems to create the total systems perspective needed.

Drilling Down Into the Model

The Causal Relationships

The causal relationship between input, practices and management policies specific to each plant is imbedded in the dynamic benchmarking model, and is the key to defect identification and elimination, as well as achieving reliability improvements.

There are two types of diagrams that illustrate the causal relationships in our model.

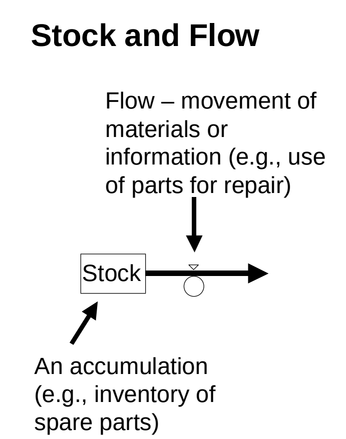

Figure 1

The first is an example of stock and flow, which simply shows the movement of materials and information. The rectangle represents various accumulations of materials -- stocks. The arrows represent the flow of the stocks.

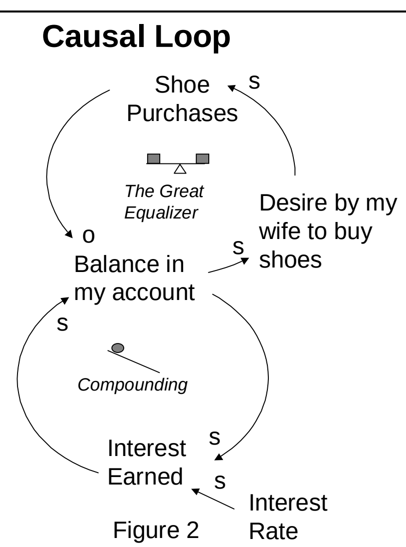

Figure 2

The second type of diagram is a causal loop model, which connects variables with arrows. The arrows represent a relationship between two variables. The letters “s” and “o” indicate the direction of the relationship. An “s” indicates that the variable moves in the same direction, and an “o” indicates that the variable moves in the opposite direction.

Equipment Flows in the Model

Let’s examine the causal relationships within different portions of the model.

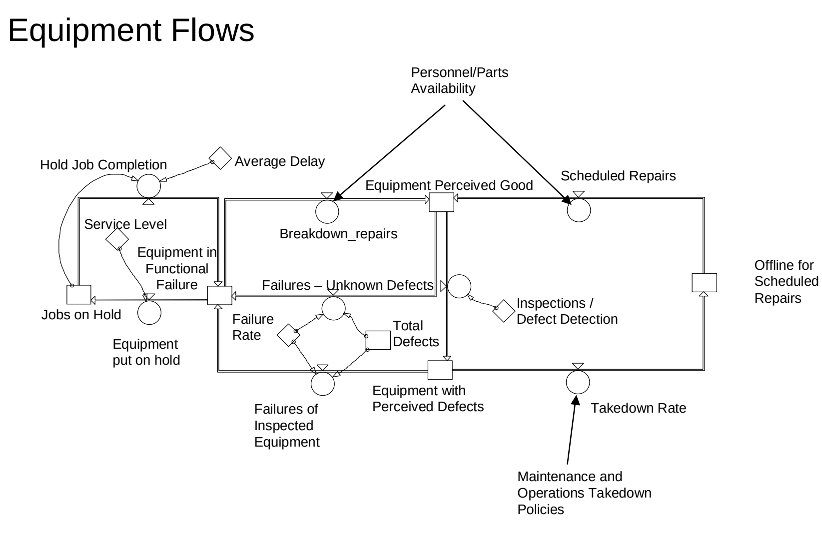

Figure 3

The first example, shown in Figure 3, is the backbone of the entire model. In it the "equipment perceived good" stock represents all of the equipment without any known defects. If a defect is detected in that equipment, then its' status moves to the category of "equipment with perceived defects" stock. Defect detection can be done through a formal inspection, by operators conducting rounds or by a root cause being detected during a repair or proactive intervention.

If the organization’s policies support planned work, then the machine will be taken down and be off line for repairs. Based on priorities, personnel and parts availability, scheduled repairs are completed to bring the equipment back on line.

If the defects in the equipment are not detected, or they are detected but the organization’s policies do not support planned work, the equipment then fails at random. It then sits in the reactive backlog "equipment in functional failure" stock, until there are sufficient resources to repair the defect and bring the equipment back on line.

Reactive Repairs

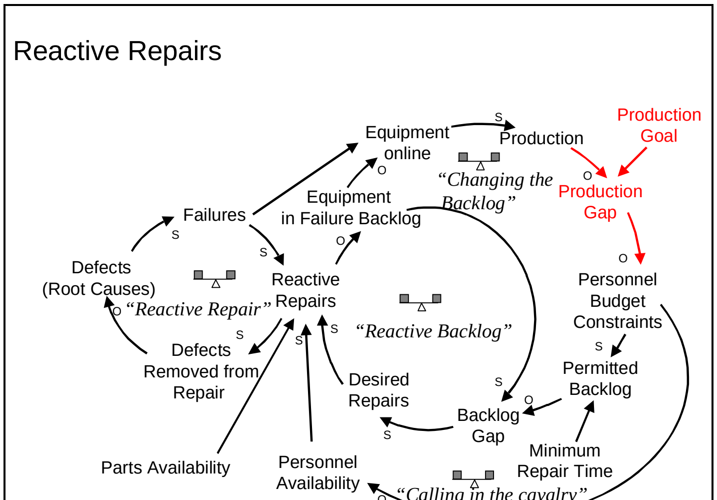

Figure 4

The next example, in Figure 4, shows the process for when equipment fails reactively and goes through a "reactive repair" loop. Repairs are completed as personnel and parts become available, and the symptomatic cause of the failure is eliminated.

The "reactive backlog" loop exists largely because organizations want to minimize mechanic idle time or because they simply have more work than can be done. When the backlog is low, no extraordinary steps like high overtime or excess contractors are implemented to complete the work. But when the backlog starts to make the organization miss its production targets, the organization will then respond by calling in the cavalry – adding resources through overtime and contractors

Defects and Failures

Defects are the root causes of functional failures in the plant. We define defects as "any deviation from perfection that creates a loss in production, waste, safety incidents, or environmental excursions." Defects, as shown in Figure 5, come from the way that the organization operates its equipment, the quality of maintenance craftsmanship, wear and tear from production, spare parts not meeting specification and poor design.

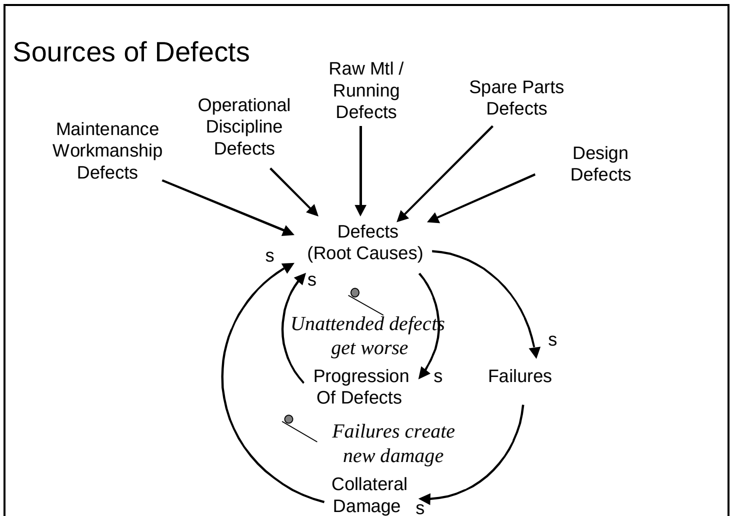

Figure 5

Unfortunately, defects breed more defects. As seen in the "Unattended defects get worse" loop, defects tend to grow worse over time if unattended -- today's defect that has little or no operational consequences will most likely be the cause of tomorrow's catastrophic failure. Failures also create defects by causing collateral damage.

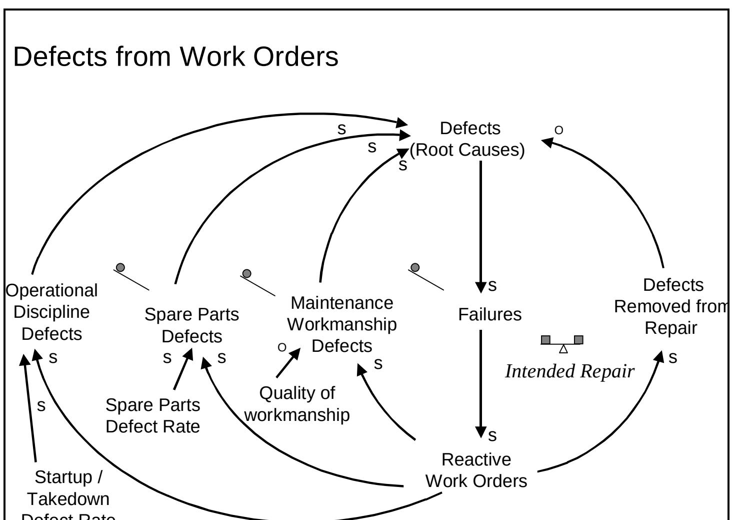

Figure 6

In the course of repairing defects, poor workmanship, poor spare parts quality and poor practices in startup and shut down can lead to new defects and new problems. Often these defects will show up as "infant mortality" failures where a system will fail several times in rapid succession after a repair. Figure 6 shows these unintended consequences of doing repair work. The rate at which defects are added through repair depends on the skills, standards and culture of the organization.

The Standard Paths to Reliability

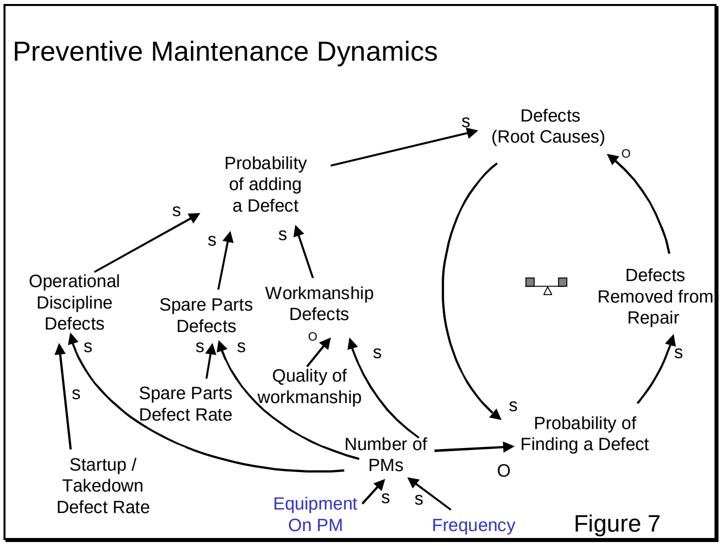

Figure 7

There are two standard solutions for reliability improvement – preventative maintenance (PM) and condition based work orders.

All else being equal, when a plant adds PMs by either adding to the percent of equipment on PM or by upping the frequency of PM on existing equipment, the chances of finding and fixing a defect go up. This is the primary loop on the right side of Figure 7. Unfortunately, not all things are equal. A classic illustration of this point is changing the oil in your car. If you change the oil in half the miles that your manufacturer recommends, you may actually take some defects out earlier. If you change it every day it is likely that you are removing no defects most of the time.

In addition, every PM represents an intervention with the equipment -- and therefore an opportunity to *introduce* a defect. At some point it is more likely that an organization will introduce a defect while conducting a PM than it is they will correct one. These can be seen in the left hand loops in Figure 7.

Therefore, planned maintenance should only be set up for equipment and on a frequency where the probability of finding a defect is well above the probability of adding defects – given average operating and maintenance practice this point is at about 30% probability of finding a defect on takedown inspections, and 17 percent on non-takedown inspections. Otherwise, an organization will be pushed past the tipping point, where PM is actually doing more harm than good as shown in Figure 8.

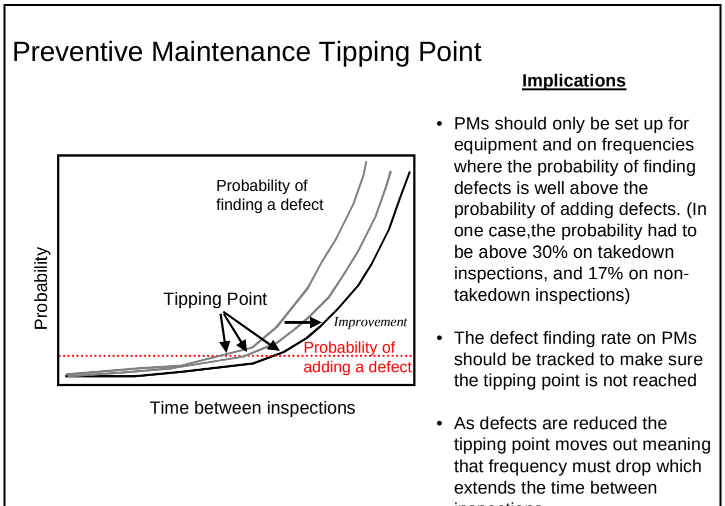

Figure 8

An organization must also track its success rate and make adjustments as reliability improves. Planned maintenance becomes a less effective strategy as an organization moves toward world-class performance. If PM set up can be done with some proactive defect elimination (e.g., Reliability Centered Maintenance) it can be even more effective.

Condition Based Maintenance Work

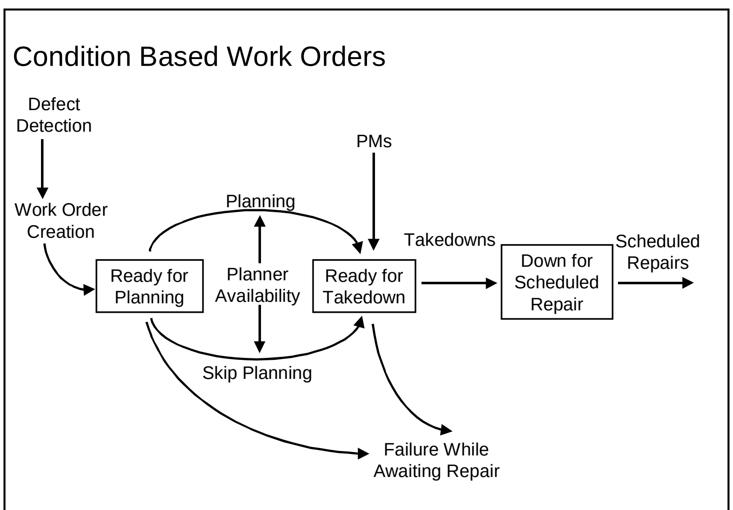

Figure 9

Conditioned based work orders (Figure 9) are another part of effective reliability programs. Like PM, scheduled work is done prior to functional failure and actual losses. This is a critical distinction that many organizations do not make. Often organizations report 80-90% planned work but a closer inspection reveals that most of this work (50-90%) is really reactive backlog work.

Conditioned based work starts with defect detection. The detection of the defect leads to a work order that flows to a planner, who outlines the sequence of activities to complete the work order, designates the proper skills to perform the work and ensures that all necessary parts, tools and equipment are available. When planning is complete, the work order moves through the takedown process. Assuming resources are available, a scheduled repair removes the defect and the equipment is placed back on line.

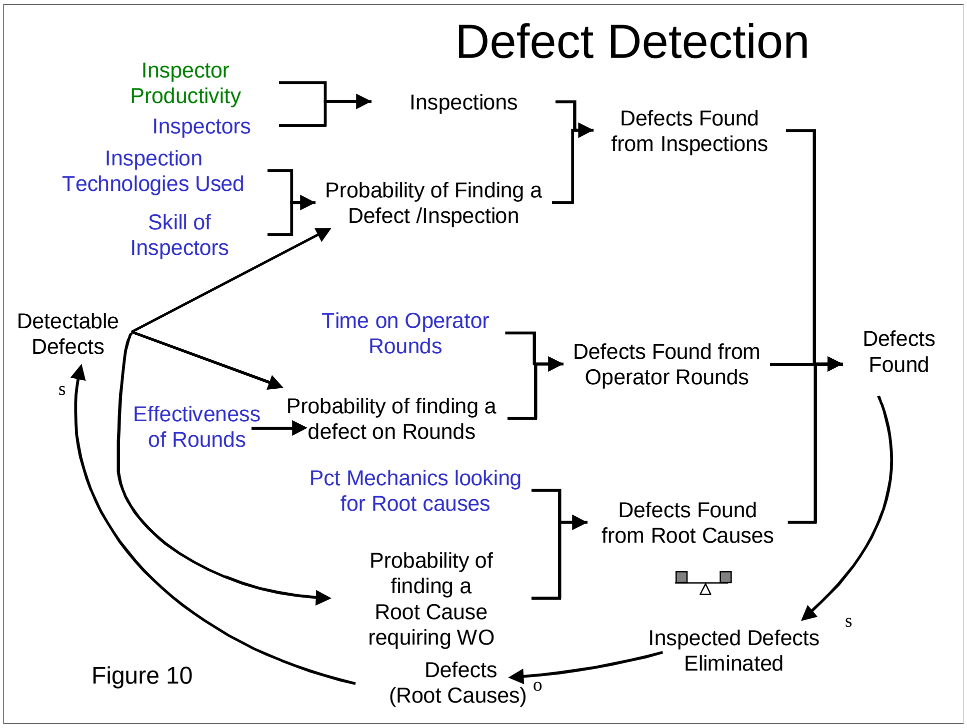

Figure 10

There are three primary ways that defects are detected proactively and are put into the scheduled maintenance process: formal inspections done by the inspection specialist, operator rounds and root cause analysis.

As shown in the top left corner of Figure 10, more inspections, whether through additional inspectors or greater productivity, leads to an increased number of defects detected. However, as we saw with PM, inspections will have diminishing returns as detectable defects are discovered and repaired. Unlike PM, there does not tend to be a great chance of introducing defects so while inspection efficiency may suffer over time, equipment performance will not.

Operator rounds work in a similar way. They tend to be a less technical inspection but often with a much keener sense of how the equipment has been running and what is “normal”. The effectiveness of these rounds can be a key leverage point.

The final source of detectable defects is root cause analysis. In the course of fixing one defect, the operators, mechanics and engineers, if properly trained and motivated, can find further root causes that can be eliminated. If systems are in place to collect these, then they can also be a source of scheduled work. Our modeling indicates that quality operator rounds and root cause analysis are critical for achieving world-class performance. While formal inspections are important, especially for highly technical areas, it is impractical to inspect your way to world-class

Planning and Scheduling

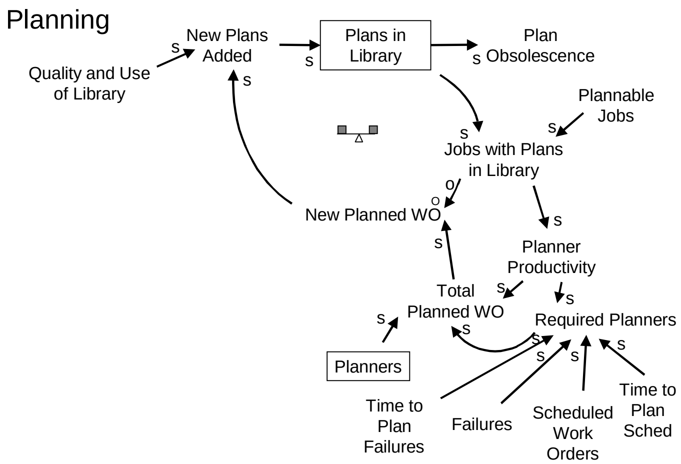

Figure 11

Planning is a key element of condition based and PM work. The amount of scheduled and reactive work and the productivity of planners determine the number of planners required. The number required versus the number available determines how much planning work gets done and how much gets deferred or skipped. If the organization has a planning library, (one of the value-adding functions of a computerized maintenance management system (CMMS)), job templates can be created and stored. The quality and use of these libraries is one of the inputs into the model based on observed data. Template plans greatly enhance planner productivity (doubling it according to our data gathering).

Scheduled work increases productivity and reduces downtime. The total time spent on a repair is a combination of different times that we have estimated for this model (Figure 12). Diagnosis, coordination, administrative and parts time are all reduced; actual wrench time is assumed to be similar for comparable jobs.

In our studies, we found that an effectively planned and scheduled work order would take 55% of the time of a reactive work order with essentially the same work. If the standard reactive job in this facility were 27.9 hours that same job planned and scheduled would be 15.4 hours.

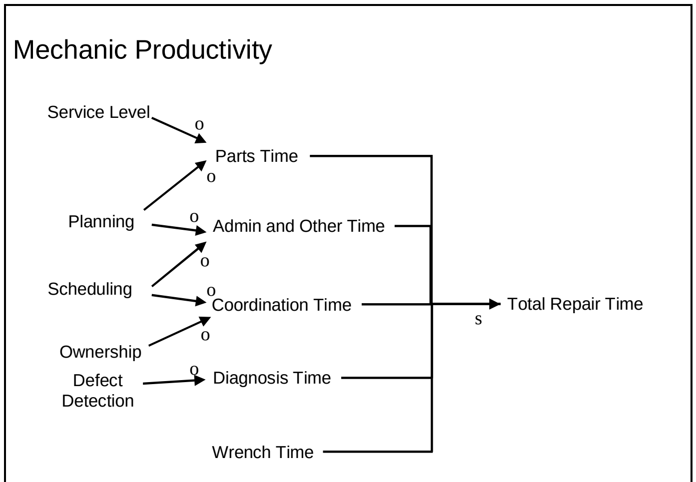

Figure 12

The major efficiency benefit of planned and scheduled work is from the planning; the second key benefit comes from the scheduling.

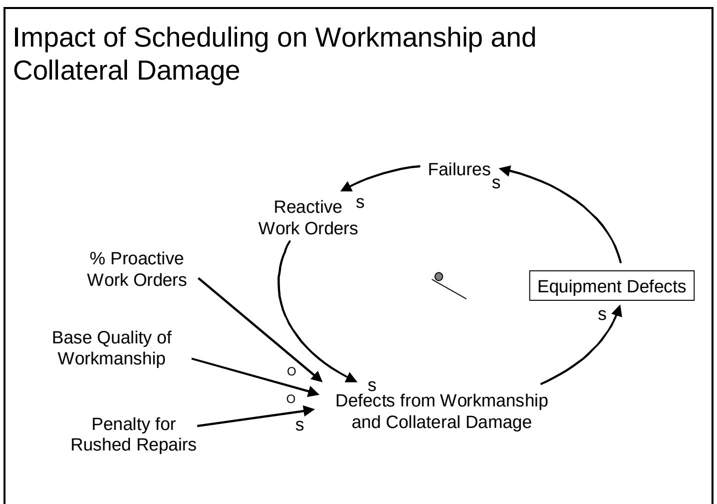

Figure 13

By reducing failure events, scheduled work reduces collateral damage from failures and reduces rushed reactive repairs that are inherently lower in workmanship. The assumption in our model is that reactive repairs are 20% more likely to introduce an error due to faulty repair than a scheduled repair.

Root Cause

Root cause repair was one of the highest leverage points in the model. We found that $13 million of net present value could be achieved over three years by implementing a good root cause program. When the organization is trained and motivated to find the root cause of failure, not only does the "Standard Repair" get done, as shown in Figure 14, but the organization eliminates the source of the defect which keeps it from recurring. Root cause repair depends on the willingness of operators and mechanics to look for the root problem. We call that ownership. It also depends on the information systems of the organization.

The clarity of work orders, in terms of giving operating conditions and specifics about the failure, can help lead to the root cause. Often the person who wrote the work order is not around when the repair is made which means that the work order must be clear. The history that is kept on the equipment also helps identify recurring problems. The ability to find root causes is also influenced by the skills of the workforce. If the workforce has been trained to ask why and has the technical skills to determine failure modes, they are more likely to get to the root cause. Finally, management policies need to support root cause analysis. All of the skills and motivation will mean little if inadequate time and tools are made available. We found a good program for keeping high quality work histories on equipment can yield an additional $5 million of net present value over three years.

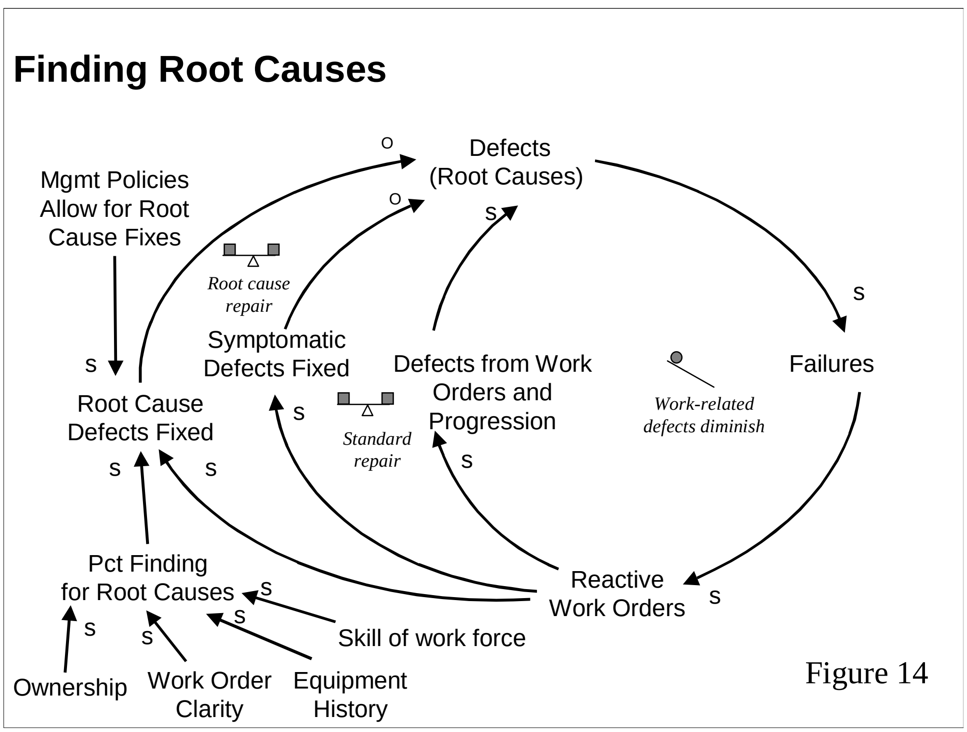

Figure 14

Many Action Teams are Essential

Since finding root causes and many other behavior changes are dependent on ownership, it is important to understand where ownership comes from. Ownership is defined as peoples' willingness to initiate and participate in proactive improvements. Many things can improve and diminish ownership including trust between management and hourly, clarity of goals, and authority to make changes. In our experience, nothing breeds ownership better than a combination of engagement and success. Action teams focused on eliminating small but nagging defects, give people a chance to get engaged and make a difference. When teams are successful, two things happen. As seen in the "Engagement" loop in Figure 15, success in eliminating a defect drives ownership. People who taste some success are typically hungry for more. This leads to further self-generated actions and more success.

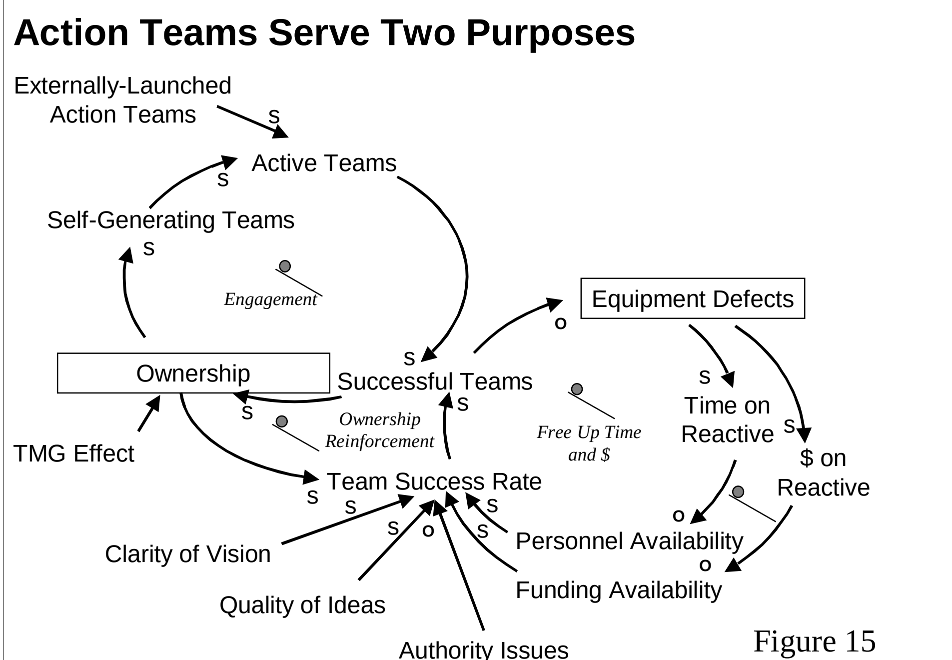

Figure 15

Success also leads to fewer defects, as shown in the "Free Up Time and $" loop, which reduces reactive work freeing up personnel and money to be applied to other initiatives. Our model shows that the Net Present Value of having many teams to help in the elimination of defects was worth $60 million over three years in one case. The number of teams required to achieve this level of performance is about 1 team for every 5 employees per year. Since we recommend that cross-functional teams should have 4 to 9 employees, this amounts to every employee being on a team each of the first three years.

Management Policies

Stores Inventory

The inventory level on hand determines the service level of a plant. Low service levels lead to higher costs, wasted mechanic time and lost production. Presumably management has a target service level and when it is not being met the inventory level is raised until the plant is running at the service level goal. This dynamic can be seen in Figure 16 in the "Keep the Plant Running" loop.

The competing loop is capital costs. When inventory levels are increased to keep service levels high, the cost of inventory in terms of capital increases and the inventory turns go down. Typically the financial people in the organization will be watching these numbers and will have their own goals for inventory turns or parts inventory as a percent of replacement value. To keep costs on track, they will push for inventory reductions as shown in the "Keep the Financials in Line" loop.

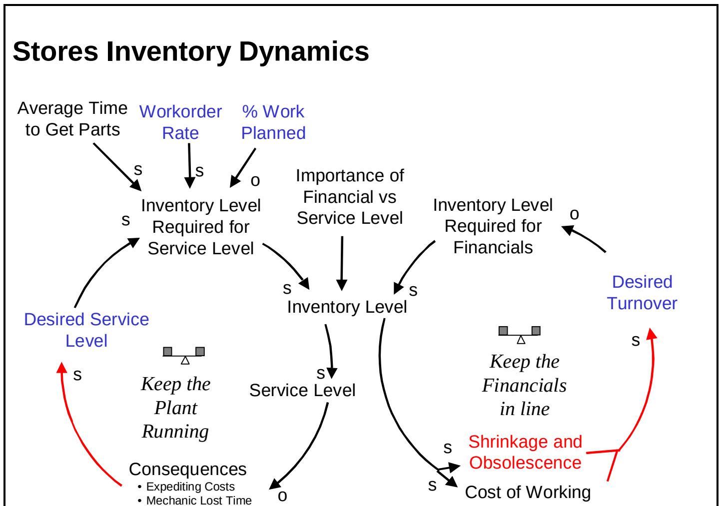

Figure 16

Based on the politics and culture of the organization, these two goals will compete and settle into an inventory level that balances these needs. What many people fail to see is that there is no leverage in either of these policies; either production suffers to reduce capital costs or capital costs rise to enhance production. The leverage point is to eliminate the <u>need</u> for the inventory, which can only come through operating more efficiently – eliminating defects, implementing more planned and scheduled maintenance, and shortening lead-time to get parts.

Maintenance Time Allocation

Once planned maintenance or scheduled work reveals defects, it's time to get to work. Policies unique to each plant will dictate how, when and by whom this work will be completed.

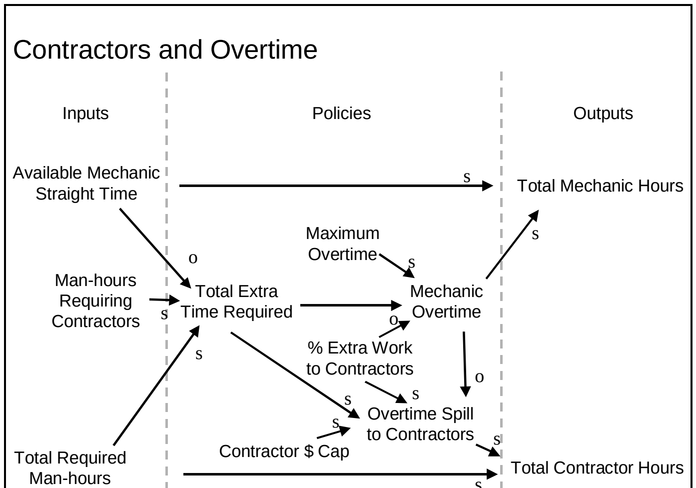

Figure 17

Staffing of maintenance work is accomplished through both internal resources and contractors. Factors in the model shown in Figure 17, are: the number of mechanics and straight time hours available; the amount of work hours requiring mechanics; and the amount of work requiring specialized outside contractors.

The difference between the amount of work hours required, less the specialized requirements and the amount available by internal resources determines which tasks require overtime, specialized contractors or must be delayed due to budget constraints. Expense goals or caps for overtime and contractors within budgets often set the policy that determines the level of maintenance work that will be performed.

Operator Time

Where operators spend their time is highly dependent on how the plant is running and management priorities. In our model, operators spend their time running the equipment by monitoring and controlling, taking down and starting equipment, housekeeping, loading and unloading product and doing rounds to inspect their equipment as shown in Figure 18.

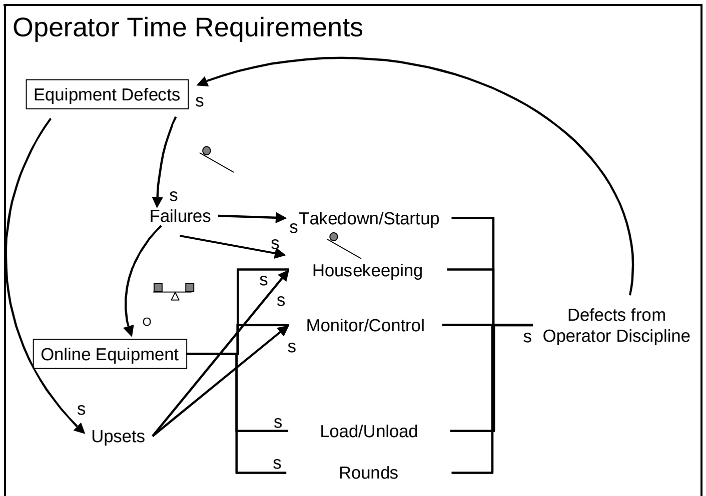

Figure 18

With the exception of takedown and start up, production levels determine how much time operators spend in each of these areas. Failures, defects and upsets (Figure 19) also determine where operators spend their time; each can, in turn, significantly impact productivity. As failures go up more time must be spent on takedown / startup and housekeeping.

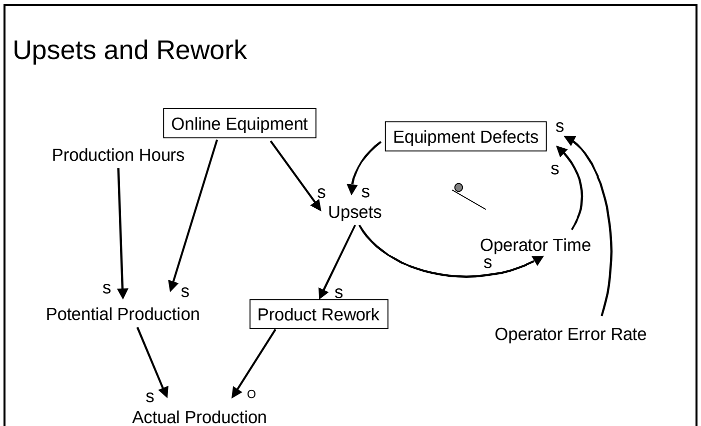

Figure 19

Computerized Maintenance Management Systems

The computerized maintenance management system (CMMS) and the work systems that accompany it are the most frequently discussed and implemented items in a reliability improvement program.

There are nine distinct impacts that a CMMS can have on performance. What is interesting in looking at this list is that the system alone does very little. The quality of the use of the system, adherence to standards and diligence in making sure that the data is correct and complete really drive performance. A CMMS implementation that does not explicitly deal with influencing behavior will produce little result.

Elements of a Computerized Maintenance Management System		
Element	**Impact**	**Improvement**
Planning Library Use and Quality	Planner productivity	Can double planner productivity
Planning	Mechanic productivity, parts reduction and reduced downtime	39% improvement in productivity
Work scheduling systems	Mechanic productivity, parts inventory reduction, reduced downtime and fewer defects from rushed jobs and collateral damage	23% improvement in productivity 20% better workmanship
Work Order Clarity	Finding root causes Productivity of Mechanics	35% improvement in finding root causes. Can improve productivity by 30%
Equipment History	Quality of improvement ideas Finding root causes	50% improvement in the quality of ideas for proactive intervention. 20% improvement in finding root causes.
Inventory Control	Stores effectiveness/ Dead stores	30% swing in dead/inactive stores
PM System	Allows PM's to be created and executed	Depends on policies
Condition Monitoring System	Defect detection	Can double the likelihood of finding a defect versus inspection and rounds only
Priority System	Determines what people work on (reactive vs. scheduled)	Depends on policies

Safety

Safety and reliability go hand in hand. In every implementation where we have impacted reliability at a client, safety has improved as well.

The idea of small root causes coming together to cause a more catastrophic problem is very similar. Our model of safety comes from a review of behavioral safety studies. The research there suggests that there are two key influences on safety: the manufacturing environment that determines the number of potential high-risk events, and the impact of individual behavior in the plant environment.

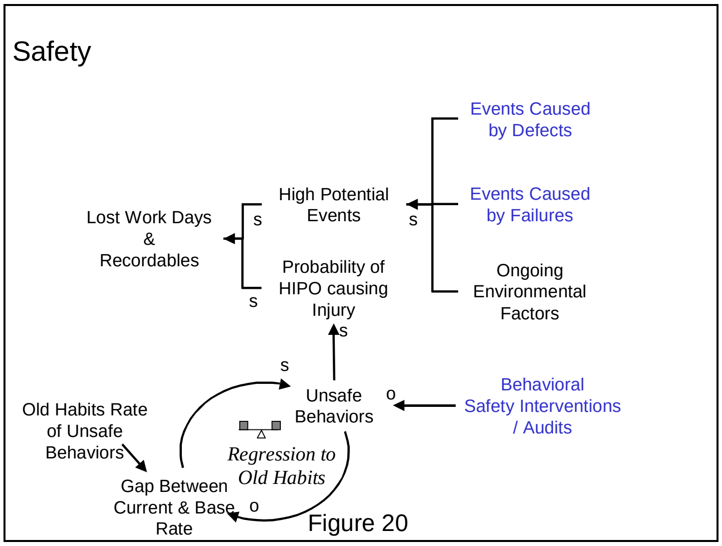

Figure 20

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As shown in Figure 20, the level of risk in the environment is highly dependent on the reliability of the plant. Every unplanned outage presents a risk. In some plants, this can be the risk of fire or explosion. In other plants it can mean flying debris. In all cases, failures mean having to take some corrective action and corrective action is inherently dangerous.

Defects can also be a potential hazard. A small leak that is not yet considered a failure may result in a slipping hazard. When these defects and failures are eliminated the number of high potential events falls dramatically.

The second element of safety from the behavioral safety approach is the behaviors of the individuals in the environment. Time spent reinforcing safe behaviors and looking for and eliminating unsafe ones allows people to not get hurt even when surrounded by hazards. As the "Regression to Old Habits" loop suggests this is a continual battle, and if behavioral changes are not consistently reinforced they will erode over time.

Manufacturing Cost

Production, upsets and defects also determine the variable, non-labor costs of production. There is an ideal cost of energy, waste, disposal and consumables per unit of production. There is also a cost for each that is associated with upsets, along with a relationship between energy costs and defects. Figure 21 shows the relationships between defects and the cost of manufacturing.

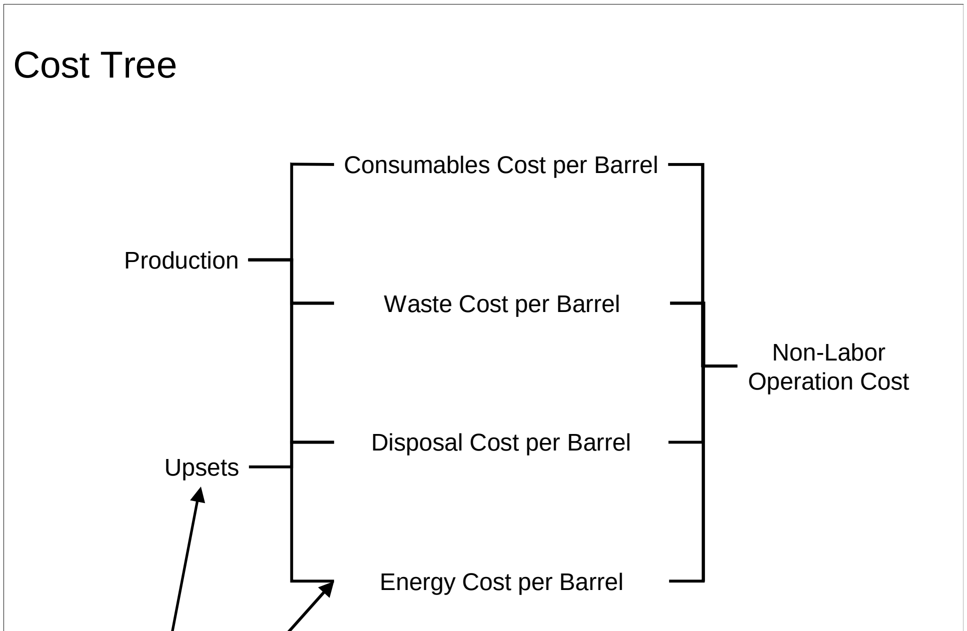

Figure 21

Based on the actual data from client implementations, we have estimated the split between these variables: generally 80% of the waste in operations comes from upsets and failures and only 20% are “unavoidable” due to design. A reduction in defects can result in a significant reduction in variable costs. We have found that a typical reactive plant will spend 12% more in these areas than a world-class plant for the same level of production.

Summary

The details of all these mechanisms are incorporated into a System Dynamics model done with Powersim software that uses the stock and flow diagram approach to create the model. The inputs from a facility are fed into the model using Microsoft Excel spreadsheets and the outputs are returned to the spreadsheet. This allows us to run several scenarios for the plant in question and compare them side-by-side. Using this approach we can see what the future of the plant would be if the management implemented a particular set of best practices and management policies. From our use of the model so far we have seen that many of the traditional approaches to reliability improvement have limited potential without changing behaviors. At one client we ran over 25 scenarios trying different combinations of best practices. We identified over $125 million in improvement opportunity. Half of the opportunity identified was realized through building ownership in the hourly workforce to look for and eliminate defects.

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