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A Novel Rework Costing Methodology Applied To a Bus Manufacturing Company

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Abstract

This paper focuses on the quality costs analysis in the automotive industry, specifically a bus manufacturing company. The main goal was to improve the quality costs indicator, by providing means to evaluate the failure cost within the productive process. Kaizen-lean principles were used as methodology. A quality cost analysis was made based on literature review and in an ISO standard in quality costs. Process analysis was made based on the PDCA (Plan, Do, Check, Act) cycle. As the main achievements of this article, the quality costs were identified as well as its sources. Then, by collecting a very significant amount of data, from various departments, regarding each of the identified costs, it was possible to measure these costs and create a database to scorecard them – including rework costs. Due to the lack of rework costs information, a great part of this analysis focused on data collection and estimating/calculating these associated costs. Thus, it was possible to develop associated KPI's (Key Performance Indicators) to support decision making and a graphic indicator to show the overall balance between quality costs and non-quality costs. In this process, some difficulties were found as well as some opportunities for improvement. The critical ones were implemented during this project, while the others are scheduled for future work. In terms of a more technological approach to these studies, some autonomous systems can exist, although it comes at a great cost. However, the 4.0 Industry concept is evolving and fits perfectly in the quality costs monitorization context: an integrated information system with a global data network allows for a quick check-up of all the quality costs, by category, while freeing employees from doing this work manually.

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1. Introduction

Within the current highly competitive context of the automotive industry, companies need to be in a state of constant evolution and ability to adapt to the market's requirements. This competitiveness in the industry requires a compromise between high levels of productivity, efficiency and innovation, while promoting quality through a zero-defects and first-time-right culture [1, 2]. In this sense, the Toyota Production System (TPS) [3-5] proved to be very successful in improving productivity levels by reducing unnecessary activities and waste [6]. Later, in the 1990's, the TPS would influence a new concept of "Lean Manufacturing", proposed by Womack et al. [7, 8]. Even more tools and techniques were developed within the culture of processes' continuous improvement and waste reduction. Parallel to this, the concept of Quality and Quality Management systems also benefited from the TPS and Lean cultures, since they provide powerful tools to reduce poor quality costs and improve processes. The Costs of the Quality theme is introduced here, as a method for measuring and monitoring the company's performance on poor quality [9-11]. Additionally, this developed into an important auxiliary tool for companies strategic planning, allowing to establish periodic objectives and control them.

The work presented in this article was developed within an industrial environment of a bus manufacturer (CaetanoBus), and its main objective was to analyze the existing quality costs and creating performance indicators (KPI). The article's structure is divided into five sections: the first corresponds to this Introduction; Section 2 deals with the theoretical research regarding the article's issues; Section 3 refers to the methodology used in this study; Section 4 describes the work develop according to the adopted methodology and, finally, Section 5 contains the discussion of the general results and conclusions of this work.

2. Literature review

Nowadays, companies within the automotive industry face an environment of tremendous competition that forces them to continuously adapt. The implementation of an effective Total Quality Management system, supported by the Lean and TPS ideologies, seems to be essential for the company's ability to maintain its competitiveness. This is not different in the bus manufacturing industry. Ever since 1910-1920, with the innovations introduced by Henry Ford [7, 12, 13], the automotive industry evolved from the mass production and standard work methodologies, to the more flexible TPS and, later, to the Lean Manufacturing. While Ford focused on maximum productivity, the Toyota approach was to apply a continuous improvement culture (both in processes and people) [14] to reduce waste and organize space and information. This also led to the Just-in-time (JIT) concept, the 5S, the Value-Stream-Mapping (VSM) and other powerful techniques of the company's improvement. In 1990, the Lean adopted the TPS concepts and developed them while focusing on client's satisfaction [7, 15]. At the same time, the concepts of Quality also evolved, adopting TPS and Lean's tools to improve companies. It also explores the TPS concept of eight wastes (MUDA), which identifies specific costs within production for which clients do not expect to pay [11, 16, 17]. This waste can then be indirectly attributed to the Costs of Poor Quality, in the sense that they do not meet clients' requirements.

In terms of measuring the quality/poor-quality impact within an organization, some different approaches on CoPQ measuring models appeared [9, 18]. This sort of studies allows to quantify the amount of poor quality, quality problems themselves and to justify an extra effort to deal with quality problems in general. It also allows for a detailed report on cost data and to guide the company's improvement progress. Still another possibility, is to have a distinct notion of the poor-quality costs directly associated with a specific product. As a basis for this work, the Portuguese Standard NP4239 (1994 revision) was consulted and used as a guideline to map and categorize all the costs. The model is based on the PAF (Prevention, Appraisal and Failure) [19] scheme, in which Failure costs (internal and external), Prevention and Appraisal costs are considered. According to this model, the total quality cost is the sum of prevention-appraisal and failure costs; Quality costs are defined by the sum of prevention and appraisal costs; and Poor-quality costs are represented by the internal plus the external failure costs. This scheme was originally designed by Juran, but the current quality costs categories used were established by Feigenbaum, as Kim and Nakhai stated [20]. It is currently almost universally accepted as a standard for an initial quality costing study, considering that it is a simpler model based on the company's activities. The PAF model was adopted by both the British Standard Institute and the American Society for Quality Control and it is also the most widely employed method for quality costing [21]. An example of a quality costs study was developed in a woodworking company in Slovakia, where the applied methodology was very similar to the work described in this article [11]. After a categorization of each cost type, the company's activities were considered individually, resulting in an overall distribution of the quality costs, per category.

3. Methodology

As a starting point for this study, a literature revision was made, based on quality themed books and scientific articles, Toyota Production System/Lean Manufacturing implementations and, finally, on Costs of Quality (COQ) documentation. Subsequently, the study follows a PDCA cycle methodology, where the Plan phase occurs to diagnose and analyze the current state of the company in terms of poor quality cost-generating activities. Secondly, the Do phase emphasizes on measuring each cost of poor quality, while grouping it as internal or external failure costs. The third phase, Check, consists of verifying the results and calculating its impact on the product value, in the form of an indicator (KPI). Finally, the fourth phase is Act, which appears as a form of conclusion to the study and suggests possible ways of reducing the CoQ.

4. Cost of Quality Analysis

The overall Costs of Poor Quality (CoPQ, as defined in this article) study starts by identifying potential cost-generating activities in the company. All the company's internal processes (included but not limited to the productive sectors) were analyzed and accounted for applying the Portuguese Norm for Quality Costs Quantification NP4239 from 1994's revision. Thus, based on a PAF costing model, it was possible to separate the internal from the external failure costs, as well as the prevention and appraisal quality costs while mapping all of it. Afterwards, the cost measuring was based on each individual activity generating CoPQ, whilst developing a method to estimate the rework costs. This was followed by an extensive analysis of all this data, resulting in the development of new KPIs to study the CoPQ impact on the product and, consequently, on the organization.

4.1 Poor Quality cost-generating activities and cost mapping – Plan

The Plan phase consisted mainly of running a current state diagnostic and identifying potential CoPQ generating activities. Based on the Portuguese Standard NP4239 and the common PAF model, it was possible to create a simple Ishikawa Diagram to define these activities – as seen in Fig. 1 and Table 1.

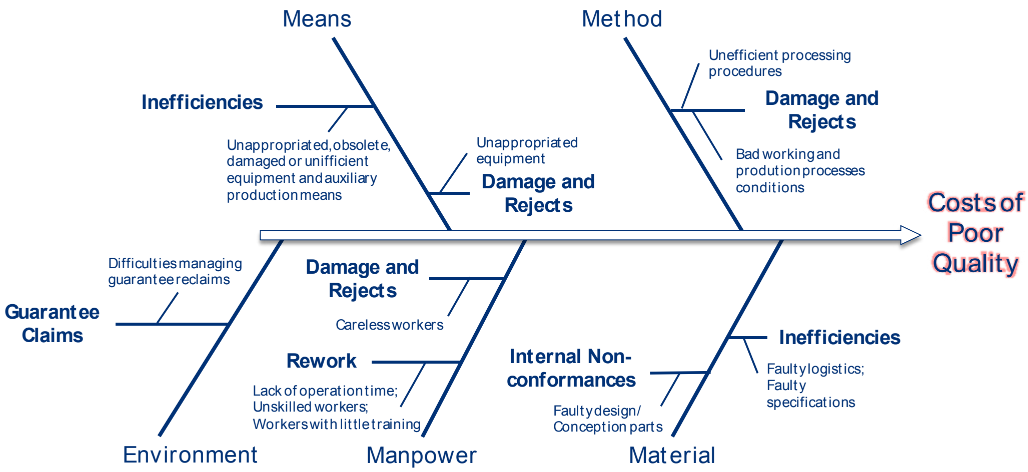


Fig. 1. Ishikawa Diagram identifying the main activities causing CoPQ.

Table 1. Identified Costs of Quality/Poor Quality generating activities.
(*- Prevention and Appraisal costs are treated as "Quality" costs in the literature, as was in this study).

PAF model cost type	Organization CoQ/CoPQ - activity	Description
Prevention*	1. Quality Department costs (and Inspection)	Annual Prevention and Inspection (appraisal) costs grouped
Appraisal*		
Failure (Internal)	2. Internal Non-conformances	Non-conformances detected in the productive process with internal responsibility (e.: faulty design, production)
	3. Material Damage and Rejects	Damaged materials in the production process and concept rejects
	4. Production Inefficiencies	Delays and inefficiencies caused by missing parts/equipment and logistic faults
	5. Rework	Product reworking to meet product conformance and quality levels
Failure (External)	6. Guarantee Claims	After-sales and zero-kilometre customer claims

4.2 Costs measuring - Do

Considering all the CoQ mapped (as seen in
Table 1), the method for quantifying and measuring followed a simple methodology based on the man-hour labor cost. Except for the 1. Quality Department costs – whose costs are agglomerated monthly in a specific database -, all of the above-mentioned activities are monitored using an individual file (an excel) or database. This eventually became problematic as a great amount of data was spread over the domain of various departments, not centralized. To illustrate: the Internal non-conformances (2.) are managed by the sub-department of inspection, within the Quality Department; the damaged materials and rejects (3.) are overseen by the production sector, as well as the Inefficiencies (4.); Rework (5.) costs are monitored and automatically calculated (project developed in this study) in a database, supported by product quality inspection reports; and Guarantee claims (6.) costs are controlled and registered in an online platform with direct communication link with costumers. Summing up, Table 2 specifies the collected data for each activity, who's responsible for it and the software support used to manage this information.

Table 2 - Specific cost data \for each Costs of Quality/Poor-Quality generating activity.

CoQ/CoPQ - activity	Collected data	Who	Support
1. Quality Department costs (and Inspection)	Monthly costs report for activities regarding quality assurance; staff expenses, audits, calibrations, experimentation, jigs and production auxiliaries; Monthly costs from the inspection staff	Quality staff; Quality Inspection staff	ERP (SAP)
2. Internal Non-conformances	Daily costs from non-conformances detected in the productive process with internal responsibility (e.: faulty design, production)	Production detects; Quality staff registers	Excel; Quality Database
3. Material Damage and Rejects	Daily costs from damaged materials in the production process and concept rejects	Production registers	Excel; ERP (SAP)
4. Production Inefficiencies	Daily costs from delays and inefficiencies caused by missing parts/equipment and logistic faults	Production registers	Excel
5. Rework	Daily costs caused by product rework to meet product conformance and quality levels	Quality staff	Quality Database
6. Guarantee Claims	Monthly costs from the after-sales and zero-kilometre customer service and guarantee claims.	After-sales Customer Service	Excel; Extranet platform

To successfully accomplish this research's objectives, all the information cited on Table 2 was collected and transformed in the equivalent costs for the year of 2017. The (2.), (3.), (4.) and (6.) support documents, being based in excel, were simply changed to calculate the respective CoPQ, thus creating a very flexible data table. The costs were calculated based on the registed man-labor hours, parts costs, delay times, etc. The Prevention and Appraisal costs, represented in (1.), were already available, since it's part of the monthly financial control per department. Finally, the rework (5.) costing required the development of an upgrade of an existing database, allowing for an automatic costs calculation based on inspection reports.

4.2.1 Rework Costing - Do

The rework costing model was an extensive task mostly due to the large amounts of data required. Although, in the beginning, it was not possible to estimate these costs, there was a very large amount of data to work with. In this case, the rework activities are carried after an inspection report highlighting the detected non-conformances. From start to finish, the assembly line has 6 Quality Doors (QD), located on crucial points of the productive process as Fig. 2 illustrates. Since an inspection report is made for each QD, we are left with a total of six reports per unit. The sixth QD inspection (on QD5) is particularly thorough and extensive, taking into consideration the fact that it is the final inspection of the vehicle.

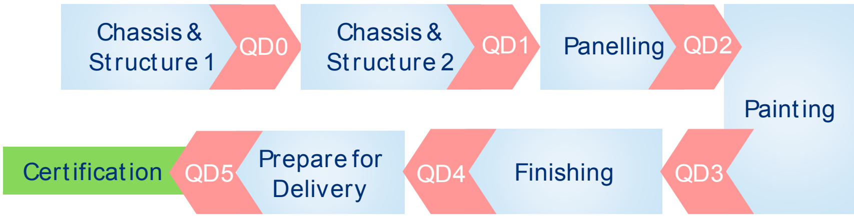
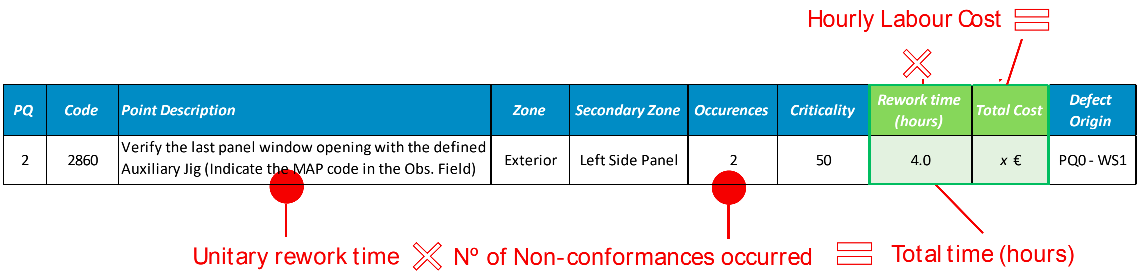


Fig. 2. Generic Production Process of a Bus.

As previously mentioned, the Rework costing model was developed in this project and supported by an existing database. The next figure, Fig. 3, shows a very simple example of how it works, based on the database's format.



PQ	Code	Point Description	Zone	Secondary Zone	Occurences	Criticality	Rework time (hours)	Total Cost	Defect Origin
2	2860	Verify the last panel window opening with the defined Auxiliary Jig (Indicate the MAP code in the Obs. Field)	Exterior	Left Side Panel	2	50	4.0	x €	PQ0 - WS1

Fig. 3. Inspection database and new changes.

Using the very large amount of information gathered on every vehicle's defects along the production line - reported in every QD ("PQ" in **Error! Reference source not found.**) -, we started by attributing a specific work time to every inspection point. In the example above, the inspection point "2860" had been linked to a 2,0 hour rework time, if faulty. Then, two columns were added to calculate the total rework time and consequent rework cost. This procedure was then extended to all the existing inspection points – nearly 6000. As a result, the organization now has an automatic and quick tool to measure rework costs based on the inspection process. It also allowed filtering this new information by vehicle model, Quality Door or a specific chronological interval as shown in Fig. 4.

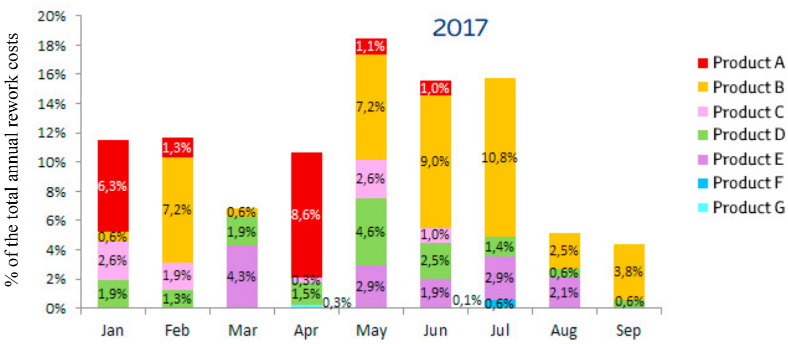


Fig. 4. Rework costs distribution, in 2017, by product model.

4.3 Costs of Quality impact on the product (KPI's) – Check

The "Check" PDCA phase started by gathering all the calculated CoPQ and analyzing them. At this point, plenty of different analyses and charts were plausible, but one started by elaborating a Pareto's Diagram to identify the most meaningful activities (see Fig. 5**Error! Reference source not found.**).

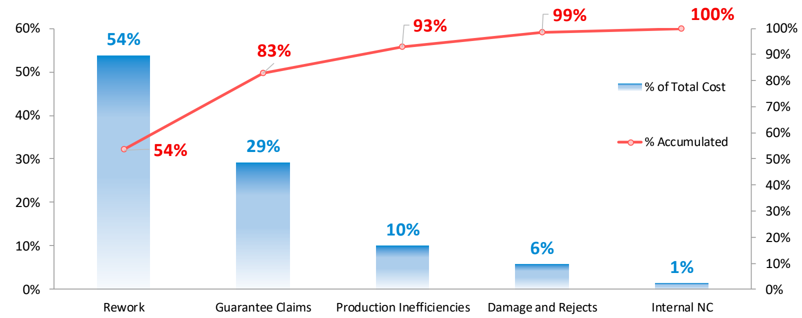


Fig. 5. Pareto Diagram of the CoPQ measured.

It was easy to understand that the rework tasks represent the main portion (54%) of the overall CoPQ, making it the main concern to take into consideration in the strategic overview. Another important factor is the overall balance between the efforts to prevent poor quality and the CoPQ themselves, as Fig. 6 shows.

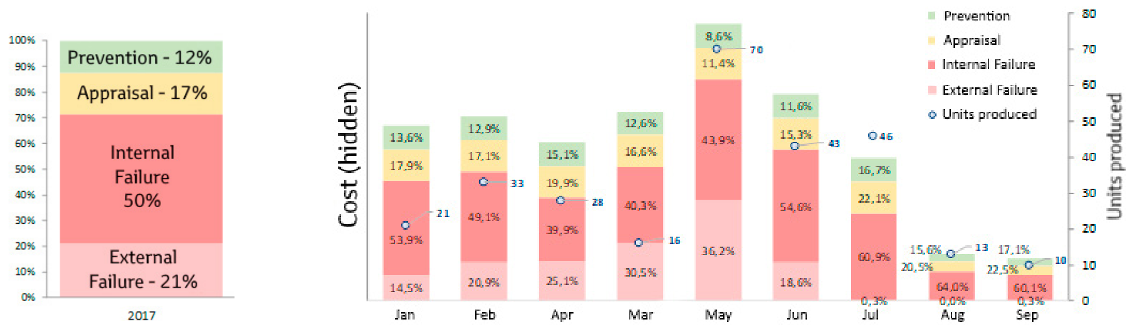


Fig. 6. Annual and Monthly balance between cost categories in 2017.

This graphic demonstrates the costs distribution for each month of 2017, with the respective number of units assembled. There is a noticeable similarity between each month's appraisal and prevention costs, as they represent the number of people and resources in the Quality Department (including Inspection). On the other hand, the number of produced units seems to have a strong correlation with failure costs. Another possible approach is dividing the CoPQ by product, which allows for a good comparison between total poor-quality costs. Fig. 7 shows a Pareto's Diagram representing the overall CoPQ distribution between all product models.

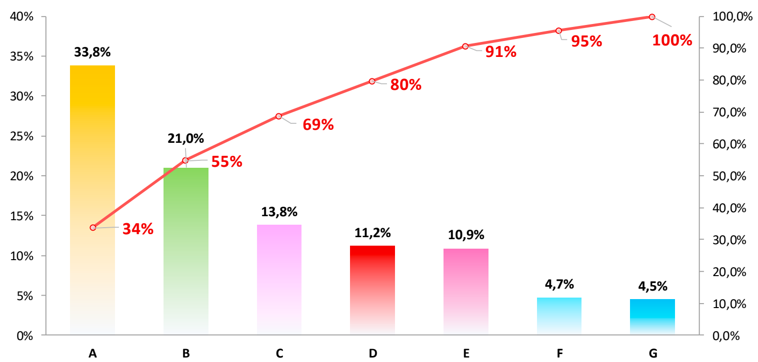


Fig. 7. Pareto Diagram with for the overall CoPQ distribution by product model (A, B, C, D, E, F, G).

This last analysis posed some limitations as one could not understand to what extent this "poor quality" was present in each model's selling price. Instead, another table was prepared to evaluate the impact of these CoPQ on the product value (Table 3 – Models F and G not included as their production in 2017 was very scarce).

Table 3. CoPQ influence on the selling value of each model by activity.
(%CoPQ – Costs of Poor Quality Proportion %Value – percentage over product's value
RW – Rework; GC – Guarantee Claims; D – Damage and Rejects; IN – Inefficiencies; NC – Internal Non-conformances)

Model	Indicator	RW	GC	D	IN	NC	Total
C	% CoPQ	40,62%	42,20%	11.13%	5.57%	0,48	100%
	% Value	2,22%	2,31%	0,42%	0,16%	0,02%	5,13%
E	% CoPQ	70,46%	-	-	26,25%	3,29%	100%
	% Value	1,62%	-	-	0,61%	0,08%	2,31%
A	% CoPQ	66,09%	26,96%	2,99%	3,15%	0,80%	100%
	% Value	2,13%	0,87%	0,10%	0,10%	0,03%	3,23%
D	% CoPQ	70,43%	11,54%	4,37%	11,65%	2,01%	100%
	% Value	2,35%	0,39%	0,15%	0,39%	0,07%	3,35%
B	% CoPQ	42,21%	35,62%	9,33%	10,75%	2,09%	100%
	% Value	0,87%	0,73%	0,19%	0,22%	0,04%	2,05%

With this new information, it was possible to analyze the poor-quality effects on each product, as well as to understand which activity contributes to it the most (see Table 4). The next table shows an example of a presentation for the overall and per unit costs of each measured activity, providing a notion of how much "poor quality" is generated per product.

Table 4. Controlling report - mean and total values of CoPQ for each model and activity (not real values).
(QD – Quality Door; RW – Rework; GC – Guarantee Claims; D – Damage and Rejects; IN – Inefficiencies; NC – Internal Non-conformances)

Model		GC	NC	D	RW						IN	Total
					QD0	QD1	QD2	QD3	QD4	QD5		
C	Total	12413 €	142 €	3274 €	879 €	5 €	1007 €	1072 €	-	8985 €	1639 €	29415 €
	Per/unit	477 €	5 €	126 €	34 €	0 €	39 €	41 €	-	346 €	63 €	1131 €
E	Total	-	931 €	-	1674 €	20 €	1756 €	2064 €	-	14405 €	7419 €	28269 €
	Per/unit	-	23 €	-	41 €	0 €	43 €	50 €	-	351 €	181 €	689 €
A	Total	23928 €	714 €	2657 €	796 €	16 €	1962 €	5720 €	28219 €	21947 €	2800 €	88760 €
	Per/unit	352 €	11 €	39 €	12 €	0 €	29 €	84 €	415 €	323 €	41 €	1305 €
D	Total	4215 €	734 €	1597 €	27 €	7 €	948 €	245 €	11878 €	10389 €	4255 €	36524 €
	Per/unit	141 €	24 €	53 €	11 €	0 €	32 €	83 €	396 €	346 €	142 €	1217 €
B	Total	19338 €	1137 €	5064 €	22 €	115 €	310 €	3989 €	15 €	18469 €	5938 €	54296 €
	Per/unit	191 €	11 €	50 €	0 €	1 €	3 €	39 €	0 €	183 €	58 €	538 €
F/G	Total	16438 €	33 €	2453 €	36 €	67 €	757 €	3361 €	-	-	4198 €	27342 €
	Per/unit	1174 €	2 €	175 €	3 €	5 €	54 €	240 €	-	-	300 €	1953 €
	Total	78688 €	3767 €	15488 €	3524 €	237 €	6939 €	19217 €	40923 €	75744 €	29932 €	264607 €

4.4 Costs of Quality review and improvement – Act

Finally, the Act phase consisted of a review of the results obtained for the company's performance on CoPQ, which were then disclosed to the company's management and administration. This review should work as a mechanism to identify critical points in the company's processes, setting new goals or update current ones and help to focus on cost reduction actions.

As regards to some of the results we obtained, from a global CoPQ point of view, it was possible to clearly identify the rework activity as the most significant. For that reason, it should become a focal point for the organization's efforts to reduce CoPQ and consequently increase profit margins. After-sales claims, being directly associated with product quality issues, also represented a significant portion of CoPQ. Regarding the model comparison study, it became possible to pinpoint which products were most affected by poor quality issues. Seeing as this directly affects the company's profits on these models (with one model having CoPQ equivalent to up to 5% of its value), the organization should consider this information when planning strategically. On the other hand, it is also noticeable how much influence each activity has on each model, making a good tool for assisting decision-making processes. There was also an improvement when it comes to the balance of the overall costs of failure (internal or external) and quality efforts (prevention and inspection). This became one of the main goals of this study, providing an easier and a visually comprehensive way to understand the overall balance. It became particularly useful in terms of measuring each cost category and monitoring the quality efforts as well as whether they sufficed.

5. Discussion and Conclusions

In conclusion, as various authors have stated [9, 17, 22-25], quality cost studies represent an effective management tool, as they constitute a performance indicator for quality management systems. It is also easily associated with the TPS, Lean Production and continuous improvement cultures as they work as a tool to measure waste costs. ISO 9001 standard based quality systems also benefit from this tool, since process monitorization is a recommended activity. A study on Quality Costs proved itself to be very beneficial for an organization but it also requires some investment efforts. Most companies do not invest on this, since they do not immediately take advantage of it from a financial point of view. Although this may be true in an initial CoQ study, if the company manages to develop a simpler and automatic – hence more effective - way of calculating this data, they can benefit from having a cycle of constant performance monitorization. It should be a powerful tool for supporting decision-making and, at the same time, very flexible: by analyzing the overall balance between cost categories; by defining specific time intervals; by analyzing a specific product; or by identifying each activity's cost. A good future prospect for an increased use of this tool, is the Industry 4.0's concept of "Big Data" and autonomous systems. As it is, one of the main disadvantages of CoQ monitorization is the effort that is required to implement it. However, if these calculations and monitorization were to become autonomous and computerized, this hindrance would disappear.

Finally, it is important to emphasize that this work represents a generic procedure for an initial CoQ study, based on a real and much more complex work. Despite already taking into consideration the ISO 9001's recommendations and the Portuguese Standard (NP4239: 1994) on how to quantify quality costs as a guideline, it is essential to take into account the distinct activities of each company and industry. In this particular case – a bus manufacturing facility –, rework costs proved to be the main source of poor quality costs, but that certainly is not the case in other industries. The CoQ monitoring, as any competitive company, should be dynamic and (must be) focused on the objectives of continuous improvement.

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