

Defect analysis for quality and productivity improvements in a manufacturing system

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¹Department of Mechanical and Manufacturing Engineering, and ²Department of Biosystems Engineering, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada. *Email: tmekkawy@cc.umanitoba.ca

ElMekkawy, T.Y., Hachkowski, P.A., Strong, D. and Mann, D. 2006. **Defect analysis for quality and productivity improvements in a manufacturing system.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **48**: 7.9 - 7.12. Disparity in labour costs around the world make it difficult for manufacturers located in developed countries to compete with manufacturers located in developing countries. To offset this disparity, manufacturers in developed countries must improve productivity either by increasing the value of goods produced or by using fewer resources during production. The objective of this paper is to analyze the potential productivity gains associated with the elimination of manufacturing defects. Thirty-five manufacturing defects were tracked to learn their effect on the production system. Cost of correcting a manufacturing defect and customer dissatisfaction associated with discovery of a manufacturing defect were both used to determine the impact on productivity. Reducing the likelihood of defects is the most attractive option when dealing with manufacturing defects that can potentially reach the customer. **Keywords:** manufacturing defects, cost analysis, productivity improvement.

Les grandes différences dans les coûts de main d'œuvre à travers le monde ont comme conséquence que les manufacturiers établis dans les pays industrialisés ont des difficultés à concurrencer les manufacturiers dans les pays en voie de développement. Pour amoindrir ces disparités, les manufacturiers dans les pays industrialisés doivent améliorer leur productivité, soit en augmentant la valeur des biens produits ou bien en utilisant moins de ressources durant la production. L'objectif de cette publication est d'analyser le potentiel de gains de productivité associé avec l'élimination des rejets manufacturés. Trente-cinq rejets manufacturés ont été sélectionnés pour évaluer leur effet sur le système de production. Les coûts associés avec la correction de rejets manufacturés et l'insatisfaction associée à la découverte du rejet vécue le consommateur ont été utilisés pour déterminer l'impact sur la productivité. Réduire la probabilité d'occurrence des rejets constitue l'option la plus intéressante lorsque l'on considère des rejets manufacturés qui pourraient potentiellement se rendre jusqu'aux consommateurs. **Mots clés:** rejets manufacturés, analyse de coûts, amélioration de la productivité.

INTRODUCTION

Manufacturers in developed countries must significantly increase productivity to remain competitive with manufacturers in developing countries, which can produce labour intensive goods at lower cost. Productivity is sometimes measured in goods produced per hour or production per employee. However, the complete definition of productivity must be in terms of

dollars. Productivity is the value of goods produced divided by the value of resources used (Hilton et al. 2001). Productivity can be increased in a number of ways: reducing cost, increasing efficiency of use of raw material, or increasing product quality. Any reduction of material or labour used to make defective products will decrease costs and, therefore, increase productivity.

Cost of quality is usually divided into four categories: appraisal costs, prevention costs, internal failure costs, and external failure costs (Evans and Lindsay 2002). These categories are deemed useful for organizations to determine their quality costs and in which category they should concentrate their quality investments. Weheba et al. (2004) proposed a mathematical model that accounts for the value of process improvement. Quality costs are divided into reactive costs, such as the cost of inspection and rework, and proactive costs, which are costs of defect prevention activities. By using these cost models together, a manager can determine the net worth of a quality improvement initiative and hence set a budget for a project that still results in a net decrease in total quality costs.

Effective analysis of quality defects is vital to reach the proper conclusions concerning how to handle defects when they occur or how to prevent them from happening. A trend in the literature on defect analysis is that the use of more than one approach is required to make the analysis most effective (Finlow-Bates et al. 2000). Some authors advocate the use of analysis methods not traditionally used in quality control, such as Failure Modes and Effects Analysis (FMEA). One shortcoming in most quality and problem solving methodologies is that the problem solver is expected to eventually reach a root cause of the problem once it has been identified. There are other methodologies that are reported in the literature for improving productivity and quality: Total Quality Management (TQM), Six Sigma, Kaizen, 5 S, Just In Time (JIT), Statistical Process Control (SPC), and ISO9001. In spite of all of these tools, many companies still find it difficult to identify the quality improvement options offering the highest return or to quantify the financial payback of these investments. The reason for these difficulties is the lack of adequate methods for determining the financial consequences of poor quality. Few companies have adequate capability to track quality related costs, such as scrap, rework, warranty claims, and expenditures of the quality department.

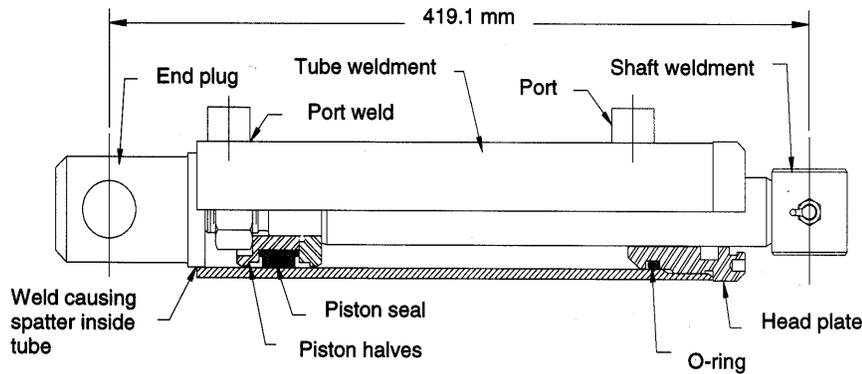


Fig. 1. Representative cylinder assembly.

The main goal of this paper is to analyze the effects that manufacturing defects can have on the product quality and productivity of a production system. Thirty-five manufacturing defects were tracked to analyze their effect on the whole production system at ABC Manufacturing. ABC Manufacturing is an aftermarket producer of agricultural front-end loaders, mounting kits, and accessories located in Manitoba, Canada. Data on these defects were collected concerning the effect of the defect on production flow and cost. This paper presents a method for determining the correct quality improvement and inspection strategies for specific production processes, based on cost control, that can be used to reduce the likelihood of manufacturing defects.

DATA COLLECTION and ORGANIZATION

Thirty-five manufacturing defects, which occurred in 2004 at ABC Manufacturing, were compiled from non-conformance reports (NCR). Interviews were done with various employees to determine more information about the cause of each defect and the action that was taken when the defect was found. After collecting information related to each defect type, data were separated and tabulated into two sets: defect flows throughout the plant; and rate of defect incidence. The defect flows data set was intended to track and record the flow, or possible flow, of defects throughout the plant. The defect incidence data set was intended to represent the actual occurrence of defects in production.

DEFECT ANALYSIS

This section presents a detailed analysis of one defect example called “weld spatter inside cylinder tubes”. This defect was chosen because it was recently discovered and has contributed to many seal and cylinder replacements, which are very costly. The process routing for the hydraulic cylinder includes: saw, drill holes, tube, weld first port, machine threads, skive and furnish, tack and weld end plug, weld second port, drill hole in end plug, wash, and tube weldment. The cylinder tube weldment shown in the cylinder assembly is comprised of three different parts: the cylinder tube, two ports, and a cap or end plug (Fig. 1). The first step to make the cylinder tube weldment is to saw-cut the cylinder tube to length. Next, the tubes are moved to a drill where the holes for the hydraulic ports are drilled. After the holes are drilled, the first port (near the rod-end of the cylinder) is welded onto the tube. After the welding operation, the internal threads are machined into the tube. In the next operation, the inside of the

tube is skived (a material removal process) and roller burnished in one operation to achieve the final finished inside diameter measurement, surface hardness, and surface finish required for long cylinder life. Once the inside of the cylinder tube is finished, the end plug is welded to the cylinder tube. This is a semi-automatic process. The operator loads the parts into the jig and initiates the welding cycle. The end plug is then welded to the tube using pre-programmed weld parameters while the tube rotates, ensuring a consistent, repeatable weld. To complete the cylinder tube weldment, the second port is welded onto the tube and a mounting hole is drilled

into the end plug. The cylinder tube is then washed to remove any debris and cutting fluids before it is moved to the assembly area. In the assembly area, the hydraulic cylinder is completely assembled. Each cylinder is then tested for leaks at maximum rated pressure using a dye and special light. Finally, the cylinder is hung on a load bar on the overhead track and transported to the paint line.

The defect of weld spatter inside the cylinder tube is created when the end plug is welded to the cylinder tube. As shown in Fig. 1, the end plug is simply inserted into the cylinder tube to a specific depth. This arrangement leaves a perfect joint to place a strong fillet weld. Even though the fit between the end plug and the tube is relatively close (0.254 mm), some weld spatter can find its way through or around the weld puddle and inside the cylinder tube, where it can freeze to the side of the tube. Weld spatter is very hard and is not likely to be completely removed by the washing process. Presently, there is no inspection or spatter removal process for the inside of the cylinder tube. The cylinder is assembled, tested, painted, and shipped to a customer, either alone or as part of a larger assembly.

Weld spatter inside the cylinder tube can have many different effects on system performance. The spatter may be removed from the cylinder wall during operation of the cylinder and have no effect on the cylinder. However, the spatter will contaminate the hydraulic oil and, if not trapped by a filter, could cause significant damage to a hydraulic valve or pump. The spatter may also stay attached to the cylinder wall throughout the life of the cylinder. In this case the most likely effect is damage and premature wear of the piston seal as the piston travels back and forth over the bead of spatter. This damage will cause the seal to stop working properly and the cylinder to leak internally at high pressure. Since the seals are replaceable, the customer will most likely replace them. However, if the seals do not last for their expected life the customer may opt to return the cylinder for replacement. Once the cylinder is returned, it is current practice to disassemble and inspect them. It is only then, that weld spatter is discovered.

There are many possible solutions to this problem. One possible solution is to inspect each cylinder tube after welding and manually remove the spatter. However, there is the possibility that the spatter may be missed at inspection. Another solution is to perform another operation on the inside diameter of every tube to remove any spatter that may be present. This type of operation could be a simple process that would scrape

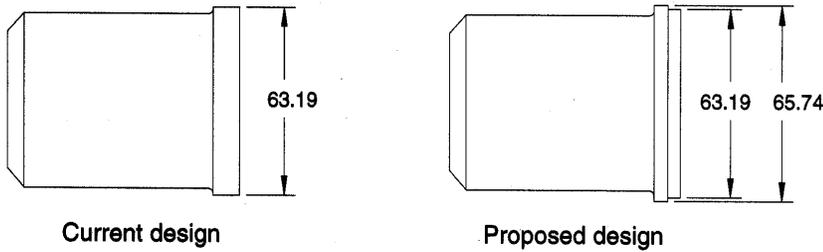


Fig. 2. Proposed design change for hydraulic cylinder and plug. (Dimensions in millimeters)

off any spatter stuck to the inside of the tube. However, since the inside diameter of the tube has already been skived and burnished to exact dimension and surface conditions, an additional operation would be redundant and may score the cylinder tube. For some additional cost, a step can be machined into the end plug so it covers the end of the cylinder tube (Fig. 2). Since the fit between the end plug and the cylinder tube is very close, a very small step would be required and there would be no effect on the size or quality of the weld. Another benefit of the end plug redesign is that complicated fixturing would not be required to tightly control the depth that it is inserted into the tube. It would merely have to be held in place.

This design change is not without its drawbacks. Machining the step requires a more complicated program for the CNC lathe and would require additional machining time. The main drawback to this change lies in the material required. Since the inside diameter of hydraulic cylinders are exclusively common tube sizes, the end plug is currently machined from round bar stock of the same common size. Adding the step slightly larger than the inside diameter of the cylinder would require a larger diameter round bar. For the end plug shown in Fig. 2, the next common size of raw material would be 76.2 mm, which would cause a lot of material waste. The alternative is an uncommon size like 66.675 or 69.85 mm. Fortunately, ABC Manufacturing would likely have the volume requirements of the uncommon size to procure it at a reasonable cost.

COST ANALYSIS FOR QUALITY IMPROVEMENT

The cost of quality is generally defined as the difference in profitability between the “as is” and the improved situation (Gardner et al. 1995). For the purpose of this paper, the cost analyses treat each manufacturing defect in a consistent manner. Costs are analyzed at comparable stages in the manufacturing process, regardless of when the defect was actually identified and what repair strategy was employed. If applicable, the paper addresses the following five points for each defect:

- (i) The cost of repairing the defect if it is identified immediately.
- (ii) The cost of repairing the defect if it is not identified until it has stopped production or reached the customer.
- (iii) The cost in point (i), but the repaired item is only acceptable if it shows no evidence of being repaired.
- (iv) The cost in point (ii), but the repaired item is only acceptable if it shows no evidence of being repaired.
- (v) The cost of improving the production process so that the likelihood of the defect occurring is reduced.

Costs were calculated using ABC’s standard hourly rates for each production operation. Data for standard batch sizes, set up times, and run times were collected from work order receipts. Data for repairs and rework were either collected from work order receipts or from estimates made from the authors’ experience. Costs for new equipment were supplied by outside vendors where required. Capital expenditures were spread over a period of ten years at an assumed prime rate of interest.

When the cost analysis involved the replacement of a part, either to the customer or during production, the total annual cost of that option was calculated using the general formula:

$$CR = CP \times N \times D \quad (1)$$

where:

- CR = cost of replacement,
- CP = cost of part to be replaced,
- D = proportion of defective parts produced by this process, and
- N = number of parts produced per year.

When the cost analysis requires a change in process or the addition of a process, the calculations follow the general formula used at ABC Manufacturing for all cost analysis calculations on an annual basis:

$$CP = \left\{ (M \times \$M) + \sum_{i=1}^m \left[\frac{TS_i \times \$LS_i}{LS} + (TR_i \times \$LR_i) \right] \right\} N \quad (2)$$

where:

- M = quantity of raw material,
- $\$M$ = cost per unit of raw material,
- TS_i = set up time required in hours,
- $\$L_{si}$ = hourly rate for set up process,
- TR_i = run time required for production process,
- LS = batch size,
- $\$LR_i$ = hourly rate for production process, and
- m = required number of operations to manufacture part.

In most cases, quality improvement projects cannot be implemented without incurring some cost. At the same time, creating and either repairing or replacing defective products also costs money. Projects designed to reduce the number of defective items created must be carefully analyzed to determine whether they result in increased total cost due to increased cost of quality.

This section includes a detailed cost analysis of “weld spatter inside cylinder tubes” and a summary cost analysis of four other defect types. Using the data in Table 1, the five points listed above were addressed to calculate the costs associated with the various methods of dealing with the cylinder tube weldment defect. The results of such an analysis clearly indicate the potential cost of quality. This type of analysis is also useful when considering increasing the cost of a part to improve quality since the increase in cost of the part is compared to the current cost incurred because of poor quality. The results of the analysis are summarized in Table 2.

Table 1. Data used in cost analysis.

Parameter	Value
Labour rates (hourly)	$\$L_{S1} = \$36.00, \$L_{S2} = \60.00 $\$L_{R1} = \$36.00, \$L_{R2} = \60.00
Number of end plugs welded each year	N = 4500
Standard batch size	LS = 400
Current defect rate (estimate)	D = 1%
Cost of cylinder tube weldment	\$30.28

As described in the previous section, weld spatter frozen to the inside surface of a hydraulic cylinder may have several detrimental effects on the total system performance, including seal damage and contamination of hydraulic oil, potentially causing damage to other components of the hydraulic system. The most likely effect is damage of the cylinder seals. Costs were calculated based on the assumption that each defect would be handled the same way, thus allowing a comparison of the total annual cost of each method for handling the defect.

Since the repair of the defect is not desirable, it follows that the only action that should be taken involves restoring the cylinder tube to the same condition as an item that was not repaired. Referring to (ii), (iii), and (iv) in Table 2 reveals that this action results in estimated annual costs of \$4455.00, \$1816.20, and \$4556.25, respectively. Since these costs rely heavily on defect rates and customer complaint levels, the cost of reducing the likelihood of this defect occurring should be carefully considered.

The results of the analysis in Table 2 reveal that redesigning the end plug as proposed previously would come at an additional annual cost of \$2434.54. In addition, the proposed end plug design would eliminate this defect from production. Even though all cylinder tubes that exhibit this defect in section (iii) of Table 1 would be scrapped, some defective tubes will get through the inspection process without being detected. Therefore, eliminating this defect from production and hence not allowing it to reach the customer is worth the extra \$466.21 (\$2278.80-\$1812.59) annual investment to produce the redesigned end plug. It can be noted from Table 2 that an annual savings of approximately \$12,000, \$500, and \$145 for defects # 2, 3, and 5, respectively, will be realized if the new processes are adopted. Moreover, the defect will not reach the customer in all cases which imply a higher order of magnitude of savings compared to the former savings

Table 2. Results of cost analysis.

Cost type number	Defect number				
	1	2	3	4	5
(i)	*N/A	335.95	5.93	31.16	N/A
(ii)	4455.00	5400.00	3240.00	3000.00	N/A
(iii)	181620	768.00	800.98	31.16	N/A
(iv)	4556.25	5400.00	28130.4	3000.00	629.19
New product/process	20823.30	43742.47	26200.40	N/A	2582.04
(v) Original product/process	18544.50	55600.00	26699.20	N/A	2726.49
Difference	2434.54	-11857.53	-498.80	N/A	-144.45

*N/A - not applicable

figures. With respect to defect #4, an information system was suggested to reduce the likelihood of occurrence of this defect. It is beyond the scope of this paper to make an estimation of this information system.

CONCLUSIONS

This paper presents a method for evaluating the economic impact of manufacturing defects on the productivity of a manufacturing system. Special attention was given to the cost of poor quality. Cost of repairing a defect was calculated for the following conditions: time of defect detection (immediately vs. by the customer), customer's expectation of quality (i.e., repaired item shows no evidence of being repaired), and reduction of defect occurring. Reducing the likelihood of the defect occurring was found to be the best option.

Possible directions for future work can be split into two categories. The first is the continuation of the analysis of defect examples in this paper. By further analyzing more of the defects in this paper, it is possible that a pattern for handling defects may appear. Similar work should also be done at a different organization to determine whether the results and conclusions drawn in this paper can be paralleled across the manufacturing sector or whether they are specific to ABC Manufacturing.

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