REDUCTION OF UNSCHEDULED MAINTENANCE OF BULK CARPET FIBER TEXTURIZING EQUIPMENT

by

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(ABSTRACT)

This project involved the measurement and reduction of unscheduled equipment maintenance in the final stage of a nylon-6 bulk continuous filament process. The SINTEX operation was selected because the cost of poor quality (COPQ) was estimated to be higher here than elsewhere in the process. An accurate measure of the time lost was obtained by measuring the time spent on unscheduled maintenance for a typical machine for forty-eight days. Area personnel ranked potential causes for the most frequent baseline repairs in a Failure Modes and Effects Analysis (FMEA.) Using the causes listed in the FMEA, an experiment was designed with three treatments; cleaning the draw and separator rolls, checking and adjusting threadpath, and maintaining a vibration standard. Results from the experiment showed that the combination of adherence to a vibration standard and weekly inspection and repair of the threadpath reduced unscheduled maintenance by 69 percent over the baseline.

Maintaining the demonstrated gains would involve monitoring the amount of

unscheduled maintenance downtime and require entering the data recorded at each of fourteen lines daily into a database. This would require hundreds of hours per year. Therefore, an automated maintenance reporting system is recommended to allow a timely response to the unscheduled maintenance system possible.

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

> There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in introduction of a new order of things, because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new.
>
> Machiavelli: The Prince
> 1469-1527

Executive Summary

Problem Description

This project involved improvement of part of a nylon-6 Bulk Continuous Filament (BCF) process. The effort centered on the last step in the production of the fiber, the SINTEX operation. Here, the yarn is drawn, texturized, and commingled before it is sold to carpet mills. It is in SINTEX that the yarn has the highest value since it is at the end of the production process. As the final manufacturing step, the cost of poor quality due to equipment malfunction or unavailability, includes the cost of all labor, utilities, material, and overhead accrued from the beginning of the process to the SINTEX operation. Therefore, a minute of equipment down time is worth more here then elsewhere in the process. Using this logic, SINTEX was selected for study. Maintenance costs in SINTEX had previously been calculated solely on the cost of repair parts and direct labor. This project first developed a reliable estimate of the additional cost of unscheduled maintenance in the SINTEX area expressed as minutes of lost production time. (As the "bottom line" cost of lost production time varies with the market rate of the fiber produced, the unit of measure *machine minutes lost to unscheduled maintenance per day* was selected to allow direct comparison of performance over time.) Then the investigator was to identify and test ideas that would reduce the unscheduled maintenance without redesign of the basic equipment configuration. The goal was to increase equipment uptime 0.5 percent.

Solution Strategy

As extensive redesign of the equipment was outside the scope of this effort, the traditional top-down systems engineering approach was not followed. Instead, focus was placed on how the maintenance process was managed. Emphasis was placed on actions that would eliminate the unscheduled maintenance events, or change them from reactive and unscheduled to predictive and controlled (scheduled). Overall strategy followed that outlined by Harry Mikel, where the improvement process was divided into four stages: measurement of the current system, analysis of variables, testing means of improvement, and control of the improved process.[1] Although the remaining chapters will describe each phase in detail, a brief description of the activities is included here.

During the measurement phase, maintenance repairs to two lines in SINTEX were recorded for forty-eight days. Machine downtime ranged from 0 - 1,796 minutes per day with an average of 611 minutes. This translated to 0 - 6.92 percent (average 2.36 percent) of machine availability. The data collected provided an estimate of the capability of the unscheduled maintenance repair process to meet the Area's requirement that not more than 2 percent of machine availability be spent on unscheduled maintenance. The most frequent repairs were also identified. Four repairs comprised 52 percent of all unscheduled maintenance events. These were selected for additional study.

The analysis phase produced a further refinement of the study's focus and a deeper understanding of the actual controls in place to detect impending machine failure. Operators and maintenance mechanics assigned to SINTEX participated in a Failure Modes and Effects Analysis (FMEA). They ranked 69 potential causes for the four repairs targeted for further analysis. The causes fell into two groups; where current controls were adequate but not followed, and where current controls were inadequate and a better technique was available.

Information gathered in the FMEA and from the baseline data was used to design

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[1]Mikel J. Harry, *The Vision of Six Sigma: A Roadmap for Breakthrough* (Sigma Publishing Company, Phoenix, AZ, 1994) pp. 21.7-22.2.

an experiment in the improvement phase of the project. Three treatments were employed on one line in SINTEX over a period of forty-eight days. Unscheduled repairs were recorded in the same way as during the measurement phase. Results were analyzed for effects of the treatments on unscheduled maintenance. The only treatment group that resulted in a statistically significant reduction in unscheduled maintenance time was that which included maintaining a vibration standard of 0.11 in/sec and checking and adjusting the threadpath weekly. This combination of actions showed a decrease of 31 percent in time down per day or an increase in equipment availability of 0.95.

During the control phase, relationships between previously identified treatments and their effects on unscheduled maintenance were used to develop a plan permanently to reduce unscheduled maintenance time. This plan had three main thrusts, establishing and maintaining a vibration standard for SINTEX, checking and adjusting the threadpath on the panel once a week, and installing a networked computer-based maintenance reporting system to hold demonstrated gains.

Results and Conclusions

A Pareto analysis of repair frequency measured during the baseline period showed that actual material cost was a small portion of the top 50 percent of repairs.[2] The real cost

[2]This is based on internal financial documents.

driver was production loss while the machine was down for maintenance. The SINTEX machine lost an average of 611 minutes per day, or 2.36 percent to unscheduled maintenance. Maintenance response (pre maintenance time) was much higher than actual repair time for all crafts.

Adhering to a vibration standard for the panel rolls and a weekly inspection and repair of the threadpath resulted in a 31 percent reduction of unscheduled maintenance time, or an increase in machine availability of 0.95 percent. The project's goal of a 0.5 percent improvement in machine availability was met.

Recommendations

Topics worth further investigation became apparent during the course of this study. The overall mechanical performance could be enhanced if a traditional systems engineering top-down analysis of the SINTEX machine were performed. Particular emphasis should be placed on component and sub-assembly reliability and maintainability. Part of the analysis should be a reassessment of the entire maintenance concept, to include maintenance actions currently performed by mechanics that would be more efficiently performed by operators. This study could serve as the preliminary steps to implementing a total productive maintenance (TPM) program in SINTEX. A feasibility study on the establishment of a TPM program in SINTEX should be conducted. The study should rely heavily on input from teams of SINTEX operators and maintenance mechanics. These teams would promote operator and mechanic teamwork and involvement in the area.

CHAPTER 2

MEASUREMENT PHASE

Process Description

The Bulk Continuous Filament (BCF) process is divided into three stages: Polymerization, Spinning, and SINTEX. An overall process is shown in Figure 1.

Polymerization

Polymerization involves converting caprolactam into a long chain polymer called nylon-6. Caprolactam, a six-carbon ring molecule, is heated with water to break open the ring, thus forming a straight chain molecule that then links end to end with other molecules forming a long chain. Four reactor vessels are used to accomplish this task. The first is used to break the ring and to mix the caprolactam with various additives to impart desired yarn properties. Vessel number two is used to lower the process pressure and to begin the polymerization process. Vessels number three and four are vacuum vessels that remove unreacted caprolactam and water from the melt. This drives the reaction to longer chains and

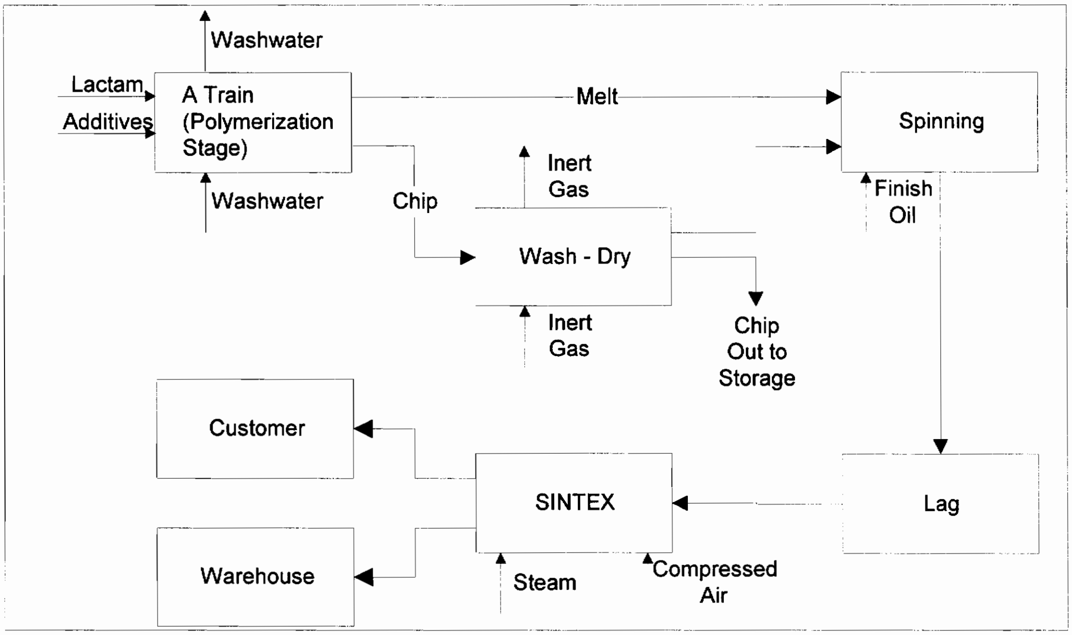

Figure 1. Process map for BCF conversion.

therefore higher viscosity. The fourth vessel is called a finisher because it finishes the polymerization and allows the reaction to come as close as possible to chemical equilibrium. The polymer is pumped to two different locations. One part, approximately one half the total polymer volume, is pumped to an extrusion area where the polymer is extruded into strands much like spaghetti. The strands are cooled with water and then chopped into one-eighth inch chips. These chips are pumped in a slurry to a vessel in which they are washed. Washing removes unreacted caprolactam. Chips are pumped from this vessel as a slurry to a rotating piece of equipment that separates the water from the chips. The chips fall into another vessel called a dryer. Hot dry inert gas is circulated through the chip bed.

Circulation of the gas dries the chips to approximately 20 percent moisture. The chips are then conveyed to a storage/blending tank and then conveyed to the spinning area. The other half the polymer stream pumped out of the finisher is pumped directly to the spinning area as a melt.

There is an alternate route for the chips. They can be "chipped out" of the system and piped into lever packs for storage and later use. This is a manual operation and is used when downstream equipment is not available to handle the normal amount of polymer (such as when equipment availability is low due to planned or unplanned maintenance).

Spinning

Chips conveyed from Polymer first go to a tank found directly above a line of spinning equipment. Chips are directed through a series of pipes and conveyors to extruders which melt the chips into a molten stream. The stream is metered via precisely controlled gear pumps to spinning positions. Each extruder feeds four gear pumps that each feed one spinning position. All four spinning positions and four gear pumps are called a block. This is a unit of production. From four to fifteen blocks is a spinline. The polymer that arrives in the spinning area as a hot melt is not extruded, but is piped directly to the block and gear pumps. After the gear pumps, the polymer is forced through a spinnerette. This is a flat metal plate in which holes, in the shape the polymer is to take, are drilled. The number and shape of the holes determine some end properties of the product. Molten fiber is forced though the holes in the spinnerette and immediately subjected to cool dry air. The air quenches or solidifies the molten polymer into a fiber as it drops from the third to the first floor. On the first floor Godet rolls catch the yarn as it leaves the quench stacks. These rolls are precisely driven and with the gear pumps control the denier of the fiber, or the thickness of each filament strand. The fiber next gets a coating of finish via a kiss roll and is wound on a cardboard tube to a weight of approximately 38 pounds. At this time it is removed from the winder and placed on buggy and moved to the lag area before final processing in SINTEX.

SINTEX

SINTEX is an acronym for SINgle end TEXturing. Eighteen panels, or machine positions, make up one line. A total of 14 lines, or 252 panels is in the SINTEX area. Yarn is creeled behind the SINTEX machine (Figure 2). The ends of the undrawn yarn are fed though the machine to the first rotating roll. This roll pulls yarn out of the creel and acts as an anchor for the next roll. Yarn is fed around the heated second roll to the heated number three roll (Figure 3). Roll number three's surface speed is three times the surface speed of the number one roll. The yarn is drawn as it traverses these three rolls. Next the yarn is aspirated with superheated steam into a texturizing jet, or stuffer tube. The yarn at this point

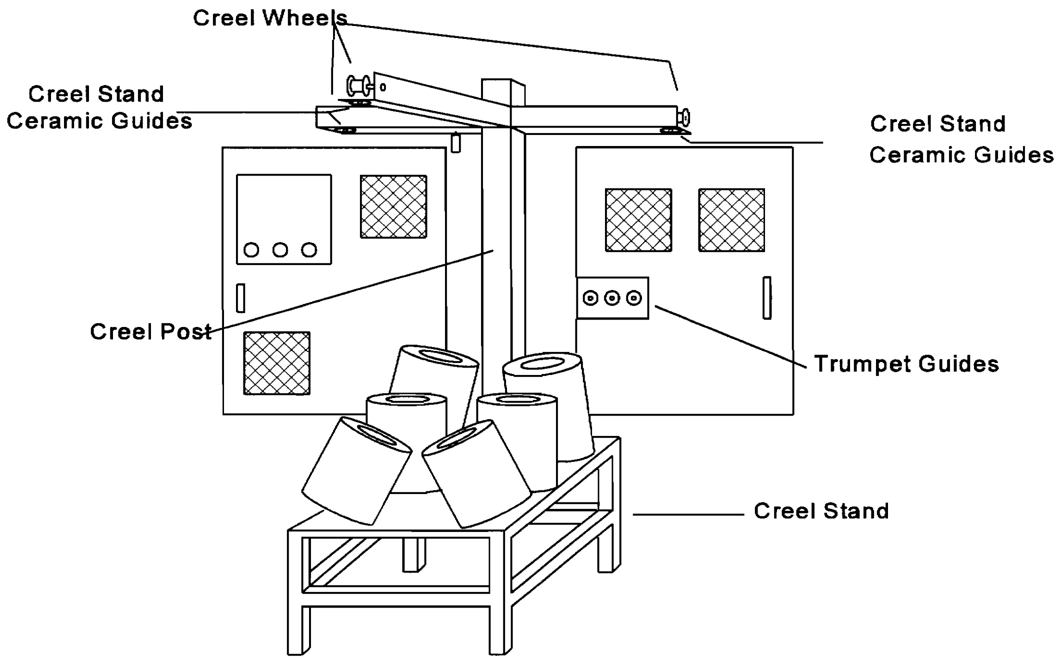

Figure 2. The creel and rear of a SINTEX panel.

is very close to its melting point. As the yarn enters the stuffer tube, it impacts on a plug of yarn. This impact causes the yarn to fold over onto itself which leaves a rolling crimp. Yarn leaves the stuffer tube, is allowed to cool slightly and is fed over the number four roll and from there, over the number five roll. Since the number four roll pulls the yarn out of the stuffer tube, its speed determines how much crimp is imparted to the yarn. The yarn leaves the number five roll and is fed through a commingler, a device that intermingles the filaments of the thread line so that the yarn does not flair during further processing at the customers' carpet mill. The yarn leaves the commingling device and is wound onto a cardboard tube in an automated winder. The result is a package of approximately twelve pounds.

The yarn is inspected, graded, and packed into boxes of thirty-two packages each and shipped. Customers include mills that weave the fiber into carpets for residential and industrial use.

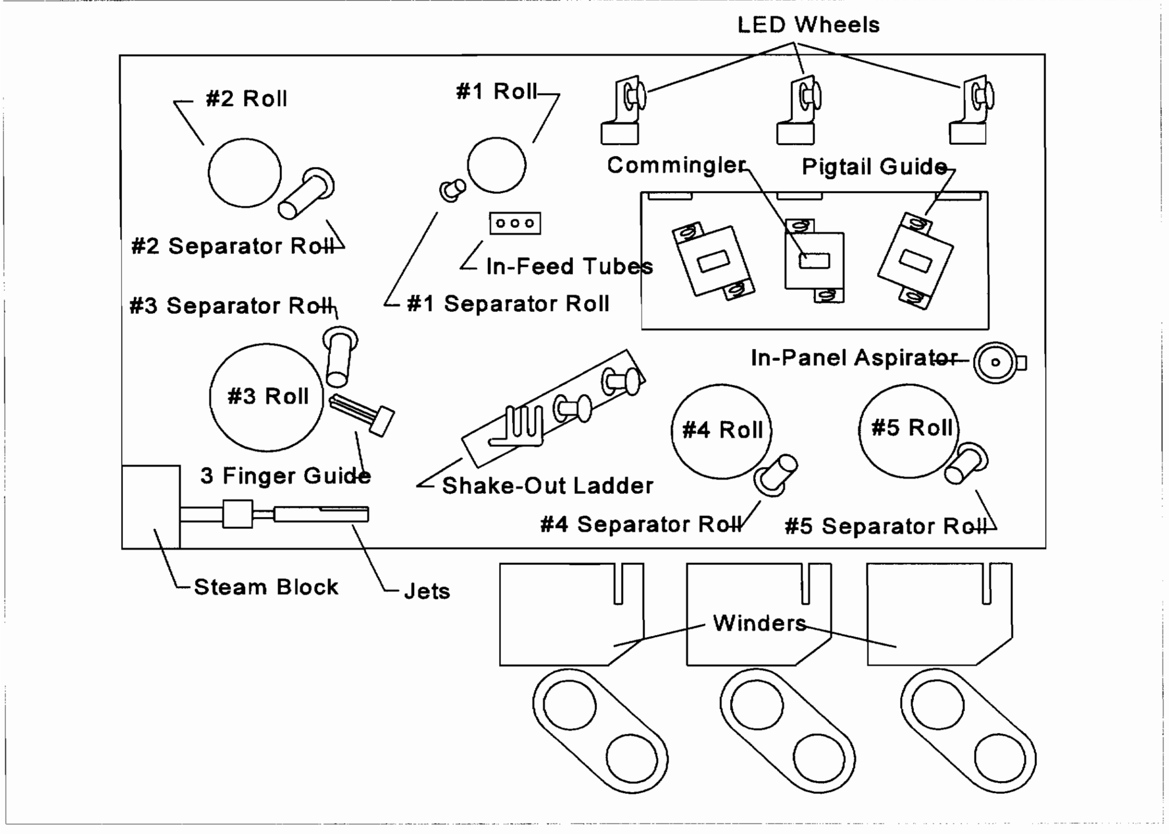

Figure 3. The front of a SINTEX panel.

SINTEX Layout

Eighteen panels make up one SINTEX line. Twelve lines are arranged in tandem in the main production area with an additional two lines located in an expansion of the main building. The expansion is reached via a hallway and its lines are approximately five hundred feet from the main SINTEX area. Each of the fourteen lines is bisected by an operator's console between panel numbers nine and ten. Here operators write requests for maintenance action on a form.

SINTEX Maintenance Staffing

Two Field Machinists (FM) are assigned to SINTEX each shift. They make rounds of the operators' consoles and do mechanical repairs listed by the operators. Occasionally one Field Machinist will be temporarily assigned elsewhere in the plant to cover an emergency. One Instrument Mechanic (I) is assigned to the area during the day and evening shifts and an Electrician (E) is in the area during the day shift. The Electrician and Instrument Mechanic also make rounds to decide what repairs are to be done. During the night shift, SINTEX is covered by the plant shift Electrician and Instrument Mechanic.

Management Model of the Maintenance System

How the unscheduled maintenance repair is managed can significantly affect equipment downtime. Who determines when a repair is required, how the mechanic is notified, and what determines when a repair is successful are key elements in the management process. Inefficiencies in transmitting information between parties could adversely affect the amount of time the equipment is down. A model of the management process would be an appropriate first step to understanding how it works.

The Management System Model uses a systems approach to define the relationships and responsibilities of the information components of a process.[3] The model can be applied to the unscheduled maintenance system because "[a]ll people are managers in a general sense, because they use information to make decisions affecting their own domains of responsibility."[4] The three components of the model are *who manages*, *what is managed*, and *what is used to manage*. Adapting the Management System Model for unscheduled maintenance in SINTEX (Figure 4), *who manages* is the operators, maintenance mechanics, and the maintenance coordinator. Operators decide when a panel needs repair, and if the problem is beyond their ability to fix, and which craft to request. The maintenance mechanic decides if there is a problem, if the repair is within his craft, or if the repair involves a second craft. The maintenance coordinator reviews the daily repair sheets and arranges scheduled

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[3]H. A. Kurstedt and P. M. Mendes, "Automated Performance Monitoring Provides a Strategic Management Tool for Crisis Management," *Computers & Industrial Engineering* **19**, pp.185-187 (1990).

[4]*Ibid*, p. 186.

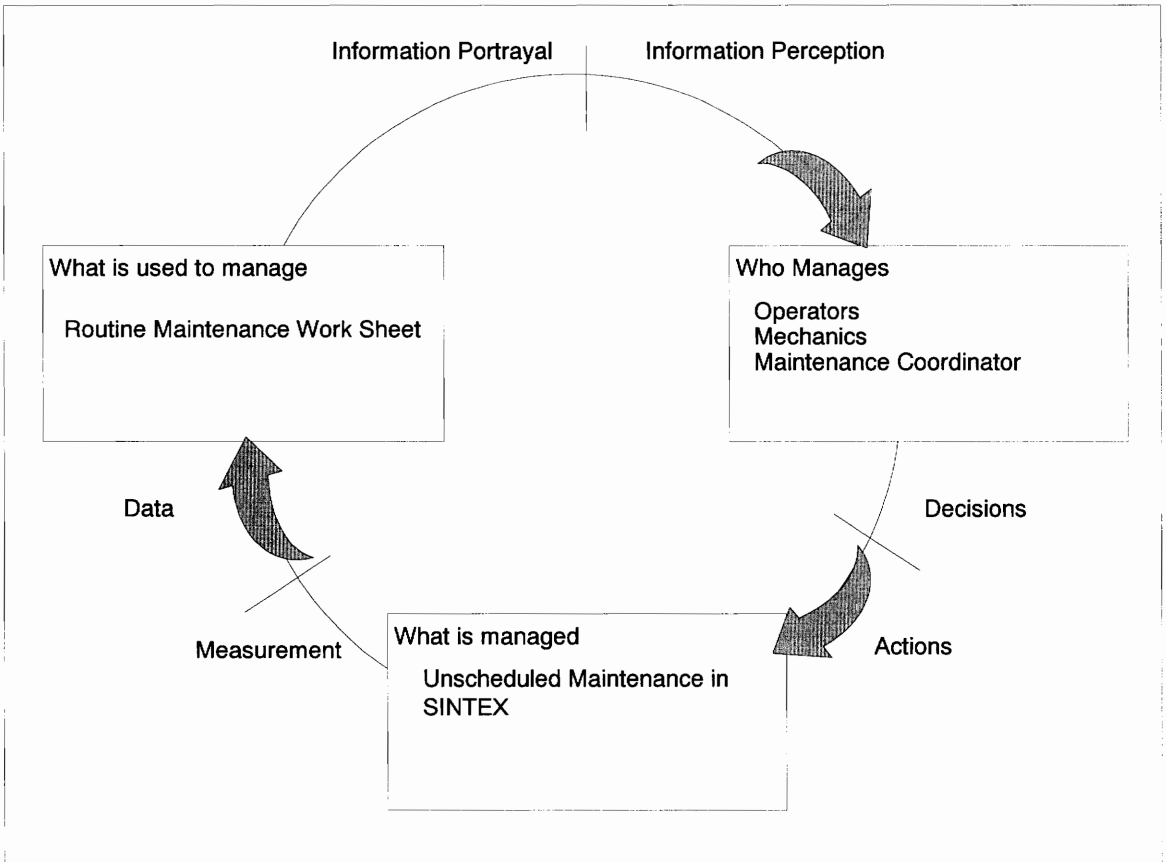
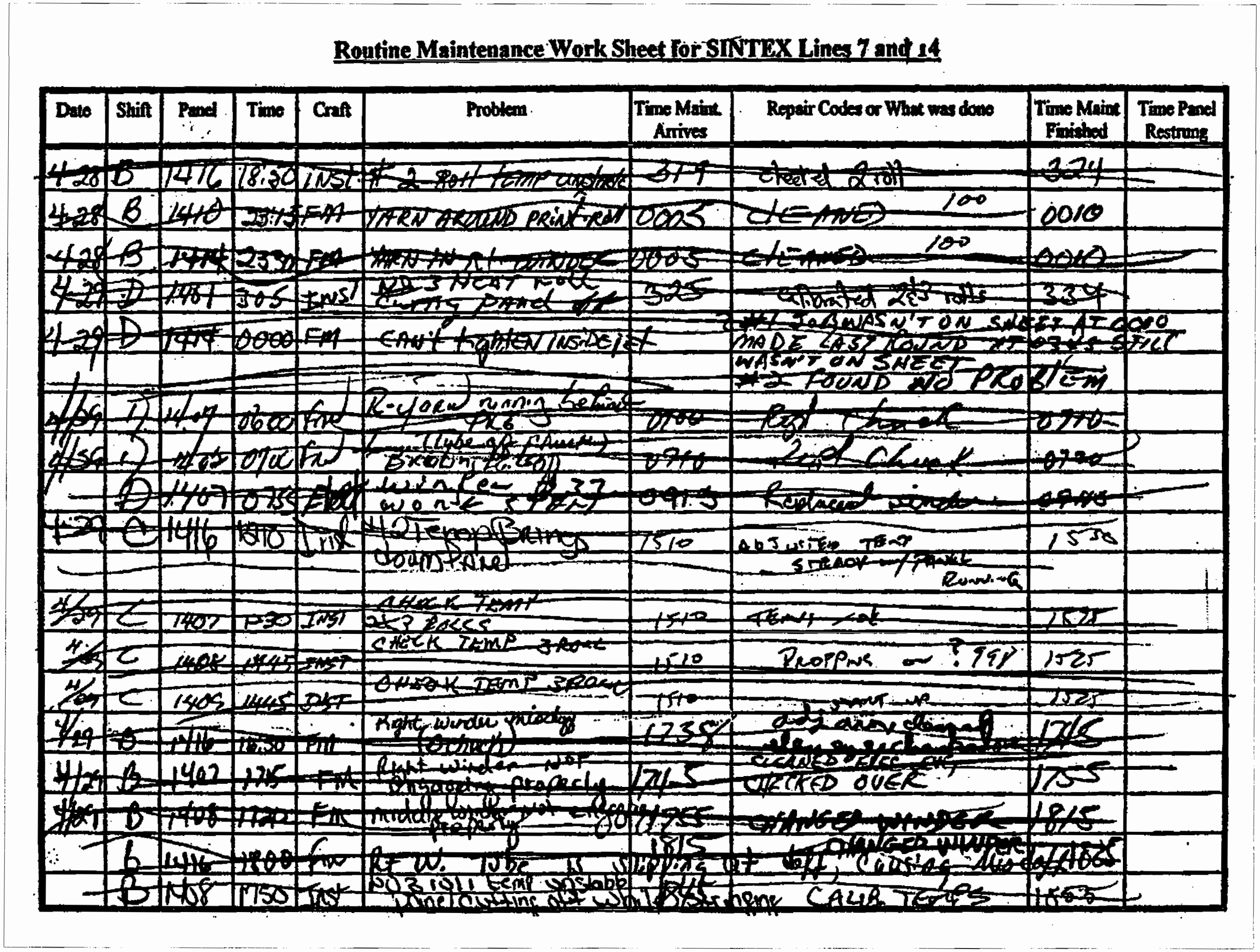


Figure 4. The Management System Model adapted to SINTEX unscheduled maintenance. (Model adapted from Kurstedt, 1990.)

maintenance if it is warranted in his judgement. The "Routine Maintenance Repair Sheet" is *what is used to manage*. (See Figure 5.) Once a day the sheets are collected and reviewed by the maintenance coordinator. They are bundled together by month and stored. Long term analysis of maintenance trends involves retrieval of the appropriate sheets deciphering handwriting, and entering repairs into a database for further manipulation. Due to its labor intensive nature, this is rarely done.



Routine Maintenance Work Sheet for SINTEX Lines 7 and 14

Date	Shift	Panel	Time	Craft	Problem	Time Maint. Arrives	Repair Codes or What was done	Time Maint Finished	Time Panel Restrung
4-28	B	1416	18:30	INST	#2 Roll temp unstable	319	checked 2 roll	324	
4-28	B	1410	23:15	FM	YARN AROUND PRINT ROLL	0005	CLEANED 100	0010	
4-28	B	1414	2350	FM	[illegible]	0005	CLEANED 100	0010	
4-29	D	1401	305	INST	[illegible] 3 HEAT ROLL Cutting panel off	325	adjusted 2&3 rolls	334	
4-29	D	1414	0000	FM	CAN'T tighten INSIDE jet		#1 JOB WASN'T ON SHEET AT 0000 MADE LAST ROUND AT 0345 STILL WASN'T ON SHEET #2 FOUND NO PROBLEM		
4/29	D	1407	0600	FM	R-yarn running behind PR6	0700	[illegible]	0770	
4/29	D	1405	0700	FM	(Tube off [illegible]) [illegible]	0740	[illegible] Check	0720	
	D	1407	0755	FM	[illegible] WORK [illegible]	0913	Replaced [illegible]	0945	
4-29	C	1416	1510	INST	#2 Temp Bring down Panel	1510	ADJUSTED TEMP STEADY w/PANEL RUNNING	1530	
4/29	C	1407	1530	INST	CHECK TEMP 2&3 ROLLS	1510	TEMP OK	1525	
4/29	C	1408	1445	INST	CHECK TEMP 3 ROLL	1510	DROPPING [illegible] 998	1525	
4/29	C	1405	1445	INST	CHECK TEMP 3 ROLL	1510	[illegible]	1525	
4/29	B	1416	18:30	FM	Right winder missing (Bunch)	1735	[illegible]	1716	
4/29	B	1407	1715	FM	Right winder NOT engaging properly	1715	CLEANED ELEC. EYE CHECKED OVER	1755	
4/29	B	1408	1720	FM	middle winder not engaging properly	1755	CHANGED WINDER	1815	
	B	1416	1800	FM	RT W. Tube is slipping off	1815	CHANGED WINDER [illegible]	[illegible]	
	B	1408	1750	INST	[illegible] 3 roll temp unstable [illegible]	1845	[illegible] CALIB TC's	1855	

Figure 5. A sample "Routine Maintenance Repair Sheet" showing where there could be a disconnect at the information portrayal - information perception interface.

What is managed can be described in greater detail using an exploded conceptual model (Figure 6). The input, what the operator observes, is depicted in greater detail in the Failure Modes and Effects Analysis (Appendix B). The process, unscheduled maintenance repair, is treated in further detail in the next section.

Output of the process, a panel running to specification, is subject to the operator's interpretation. Interviews with twenty-three operators from SINTEX showed that "to specification" is not uniformly defined, but changes according to the operator's skill and understanding the equipment's workings.

Process Map

The actual process managed, the unscheduled repair, is shown in a detailed process map (Figure 7). The repair process was mapped by questioning the operators and mechanics

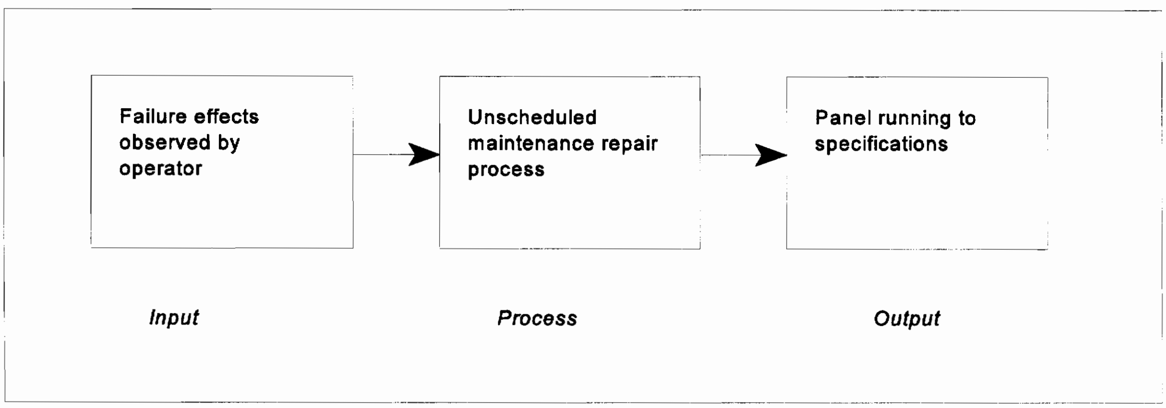


Figure 6. An input-output model showing *what is managed* in greater detail.

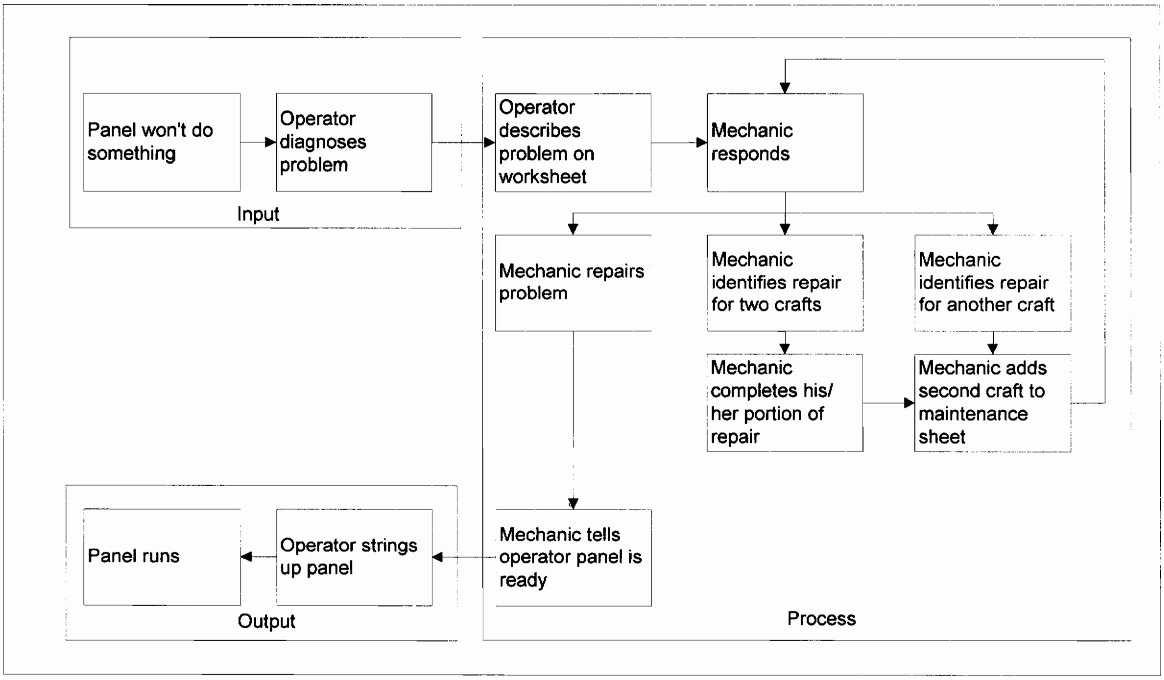


Figure 7. Detailed process map of the unscheduled maintenance repair. The steps of the input-output model (Figure 6) label the corresponding areas of the map.

assigned to the test lines and by observing the maintenance process during the project. Interviews with operators and maintenance mechanics suggest that there is not a universally accepted definition of the kinds of problems operators fix or which problems can be repaired by each maintenance craft.

Baseline Measurement

Since production did not have historical repair data in a useful format, the first step was to measure the repair activity on two lines for forty-eight days. Routine Maintenance

Worksheets were collected daily and the information shown in Table 1 was entered into a spreadsheet. From this data, a baseline of the unscheduled maintenance process was obtained. Following Pareto's reasoning that 20 percent of causes are responsible for 80 percent of the problem, further efforts were focused on the four repairs that accounted for over half of all repairs reported during this period.[5] A summary of the repairs and the responsible craft is included in Table 2. The repairs are displayed in the traditional graphical format in Figure 8.

Table 1. Data used for analysis and its source.

Data	*Who Provides*	*Used in Experiment*
Date problem written on sheet	Operator	yes
Time problem reported	Operator	yes
Shift problem reported	Operator	no
Problem description	Operator	yes
Time maintenance starts work on problem	Mechanic	yes
Repair(s) performed	Mechanic	yes
Time repair finished	Mechanic	yes
Time operator restarts panel	Operator	no

The unscheduled repair event is divided into three parts. The first part is the time spent after the panel is shut down due to a malfunction until the appropriate craftsperson

[5]Michael Brassard and Diane Ritter, *The Memory Jogger II*, (GOAL/QPC Methuen, MA, 1994) p.95.

Table 2. Pareto ranking of baseline repairs. Repairs selected for further study are shaded.

Repair	*Frequency*	*% of Total*	*Cumulative %*	*Responsible Craft*
Adjust threadpath item	139	17.73	17.73	FM[6]
Nothing to fix	110	14.03	31.76	FM, I, E
Adjust temperature	86	10.97	42.73	I
Remove yarn	71	9.06	51.79	FM
Replace traverse guide	67	8.55	60.33	FM
Adjust winder chuck	66	8.42	68.75	FM
Clean electric eye	58	7.40	76.15	I
Replace winder	30	3.83	79.97	FM
Replace accelerator belt	27	3.44	83.42	FM
Repair pressure regulator	24	3.06	86.48	FM
Retension #4 roll belt	23	2.93	89.41	FM
Adjust winder pressure	18	2.30	91.71	FM
Replace jet block	12	1.53	93.24	FM
Reset switch	12	1.53	94.77	I, E
Replace jet lock washer	9	1.15	95.92	FM
Cleaned lines	9	1.15	97.07	FM
Replace chuck spacer	7	0.89	97.96	FM
Reset breaker/replace fuse	6	0.77	98.72	E
Replace winder cam	4	0.51	99.23	FM
Clean roll	3	0.38	99.62	FM
Replace winder damper	3	0.38	100.0%	FM

[6]Baseline repairs were performed by the three crafts in the following ratios: Field Machinist (FM) 70%, Instrument Mechanic (I) 20%, and Electrician (E) 10%. Total number of repairs equals 784.

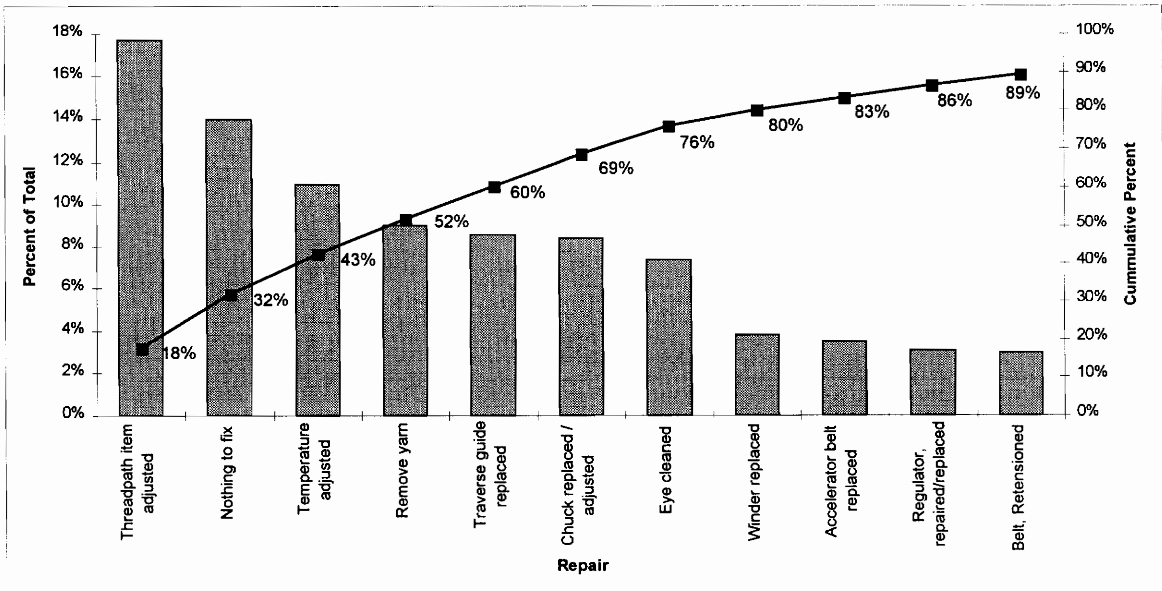


Figure 8. A graphical representation of the most frequent repairs performed during the baseline measurement period.

arrives (pre maintenance time). The second part is time the craftsperson spends fixing the problem (repair time). The last part is time the panel is down after it is repaired until the operator strings it up (post maintenance time). The baseline data was used additionally to get an idea of what proportion of the average unscheduled maintenance event was due to pre maintenance time, and what proportion was due to repair time. Post maintenance time was consistently 15 - 20 minutes whatever the type of repair performed.

Events were categorized according to the maintenance craft expected by the operator to do the repair. The results of maintenance response and repair times by craft are shown in Figures 9 and 10. The data shows that the typical repair time for each craft is insignificant compared with the pre maintenance time. Actual repair time ranges from 22 percent for mechanical work to 6 percent for instrument and electrical repairs of the total job time. These estimates use the median of each population to reduce the effect of extreme outliers.[7] The baseline data also revealed that pre maintenance times despite craft display long, thick tails in the right of the mean (above the mean in Figures 9 and 10). The kurtosis is most likely due to the practice of assigning maintenance personnel to other areas of the plant, as described earlier. This tends periodically to increase craftsperson response.

Baseline Capability Measurement

Production availability for one line (machine, or DTC) in SINTEX is calculated using the formula $A = \frac{Min}{Day} \times 18 \frac{Panels}{Machine}$ and is measured in *machine-minutes per day*.[8] As part of the SINTEX area's quest to reduce all sources of the Cost of Poor Quality (COPQ), a goal for unscheduled maintenance was to not exceed 2 percent of machine availability per day.[9] One line (DTC-7) was selected as a typical SINTEX machine to decide the capability of the maintenance system as a whole to meet this requirement consistently. Data recorded over forty-eight days indicated that unscheduled maintenance ranged from zero to 1796

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[7] J. M. Juran and Frank M. Gryna, *Quality Planning and Analysis: From Product Development Through Use*, 3rd edition (McGraw-Hill, New York, 1993) p.185.

[8] The availability of one SINTEX line is 25,920 machine-minutes per 24 hour day.

[9] Two percent translates to 518.4 minutes per 24 hour day.

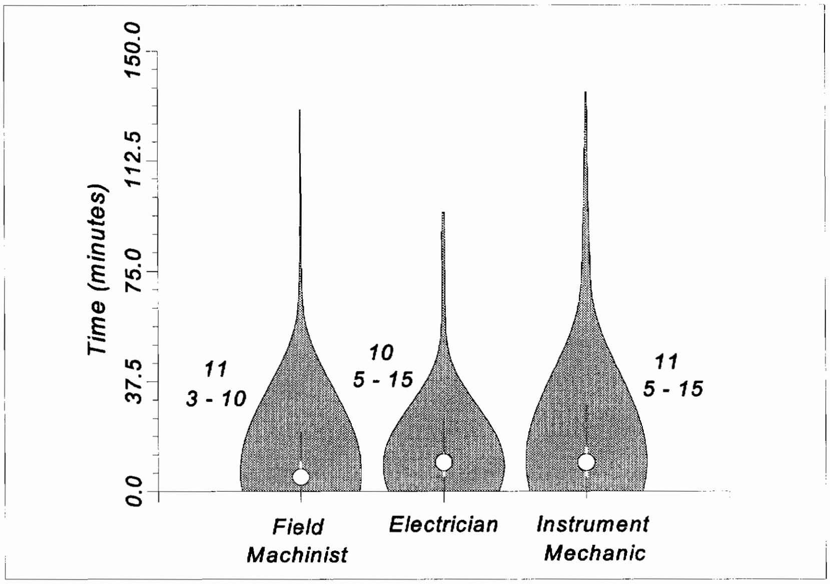

Figure 9. A violin plot of the baseline repair times for the three crafts. The median and 25th-75th percentiles are listed beside each distribution.

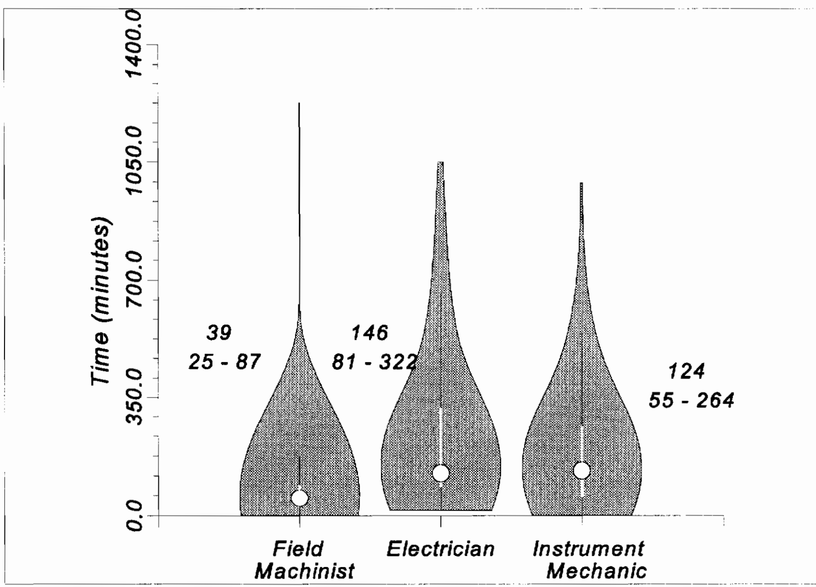

Figure 10. A violin plot of the baseline pre maintenance times for the three crafts. The median and 25th-75th percentiles are listed beside each distribution.

minutes per day with a mean value of 611 minutes. This translates to zero to 6.9 percent (mean value of 2.36) of total machine-minutes available.

The natural skewness of the distribution makes the traditional method of calculating the process capability (Cp_k) highly inaccurate.[10] However, inspection of a distribution of the values obtained during the baseline period (Figure 11) shows that fully 50 percent of the days the unscheduled maintenance time exceeded the 2 percent goal. Clearly, this is not a process that can consistently fall within the specification range. The unscheduled maintenance system for SINTEX could not be considered "capable."

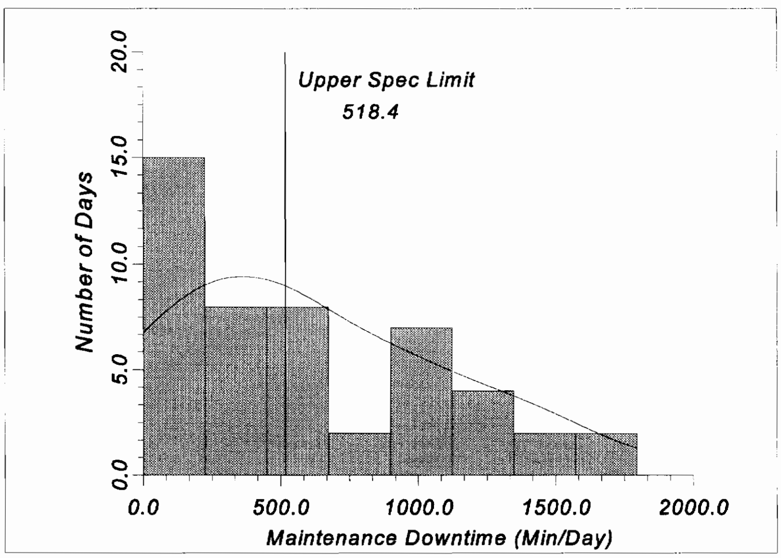

Figure 11. A histogram showing the distribution of downtime for DTC-7 over the 48 day baseline period.

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[10]Berton H. Gunter, "The Use and Abuse of Cp_k, Part 2," *Quality Progress*, pp. 108-109 (1089).

Cost of Poor Quality

Traditionally the cost of poor quality due to unscheduled maintenance in SINTEX has been calculated solely on the cost of direct labor and repair parts. This approach may significantly underestimate the actual cost. Using results obtained from the baseline, direct labor accounts for six to 22 percent of total maintenance time (Figures 9 and 10). In addition, the four repairs that account for over half the unscheduled maintenance requests do not require replacement parts (Table 1).

An alternative definition of the cost of poor quality is an "avoidable process loss."[11] This definition can be applied to SINTEX unscheduled maintenance as nylon fiber that was not produced due to an unpredicted equipment failure. This definition includes the pre maintenance and the repair time calculated as lost product. The value of the lost product should include the cost of all labor, utilities, material, and overhead accrued from the first manufacturing step to the SINTEX operation as established by Cole.[12] This cost expressed per *machine minute in SINTEX* is shown in Figure 12. These figures were determined using the Cost Breakdown Structure developed by Blanchard and Fabrycky and modified for a

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[11]Juran, p. 17.

[12]Robert E. Cole, "How to Gain the Competitive Edge: Improving Quality Through Continuous Feedback," *Management Review*, October 1983, p. 10.

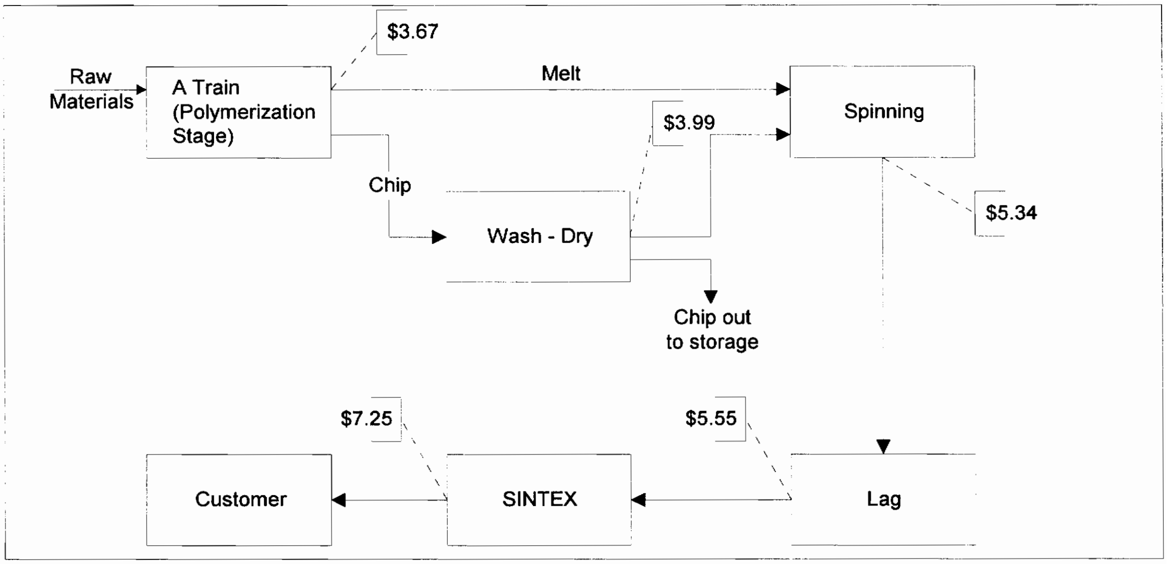

Figure 12. The BCF process map showing the accrued cost of poor quality expressed per *machine minute in SINTEX.*

mature manufacturing operation.[13] This is shown in detail in Appendix A.

Analysis of the Measurement System

From a systems point of view, there are several key points regarding this measurement system. First, it requires a high level of compliance from operators and mechanics to accurately record arrival and repair times. Second, the data sheet itself is a source of error.[14] Handwriting can be misinterpreted. There may be insufficient space on

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[13]Benjamin S. Blanchard and Wolter J. Fabrycky, *Systems Engineering and Analysis*, 2nd edition (Prentice Hall, Englewood Cliffs, NJ, 1990) pp. 659-681.

[14]According to individual interviews with maintenance personnel assigned to SINTEX.

the sheet adequately to describe a problem or the repair. Third, operators have varying levels of expertise on the SINTEX panel. Some may not have the skill to describe a problem adequately enough for a mechanic to make a timely diagnosis. Fourth, the amount of data generated daily requires hours of data entry. This injects a delay in obtaining a "snapshot" of the maintenance system's performance and obstructs the ability to make a real-time response. Any one of these items can interfere in the *measurement* to *data* interface on the Management System Model. Data is useful only if it is accurate, timely, and relevant.[15]

Summary of Measurement Phase

During the measurement phase, the most frequent repairs were identified and the focus of further study narrowed. Baseline data on pre maintenance and repair times was obtained for all three crafts. Repair time ranged from 22 to 6 percent of total job time. Pre maintenance and repair times exhibited kurtosis to the right of the mean. This was attributed to the practice of assigning maintenance personnel outside the SINTEX area.

One line was measured for forty-eight days to establish the capability of the maintenance system as a whole. The percent of available machine minutes that the line lost per day were calculated to be 0 - 6.9 percent, with an average value of 2.36 percent. By

[15] D. T. Hill, C. P. Koelling and H. A. Kurstedt, "Developing a Set of Indicators for Measuring Information-Oriented Performance," *Computers & Industrial Engineering* **24**, pp.379-390 (1993).

inspection of the distribution of baseline values, it was determined that the maintenance process was not capable of consistently falling within specification limits of 0 - 2 percent of machine availability.

This project also developed a more comprehensive estimate of the total cost of poor quality due to unscheduled maintenance in the SINTEX than what had been previously used. The unit of measure is *machine minutes lost to unscheduled maintenance per day.*

CHAPTER 3

ANALYSIS PHASE

Failure Modes and Effects Analysis

Once the baseline data was collected, the next step was further to refine the study's focus. The tool used was a Failure Modes and Effects Analysis (FMEA).[16] Twenty-three operators from the two lines that produced the baseline data and nine maintenance mechanics assigned to the area participated in this phase. This group represented more than 300 years combined experience working in SINTEX. With the investigator acting as facilitator and coach, they used unstructured brainstorming to identify more than 69 potential causes for four of the most frequently performed repairs identified during the baseline recording period. They also identified current controls for prevention of the unscheduled repair.[17]

For this study the level of detail stopped at the point where it was determined that

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[16] Chrysler Corporation, Ford Motor Company, and General Motors Corporation, *Potential Failure Mode and Effects Analysis (FMEA)*, 1995, pp. 25-45.

[17] Brassard and Ritter, pp. 19-22.

a potential cause could be detected and a repair scheduled. For example, if it were determined that a "main drive motor failure" could be detected with an available test or inspection method and the repair scheduled, the underlying causes of the drive motor failure were not pursued.[18] The completed FMEA is included in Appendix B.

Failure Modes and Effects Analysis Summary

Events were ranked based on severity (the number of panels affected), frequency of occurrence, and how far into the future failure could be predicted. Further analysis divided the events into three groups based on the adequacy and use of current controls. The results are summarized in Table 3.

Table 3. Summary of adequacy of current controls from FMEA.

Status of Current Control	*Number*	*Percent of Total*
Current control adequate, but not followed.	56	81
Current control adequate and followed.	2	3
Current control not adequate, better method available.	11	16
Total	69	100%

An example of an adequate current control that is not followed is the visual inspection of set screws in the steam block and shake out ladder guide. They wallow out

[18]The FMEA will be expanded in future to include all failure modes in detail.

from the allen wrenches used to adjust the assemblies. The control is to make a periodic inspection and to change the screws when that position is scheduled to be down. An example of an inadequate control is the determination that a bearing has failed by the sound of metal grinding. Vibration analysis is the preferred method, since it can predict impending failure several days to weeks in advance.

Management of Maintenance

During the initial phases of the study, problems were identified that inhibit the efficient transmission of information between managers of the unscheduled maintenance system. As previously stated, inefficiencies in the information flow can adversely affect the time equipment is down for repair. Figure 13 shows the Management System Model for unscheduled maintenance. Problems with the management system are listed on the diagram at the interface they affect.

Any control plan to improve the unscheduled maintenance in SINTEX should address each of these issues for maximum effectiveness. Technical changes alone cannot produce the kind of lasting process improvement required by the area.

Summary of Analysis Phase

This phase served further to refine the study's focus by identifying and ranking

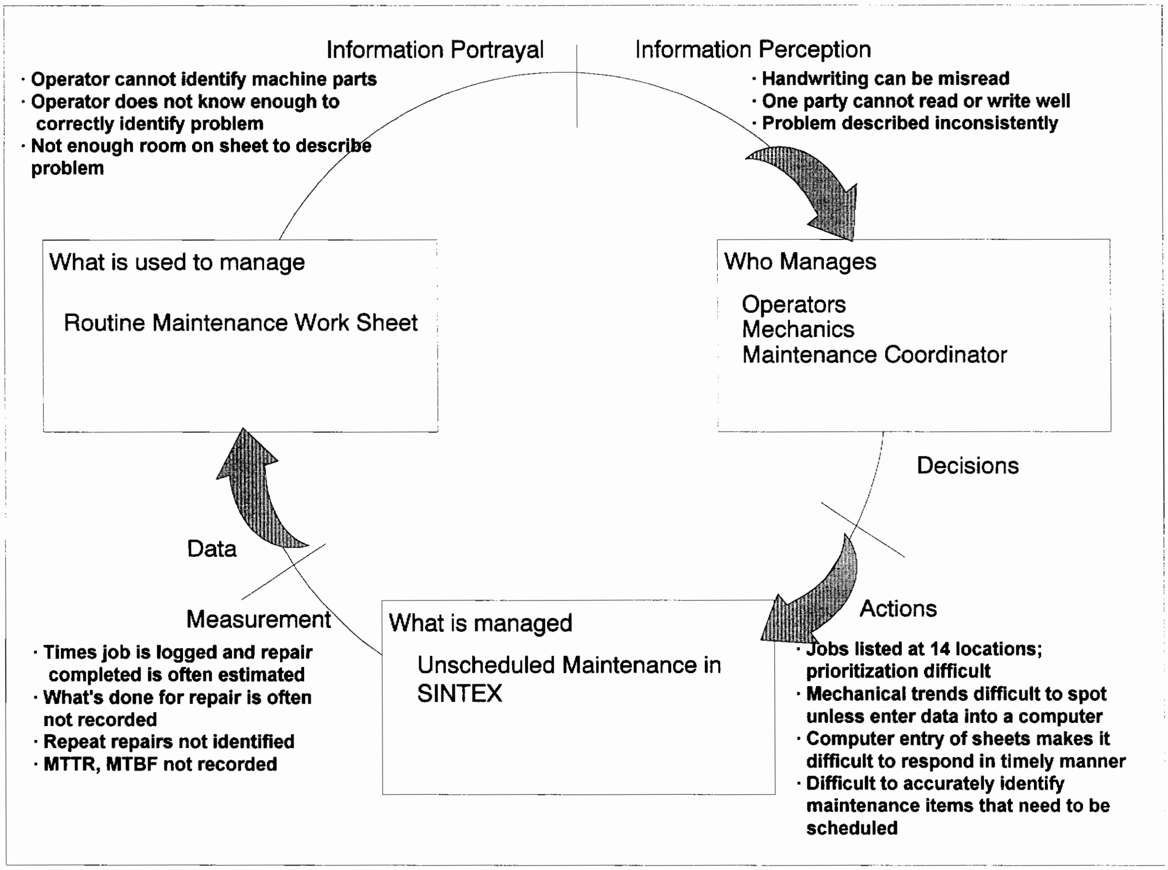

Figure 13. Problems with the current system that inhibit smooth transition of information between interfaces of the Management System Model. (Model adapted from Kurstedt, 1990.)

causes for the most frequent repairs recorded during the baseline period. Additionally the causes were grouped by the adequacy of their prediction method. This was overwhelmingly reactionary.

This phase also served to get "buy in" from the operators and mechanics assigned to the line where the experimentation of the improvement phase occurred. "Shop floor" participation was an important aspect throughout this project. Additional effort was asked of each operator and mechanic to record more data about the test lines than was required on other SINTEX machines. By developing the FMEA and later deciding what variables to test, the group had more ownership of the project and was more inclined to provide the extra effort.

An effective control plan should address the issues that inhibit the free flow of information between managers of the maintenance system. This will meet the project's objective to permanently improve SINTEX equipment availability by reducing time spent on unscheduled maintenance.

CHAPTER 4

IMPROVEMENT PHASE

Selective Preventive Maintenance Experiment

Experimental Design

The operators and maintenance mechanics who participated in the FMEA were presented with the Pareto chart (Table 1) of the most frequent repairs performed in SINTEX. They brainstormed and set priorities for treatments they thought would be most effective. The group then came to consensus using nominal group technique on the treatments to test.[19] The reasoning behind this approach was that with more than 300 years combined experience in SINTEX, these people would be the most familiar with the process and would probably have an intuitive understanding of what works.

Objective

The experimental objective was to decide if the treatments identified below would

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[19]Brassard and Ritter, pp. 91-95.

result in an overall decrease in time the positions were down for unscheduled maintenance. The experiment was conducted for 48 consecutive days on one SINTEX line, DTC-7.

Output Variables

- The total unscheduled maintenance time for the treatment group per day.
- The number of requests for a threadpath item adjustment.
- The number of false maintenance calls.[20]
- The number of requests for yarn removal.
- The number of requests for temperature adjustment.

Input Variables and Design

Seven line was split into three treatment groups.[21] The groups were kept together due to vibration carry-over from unbalanced to balanced panels.

Control group

- Nothing done out of the usual panel checks and preventive maintenance.[22]

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[20]False maintenance calls occur when an operator requests that a position be repaired and the maintenance mechanic finds nothing that requires repair.

[21]George E. P. Box, William G. Hunter, and J. Stuart Hunter, *Statistics for Experimenters*, (John Wiley & Sons, Inc., New York, 1978) pp. 93-106.

[22]"Out of the usual" varies among operators based on personal interviews. Since it was the intention of the project to be as unintrusive to the unscheduled maintenance system as possible, no attempt was made to change individual operator behavior. However, the same operators were assigned to the SINTEX line during the entire experiment.

Rolls cleaned group (The following was done once a week.)

- Fly waste (fuzz from yarn and loose yarn strands from breakouts) brushed from the panel and winder.
- Rolls 1-5 cleaned with water. (See Figure 3.)

Mini-PM and vibration standard group (The following was done once per week.)

- Fly waste cleaned from the panel and winder.
- Rolls 1-5 cleaned with water.
- Threadpath components checked for burrs, proper alignment, and adjusted.
- Yarn removed from behind rolls 1-5 and LED wheels.
- Vibration of all rolls monitored and corrected not to exceed 0.11 in/sec (with normal spectra).
- The electric eye cleaned.
- Heated rolls (numbers 2 and 3) checked for accuracy and calibrated if required.

Results and Conclusions

To reduce carry-over effects among treatment groups, a two-panel buffer zone between treatments was excluded from analysis. The control group consisted of panels 701-704, the roll wash group panels 707-710, and the mini-PM group panels 713-716. Panels

705, 706, 711, 712, 717, and 718 were excluded. Experimental results of the key output variables described in Chapter 4 follow.

Total Unscheduled Maintenance Time per Day

The total time in minutes each treatment group was down due to unscheduled maintenance by all crafts was compared. Upper and lower specification limits were set at zero and 2 percent of available time for four panels, 115.2 minutes. Both treatments had less unscheduled maintenance. (See Figures 14-16.) However, only the mini-PM group displayed statistically significant reduction in total downtime per day when compared with the control group. (The test criterion was calculated to be 0.416667, at a test $\alpha=0.025$, the critical value was 0.2776.) The Kolmogorov-Smirnov test was used to test for significance due to the kurtosis present in the data.[23] The mini-PM group was also the only treatment whose distribution shifted toward zero. A summary of the results for each treatment group is in Table 4.Following the logic used in comparing the capability of the unscheduled maintenance system during baseline measurement, the mini-PM group became more capable than the untreated and roll-wash treated groups. 67 Percent of the mini-PM group's maintenance values fall within the specification limits, versus 50 percent for the other two groups. Although it is not to 3-sigma standards, the mini-PM group is obviously better able

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[23]Hintze, p. 247.

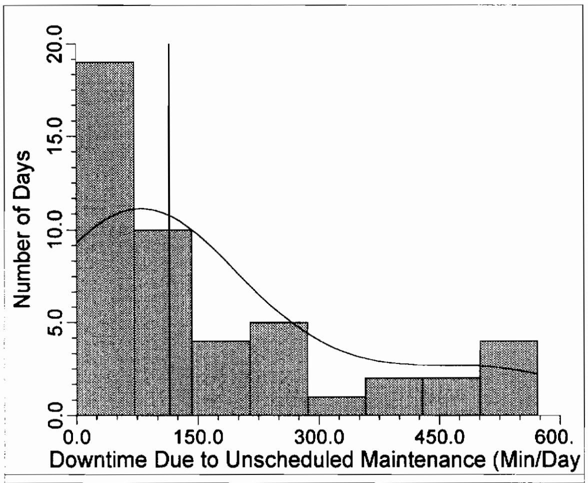

Figure 14. Downtime for all crafts positions 701-704. Vertical line represents upper specification limit (ULS) of 115.2 minutes.

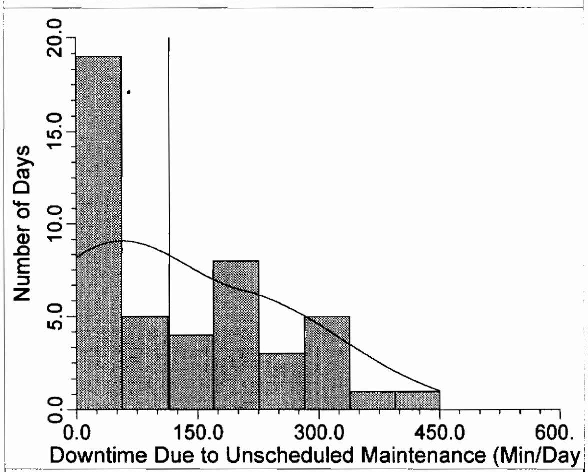

Figure 15. Downtime for all crafts positions 707-710. Vertical line represents ULS of 115.2 minutes.

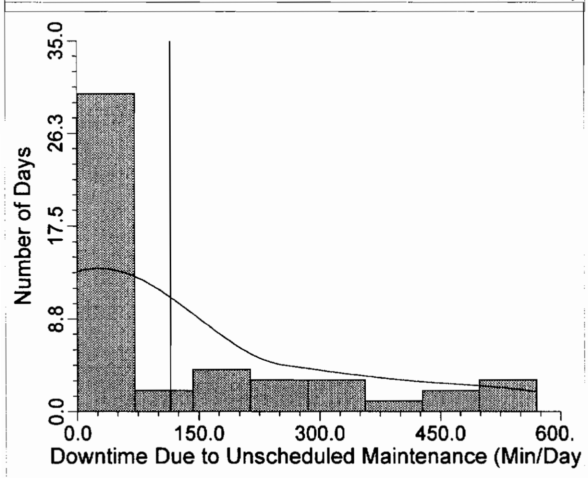

Figure 16. Downtime for all crafts positions 713-716. Note shift of distribution to zero. ULS of 115.2 minutes is represented by vertical line.

Table 4. Summary of results on unscheduled maintenance downtime.

Treatment Positions	*Median Downtime per Day (Minutes)*	*Percent Downtime[24] per Day*	*Days Above Upper Limit (Percent)*	*Reduction in Downtime (Percent)*
Control 701-704	110.0	1.91	50	---
Roll Cleaned 707-710	112.5	1.95	50	9.45
Mini-PM 713-716	4.0	0.07	33	31.08

consistently to meet the specification limits than the other two groups.

Downtime for Mechanical Repairs

Since 70 percent of all repairs recorded during the baseline period and three of the four targeted repairs were performed by field machinists, it is of interest to examine the impact of the treatments on mechanical repairs alone. The results of the treatments on mechanical work is shown in Figure 16. The mini-PM group (positions 713-716) experienced a statistically significant reduction in downtime over the control group (positions 701-704).[25] Although the roll-wash group did display less downtime for

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[24]Total available panel minutes per day is 5,760 minutes for the four panel test populations.

[25]Using the Kruskal-Wallis one-way analysis of variance on ranks, with a test α=0.05, the chi-square value was 10.44 (adjusted for ties), and the probability level 0.0054.

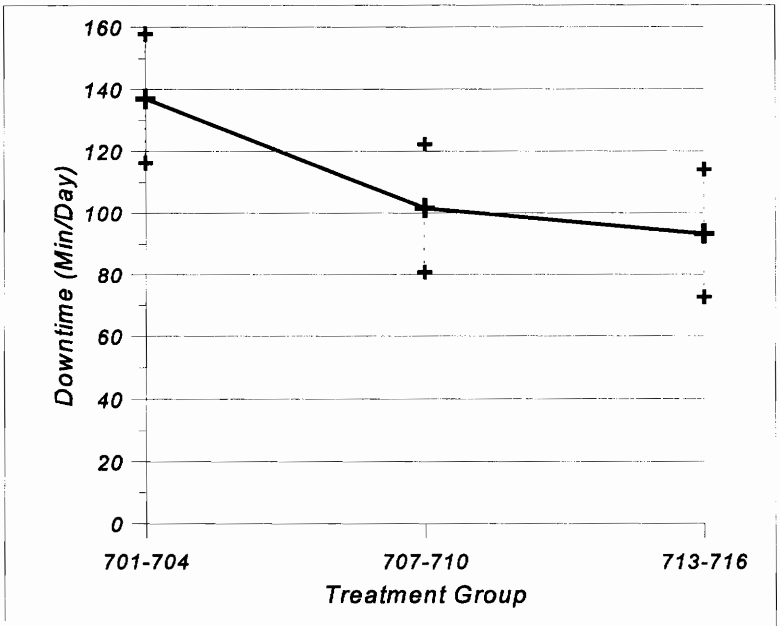

Figure 17. The effect of the treatments on downtime for unscheduled mechanical repairs. Upper and lower confidence limits are shown for each point.

mechanical repairs, it was not statistically significant.

Number of Threadpath Items Adjusted

The number of threadpath items that required unscheduled adjustment decreased by 67 percent for the roll wash group and 83 percent for the mini-PM group. This result may be due to the preventive nature of the treatments. Cleaning the fly waste before it has a chance to wrap itself into a threadpath component and knock it out of alignment may prevent the majority calls for threadpath adjustment. The added benefit of searching weekly for a

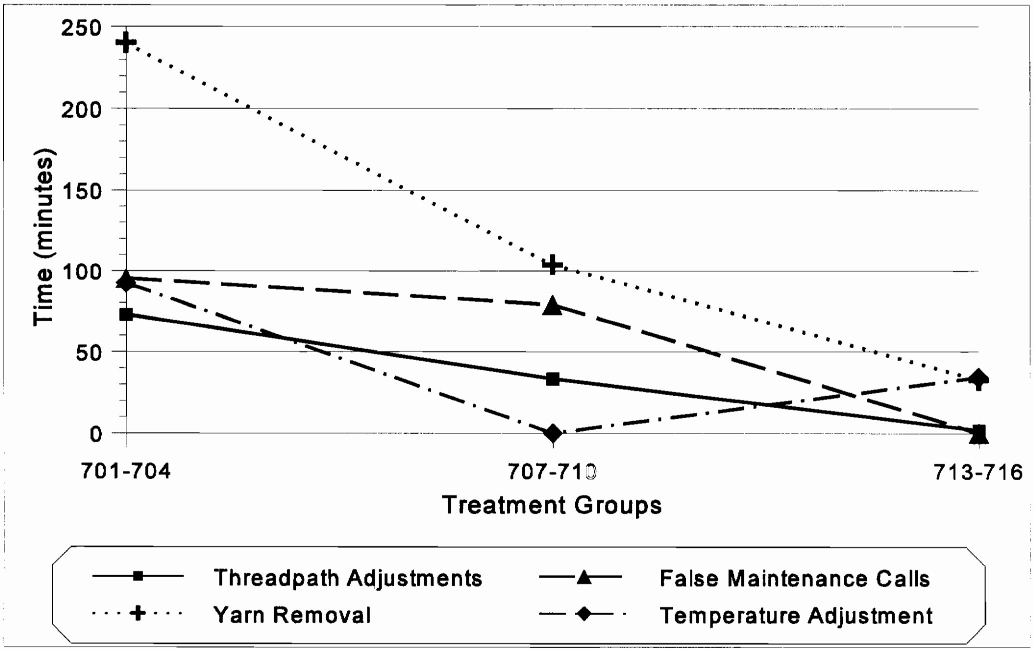

Figure 18. The effect each treatment had on the time spent on the four targeted repairs.

threadpath item that is about to fail (the mini-PM group) is responsible for the additional 16 percent decline in threadpath adjustments. This group showed statistically significant improvement.[26] The effect each treatment had on time spent adjusting threadpath items is shown in Figure 18.

The Number of False Maintenance Calls

The number of false maintenance calls decreased by 40 percent for the roll-wash

[26]Using the Kruskal-Wallis one-way analysis of variance on ranks, with a test α=0.05, the chi-square value was 8.2 (adjusted for ties), and the probability level 0.0042.

group and 100 percent for the mini-PM group when compar ed with the control. The time spent on false maintenance calls is shown in Figure 17. The mini-PM group's result was significantly less than the control group.[27] One hypothesis is that these calls may indeed not be "false." There may be something mechanically wrong with the panel such as moderately high vibration or the early stages of a component failure but the mechanic does not detect it. The preventive maintenance actions taken by the treatments may prevent the ultimate failure of the component. For example, in the roll-wash group, removing yarn fuzz from the panel before it gets behind and binds a roll would prevent a failure. In the mini-PM group, a more aggressive approach was taken. In this group the threadpath components were checked for impending failure weekly, and replaced if required.

Number of Requests for Yarn Removal

Both treatments reduced the number of requests for unscheduled yarn removal by 75 percent compared with the control group. Time spent removing yarn for each of the three treatments is shown in Figure 17. The yarn removal time for the mini-PM and roll wash groups were significantly lower than the control.[28] There was no additional benefit shown

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[27]Using the Kruskal-Wallis one-way analysis of variance on ranks, with a test $\alpha=0.05$, the chi-square value was 7.76 (adjusted for ties), and the probability level 0.0053.

[28]Using the Kruskal-Wallis one-way analysis of variance on ranks, with a test $\alpha=0.05$, the chi-square value was 10.67 (adjusted for ties), and the probability level 0.0048.

by checking the threadpath weekly and maintaining a vibration standard. Evidently, once yarn wraps are removed initially, brushing loose pieces of yarn from the panel weekly is sufficient to prevent yarn bits from forming wraps behind the moving components. It is interesting that this activity has been timed to take an average of 7 minutes. Based on average frequency, response and repair times, the payback of total time saved is 20 to 1.

Number of Requests for Temperature Adjustment

Weekly calibrations of the number 2 and 3 heated rolls reduced total number of unscheduled calibrations over the life of the experiment. The number of calibration requests per position did not vary significantly between the original baseline and positions not routinely calibrated during the experiment (positions 701-704, and 707-710). However, time spent performing calibrations was significantly less for the calibrated positions (707-710) than the two other groups.[29] The difference between these positions and the calibrated positions (713-716) implies that the temperature controller is drifting between routinely scheduled calibrations. The work done during the routine calibration may eliminate a more extensive check of the circuitry. A follow-up study will be done to learn the optimum calibration interval.

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[29]Using the Kruskal-Wallis one-way analysis of variance on ranks, with a test α=0.05, the chi-square value was 10.6 (adjusted for ties), and the probability level 0.0136.

CHAPTER 5

CONTROL PHASE

Summary of Control Plan Development

The control plan was developed with the maintenance coordinator and the vibration technicians. It has three main thrusts, maintaining a vibration standard for all rolls in the panel, doing a mini-PM on each panel once a week, and installing a networked computer-based maintenance reporting system.

Vibration Standard

The experimental results showed that maintaining an upper limit of 0.11 in/sec for all rolls in the panel reduced unscheduled downtime for maintenance. Currently one technician checks SINTEX every ninety days and issues a report listing panels with high vibration. Since specific repair work done by each mechanic is not kept, feedback to improve repair integrity is not possible, nor timely if it comes three months after the repair. In addition, the vibration technician is not seen in a positive role, rather as an enforcer of the "correct method." The solution is to train all Field Machinists working in SINTEX vibration analysis. The technician assigned to the area will train the mechanics "on the job" using a laptop personal computer to bring the analysis software to the SINTEX panel. All shift Field Machinists will be issued a vibration analyzer. The vibration technician will be available as a technical expert if required.

The benefits of this approach are threefold. First, the mechanic gets immediate feedback on the quality of his or her repair and can make corrections before leaving the job. Second, the mechanic checks his own work and does not feel that someone else is policing his work. Third, every mechanic in SINTEX will have been trained in a tool that can reduce the time spent diagnosing a mechanical problem.

Mini-PM

The experiment showed the benefits of ensuring that the threadpath components are properly aligned. This procedure was timed and took approximately 15 minutes per panel. The specific actions included the following.

- Fly waste brushed from the panel and winder.
- Rolls 1-5 cleaned with water.[30]

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[30]Although roll cleaning did not reduce maintenance time significantly, it did show significant decrease in the interruption rate per hour (a measure of process ability) in other studies. It is therefore included in recommended control effort.

- Threadpath components checked for burrs, proper alignment, and adjusted.
- Yarn removed from behind rolls 1-5 and the LED wheels.

It is recommended that an operator and/or a mechanic do the tasks listed above once a week and whenever the line is scheduled to be shut down.

Maintenance Reporting System

It became apparent to the investigator that a permanent improvement to the unscheduled maintenance system would not be possible until the problems at the Management System Model interfaces are addressed. (See Figure 13.) A significant amount of time was required during this project to take each Routine Maintenance Repair Sheet (Figure 6), interpret the handwriting, and enter the data into a database so statistical analyses could be run and process indices calculated. It was estimated that to do this for all fourteen lines daily would require too much labor to be practical. A solution to the data entry problems would be to automate the capture of maintenance data.

A Windows™-based networked maintenance reporting and management system will be installed. This system will solve the labor issue of data entry and address MSM interface issue. A workstation will be at every operator's console. The user interface will be a graphical depiction of the SINTEX line and main parts of the panel. Operators point the mouse at the area where they are having trouble and a menu of most frequent repair requests appears. The operator clicks on the correct problem description, or may type in a comment.

How the maintenance reporting system addresses the Management System Model interface problems of the current system is included in Table 5.

Table 5. How the maintenance reporting system addresses MSM Interface problems of the current system.

Current System Measurement/Data Interface	*Improved System Measurement/Data Interface*
Time job logged and finished estimated, providing inaccurate measures.	The software will automatically date and time stamp the record, resulting in greater reliability of downtime measurement.
Repair specifics not recorded, therefore losing a significant part of the event record.	A screen prompts the mechanic to record a complete description of the repair. This will include this information in more event records.
Recurring repairs not easily identified.	This software will generate a report to identify recurring repairs based on user requirements. The software generates a pop-up window in the Job Log window that lists all repairs performed on each panel listed over that previous 24 hours.
Reliability indices such as Mean Time to Repair and Mean Time Between Failure cannot be current determined due to excessive labor required to enter data into a database.	The software will generate a report that includes the reliability indices.

Table 5. How the maintenance reporting system addresses MSM Interface problems of the current system.

Current System Information Portrayal/ Perception Interface	*Improved System Information Portrayal/ Perception Interface*
The operator cannot identify machine parts, making problem description vague.	A graphic interface allows the operator to select the specific part of the equipment he wishes to report. This should improve the accuracy of the report.
Operators do not know enough to identify the problem correctly. The same problem will be described accordingly to each operator's understanding of the panel's functioning. The mechanic spends more time diagnosing what is really wrong with the equipment than is necessary.	Pull down menus describe 90 percent of all problems recorded over the test period. This standardizes the description of these problems to terminology upon which operators and mechanics have agreed.
Not enough room on the Routine Maintenance Worksheet to describe the problem.	Pull down menus have concise problem descriptions. In addition, operators can enter up to 80 characters of text.
Current System Decisions/Action Interface	*Improved System Decisions/Action Interface*
Jobs are listed at 14 locations - prioritization of repairs by mechanics difficult to reduce total downtime.	All current jobs may be viewed at any terminal connected to the network in the plant. This allows the mechanic to prioritize jobs and arrive at the job with the correct parts.
Since the mechanics must travel from line to line even to see if there is a repair required. This builds in a lag time in responding to a request for maintenance.	The database will be updated every few seconds preventing the wait lag of the current system.
Mechanical trends are difficult to spot.	Trends will be reported by the system based on user requirements.

Cost Benefit Analysis

Development and implementation of the system as described will cost approximately $300,000. Taking a conservative approach, that the change from the current rounds-based to a prioritized maintenance response system will reduce only the Field Machinists' response time by 3 percent, the system will pay for itself in 3 years. This payback is based on the additional machine availability and revenue generated from the ensuing production. The return on investment averaged over five years from project onset is 28 percent. The specifics of the cost-benefit analysis are included in Appendix C.

CHAPTER 6

SUMMARY OF RESULTS

The project's objectives were 1) to develop a reliable estimate of additional cost of unscheduled maintenance expressed as minutes of lost production per day, and 2) identify and test ideas that would reduce these costs. The goal was to reduce increase equipment availability by 0.5 percent. Analysis of unscheduled repairs measured during the forty-eight-day baseline period showed that repair cost was overwhelmingly determined by the cost of poor quality incurred by lost production time. The cost of unscheduled maintenance was best expressed as minutes of lost production time. The SINTEX machine lost an average of 611 minutes per day, or 2.36 percent of machine minutes per day.

Thirty-two operators and maintenance mechanics identified possible treatments that would reduce unscheduled maintenance. The reasoning behind this approach was that people who work on the equipment over a long period would be the most familiar with the process and would have an intuitive understanding of what works. An experiment was conducted on one line over forty-eight days. The positions that reduced roll vibration to less than 11 in/sec and had weekly inspection and repair of the threadpath had a 31 percent reduction in unscheduled maintenance time over the control positions. This treatment was statistically significant using the Kolmokov-Smirnov and Kruskal-Wallis analyses of variance. Treatment results translated to an increase in machine availability of 0.95 percent. A change to the scheduled maintenance on the machines was recommended based on the experimental results.

Problems were identified in the current system of reporting and prioritizing unscheduled repair work that would prevent a permanent improvement in the unscheduled maintenance system. An automated system of data capture would be required to allow timely response to trends in the maintenance system. The system developed had a graphical user interface. This also served to address problems in the Management System Model information portrayal to perception, measurement to data, and decisions to actions interfaces.

In conclusion, the study's objectives and goals were accomplished. Additionally, the implementation of the scheduled machine maintenance and the automated data system will allow the productivity gains shown in the experiment to become permanent.

Recommendations

Areas worth further investigation became apparent during the course of this study. It is recommended that a traditional systems engineering top-down analysis of the SINTEX machine be completed in the near future. Particular emphasis should be placed on component and sub-assembly reliability and maintainability. Specific items which should be addressed are the costs and benefits of staging partially or completely assembled components in the area versus the present system of repair using piece parts at the machine.

Primary candidates for this treatment would be assemblies which require more than one craft to repair, such as the number 3 heated roll. The number 3 roll assembly consists of a housing with bolted connections, shaft, bearings, roll heater, roll, thermocouple, and rotating coupling. Under the present system if, for example, a bearing fails in this unit a Field Machinist first removes the roll. The area Instrument Mechanic then removes the thermocouple, roll heater and rotating coupling. The Field Machinist returns and replaces the bearing and shaft. The Instrument Mechanic then replaces the heater and thermocouple and the Field Machinist replaces the roll. The Instrument Mechanic returns one last time to check the thermocouple calibration before the panel can be returned to service. Each time the job is "handed-off" to another craft, more pre maintenance time is added to the total repair time. If all the components were assembled, calibrated and balanced and the entire unit staged in SINTEX, the job of replacing a failed bearing would be much simpler. The entire number 3 roll assembly would be removed and a new assembly installed. The entire operation would be performed by a Field Machinist, including plugging the thermocouple connector into the panel.

Based on the outcome of this analysis, it may be worthwhile to expand the effort and perform a systems engineering analysis of the entire BCF conversion process or even the entire plant. Many production facilities have seen significant benefits from taking a systems engineering approach on a plant-wide basis.

Another area suitable for further investigation is the implementation of a total productive maintenance program for SINTEX. Total productive maintenance (TPM) is a method of maximizing machine effectiveness by using a thorough system of preventative and operator performed maintenance. Active participation by operators in the care of their machines through teamwork with the area maintenance mechanics is one of the program goals.[31] The concept has been developed and promoted over the last twenty years by Seiichi Nakajima and the Japan Institute of Plant Maintenance.[32,33]

It is recommended that a feasibility study be performed on the SINTEX system to determine the viability of a TPM program. The study should incorporate the results from the top-down analysis of the SINTEX machine. In addition, the study should incorporate the topics recommended by Hartmann; a) equipment utilization, b) equipment effectiveness, c) equipment condition, d) employee skills gap analysis, e) total current employee skill level,

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[31]Edward H. Hartmann, *Successfully Installing TPM in a Non-Japanese Plant*, (TPM Press, Inc., Allison Park, PA, 1992) pp. 15-16.

[32]Seiichi Nakajima, *Total Productive Maintenance (TPM)*, (Productivity Press, Portland, OR, 1988.)

[33]Seiichi Nakajima (ed.), *TPM Development: Implementing Total Productive Maintenance*, (Productivity Press, Portland, OR, 1989.)

f) level of employee motivation, g) employee department turnover, h) current maintenance actions, I) proposed maintenance actions, j) management of maintenance, k) the department maintenance organization, l) housekeeping, and m) the plant culture.[34] SINTEX operators and maintenance mechanics should actively participate in all aspects of the feasibility study. This will serve to increase operator and mechanic involvement in the area and promote buy-in for the study's recommendations should they be implemented. It will also increase operator knowledge of maintenance issues, and begin to promote teamwork between operators and maintenance mechanics.

Based on the results of the feasibility study, SINTEX may be suitable for a pilot test of TPM. This may also be suitable for implementation across the entire plant.

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[34]Hartmann, pp. 148-149.

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APPENDIX A

Manufacturing Costs for BCF Fiber

The first step to determine the cost of poor quality of product lost due to unscheduled maintenance is to determine which costs should be included. It was decided to use the cost breakdown structure developed by Blanchard and Fabrycky and modify it for a mature manufacturing system.[35] The costs that are included are shown in Figure 19. The estimated cost by category and production step is shown in Table 6.[36]

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[35]Blanchard and Fabrycky, pp. 659-681.

[36]As actual costs are confidential, the values shown are typical of a BCF production facility.

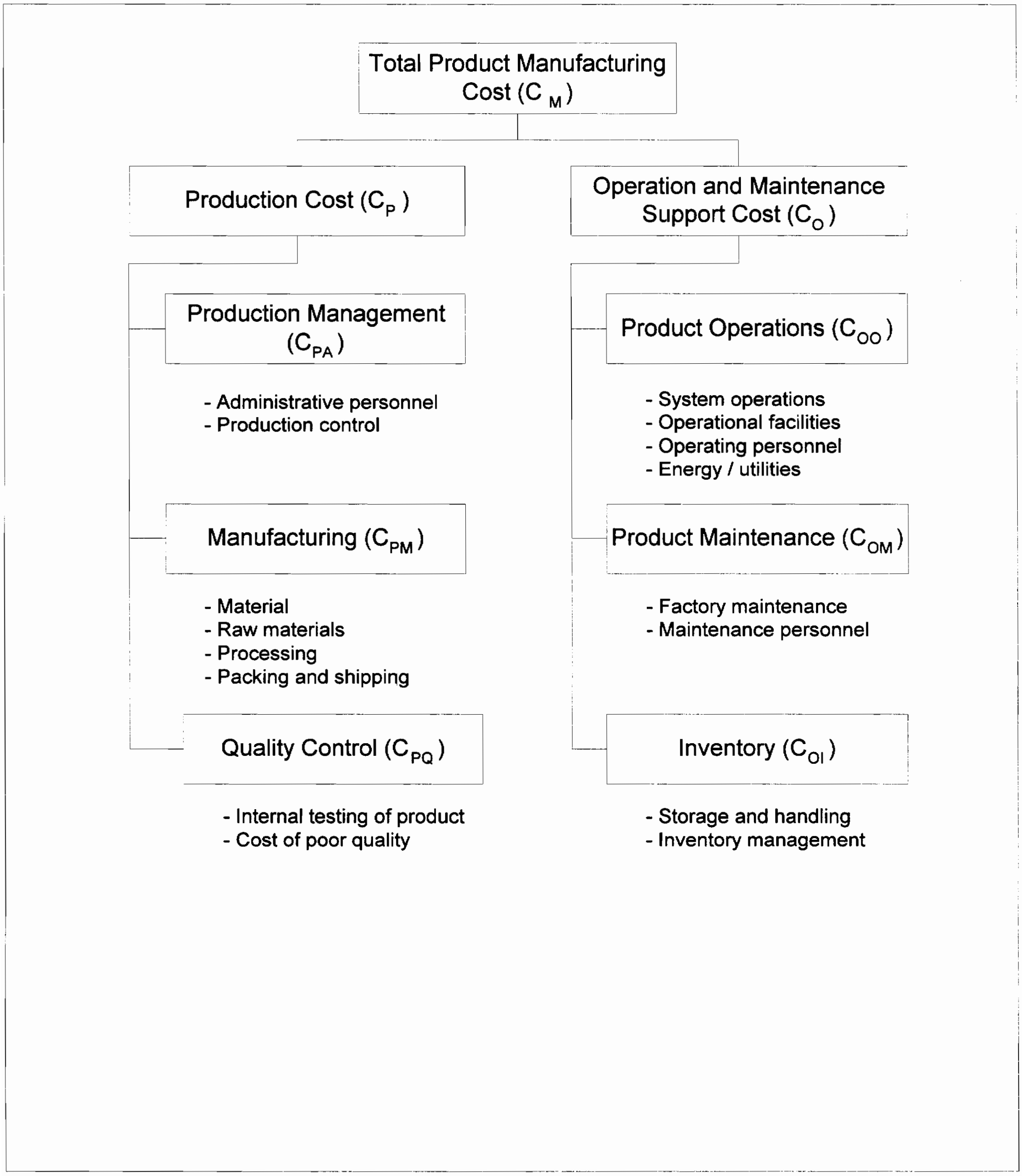

Figure 19. The cost breakdown structure for the manufacture of BCF fiber. (Adapted from Blanchard and Fabrycky, 1990.)

Table 6. Calculation of the cost of BCF by process step.

Item	Cost Category	Process Step: Polymerization	Wash/Dry	Spinning	Lag	SINTEX
Production Management	Cpa					
Administrative personnel	Cpa	$200,000	$200,000	$200,000	$200,000	$200,000
Production control	Cpa	$300,000	$300,000	$300,000	$300,000	$300,000
Total Production Management	Cpa	$500,000	$500,000	$500,000	$500,000	$500,000
Manufacturing	Cpm					
Raw Materials	Cpm					
Lactam	Cpm	$93,556,800				
Additive A	Cpm	$975,000				
Additive B	Cpm	$1,750,000				
Finish Oil	Cpm			$4,500,000		
Total Raw Materials	Cpm	$96,281,800	$0	$4,500,000	$0	$0
Packaging Materials	Cpm					
Lever Packs	Cpm	$50,000	$650,000			
Tubes	Cpm			$3,500,000		$5,000,000
Boxes	Cpm					$2,500,000
Bags	Cpm	$100,000	$475,000			$1,750,000
Labels	Cpm		$175,000	$750,000		$900,000
Total Packaging Materials	Cpm	$150,000	$1,300,000	$4,250,000	$0	$10,150,000
Processing	Cpm	$1,700,000	$700,000	$2,200,000	$500,000	$1,700,000
Shipping	Cpm	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Total Manufacturing	Cpm	$99,131,800	$3,000,000	$11,950,000	$1,500,000	$12,850,000
Quality Control	Cpq	$185,000	$120,000	$1,225,000	$975,000	$1,625,000
Total Production Costs	Cp	$99,816,800	$3,620,000	$13,675,000	$2,975,000	$14,975,000
Product Operations	Coo					
System Operations	Coo	$2,000,000	$1,300,000	$1,435,000	$1,400,000	$3,200,000
Operational Facilities	Coo	$1,000,000	$700,000	$1,000,000	$300,000	$1,800,000
Operating Personnel	Coo	$15,000,000	$500,000	$17,000,000	$500,000	$21,000,000
Utilities	Coo					
Heat Transfer Fluid	Coo	$1,650,000	$350,000	$1,650,000		$750,000
Steam	Coo	$2,500,000	$128,000	$850,000		$4,500,000
Nitrogen Gas	Coo	$1,750,000	$1,250,000	$75,000		$500,000
Compressed Air	Coo	$950,000	$265,000	$165,000		$3,500,000

Table 6. Calculation of the cost of BCF by process step.

Item	Cost Category	Process Step: Polymerization	Wash/Dry	Spinning	Lag	SINTEX
Power	Coo	$8,500,000	$975,000	$8,500,000		$4,750,000
Climate Control	Coo	$750,000	$65,000	$1,975,000	$365,000	$2,250,000
Washwater [2]	Coo	$2,950,000				
Total Utilities	Coo	$19,050,000	$3,033,000	$13,215,000	$365,000	$16,250,000
Total Product Operations	Coo	$37,050,000	$5,533,000	$32,650,000	$2,565,000	$42,250,000
Product Maintenance	Com					
Maintenance Personnel	Com	$1,000,000	$500,000	$750,000	$145,000	$1,500,000
Factory Maintenance	Com	$3,000,000	$750,000	$3,500,000	$500,000	$5,500,000
Total Product Maintenance	Com	$4,000,000	$1,250,000	$4,250,000	$645,000	$7,000,000
Inventory	Coi					
Storage and Handling	Coi	$1,200,000	$1,200,000	$1,200,000	$1,200,000	$1,200,000
Inventory Management	Coi	$800,000	$800,000	$800,000	$800,000	$800,000
Total Inventory	Coi	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Total Operation and Maintenance						
Support Cost	Co	$43,050,000	$8,783,000	$38,900,000	$5,210,000	$51,250,000
Cost of Poor Quality [3]	Cpq	$4,246,205	$999,107	$4,214,983	$655,664	$5,307,757
Total Cost per Year		$142,866,800	$12,403,000	$52,575,000	$8,185,000	$66,225,000
Cost per Pound		$1.36	$0.12	$0.50	$0.08	$0.63
Cost per SINTEX Machine-Minute		$3.67	$0.32	$1.35	$0.21	$1.70
COPQ / SINTEX Machine-Minute [4]		$3.67	$3.99	$5.34	$5.55	$7.25

[1] Allocated equally across departments.
[2] Includes re-processing costs.
[3] Based on average equipment unavailability
[4] One machine-minute produces 2.7 lbs of BCF fiber.

APPENDIX B

Failure Modes and Effects Analysis

Twenty-three operators and nine maintenance mechanics assigned to SINTEX ranked potential causes for the four most frequently performed unscheduled repairs from the baseline recording period. The four repairs comprised 51.79 percent of baseline. They were; adjusting an item in the threadpath (17.73 percent), nothing to fix (14.03 percent),[37] adjusting the heated roll temperatures (10.97 percent), and removing yarn (9.06 percent). They used the scales in Table 7 to determine the severity, frequency of occurrence, and current method of prediction of each of the failure modes. The results are included in a Failure Modes and Effects Analysis. (See Table 8.)

The columns labeled "Actions Recommended" and "Resp." (an abbreviation for "Responsible Party ") were determined from the findings from the experiment described in Chapter 4. The actions described in these columns formed the basis of the control plan to sustain improvements in SINTEX unscheduled maintenance.

[37]The group felt that the repair "nothing to fix" could be included under all of the failure modes listed but manifests itself at the beginning stage of failure, where it could be easily overlooked. This repair is therefore not listed separately in the FMEA.

Table 8. Process/Product Failure Modes and Effects Analysis (FMEA).

Process	SINTEX - Most Frequent Unscheduled Repairs Measured Over the Baseline Period	Prepared by: Linda Benson
Responsible:		FMEA Date (Orig) 2/10/95 (Rev)

Unscheduled Repair	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	SEV	OCC	DET	RPN
Adjust threadpath	Steam block jet set screws stripped	Can't tighten steam block jets	1	Allen wrenches wallow out set screws	10	Visual, upon failure	5	50	Check weekly	Operator	1	10	5	50
Adjust threadpath	3 finger guide misaligned	Strands run together	1	Finish build up on guide	10	Visual, upon failure	5	50	Check/clean weekly	Operator	1	10	5	50
Adjust threadpath	3 finger guide misaligned	Broken filaments	1	Finish build up on guide	10	Visual, upon failure	5	50	Check/clean weekly	Operator	1	10	5	50
Adjust threadpath	3 finger guide misaligned	Can't string	1	Finish build up on guide	10	Visual, upon failure	5	50	Check/clean weekly	FM	1	10	5	50
Adjust threadpath	Shake out ladder guide loose	Strands fall off nos. 4 and 5 roll	1	Front set screw wallowed out by allen wrenches	6	Visual, upon failure	6	36	Check/change weekly	Operator FM	1	6	6	36
Adjust threadpath	LED wheel binding	High tension	1	Bearing failed	7	Visual, upon failure	5	35	Vibration Analysis	FM	1	7	5	35
Adjust threadpath	LED wheel binding	High tension	1	Bearing failed	7	Audio, upon failure	5	35	Vibration Analysis	FM	1	7	5	35
Adjust threadpath	Separator roll nicked	Broken filaments	1	Separator roll rubbing on no. 3 roll	8	Visual, upon failure	4	32	Check /adjust weekly	Operator FM	1	8	4	32
Remove yarn	Creel wheel binding	Broken filaments	1	Yarn wrapped around wheel	10	Visual, upon failure	3	30	Check/clean weekly	Operator	1	10	3	30
Remove yarn	Creel wheel binding	Can't run panel	1	Yarn wrapped around wheel	10	Visual, upon failure	3	30	Check/clean weekly	Operator	1	10	3	30
Remove yarn	Creel wheel binding	High yarn tension	1	Yarn wrapped around wheel	10	Visual, upon failure	3	30	Check/clean weekly	Operator	1	10	3	30
Adjust threadpath	Shake out ladder guide loose	Strands run together	1	Front set screw wallowed out by allen wrenches	6	Visual, upon failure	5	30	Check/clean weekly	Operator FM	1	6	5	30
Adjust threadpath	Creel wheel binding	Broken filaments	1	Bearing failure	9	Visual, upon failure	3	27	Vibration Analysis	FM	1	9	3	27
Adjust threadpath	Creel wheel binding	Can't run panel	1	Bearing failure	9	Visual, upon failure	3	27	Vibration Analysis	FM	1	9	3	27
Adjust threadpath	Creel wheel binding	High yarn tension	1	Bearing failure	9	Visual, upon failure	3	27	Vibration Analysis	FM	1	9	3	27

Table 8. Process/Product Failure Modes and Effects Analysis (FMEA).

Process	SINTEX - Most Frequent Unscheduled Repairs Measured Over the Baseline Period	Prepared by: Linda Benson	
Responsible:		FMEA Date (Orig) 2/10/95	(Rev)

Unscheduled Repair	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	SEV	OCC	DET	RPN
Adjust threadpath	Separator roll nicked	Broken filaments	1	3 finger guide rubbing on separator roll	6	Visual, upon failure	4	24	Vibration Analysis	FM	1	6	4	24
Adjust threadpath	LED wheel binding	Package too small	1	Bearing failed	7	Visual, upon failure	3	21	Vibration Analysis	FM	1	7	3	21
Remove yarn	Finish build up	Roll grabs yarn	1	Heavy, oily finish builds up	10	Visual, upon failure	2	20	Clean weekly	Operator	1	10	2	20
Remove yarn	Finish build up	Broken filaments	1	Heavy, oily finish builds up	10	Visual, upon failure	2	20	Clean weekly	Operator	1	10	2	20
Remove yarn	Finish build up	Yarn wraps too far around roll	1	Heavy, oily finish builds up	10	Visual, upon failure	2	20	Clean weekly	Operator	1	10	2	20
Adjust threadpath	Shake out ladder guide loose	Strands run together	1	Back and front Guides knocked loose by aspirator	10	Visual, upon failure	2	20	Check/adjust daily	Operator FM	1	10	2	20
Adjust threadpath	Shake out ladder guide loose	Strands fall off nos. 4 and 5 roll	1	Back and front Guides knocked loose by aspirator	10	Visual, upon failure	2	20	Check/adjust daily	Operator FM	1	10	2	20
Adjust threadpath	Shake out ladder guides fell off	Big package (low tension)	1	Back and front guides knocked loose by aspirator	10	Visual, upon failure	2	20	Check/adjust daily	Operator FM	1	10	2	20
Remove yarn	Separator roll binding	Can't get all wraps on roll	1	Yarn behind roll	10	Visual, upon failure	2	20	Check/clean weekly	Operator FM	1	10	2	20
Adjust threadpath	Separator roll binding	Can't get all wraps on roll	1	Low air	9	Visual, upon failure	2	18	Hang up aspirators when finished	Operator	1	9	2	18
Adjust threadpath	Creel wheel binding	Broken filaments	1	Mounting rod loosened	6	Visual, upon failure	2	12	Check/adjust weekly	Operator FM	1	6	2	12
Adjust threadpath	Creel wheel binding	Can't run panel	1	Mounting rod loosened	6	Visual, upon failure	2	12	Check/adjust weekly	Operator FM	1	6	2	12
Adjust threadpath	Creel wheel binding	High yarn tension	1	Mounting rod loosened	6	Visual, upon failure	2	12	Check/adjust weekly	Operator FM	1	6	2	12
Remove yarn	Creel wheel nicked	Broken filaments	1	Wheel scratched by scissors	10	Visual, upon failure	1	10	Check/repair daily	Operator FM	1	10	1	10
Remove yarn	Polymer build up in steam block jet slot	Can't get jet in steam block	1	Flying yarn "fur balls" melts in slot	10	Visual, upon failure	1	10	Replace jet	Operator	1	10	1	10

Table 8. Process/Product Failure Modes and Effects Analysis (FMEA).

Process	SINTEX - Most Frequent Unscheduled Repairs Measured Over the Baseline Period	Prepared by: Linda Benson
Responsible:		FMEA Date (Orig) 2/10/95 (Rev)

Unscheduled Repair	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	SEV	OCC	DET	RPN
Remove yarn	Polymer build up in steam block jet slot	Break out yarn	1	Flying yarn "fur balls" melts in slot	10	Visual, upon failure	1	10	Replace jet	Operator	1	10	1	10
Remove yarn	LED wheel binding	High tension	1	Yarn build up	10	Visual, upon failure	1	10	Check/repair weekly	Operator	1	10	1	10
Remove yarn	LED wheel binding	Package too small	1	Yarn build up	10	Visual, upon failure	1	10	Check/repair weekly	Operator	1	10	1	10
Remove yarn	Polymer build up in steam block jet slot	Can't get jet in steam block	1	Cut out not held off steam block	10	Visual, upon failure	1	10	Follow correct cut out technique	Operator	1	10	1	10
Remove yarn	Polymer build up in steam block jet slot	Break out yarn	1	Cut out not held off steam block	10	Visual, upon failure	1	10	Follow correct cut out technique	Operator	1	10	1	10
Adjust threadpath	Burr on No. 3 roll	Can't knock wraps off No. 3 roll	1	Shell cover not tight	5	Visual, upon failure	2	10	Check/repair weekly	Operator FM	1	5	2	10
Adjust threadpath	Burr on No. 3 roll	Can't knock wraps off No. 3 roll	1	Screw backed out of shell cover	5	Visual, upon failure	2	10	Check/repair weekly	Operator FM	1	5	2	10
Adjust threadpath	Furrow in tube	Broken filaments	1	Wear by yarn	1	Visual, upon failure	10	10	Check/repair weekly	Operator FM	1	1	10	10
Adjust threadpath	3 finger guide misaligned	Strands run together	1	Guide set screw backs out, loosened guide	10	Visual, upon failure	1	10	Check/adjust weekly	Operator FM	1	10	1	10
Adjust threadpath	3 finger guide misaligned	Broken filaments	1	Guide set screw backs out, loosened guide	10	Visual, upon failure	1	10	Check/adjust weekly	Operator FM	1	10	1	10
Adjust threadpath	3 finger guide misaligned	Can't string	1	Guide set screw backs out, loosened guide	10	Visual, upon failure	1	10	Check/adjust weekly	Operator FM	1	10	1	10
Adjust threadpath	LED wheel nicked	Broken filaments	1	Cut out yarn with scissors, nick wheel	8	Visual, upon failure	1	8	Follow correct cut out technique	Operator	1	8	1	8
Remove yarn	3 finger guide misaligned	Strands run together	1	Wrap behind guide on rod	8	Visual, upon failure	1	8	Check/adjust weekly	Operator FM	1	8	1	8
Remove yarn	3 finger guide misaligned	Broken filaments	1	Wrap behind guide on rod	8	Visual, upon failure	1	8	Check/adjust weekly	Operator FM	1	8	1	8
Adjust threadpath	3 finger guide misaligned	Can't string	1	Wrap behind guide on rod	8	Visual, upon failure	1	8	Check/adjust weekly	Operator FM	1	8	1	8

Table 8. Process/Product Failure Modes and Effects Analysis (FMEA).

Process: SINTEX - Most Frequent Unscheduled Repairs Measured Over the Baseline Period

Prepared by: Linda Benson

Responsible:

FMEA Date (Orig) 2/10/95 (Rev)

Unscheduled Repair	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	SEV	OCC	DET	RPN
Adjust threadpath	No. 4 roll belt misaligned	Yarn overfeeding jets	1	Belt running on pulley edge	7	EPM low, from routine lab test	1	7	Align sheaves upon install./Vib. Anal.	FM	1	7	1	7
Adjust threadpath	No. 4 roll belt misaligned	Yarn overfeeding jets	1	Belt running on pulley edge	7	Strobe light, upon failure	1	7	Align sheaves upon install./Vib. Anal.	FM	1	7	1	7
Adjust threadpath	3 finger guide rubs on separator roll	Hard to string up panel	1	Loose set screw	7	Visual, upon failure	1	7	Check/adjust weekly	Operator FM	1	7	1	7
Adjust threadpath	3 finger guide rubs on separator roll	Broken filaments	1	Loose set screw	7	Visual, upon failure	1	7	Check/adjust weekly	Operator FM	1	7	1	7
Adjust threadpath	Separator roll nicked	Broken filaments	1	Damage from aspirator gun	6	Visual, upon failure	1	6	Check/repair weekly	Operator FM	1	6	1	6
Remove yarn	Polymer behind No. 3 roll	No. 3 roll locks up	1	Excessive wraps on roll (eye)	5	Visual, upon failure	1	5	check yarn behind roll weekly	Operator	1	5	1	5
Adjust threadpath	Pitted No. 3 roll	Broken filaments	1	Aspirator gun damage	5	Visual, upon failure	1	5	Check/repair weekly	Operator FM	1	5	1	5
Adjust threadpath	Feeder tube nicked	Broken filaments	1	Hit by aspirator gun	5	Visual, upon failure	1	5	Check/repair weekly	Operator FM	1	5	1	5
Adjust threadpath	Burr on No. 3 roll	Can't knock wraps off No. 3 roll	1	Aspirator Gun damage	5	Visual, upon failure	1	5	Check/repair weekly	Operator FM	1	5	1	5
Adjust threadpath	Creel stand ceramic guide chipped	Broken filaments	1	Creel stand post falls down	4	Visual, upon failure	1	4	Check/repair weekly	Operator FM	1	4	1	4
Adjust threadpath	LED wheel falls out	Break out	1	LED wheel screw loose	2	Visual, upon failure	2	4	Check/adjust weekly	Operator FM	1	2	2	4
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Bad shaft	1	Vibration Analaysis, upon failure	1	3	Vibration Analysis	FM	3	1	1	3
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Heater winding loose	1	Megger (Electrician)	1	3	Vibration Analysis	Instrument Mechanic	3	1	1	3
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Blown plug in vapor roll	1	Thermocouple	1	3	Thermocouple	Instrument Mechanic	3	1	1	3
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Heater run away	1	Thermocouple	1	3	Routine calibration of RTD	Instrument Mechanic	3	1	1	3

Table 8. Process/Product Failure Modes and Effects Analysis (FMEA).

Process	SINTEX - Most Frequent Unscheduled Repairs Measured Over the Baseline Period	Prepared by: Linda Benson
Responsible:		FMEA Date (Orig) 2/10/95 (Rev)

Unscheduled Repair	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	SEV	OCC	DET	RPN
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Uneven roll tempature due to water evaporation from roll	1	Thermocouple	1	3	Routine calibration of RTD	Instrument Mechanic	3	1	1	3
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Uneven roll temperature due to incorrect amount of water	1	Thermocouple	1	3	Routine calibration of RTD	Instrument Mechanic	3	1	1	3
Adjust temperature	2, 3 roll temperature not to spec.	Push "in" button and panel cuts off	3	Uneven roll temperature due to rust inside roll	1	Thermocouple	1	3	Routine calibration of RTD	Instrument Mechanic	3	1	1	3
Adjust threadpath	Feeder tube clogged	No yarn can go through tube	1	Feeder tube sucks up yarn "fur ball"	2	Visual, upon failure	1	2	Change as required	FM	1	2	1	2
Adjust threadpath	Panel yarn slot nicked	Broken filaments	1	Hit by aspirator gun	2	Visual, upon failure	1	2	Check/repair weekly	Operator FM	1	2	1	2
Adjust threadpath	Panel yarn slot nicked	Break out	1	Hit by aspirator gun	2	Visual, upon failure	1	2	Check/repair weekly	Operator FM	1	2	1	2
Adjust threadpath	Panel yarn slot closed up	Binding yarn	1	Hit by aspirator gun	2	Visual, upon failure	1	2	Check/repair weekly	Operator FM	1	2	1	2
Adjust threadpath	Trumpet guide broken	Broken filaments	1	Yarn "fur ball" damage	1	Visual, upon failure	1	1	Repair as required	FM	1	1	1	1
Adjust threadpath	Creel stand ceramic guide chipped	Broken filaments	1	Retaining o-ring on creel stand falls out	1	Visual, upon failure	1	1	Check/repair weekly	Operator FM	1	1	1	1

Table 7. Scales and abbreviations used in the Failure Modes and Effects Analysis.

Occurance Scale 1 - 10 The chances of an event occuring anywhere in Sintex within one year. 1 - one time per year 2 - one time per 10 months 3 - one time per 9 months 4 - one time per 7 months 5 - one time per 6 months (2 times a year) 6 - one time per month 7 - one time per week 8 - two times per week 9 - one time per day 10 - more than one time per day	**Severity Scale** 1 - 10 How many Sintex positions are affected when the event occurs. 1 - one position or panel 2 - affects 4-6 panels 3 - affects one-half of a Sintex line (9 panels) 4 - affects one Sintex line 5 - affects one-half of the Sintex lines (7 lines) 6 - affects 8 Sintex lines 7 - affects 10 Sintex lines 8 - affects 11 Sintex lines 9 - affects 13 Sintex lines 10 - affects all machines (power failure) (14 lines)
Definitions / Abbreviations Failure Mode - what broke Failure Effect(s) - What the Operator sees or the Lab reports Cause(s) - What caused the part to break SEV - Severity Scale OCC - Occurrence Scale DET - Detection Scale RPN - Risk Priority Number ($RPN=SEV\times OCC\times DET$) I - Instrument Mechanic FM - Field Machinist Operator - Sintex Operator EPM - Entanglements per meter (lab result) E&I - Electrician and/or Instrument Mechanic	**Detection Scale** 1 - 10 How far before failure item can be detected. 1 - Immediately 2 - detect 4 hours before failue 3 - detect 8 hours before failure 4 - detect 12 hours before failure 5 - detect 24 hours before failure 6 - detect 3 days before failure 7 - detect 7 days before failure 8 - detect 14 days before failure 9 - detect 21 days before failure 10 -detect more than 1 month before failure

APPENDIX C

Cost Benefit Analysis of the Maintenance Reporting System

Table 9. Cost benefit analysis for the SINTEX maintenance reporting system.

INPUT DATA

Phase 1 Equipment Capital		Phase 3 Equipment Capital			
Start Year	1995	Start Year	1	Full Volume Start Yea	1997
Start Month	1	Start Month	1	Corporate Tax Rate	39.60%
End Year	1995	End Year	1	Investment Tax Credit	0.00%
End Month	1	End Month	1	Finance Charge	6.00%
				Cost of Capital	13.22%
Phase 2 Equipment Capital		**Building Capital**		**Working Capital**	
Start Year	1	Start Year	1	Receiv. Days on Hand	0
Start Month	1	Start Month	1	Inven. Days on Hand	15
End Year	1	End Year	1	Payable Days on Han	30
End Month	1	End Month	1		

OUTPUT DATA

Net Presemt Value (@ 13.22%)		194
PAYBACK (YEARS)		3.06
Internal Rate of Return		40.43%
Return On Investment -	1 YEAR	22.67%
Return On Investment -	5 YEAR	28.36%
Return On Investment -	10 YEAR	37.33%

INPUT DATA	(000)
CAPITAL:	
BLDG.	0
EQUIP	295
EXPENSE	-
NET INCOME 1ST FULL YR.	47
NET INCOME 5YR AVG	44

		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Incremental Volume	(000)	175	175	175	175	175	175	175	175	175	175	0
Price	($/unit)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Freight	($/unit)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Revenue	($/unit)	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Variable Cost:												
Raw Materials	($/unit)	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
Other Raw Materials	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
By-Product Credit	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Manufacturing Supplies	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lost Sales Contributions	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Duty	($/unit)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Variable Cost	($/unit)	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
Fixed Cost:												
Salary	($000)	0	0	0	0	0	0	0	0	0	0	0
Wages	($000)	0	0	0	0	0	0	0	0	0	0	0
Maintenance	($000)	0	0	0	0	0	0	0	0	0	0	0
Utilities	($000)	0	0	0	0	0	0	0	0	0	0	0
Other	($000)	0	0	0	0	0	0	0	0	0	0	0
Total Fixed Cost	($000)	0	0	0	0	0	0	0	0	0	0	0

Table 9. Cost benefit analysis for the SINTEX maintenance reporting system.

Capital Investment:												
Building	($000)	0	0	0	0	0	0	0	0	0	0	0
Phase 1 Capital	($000)	295	0	0	0	0	0	0	0	0	0	0
Phase 2 Capital	($000)	0	0	0	0	0	0	0	0	0	0	0
Phase 3 Capital	($000)	0	0	0	0	0	0	0	0	0	0	0
Recurring Investment	($000)	0	0	0	0	0	0	0	0	0	0	0
Total Investment	($000)	295	0	0	0	0	0	0	0	0	0	0
Program Expenses:												
Construction Expense	($000)	0	0	0	0	0	0	0	0	0	0	0
Research & Development	($000)	0	0	0	0	0	0	0	0	0	0	0
Start-up	($000)	0	0	0	0	0	0	0	0	0	0	0
Marketing Expense	($000)	0	0	0	0	0	0	0	0	0	0	0
Administrative	($000)	0	0	0	0	0	0	0	0	0	0	0
Total Expenses	($000)	0	0	0	0	0	0	0	0	0	0	0