IMPLEMENTING CONTINUOUS PROCESS IMPROVEMENT METHODS IN A MID-SIZE PLASTIC COMPANY

by

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ABSTRACT

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Company XYZ had reported poor quality of particular products in the injection molding department which results in increasing cost, lead time, and customer complaints. The purpose of this study is to help Company XYZ improve product quality and manage the data for a continuous improvement plan by using the Plan-Do-Study-Act (PDSA) cycle or Deming cycle. Methods and procedures of this study include a review of literature relevant to continuous improvement, Deming cycle, seven tools of quality, costs of quality, and injection molding process. After the causes of defects were identified, solutions and procedures were recommended to Company XYZ to eliminate defects in the injection molding process.

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CHAPTER I: INTRODUCTION

Background

Quality is now involved in every kind of business: manufacturing, hospital, school, food industry, public utility, etc. This is not focused only in production areas but in service areas also. It has turned out to be a core competency for many companies to improve their competitive advantage. Why is quality important? High quality products or services are leading to business success, improved competitiveness, higher customer loyalty, and lower costs.

The costs occurred from providing high quality products or services are lower than the costs affected by the low quality products or services (Crosby, 1996) because the cost of poor quality – scrap, rework, retest, etc. – is more than the cost of doing it right the first time.

Costs of poor quality can be categorized into four categories: prevention costs, appraisal costs, failure cost (internal failure costs and external failure costs), and intangible costs (Summers, 2003). The major subcategories of internal failure costs are scrap, rework, retest, failure analysis, downtime, and downgrading. Subcategories of external failure costs are complaint adjustment, returned product and material, warranty charges, liability costs, and indirect cost.

Competitors are not only from domestic companies but also from international companies (Seymour, 1994). Therefore, customers have the right to choose companies that can satisfy their needs the best. Examples of customer needs are high quality products, low prices, fast delivery, good services, etc. Continuous Improvement Theory is one of the strategies that can help organizations to satisfy customer needs and help organizations to have greater performance.

Company XYZ is the leader in the plastic industry which applies an "integrated solution" approach to gain the competitive advantage. They have not focused only on rapid prototyping, tooling, or injection molding of plastic parts, but they integrate all of these to provide every kind of plastic services under one roof. Company XYZ's core business is offering injection molding solutions to reach customer demands. They provide injection molding in the fields of appliance, data storage, electronics, sporting goods, medical, and office furniture. Quality of plastic parts and customer service has been the focus of the company to gain market share and to satisfy their customers.

The company's business has been increased dramatically within the past couple years. Company XYZ is producing a larger variety of injection molding products than before. Some products are produced often or seasonally, but some products are produced just one or two times. They do have not enough time to experiment before producing to attain suitable settings for each product like they had in the past. New employees, which were hired to support the growing business, were lacking quality knowledge of material/product characteristics. This affected the product quality, increased both internal and external failure cost, and increased customer complaints.

Statement of problem

Recently the Company XYZ has reported poor quality of particular products in the injection molding department which results in increasing cost, lead time, and customer complaints.

Purpose of the Study

The purpose of this study is to help Company XYZ improve the product quality and manage the data for a continuous improvement plan.

Objective of this Study

1. To create a process map and evaluate the results to determine the company's current performance.
2. To identify and analyze problems in injection molding processes.
3. To create the possible solutions and make recommendations for the continuous improvement plan.

Significance of the Study

Quality problems in injection molding processes are the main problem for Company XYZ at the moment. Therefore, the results of this study will be applied to the injection molding processes to improve quality performance and establish the continuous improvement plan for the company in order to increase quality of product, increase productivity, reduce costs, and satisfy customers.

Definitions

Continuous improvement. "A management philosophy that views quality improvement as a never-ending process that will always lead to incremental improvements" (Madu, 1998, p. xxvi).

Cost of quality. "The costs associated with providing poor-quality products or services" (Conner, 2002, p. 312).

Customer satisfaction. "A gauge on how well customer requirements are designed into product or service" (Madu, 1998, p. xxvi).

Quality. "A subjective term for which each person or customer may have their own definition. Characteristics of a product or service that impact its ability to satisfy stated or implied needs. A product or service that is free of nonconformities" (Conner, 2002, p. 321).

Limitations of the Study

1. The data collected in this study is from October 2005 to December 2005.
2. This study is limited to the researcher's work experience in the field of injection molding.

CHAPTER II: LITERATURE REVIEW

Introduction

This chapter will discuss concepts of quality including continuous improvement, Deming cycle, seven tools of quality, and costs of quality. Moreover, this chapter is devoted to the review of literature which includes the concept of injection molding and processing.

Continuous Improvement

It is impossible for organizations to survive without changing or improving. The organization's ability to survive in a highly competitive business world depends on how the organization manages and adapts to demands of a changing environment (Nicholas, 1998). The change in a business environment comes from many resources: competitors create new products; competitors reduce products' prices; and competitors use new technology to improve quality of a product. Customer expectations are always changing. Therefore, many companies have had to improve in terms of products or services to satisfy customers' needs.

Continuous improvement is an ongoing effort to improve products, services, or processes. It is more focused on customer service, process improvement, higher product quality and long-term strategies (Summers, 2003). Figure 1 is flow chart that demonstrates a typical continuous improvement process. Figure 2 shows additional differences between companies that apply continuous improvement theory and traditional companies. There are different approaches to support continuous improvement theory.

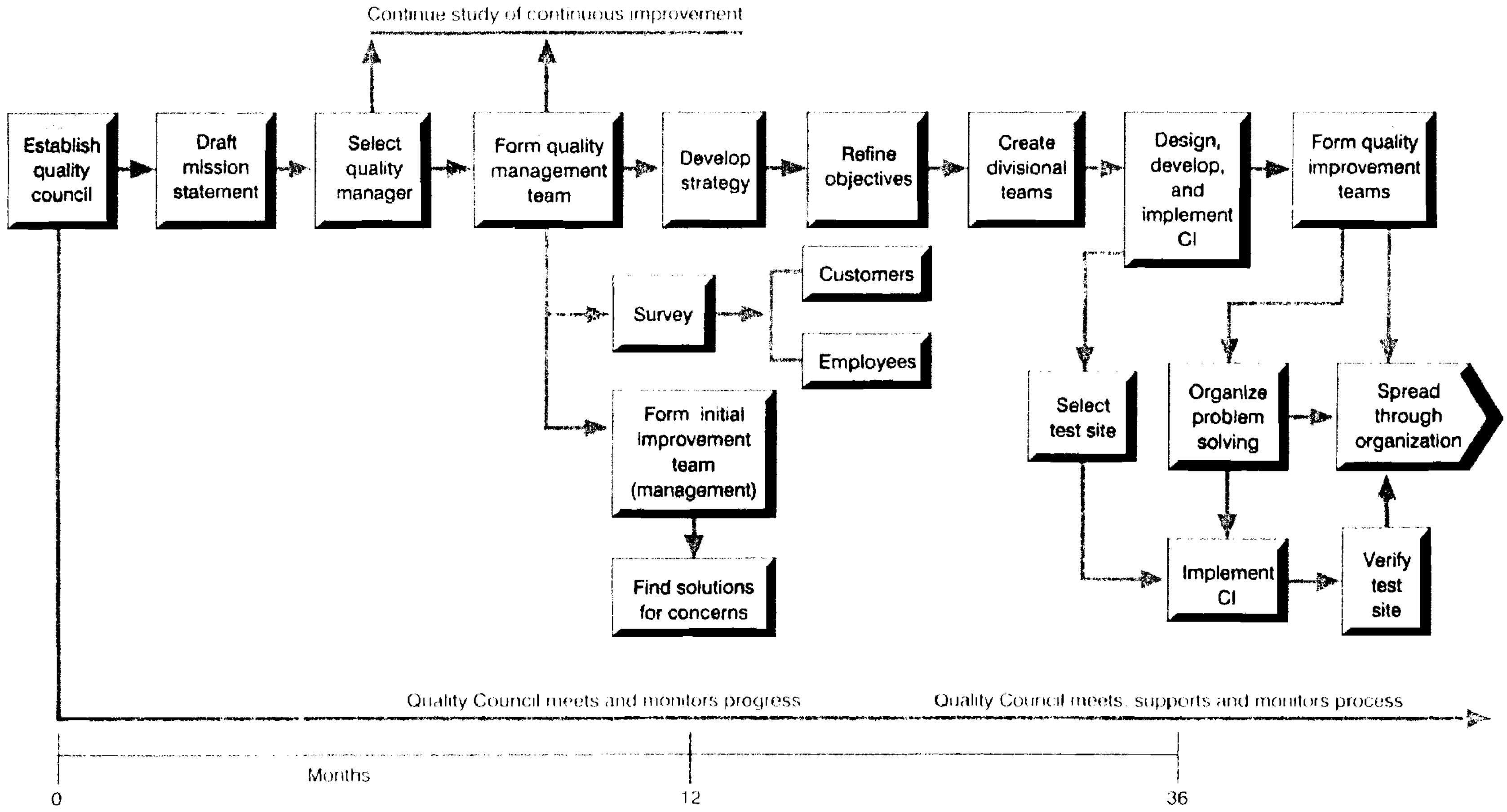


Figure 1. A Typical Continuous Improvement Process

Source: Summers, 2003, p. 18

Company Oriented Toward Continuous Improvement	***Traditional Company***
Customer Focus	Market-Share Focus
Cross-Functional Teams	Individuals
Focus on “What” and “How”	Focus on “Who” and “Why”
	Judgmental Attitudes
Attention to Detail	
Long-Term Focus	Short-Term Focus
Continuous Improvement Focus	Status Quo Focus
Process Improvement Focus	Product Focus
Incremental Improvements	Innovation
Problem Solving	Fire Fighting

Figure 2. Continuous Improvement versus Traditional Orientation

Source: Summers, 2003, p. 17

Deming cycle or Shewhart Cycle, also known as the Plan-Do-Study-Act (PDSA) cycle, is the most commonly used tool for continuous improvement. This is the methodology for identifying and analyzing problems. Some other widely used tools are total quality management, six sigma, and lean.

Deming Cycle

Deming Cycle was first called the Shewhart cycle, giving credit to its founder, Walter Shewhart (Evans & Lindsay, 2002). Subsequently, it was renamed as the Deming Cycle by the Japanese in 1950. It consists of four stages: plan, do, study, and act as shown in Figure 3. Some people simply call it the PDSA cycle. It is a scientific tool for improvement because it systematically collects information and data and also creates alternatives for continuous improvement (Nicholas, 1998). The process starts with the plan step and continues clockwise through the other steps. However it is better to picture the cycle as the ongoing cycle with no start or end to support the continuous improvement plan. Following are details for each step in the PDSA cycle.

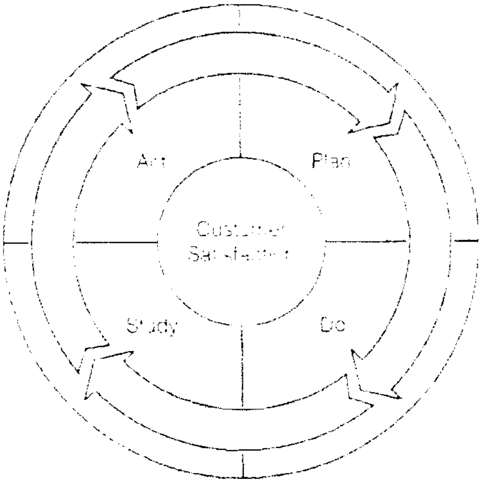


Figure 3. The Deming Cycle

Source: Evans & Lindsay, 2002, p. 587

Plan step. In this step, problem investigators are looking at the current processes and determining a plan to accomplish improvement. There are four substeps in this phase (Nicholas, 1998):

Substep one is collecting data. Dissatisfaction initiates the idea of improvement. When people are not satisfied with something or it is not as good as they thought, they will try to seek solutions to make it better and become satisfied (Nicholas, 1998). Before seeking the solution, the facts should be identified: current situation, current problem, and root cause of the problem. The data collection phase consists of observing, documenting, and analyzing the data to find the root cause of the problem.

The second substep is defining the problem. Once the problem and its root cause are clearly identified, the problem can be defined (Nicholas, 1998).

Substep three is stating the goal. A goal is defined to make everyone visibly understand and recognize the same target of each project (Nicholas, 1998). The goal is only provisional, referring to the philosophy of continuous improvement. This means it can be changed and adapted to the current situation or the near future to obtain the best result. The goal should include the scope of the project improvement (lower limits and upper limits), budget, and deadline.

Substep four is solving the problem. It is not necessary to use only one solution to solve problems (Nicholas, 1998). Multiple solutions should be considered to accomplish the goal. The considerations are based on the advantages and disadvantages and the cost and benefits of each solution. After the solutions are chosen, the method of implementing the solutions should be clearly described including the steps, a schedule, involved people, deadlines, and budget.

Do step. This step is the implementation to the plan step, preferably on a small scale (Nicholas, 1998). It is implemented on a trial basis. The results of the implementation should be observed and recorded to demonstrate the strengths and weaknesses of the solution. The plan is modifiable depending on the situation; the weak parts are eliminated and only the strong parts are maintained.

Study step. In this stage, data are collected following implementation, analyzed, and compared with expected outcomes (Nicholas, 1998). The team members should be able to describe what they learned through the improvement process and whether the problem has been solved or not. If not, the PDSA process should begin again to find the proper solutions.

Act step. In the final stage, results from the study step will be initiated the actions (Nicholas, 1998). The actions involve making the decision to retain the solutions, adjust the solutions, or abandon the solutions. If it is successful, the solutions are retained until new goals or better solutions are discovered. If it is better but some problems have not been solved, the solutions are modified to solve all of the problems. If the change did not work, the solutions are abandoned and then the PDSA cycle is repeated again with a different plan. In continuous improvement theory, even though the changes are totally successful, the actions should be reviewed again and replaced by better solutions.

Seven Tools of Quality

The seven tools of quality are used for improving processes, identifying problems, seeking root causes of problems, and solving problems. These tools are incredibly simple so all levels of workers can use them easily. The seven tools of quality can be applied together with the PDSA cycle to help the process progress more rapidly and systematically. The seven tools of quality consist of cause-and-effect diagrams, flowcharts, histograms, Pareto diagrams, check sheets, control charts, and scatter diagrams (Benbow, Berger, Elshennawy & Walker, 2002).

Cause-and-effect diagram. A cause-and-effect diagram is also called fishbone or Ishikawa diagram (Benbow et al., 2002). It is a useful tool in problem-solving situations, brainstorming, and general analysis to identify relationships between the possible causes and effect or problem. The causes are grouped into categories as shown in Figure 4 which are convenient for users to focus on. Following are four steps to construct a cause-and-effect diagram:

1. Select a single problem or opportunity (that is, effect).
2. Identify the major causes of problem or opportunity.
3. Identify the minor causes associated with each major cause.
4. Identify additional cause structure (p. 276-277).

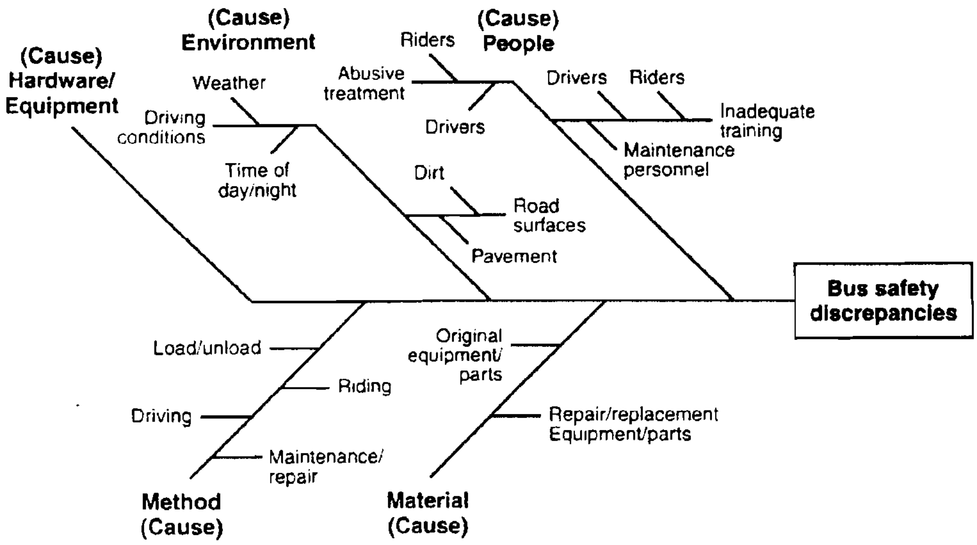
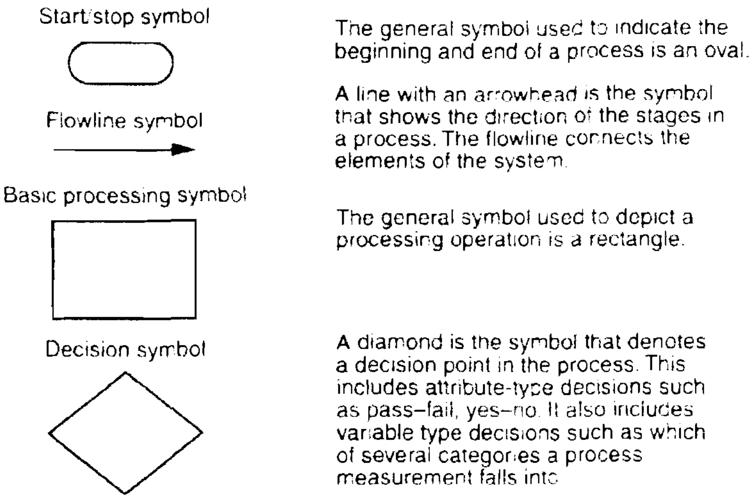


Figure 4. Example Cause-and-Effect Diagram

Source: Benbow et al., 2002, p.278

Flowchart. A flowchart is a pictorial representation of the steps in a process (Benbow et al., 2002). The steps are presented sequentially from the beginning through the end of the process which can help the readers/users recognize the unnecessary steps in the process. Following are four simple steps to create a flowchart:

1. Select a start and stop point.
2. List major steps/tasks and decision points.
3. Use standardized graphical symbols to document the process (as shown in Figure 5).
4. Review results (p. 270).



The general symbol used to indicate the beginning and end of a process is an oval.

A line with an arrowhead is the symbol that shows the direction of the stages in a process. The flowline connects the elements of the system.

The general symbol used to depict a processing operation is a rectangle.

A diamond is the symbol that denotes a decision point in the process. This includes attribute-type decisions such as pass–fail, yes–no. It also includes variable type decisions such as which of several categories a process measurement falls into.

Figure 5. Four Primary Flowcharting Symbols

Source: Benbow et al, 2002, p. 271

Figure 6 is an example of a flowchart of the process "serving tea" (Rampersad, 2001).

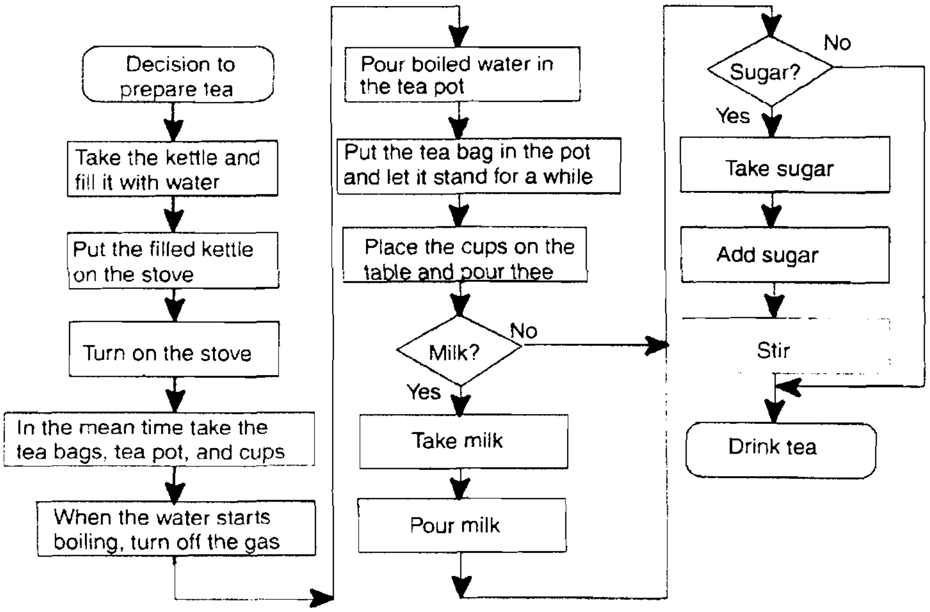


Figure 6. Example Flowchart

Source: Rampersad, 2001, p. 30

Histogram. A histogram is a tool that graphically summarizes and displays the distribution of incidence of events which are arranged into categories (Benbow et al., 2002). It uses a bar graph format to show the frequency distribution as shown in Figure 7 (Rampersad, 2001). It is also used to monitor the shape of data such as normal distribution, skewed distribution, etc. Following are five steps to construct a histogram:

1. Determine the amount of data to be collected.
2. Determine the number of columns or categories to be used.
3. Collect and record data.
4. Prepare the graphic.
5. Graph the data (Benbow et al., 2002, p. 273-274).

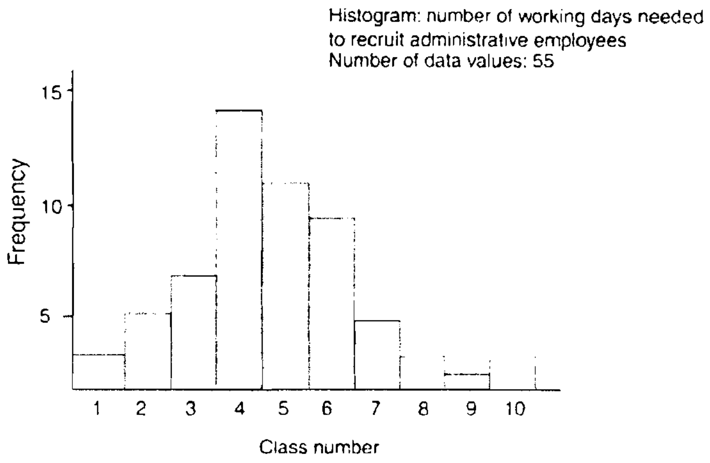


Figure 7. Example Histogram

Source: Rampersad, 2001, p. 35

Pareto diagram. A Pareto diagram is used to identify the major problems or causes in the process (Benbow et al., 2002). It is actually a histogram which is sorted from the highest frequency to the lowest frequency as shown in Figure 8 (Rampersad, 2001). The 80/20 rule uses a Pareto diagram to identify roughly 80% of problems created by 20% of factors (which are columns or categories). Therefore, the users will recognize which factors or problems should be solved first and which one can be solved later. Following are six steps to create a Pareto diagram:

1. Determine the amount of data to be collected.
2. Determine the number of columns or categories to be used.
3. Collect and record data.
4. Rank order the columns or categories of data.
5. Prepare the graphic.
6. Calculate and place on the graphic a relative frequency line above the data columns or categories (Benbow et al, 2002, p. 275).

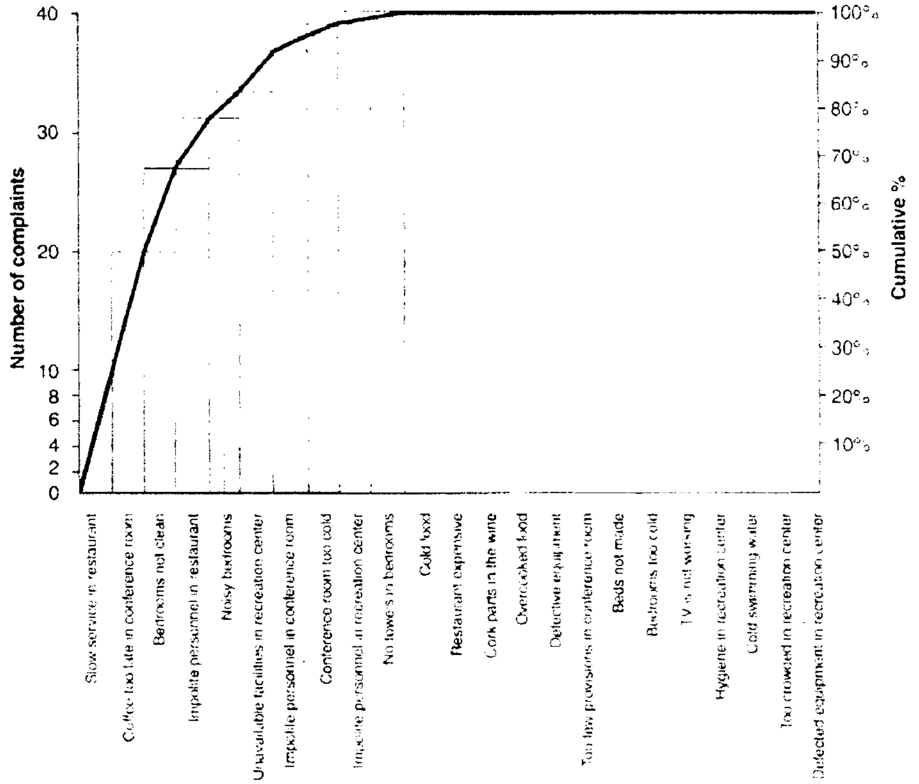
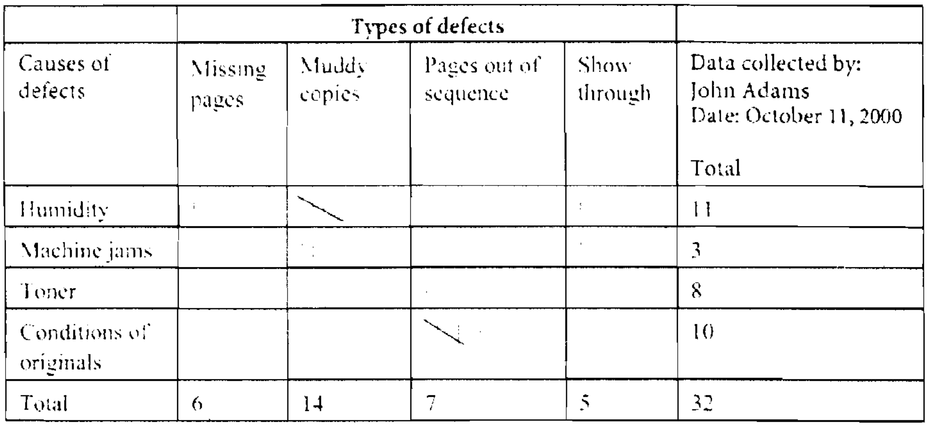


Figure 8. Example Pareto Diagram

Source: Rampersad, 2001, p. 37

Check sheet. A check sheet is a created form for collecting data and analyzing data (Benbow et al., 2002). It can be adapted to use for a variety of purposes. Mostly it is used to count how often something such as a defect happens by marking when one of the events or categories occurs as shown in Figure 9 (Rampersad, 2001). Following are three simple steps to create check sheets:

1. Design the check sheet for a given application.
2. Record the data.
3. Use the data for analysis or input to additional graphic tools such as histograms and Pareto diagrams (Benbow et al., 2002, p. 272).



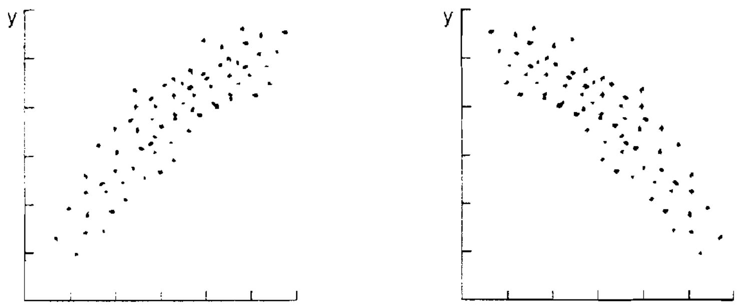
	Types of defects				
Causes of defects	Missing pages	Muddy copies	Pages out of sequence	Show through	Data collected by: John Adams Date: October 11, 2000 Total
Humidity					11
Machine jams					3
Toner					8
Conditions of originals					10
Total	6	14	7	5	32

Figure 9. Example Check Sheet

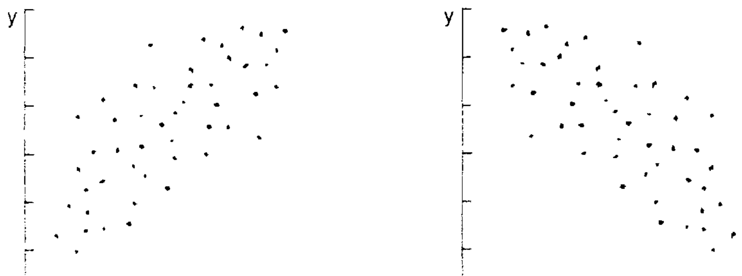
Source: Rampersad, 2001, p. 28

Scatter diagram. A scatter diagram is a graphical technique to display a relationship between two variables (Benbow et al., 2002). This can help the users to predict what will happen to the one of variables if the other is changed. According to NEN-ISO 9004-4 (as cited in Rampersad, 2001), there are six possible relationships: strong positive relationship, strong negative relationship, weak positive relationship, weak negative relationship, no relationship, and curvilinear relationship as shown Figure 10. Following are the steps to create a scatter diagram:

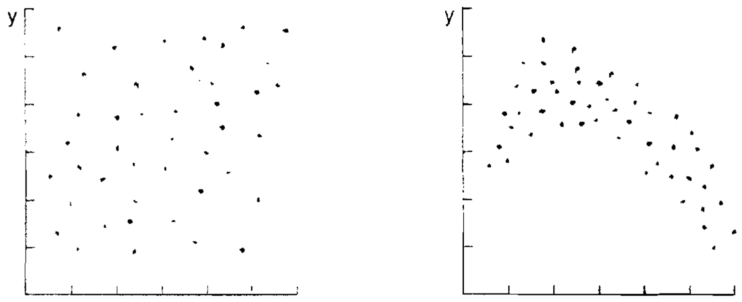
1. Select two variables of interest.
2. Set a scale for the axes.
3. Collect and chart the data.
4. Evaluate the results (Benbow et al., 2002, p. 280).



a) Strong positive relationship b) Strong negative relationship



c) Weak positive relationship d) Weak negative relationship



e) No relationship f) Curvilinear relationship

Figure 10. Example Scatter Diagram

Source: NEN-ISO 9004-4 as cited in Rampersad, 2001, p. 42

Control chart. A control chart, also called statistical process control, is used to graphically display data collected over time and the expected range of variations from this data (Tague, 1995). There are many kinds of control charts to apply but the choice depends on type of data and situation. There are two types of data: variable data and attribute data. Variable data can be measured in continuous scales such as length, time, temperature, etc. These use the variable charts to observe the variation in the processes. Examples include X-bar and R chart (averages and range chart), X-bar and S chart (averages and standard deviation chart), MA–MR chart (moving average–moving range chart), etc.

Attribute data or discrete data are only counted and cannot be measured in continuous scales such as good or bad, yes or no, number of people, number of accidents, etc (Tague, 1995). The control charts based on attribute data (that is, attribute charts) are p-chart (proportional chart), np-chart, c-chart (count chart), and u-chart.

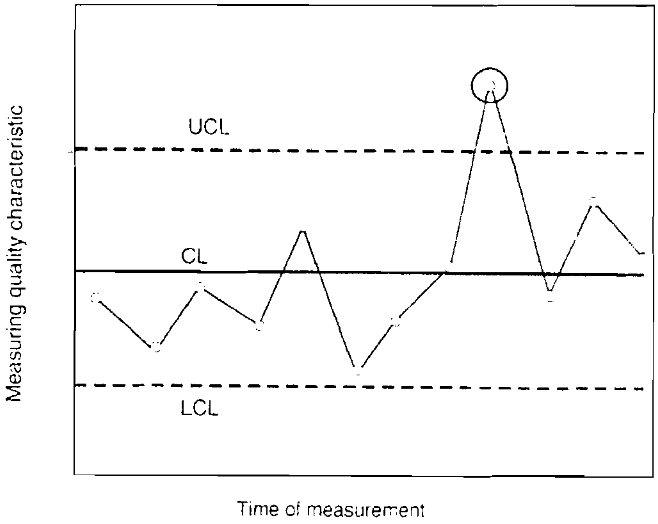
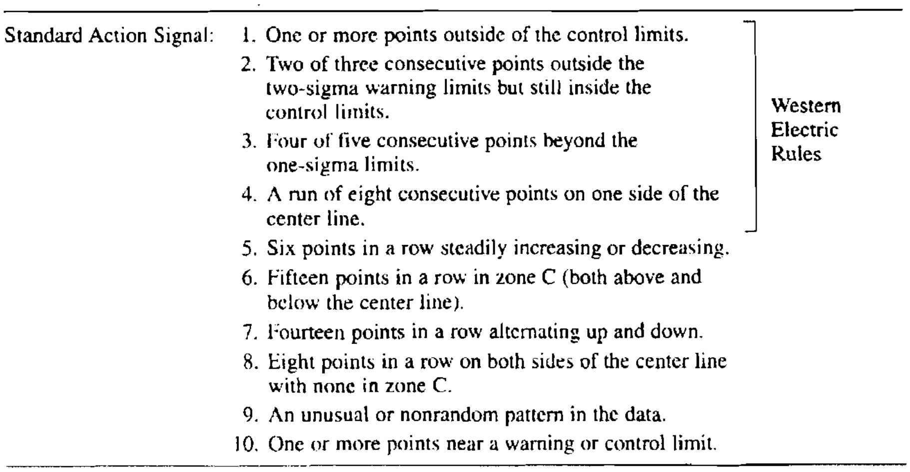


Figure 11. Control Chart

Source: Rampersad, 2001, p. 45



Standard Action Signal:	1. One or more points outside of the control limits.	Western Electric Rules
	2. Two of three consecutive points outside the two-sigma warning limits but still inside the control limits.	
	3. Four of five consecutive points beyond the one-sigma limits.	
	4. A run of eight consecutive points on one side of the center line.	
	5. Six points in a row steadily increasing or decreasing.	
	6. Fifteen points in a row in zone C (both above and below the center line).	
	7. Fourteen points in a row alternating up and down.	
	8. Eight points in a row on both sides of the center line with none in zone C.	
	9. An unusual or nonrandom pattern in the data.	
	10. One or more points near a warning or control limit.	

Figure 12. Some Sensitizing Rules for Shewhart Control Charts

Montgomery, 2005, p. 167

The control chart is composed of three major lines: central line (CL) or average line, Upper Control Limit (UCL) line, and Lower Control Limit (LCL) line as shown in Figure 11 (Rampersad, 2001). This can help the users to check that the process is in control or out of control. The basic criterion for identifying the out of control process is one or more points outside the control limit (Montgomery, 2005). Figure 12 includes some sensitizing rules for Shewhart control charts which can be used to increase the sensitivity of the control charts. Following are the steps to construct control charts:

1. Select the characteristics for applying a control chart.
2. Select the appropriate type of control chart.
3. Collect the data.
4. Draw a vertical axis (Y-axis) with the value of the quality characteristic.
5. Draw a horizontal axis (X-axis) with the time measurement or samples taken at random.
6. Draw the central line (CL), the Lower Control Limit (LCL), and Upper Control Limit (UCL) as shown in Figure 11.

7. Plot the data in the chart
8. Examine the plot for points outside the control limits as shown in Figure 12 (Rampersad, 2001, p. 44).

Quality Costs

Cost of quality is also called cost of poor quality (Summers, 2003). It is a term that is used widely but a lot of people still misunderstand its true meaning. It is not just the cost of waste, rework, and rejects but it is like an iceberg in the sea as shown in Figure 13. It includes every cost incurred by the company such as cost from inspection, dissatisfied customers, returned goods, etc. Costs of quality can be categorized into four categories: prevention costs, appraisal costs, failure costs, and intangible costs.

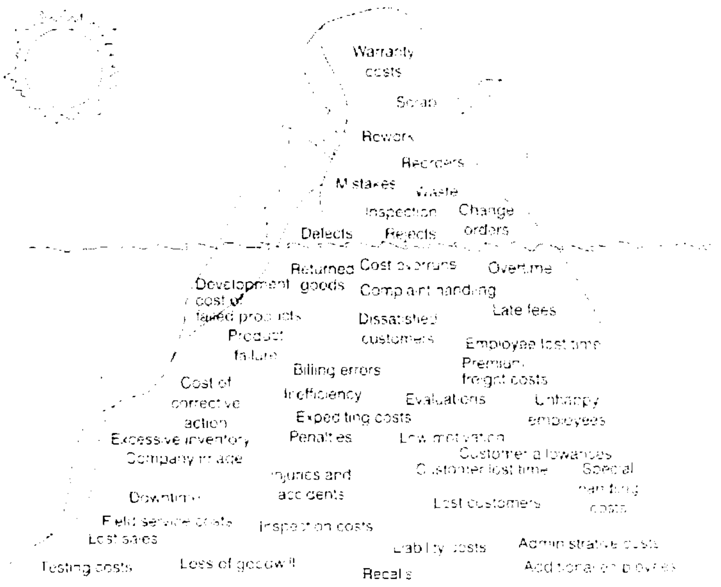


Figure 13. The Iceberg of Quality Costs

Source: Summers, 2003, p. 553

Prevention costs. Prevention costs are the costs of all activities designed to prevent the occurrence of poor quality in products or services or cost of all activities which occurred in an effort to make it right in the first time (Summers, 2003). It is the expense to ensure that all products or services have good quality and meet the customer requirements before reaching the customer. Examples of prevention costs are costs from quality planning, process control, product review, training, etc.

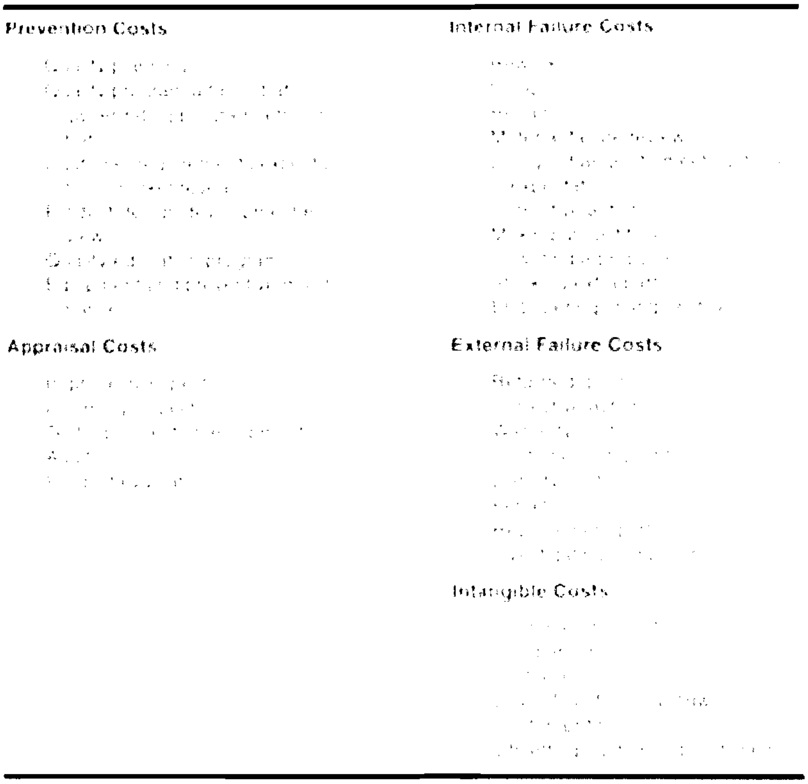
Appraisal costs. Appraisal costs are the costs associated with measuring, evaluating, or auditing products or services to ensure conformance to the quality standards, specifications or requirements (Summers, 2003). These include the costs of incoming inspection and test, product inspection and test, maintenance of testing equipment, and the cost of associated supplies and materials. The appraisal costs can be reduced if the company's capacity reaches or exceeds the quality standards of the product or service.

Failure costs. Failure costs are the result when nonconforming products or services do not meet the requirements or customer needs (Summers, 2003). There are two types of failure costs: internal failure cost and external failure costs.

Internal failure costs are incurred when the product or service fails to meet quality standards or requirements and it is found before shipping the product or providing the service to the customer (Summers, 2003). Examples are the costs of scrap, rework, retesting, or process failures.

External failure costs are incurred after the poor quality product or service is delivered to the customer (Summers, 2003). Examples are the costs of product returns, customer complaints, product recalls, or warranty charges. These costs can be reduced or eliminated if the products or services reach the requirements.

Intangible costs. Summers (2003) stated that "Intangible costs, the hidden costs associated with providing a non conforming product or service to customer, involve the company's image" (p. 557). These costs refer to an impact on long-term profitability. Examples are the costs of customer dissatisfaction, lost sales, or loss of customer goodwill.



Prevention Costs

Internal Failure Costs

Appraisal Costs

External Failure Costs

Intangible Costs

Figure 14. Categories of Quality Costs

Source: Summers, 2003, p. 558

In brief, total costs of quality are the summation of prevention costs, appraisal costs, failure costs, and intangible costs (Summers, 2003). Figure 14 shows the example of the costs of quality in each category. The prevention costs, appraisal costs, and failure costs are correlated to each other (Foster, 2001). The more we invest in prevention costs and appraisal costs, the less failure costs will occur. The tradeoff model, called the Lundvall-Juran Model, between these costs is shown in Figure 15. Therefore the company should focus on minimizing the total costs of quality by investing in prevention costs and appraisal costs to reach and not exceed the economic quality level.

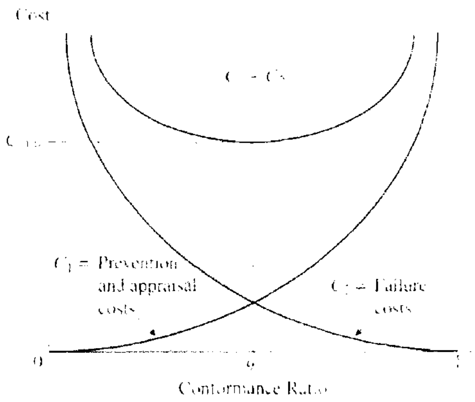


Figure 15. Lundvall-Juron Model

Source: Foster, 2001, p. 107

Injection Molding

Injection molding is the most important process used in plastic manufacturing (Osswald & Turng & Gramann, 2002). Injection molding can be used to form a wide variety of products. It increases the production rates but decreases the labor cost in manufacturing.

As shown in Figure 16, there are three main units of an injection molding machine: the clamping unit, the plasticating unit or injection unit, and the drive unit (Rauwendaal, 2000). The clamping unit is used to hold the mold together, automatically open and close the mold, and eject the finished part. The injection unit is used to melt the material and inject it into the mold. The drive unit is used to supply power to both the clamping unit and plasticating unit. There are three stages in injection molding cycle:

Stage 1: Injection of the plastic melt into the mold.

Stage 2: Holding the pressure and plasticating.

Stage 3: Ejection (p. 2).

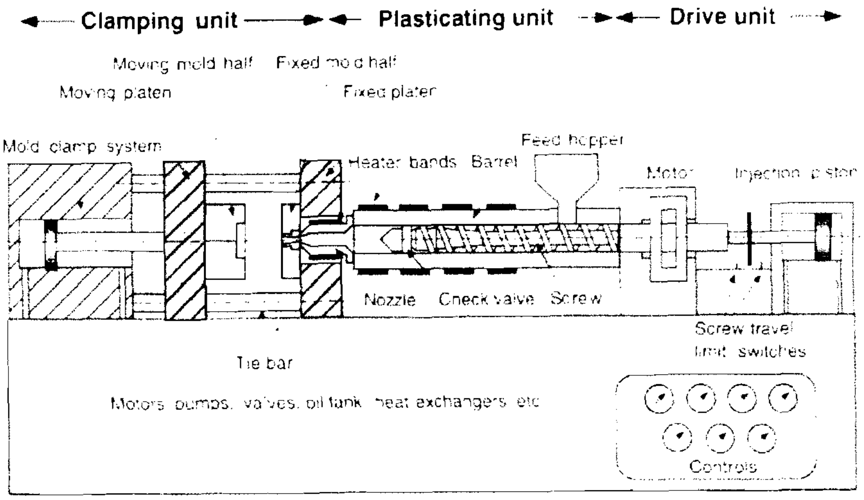


Figure 16. Schematic of a Typical Injection-Molding Machine

Source: Rauwendaal, 2000, p. 1

The melt temperature and the holding pressure are the main conditions or factors in the injection molding process to control the quality of the molding products (Osswald et al., 2002). Figure 17 illustrates the molding diagram. The low melt temperature creates a short shot or unfilled cavity and the high melt temperature creates a degradation of material. The low holding pressure causes the shrinkage or low part weight to the product and the excessive holding pressure causes the flash on the product surface.

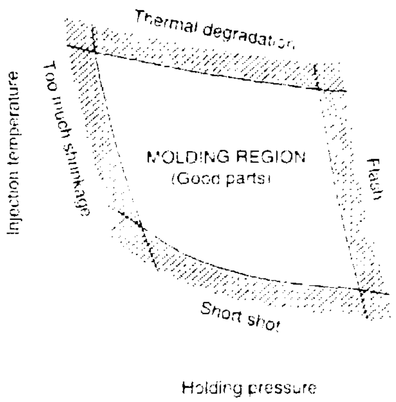


Figure 17. The Molding Diagram

Source: Osswald et al., 2002 p. 17

CHAPTER III: METHODOLOGY

Introduction

The purpose of this study is to help Company XYZ improve product quality and manage the data for a continuous improvement plan, then provide feedback to the company for the future improvement. The objectives of this study are to create a process map, evaluate the data to determine the company's current performance, identify and analyze problems in injection molding processes, and create possible solutions and make recommendations for the continuous improvement plan. This chapter is devoted to describing the methods and procedures used to achieve the objectives of the study.

Define

The first task in this section was to define the current performance of the injection molding process. Reports from the production and operation department and quality department about the product quality and effects of poor quality products would be gathered. The second task was to identify a process map of the injection molding process. The purpose of a process map was to understand the sequence of activities from the beginning through the end of the process which can help to recognize any unnecessary or missing steps in the process. The last task was to define future performance and state the goal of improvement including the improvement activities to reduce and control the number of defects in the injection molding process.

Data Collection

Data collection was separated into two main groups: production and cost of poor quality. The production segment included the total produced quantities, rejected quantities, and type of defects in each product. Cost of poor quality included prevention costs, appraisal costs, internal failure costs and external failure costs. To minimize the chances of misleading results, the following steps were taken.

1. Data was collected from one injection molding machine.
2. Data from all of the products was recorded.
3. The measurement was 100% inspection.

Data Analysis

The seven tools of quality were used to analyze data, identify problems, seek root causes of problems, and solve problems. The main functions of each tool used in this study follow:

- A flowchart was used to identify the process map of the injection molding process.
- Check sheets were selected to count how often the defect happened in the process.
- A cause-and-effect diagram was used to identify the type of defect and causes of each defect in the process.
- A histogram and Pareto diagram were used to identify the major problems or causes in the process.
- Control charts were used to graphically display data collected over time and the expected range of variations from the data. P charts were selected because the data collected in this study was attribute data.
- Scatter diagrams were used to study the relationship between the temperature and defects, and between the pressure and defects.

CHAPTER IV: RESULTS

The purpose of this study was to identify problems in the injection molding process at Company XYZ, provide feedback to the company for the solutions, and recommend a continuous improvement plan.

This chapter includes the company's current performance, an injection molding process map, problem identification, problem analysis, and recommendations for improvement.

Company's Current Performance and Process Map – Objective 1

Company XYZ has faced unsteady quality of injection molding products, which results in increasing cost, lead time, and customer complaints. One of the reasons for this is that the company's business has increased dramatically within the past couple years. As a result, the variety of injection molding products has been escalating. Some products are produced often or seasonally, but some products are produced just one or two times. Company XYZ does not have enough time to experiment before producing to attain suitable settings for each product like they were able to in the past. Another reason for quality issues at Company XYZ relates to new employees hired to support the growing business who lack quality knowledge of material/product characteristics.

During the last quarter in 2006, Company XYZ lost more than $40,000 from poor quality products which did not meet standards or requirements from customers as shown in Table 1. This cost was from internal failures and some appraisal costs other than prevention costs, external failure costs, and intangible costs.

Table 1: Injection molding production efficiency and cost

	Month in 2005		
	October	November	December
Total Produced Quantity	368,576	563.287	773,535
Total Rejected Quantity	11,065	16,812	25,080
Total Cost ($)	$17,129.25	$11,183.18	$12,759.84

Company XYZ produced more than 400 orders of injection molding products which was more than one million pieces of products. The quality department reported that the overall percentage of rejects or bad quality products was 3.11% which may seem fine but was not. As mentioned before, the variety of injection molding products has been escalating; therefore the bad quality percentage had large variation between products. Some products had zero defects while other products had more that 50% defects. Figure 18 shows that 132 products had more than 10% rejects and 60 products had more than 20% rejects.

Percentage of reject	Number of Products
0%	28
2%	155
4%	58
6%	21
8%	31
10%	17
12%	12
14%	19
16%	12
18%	12
20%	7
More	53
Total	425

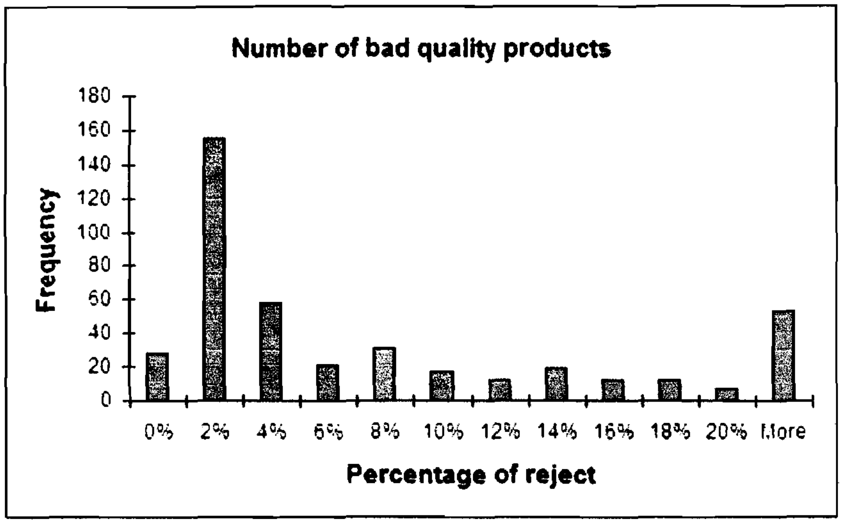


Figure 18. Number of Bad Quality Product

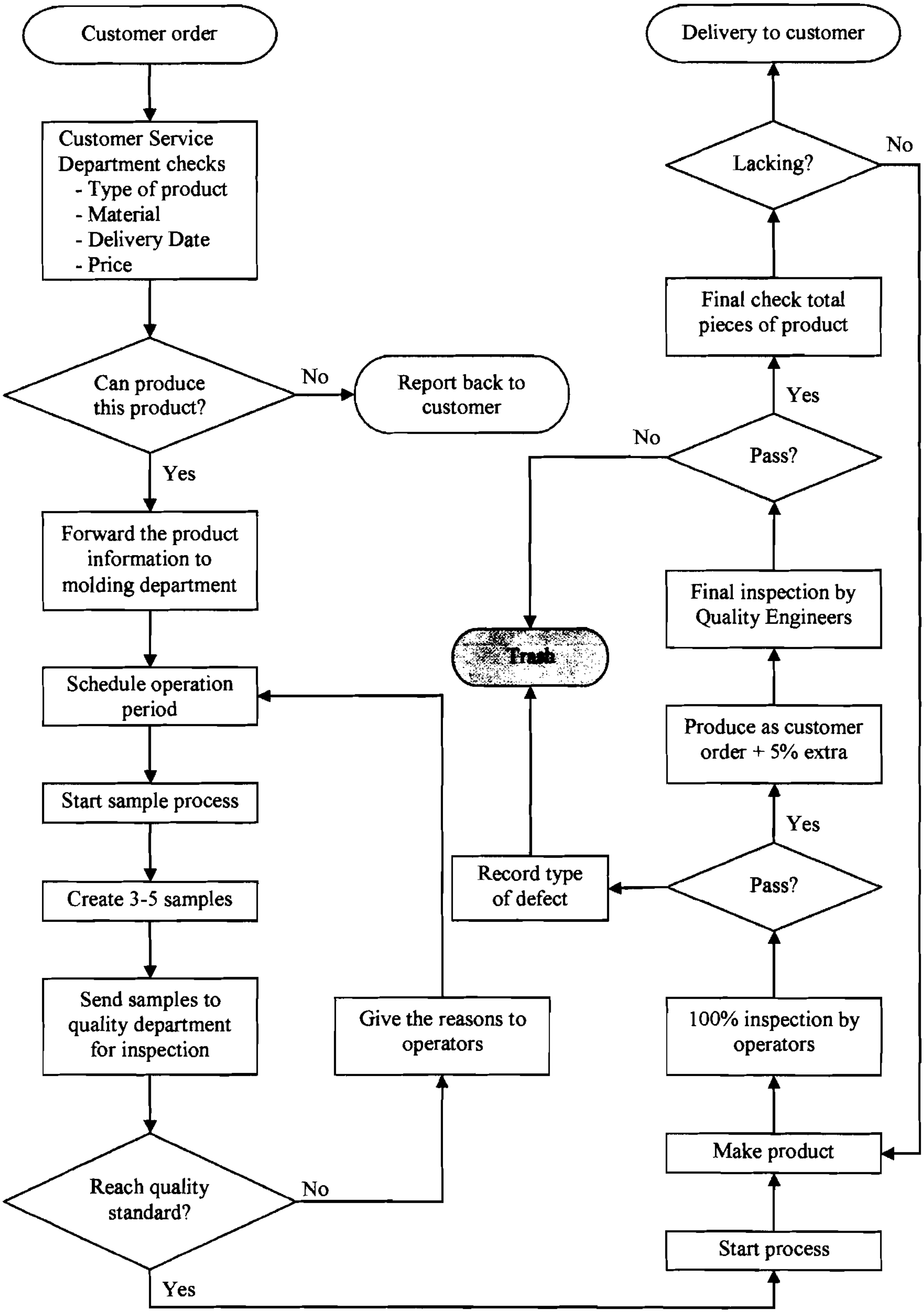


Figure 19. The Entire Process of Injection Molding

Figure 19 describes the entire process of injection molding from receipt of the customer's order to delivery of the product to the customer. This includes three main departments: customer service, quality, and production. The customer service department checks the capacity of the company before accepting the customer's order. The quality department checks the quality of product samples before production is started and inspects quality of the final products. The production department produces the products and inspects the quality of every product.

Operators in the production department produced a few samples of the product after receiving the order from the customer service department. They used their experience to set up the machine which includes adjusting the temperature and pressure level to produce the samples. After that the samples were sent to quality engineers in the quality department to check the quality of product. If the samples reach the quality standard and customer requirement, the operator can start the production process. If not, quality engineers will give reasons for denial and suggestions for improvement to the operators. After that, they will make new samples and send them to the quality department again until the samples reach the standards and requirements from customer.

The operators had another duty besides running the machine: to inspect every piece of product in reference to the 12 kinds of defects and record the number of each kind of defect: 1) short, 2) flash, 3) contaminated, 4) splay, 5) pin push, 6) scratch/damage, 7) sink/bubble/void, 8) cold slug, 9) flow line, 10) burn mark, 11) start up, and 12) last off. The products that had defect(s) which could not be repaired or recycled were classified to be scrap or trash. This created additional cost of material, labor, etc. to the company.

Quality engineers randomly inspected the finished products before delivery to the customer. After inspection by the quality engineers, if there were errors and the amount of good quality product is less than the orders, the operator has to start the whole process again to fulfill the order. Therefore, about 5% above the customer's order was produced to account for inspection errors by the operator.

Problem Identification and Analysis – Objective 2

Quality issues. The number and types of defects in the injection molding process were collected over 3 months. Every piece of product was inspected and recorded. Figure 20 shows p-charts from injection molding processes in each month.

The preceding p-chart illustrates the percentage of defects for each process, the Upper Control Limit (UCL) individually for each order, and the Upper Specification Limits (USL) from the company. There are no Lower Control Limit and Lower Specification Limit because fewer defects are better for the company. Each process had its own UCL because the number of products per process was not the same. It varied from 100 to 10,000 pieces of product so an individual UCL was most suitable. Company XYZ set up their USL equal to 5%; this meant that the number of defects per each process should not exceed 5%. If the percentage of defects exceeds five, it is out of control for the company even if it does not exceed the UCL.

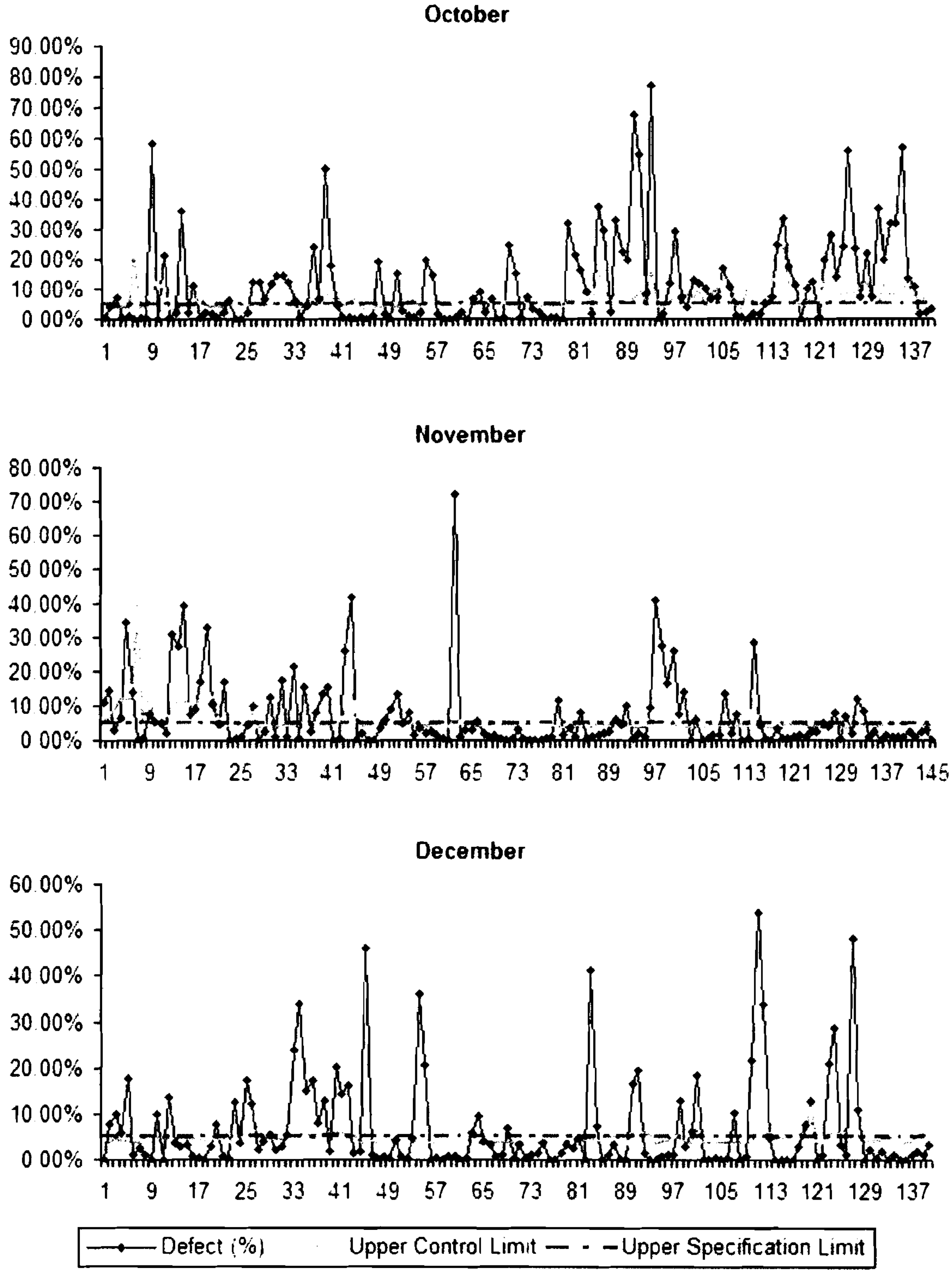


Figure 20. P-Chart

Table 2: Number of out of control processes

Month	Number of processes	Number of out of control processes			
		UCL	%	USL	%
October	140	69	49.3%	75	53.6%
November	145	50	34.5%	53	36.6%
December	140	48	34.3%	44	31.4%
Total	425	167	39.3%	172	40.5%

Table 2 summarizes the p-chart from Figure 20 and shows the information in terms of number and percentage. October had the most defects which were over 50% of total processes in the month referring to USL. There were 425 processes from customer orders in October, November, and December but 172 or about 40% of total processes were out of control. Types of defects and possible causes of each defect were indicated to solve the major problems in the processes.

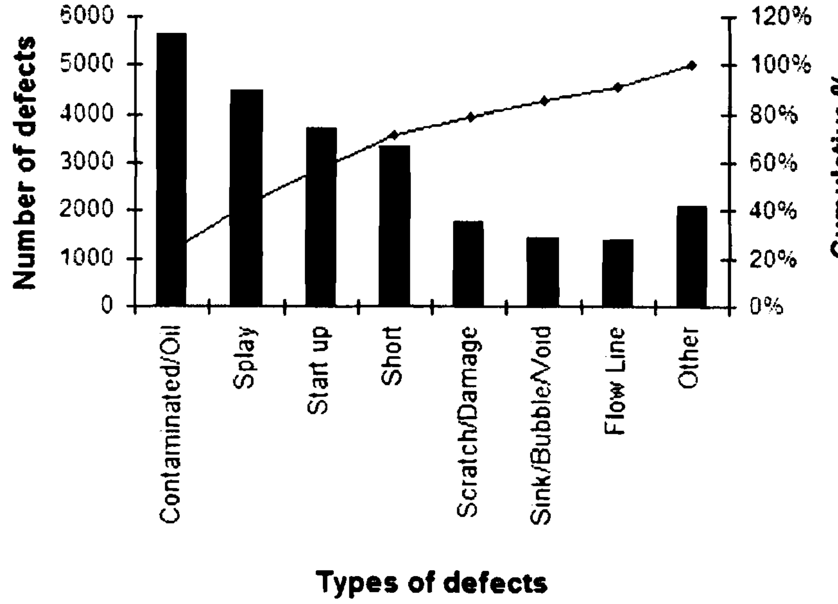


Figure 21. Number and Percentage of Defects

The quality department stated that 12 kinds of defects often occur in the injection molding process: 1) short, 2) flash, 3) contaminated, 4) splay, 5) pin push, 6) scratch/damage, 7) sink/bubble/void, 8) cold slug, 9) flow line, 10) burn mark, 11) start up, and 12) last off. Figure 21 shows number and percentage of defect. Not all of defects occurred often. Contaminated/oil defects occurred the most. The next three were splay, start up, and short problems.

Almost 80% of defects were from contaminated/oil, splay, start up, and short problems. Therefore, these four types of defects should be solved first for short-term improvement. Contaminated/oil causes the dark sports or particles on the surface of product. Splay is a glossy area on the surface of product which is usually small in size and sometimes appears as lightly tinted or silver streaks. Start up defects include all kinds of defects that occurred from the beginning of setting the machine until the machine condition is ready to produce quality products. Short or short shot occurs when the part does not completely fill.

The possible causes of each defect were summarized in Figure 22 after brainstorming with quality engineers and operators. The major causes of all defects could be categorized in four categories: machines, materials, molds, and humans.

The main causes of contaminated/oil defects were the leak of machine oil and mold assembly lubricant. Contaminated raw material was the minor cause which related to the quality of product or material handling.

Splay and silver streaks are regularly caused by gas and steam, but dirt can cause the problem too. The causes which occurred often in the injection molding process at

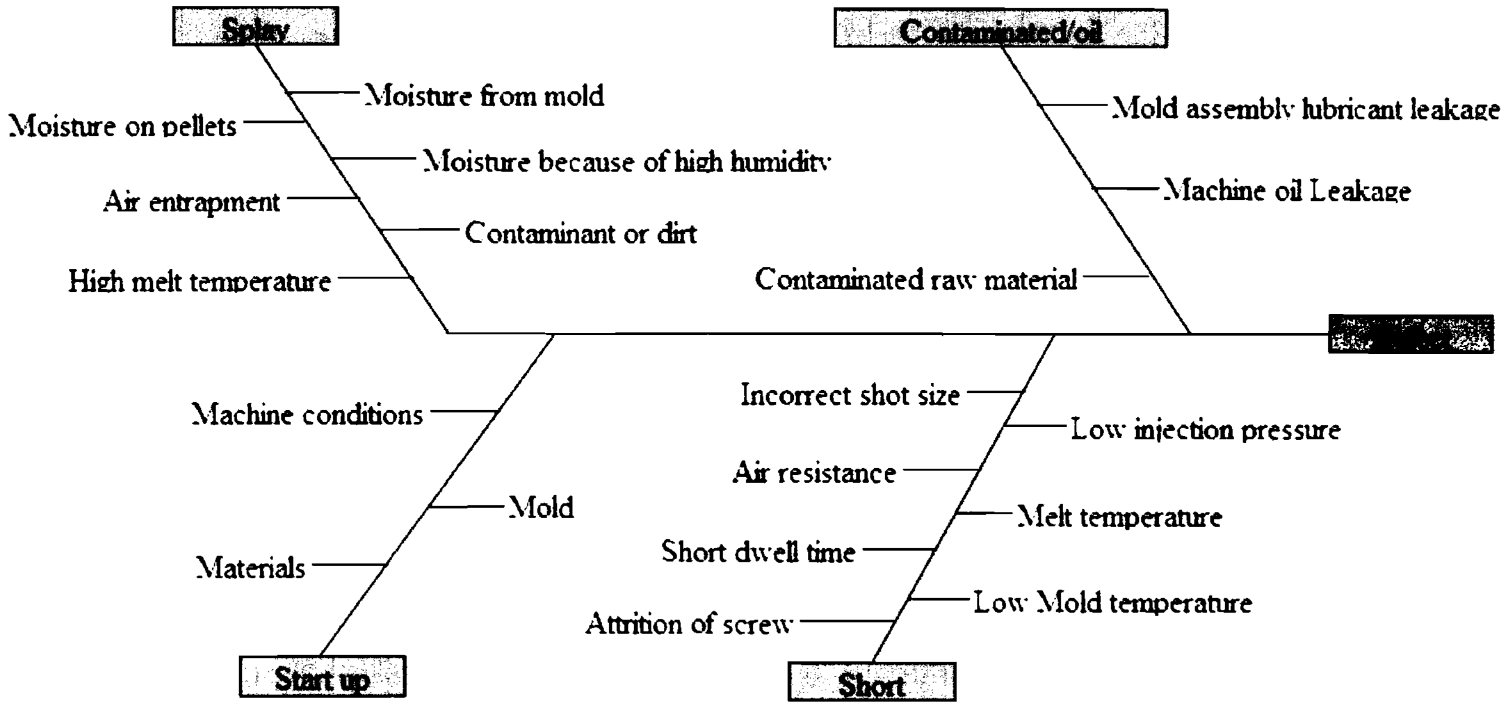


Figure 22. Cause-and-Effect Diagram

Company XYZ were moisture on pellets, moisture from mold, high humidity, dirt, air entrapment, and too high melt temperature.

Start up problems related to machine conditions, materials, and mold. Causes from materials and mold were about 10%-20% of total defects from start up problems. Eighty percent of total defects were from machine conditions including temperature and pressure setting level.

Shorts or short shots were caused by many parameters but temperature and pressure were the main factors. Specifically, improper melt temperature, low mold temperature, and low injection pressure were the causes. The less likely causes were incorrect shot size, short dwell time, attrition of screw, and air resistance.

Operator Issues. The company's business has increased dramatically within the past couple of years. Therefore, many new employees were hired to support the growing business. However, some employees were lacking quality knowledge of material/product characteristics. They were trained only to run the injection molding machine and to inspect the bad quality products in reference to the 12 kinds of defects but not to solve the confronting problems during the processes. Only production engineers knew how to solve the problems. If the problems occurred during the process, the operators had to wait for the production engineers to solve them. This increased the number of defects, cost, and processing time.

Recommendation for Improvement-Objective 3

This phase was separated into three sections. The first section is recommendations for operators to improve work efficiency. The second section is for the operators to use as a reference for the solutions to the problems leading to the four main kinds of defects:

contaminated/oil, splay, start up, and short. The last section is to guide the company for a continuous improvement plan.

Training for operators. The production managers and quality manager agreed that more training for the operators can prevent defects in the process, reduce the defects, reduce cost, save time, and increase customer satisfaction. Following is the recommended detail that should be involved in the training program:

1) Provide an introduction in the injection molding process.
2) Discuss the components of injection molding machine and their particular functions.
3) Guide the procedures for starting up and shutting down the injection molding machine.
4) Discuss the materials or polymers characteristics.
5) Describe correct injection molding machine and mold maintenance.
6) Define common defects in the injection molding process and explain their causes.
7) Provide the solutions for each cause of defects and train to solve the problems.

Troubleshooting guide. Table 3 shows solutions for each possible cause of the four main kinds of defect referring to Figure 22. These defects were general and occurred often in the process; therefore, the operators can follow this table and use it as a reference to solve the problems.

Table 3: Troubleshooting table

Possible cause	**Solution**
Contaminated/Oil:	
1) Mold assembly lubricant leakage	1) Maintain the mold as much as possible. Clean the vents if they become blocked.
2) Machine oil leakage	1) and 2) It is the operator' responsibility to find the leaks and eliminate all them as soon as possible after they occur.
3) Contaminated raw material	3.1) Use high quality product. 3.2) Report back to suppliers about the quality of product. 3.3) Train material handlers how to take care of materials. 3.4) Improve housekeeping practices.
Splay:	
1) High melt temperature	1.1) Decrease melt temperature. 1.2) Decrease nozzle temperature.
2) Condensed moisture on pellets	2.1) Dry resin pellets, per the manufacturer's recommendations, before use 2.2) Follow the material handling procedures to avoid moisture pick up.
3) Moisture because of high humidity	3) A spare dryer is required.
4) Contaminant or dirt	4) Check plastic granules and clean mold surface before using.
5) Air entrapment	5.1) Improve mold venting 5.2) Reduce screw decompression
6) Moisture from mold	6.1) Increase mold temperature 6.2) Check for water leaks and repair all leaks
Start up:	
1) Machine conditions 2) Mold 3) Materials	Follow the steps in Appendix A
Shorts:	
1) Improper melt temperature	1) Adjust melt temperature within the material supplier's recommended range.
2) Low mold temperature	2) Increase mold temperature
3) Low injection pressure	3) Increase injection pressure
4) Incorrect shot size	4) Increase shot size
5) Attrition of screw	5) Replace screw
6) Air resistance, no gas escape	6) Increase air vents
7) Short dwell time	7) Extend dwell time

Note: Summarized from "Injection molding handbook" by Osswald, T. A., & Turng, L. S., & Gramann, P. J., 2002, p. 566-568, 594-600.

An additional idea to solve the start up problems was the usage of products' histories. As mentioned earlier, operators tended to use their experience when setting up machine conditions, which was a trial and error method, resulting in increased time, scraps and cost. Sometimes the company produced similar products or exactly the same products in the past, but they did not use the historical information in setting up for the current process. Using their products' histories for a starting point rather than experimenting from the beginning can solve problems and reduce cost for Company XYZ.

The current form or "Shift Report" does not contain enough filling information for the company to use later as a reference as shown in Appendix B. Six essential parameters should be added in the form: melt temperature, mold temperature, injection pressure, hold pressure, hold time, and injection speed. Appendix C shows a modified form or "Shift Report" for operators to fill and use as further information.

Implement PDSA cycle. The last result of this research was to guide the company for a continuous improvement plan. The company had not decided to implement the continuous plan in the injection molding process. However, a continuous improvement plan can help the company to improve their quality of products and process which can also reduce cost and satisfy customer needs. The Plan-Do-Study-Act (PDSA) cycle or Deming cycle is the most commonly used tool for continuous improvement. This study already provided the plan step for the company. Following are the recommendations for Company XYZ to complete the continuous improvement plan:

1) Plan step (already provided in this research)
2) Do step: The ideas from plan step should be implemented on a small scale. The company should observe and record the result after implementing to point

out the strengths and weaknesses of the solution. The plan can be modified depending on the situation.

3) Study step: The collected data from the Do step should be analyzed and compared with the expected outcomes. Whether the problems have been solved or not, the team members will learn through the improvement process and can use this knowledge in their work or in the process for further improvement.
4) Act step: If the problems can not be solved, the PDSA process should start again to find the suitable solutions. If it is successful, the solutions can be implemented in the entire process. If it is better but some problems have not been solved, the previous solutions should be modified or used to create a new solution to solve all of the problems.
5) The Plan step provided in this study can be used to solve the problems associated with the four main defects only. Therefore, after the company solves the four main types of defects, the remaining types of defects should be solved to minimize the percentage of defects by implementing the PDSA cycle again.
6) The last section of the continuous improvement plan should involve reviewing the actions or processes annually or every six months and replacing them with better solutions.

CHAPTER V: DISCUSSION

Introduction

This chapter provides a summary, major findings, conclusions and the recommendations related to this study.

Summary

The purpose of this study was to help Company XYZ improve product quality and manage the data for a continuous improvement plan. The objectives of this study were:

1. To create a process map and evaluate the results to determine the company's current performance.
2. To identify and analyze problems in injection molding processes.
3. To create the possible solutions and make recommendations for the continuous improvement plan.

Methods

Methods and procedures of this study include a review of literature relevant to continuous improvement, Deming cycle, seven tools of quality, costs of quality, and injection molding process. The seven tools of quality was selected to help collecting and analyzing data more rapidly and systematically. These tools were also used to identify problems, seek root causes of problems, and solve problems. Every piece of product was inspected and recorded by the operators. The process map was applied to illustrate the entire process of injection molding which can help the investigators understand the process.

Major Findings

1. Company XYZ had reported poor quality of particular products in the injection molding department which results in increasing cost, lead time, and customer complaints.
2. Company XYZ did not have enough time to experiment before producing to attain suitable settings for each product like they were able to in the past.
3. Some new employees, which were hired to support the growing business, were lacking quality knowledge and injection molding knowledge.
4. From October to December, Company XYZ lost more than $40,000 from poor quality products which did not meet standards or requirements from customers.
5. There were 12 kinds of defects in injection molding process: 1) short, 2) flash, 3) contaminated, 4) splay, 5) pin push, 6) scratch/damage, 7) sink/bubble/void, 8) cold slug, 9) flow line, 10) burn mark, 11) start up, and 12) last off.

Conclusions

1. In October, there were about 50% defects out of the total processes. November had about 36% defects and December had about 31% defects. In summary, 172 processes out of 425 processes from customer orders in October, November, and December were out of control which was 40% of total processes
2. Contaminated/oil, splay, start up, and short were the main problems which made up almost 80% of defects.
3. The major causes of all defects could be categorized in four categories: machines, materials, molds, and humans.

3.1 The main causes of contaminated/oil defects were the leak of machine oil and mold assembly lubricant. Contaminated raw material was the minor cause which related to the quality of product or material handling.

3.2 The causes of splays which occurred often in the injection molding process at Company XYZ were moisture on pellets, moisture from mold, high humidity, dirt, air entrapment, and too high melt temperature.

3.3 Start up problems related to machine conditions, materials, and mold. Eighty percent of total defects were from machine conditions including temperature and pressure setting level.

3.4 Shorts or short shots were caused by many parameters but temperature and pressure were the main factors: improper melt temperature, low mold temperature, and low injection pressure were the causes. The other causes were incorrect shot size, short dwell time, attrition of screw, and air resistance.

4. The operators were trained only to run the injection molding machine and to inspect the bad quality products rather than solve the confronting problems during the processes.

Recommendations Related to this Study

1 Operator training program. Training for the operators can prevent defects in the process, reduce the defects, reduce cost, save time, and increase customer satisfaction. The training should involve the injection molding process, procedures for starting up and shutting down the injection molding machine,

characteristics of materials, injection molding machine and mold maintenance, causes of the defects, and solutions to solve the problems.

2 Troubleshooting guide. Operators can use the solutions from Table 3 as a reference to solve the four main defects: contaminated/oil, splay, start up, and short problems.

3 A modified form or "Shift Report." Company XYZ should use a modified form in the injection molding process which includes the six essential parameters: melt temperature, mold temperature, injection pressure, hold pressure, hold time, and injection speed. If this information is collected, the operators can use the products' histories to solve the start up problems which can reduce scraps and cost for Company XYZ.

4 A continuous improvement plan. PDSA cycle is the most commonly used tool for continuous improvement which can help the company to improve their quality of products and process, reduce cost, and satisfy customer needs. This study already provided the plan step of the PDSA cycle for the company. Therefore, it is recommended that Company XYZ implement the do step, study step, and act step to complete the continuous improvement plan.

Recommendations for Further Study

This study provided the procedures and solutions based on the PDSA cycle to solve only four main types of defects, although they were about 80% of the total defects: contaminated/oil, splay, start up, and short problems. A further study should be conducted to determine the procedures and solutions for the remaining types of defects to minimize the percentage of total defects and reduce cost for the Company. In addition, a further study should try different continuous improvement theories such as total quality management, six sigma, and lean to solve the problems. Results from use of each theory should be studied to find the most suitable theory to apply to injection molding processes in Company XYZ.

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APPENDIX A: Startup Issues

To resolve startup problems, the material's process window must first be determined to ensure that there is a set of conditions that can make good products.

Start by setting the process conditions to the middle of the material's process range and then adjust the process to fix any observed problems. If successful parts are not possible, determine what combination of variables must be changed to resolve the problems. These changes may include material selection, machine selection, and/or tool redesign.

Startup Issues:

OBSERVATION	**CAUSE**	**SOLUTION**
POOR KNIT LINES	Poor venting.	+ Place vents at last place to fill and at converging flow fronts + Increase size of the vents.
	Too cool a melt.	+ Increase the melt and/or mold temperature. + Increase injection speed.
PART SHORTS and has burn marks	Gas trapping/ poor venting.	+ Improve venting and/or relocate to burned area.
PART SHORTS No burn marks	Not enough material.	+ Increase shot size, if possible. If not, move to a larger machine.
	Blockage in flow at the feed-throat.	+ Reduce rpm and back pressure. + Decrease the barrel temperature in the rear.
	Not enough injection pressure.	+ Increase injection pressure.
	Material too high in viscosity.	+ Increase injection rate. + Increase process temperature. + Use a lower viscosity compound. + Increase gate and runner size.

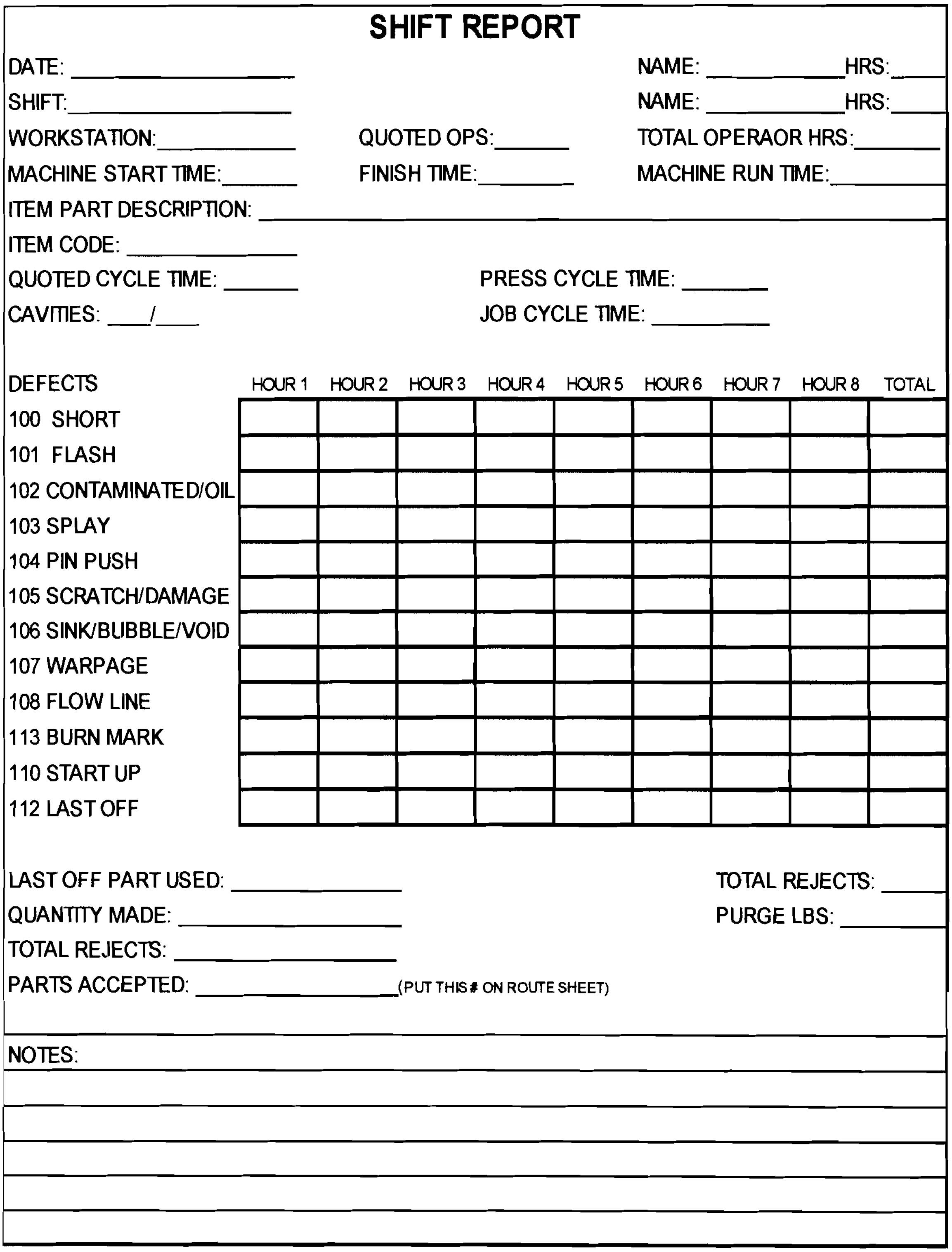
OBSERVATION	CAUSE	SOLUTION
PART FLASHES	Too much injection pressure.	+ Reduce injection pressure and time.
	Too much material.	+ Decrease shot size.
	Material viscosity too low.	+ Reduce injection speed. + Reduce process temperature.
	Tool too loose	+ Machine or dress the parting line.
	Not enough clamp capacity.	+ Use a higher viscosity compound. + Increase clamp tonnage. + Reduce thickness of the vents. + Move to a larger machine.
VOIDS OR SINKS Voids occur inside the part. Sinks pull away from the mold wall.	Material shrinkage & insufficient supply of molten material.	+ Decrease wall thickness.
	Not enough pack pressure during material solidification.	+ Increase the pack pressure and time. + Increase the gate size. + Relocate the gate to the thickest section. + Increase the runner size.
BUBBLES Part surface bulges above a bubble.	Gas entrapment.	+ Relocate the gate or modify the flow path. + Add a pin in the area to eliminate the gas trap.
FLOW MARKS Back fills	Filling from thin to thick sections.	+ Reposition the gate to a thick section.
FLOW MARKS Shadowing	Surface irregularity.	+ Radius dimples.
FLOW MARKS Folds	Uneven filling of section.	+ Relocate gate to balance the flow or reduce the runner diameter.
JETTING	High viscosity flow.	+ Increase process temperature. + Increase injection speed. + Decrease gate size. + Change type of gate. + Relocate gate to impinge.
WARPED PARTS	Anisotropic shrinkage.	+ Relocate the gate so flow occurs in only one direction.
	High molded-in stress.	+ Increase the process temperature. + Reduce the pack pressure. + Increase the mold temperature.

OBSERVATION	CAUSE	SOLUTION
SURFACE DEFECTS Uneven shine Beach marks	High molecular weight compound in highly polished mold.	+ Change to a lower molecular weight compound. + Texture mold cavity surface (EDM, sandblast, etc.)
SURFACE DEFECTS Silver streaking or splay marks	Contaminated material.	+ Check for moisture (condensation) or dry the material. + Check regrind for contaminants or moisture. Dry if required + Reduce injection speed.
	High shear in the material.	+ Increase the process temperature. + Increase the gate size.
EJECTOR PIN MARKS	Parts soft during ejection.	+ Increase mold close time. + Reduce mold temperature. + Reduce process temperature. + Texture mold surface for better release. + Increase size of pins. + Increase draft on part. + Reduce wall section. + Use a compound with mold release. + Use a harder compound.
BURNT SMELL Parts have a yellow cast	Degraded material.	+ Purge machine and observe whether problem reoccurs. + Reduce process temperature. (Particularly in rear of machine). + Reduce regrind level. + Reduce residence time. + Purge machine after shutdown. + Move to a smaller machine. + Reduce hot runner system temperatures. + Minimize dead spots in hot runner manifold.
PART STICKS IN "A" HALF or STATIONARY SIDE OF THE TOOL	Insufficient extraction force.	+ Sandblast "A" side of tool. + Polish "B" side. + Run "A" side cooler. + Put keepers in "B" half of tool. + Increase draft on part in "A" half of tool.

OBSERVATION	**CAUSE**	**SOLUTION**
PART STICKS DURING EJECTION	Insufficient ejection force.	+ Increase mold closed time. + Reduce mold temperature. + Reduce process temperature. + Reduce pack and hold pressure. + Sandblast "B" side. + Increase size of ejector pins. + Increase number of ejector pins. + Increase draft on part. + Provide air assist.
NON-UNIFORM COLOR	Poor dispersion.	+ Increase back pressure and/or screw rpm. + Change the color concentrate carrier to a material with a lower melt temperature.
	Contamination.	+ Check for clean regrind.

Source: GLS, n. d., para. 8

APPENDIX B: Original shift report



SHIFT REPORT

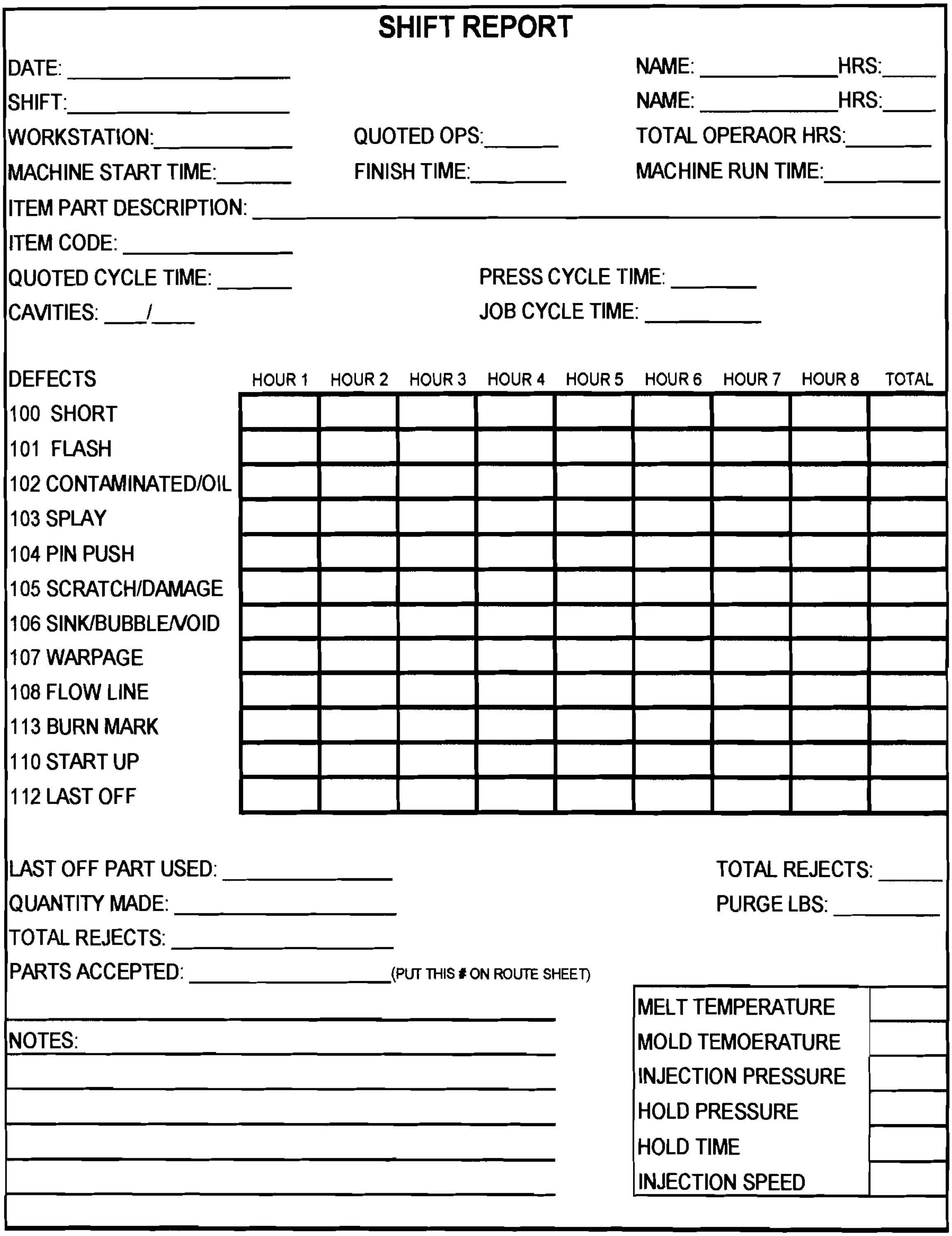
DATE: ______________ NAME: __________HRS:____
SHIFT:______________ NAME: __________HRS:____
WORKSTATION:__________ QUOTED OPS:______ TOTAL OPERAOR HRS:______
MACHINE START TIME:______ FINISH TIME:______ MACHINE RUN TIME:______
ITEM PART DESCRIPTION: ______________________________
ITEM CODE: ____________
QUOTED CYCLE TIME: ______ PRESS CYCLE TIME: ______
CAVITIES: ___/___ JOB CYCLE TIME: ________

DEFECTS	HOUR 1	HOUR 2	HOUR 3	HOUR 4	HOUR 5	HOUR 6	HOUR 7	HOUR 8	TOTAL
100 SHORT									
101 FLASH									
102 CONTAMINATED/OIL									
103 SPLAY									
104 PIN PUSH									
105 SCRATCH/DAMAGE									
106 SINK/BUBBLE/VOID									
107 WARPAGE									
108 FLOW LINE									
113 BURN MARK									
110 START UP									
112 LAST OFF									

LAST OFF PART USED: ____________ TOTAL REJECTS: _____
QUANTITY MADE: ______________ PURGE LBS: _______
TOTAL REJECTS: ______________
PARTS ACCEPTED: ____________(PUT THIS # ON ROUTE SHEET)

NOTES:

APPENDIX C: Modified shift report



SHIFT REPORT

DATE: ____________________
NAME: ____________HRS:____
SHIFT:____________________
NAME: ____________HRS:____
WORKSTATION:____________
QUOTED OPS:______
TOTAL OPERAOR HRS:_______
MACHINE START TIME:______
FINISH TIME:________
MACHINE RUN TIME:__________
ITEM PART DESCRIPTION: ____
ITEM CODE: _______________
QUOTED CYCLE TIME: ______
PRESS CYCLE TIME: _______
CAVITIES: ___/___
JOB CYCLE TIME: __________

DEFECTS	HOUR 1	HOUR 2	HOUR 3	HOUR 4	HOUR 5	HOUR 6	HOUR 7	HOUR 8	TOTAL
100 SHORT									
101 FLASH									
102 CONTAMINATED/OIL									
103 SPLAY									
104 PIN PUSH									
105 SCRATCH/DAMAGE									
106 SINK/BUBBLE/VOID									
107 WARPAGE									
108 FLOW LINE									
113 BURN MARK									
110 START UP									
112 LAST OFF									

LAST OFF PART USED: ______________
TOTAL REJECTS: _____
QUANTITY MADE: __________________
PURGE LBS: _________
TOTAL REJECTS: __________________
PARTS ACCEPTED: ________________(PUT THIS # ON ROUTE SHEET)

NOTES: ____

MELT TEMPERATURE	
MOLD TEMOERATURE	
INJECTION PRESSURE	
HOLD PRESSURE	
HOLD TIME	
INJECTION SPEED	