Qualifound – a modular tool developed for quality improvement in foundries

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Abstract

Purpose – Castings defects are usually easy to characterize, but to eradicate them can be a difficult task. In many cases, defects are caused by the combined effect of different factors, whose identification is often difficult. Besides, the real non-quality costs are usually unknown, and even neglected. This paper aims to describe the development of a modular tool for quality improvement in foundries, and its main objective is to present the application potential and the foundry process areas that are covered and taken into account.

Design/methodology/approach – The integrated model was conceived as an expert system, designated Qualifound, which performs both qualitative and quantitative analyses. For the qualitative analyses mode, the nomenclature and the description of defects are based on the classification suggested by the International Committee of the Foundry Technical Association. Thus, a database of defects was established, enabling one to associate the defects with the relevant process operations and the identification of their possible causes. The quantitative analysis mode deals with the number of produced and rejected castings and includes the calculation of the non-quality costs.

Findings – The validation of Qualifound was carried out in a Portuguese foundry, whose quality system had been certified according to the ISO 9000 standards. Qualifound was used in every management area and it was concluded that the application had the required technological requisites to provide the necessary information for the foundry management to improve process quality.

Originality/value – The paper presents a successful application of an informatics tool on quality improvement in foundries.

Keywords Quality, Integrated manufacturing systems, Foundry engineering

Paper type Research paper

Introduction

In some foundries a large number of rejections and/or large variations in defective products often occur. Even when confronted with this situation, the person responsible for the production quite often does not know the causes and the solutions for quality improvement. In addition, in many cases there is also no accurate knowledge about rejection costs. Furthermore, the defective castings are sent back to the furnace for remelting, without proper information selection and analysis that could help to improve the manufacturing performance. The main reason for this situation is the lack of a data collection system and information that can help to trace castings' defects back to the processes, operations and the factors accountable for them.

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The main purpose of this paper is to describe a tool that was developed to improve quality in foundries, helping to identify, understand and control defective castings. At first it was conceived as an Integrated Model for Quality Improvement in Foundries (IMQIF), based on the ISO 9000 and ISO-10005 standards. The integrated model then gave birth to a self-designed computer program (Qualifound), which includes data on known defects available on the ICFTA (1974) (*I*nternational *C*ommittee of the *F*oundry *T*echnical *A*ssociation) report. Qualifound integrates various quality tools and can operate in two modes, qualitative and quantitative. In the qualitative mode, cause-effect diagnostics can be made, relating the defects to the processing factor accountable for them. The quantitative analysis mode allows the evaluation of the process' performance, determining the frequency of the rejected castings, the corresponding non-quality costs, and the distribution of the defects that contributed to the rejection.

An integrated model (with five modules) for quality improvement in foundries

A casting is said to be of "good quality" whenever its relevant properties allow the fulfilment of the requirements it had been designed for. According to this definition, quality assurance in foundries can be described as a complex system of steps and rules. Those who produce castings must adhere strictly to these rules, if those requirements are to be achieved (BCIRA, 1991). In a foundry, moulds and cores production, the liquid metal preparation, the pouring and the finishing operations are the most relevant activities, which need to be properly monitored if good quality is to be guaranteed (Greenhill and Palmer, 1973). For that, it is necessary to know the causes and factors that contribute to the defects, as well as those that occur frequently, to define correction priorities. Quality has its roots in quality improvement; it is the result of efficient quality planning, taking into account both the manufacturer's and user's interests and specifications.

The IMQIF developed in the present work is shown in a simplified form in Figure 1 (the five modules are shown too) (Santos, 1999).

The model has three sub-systems containing five modules:

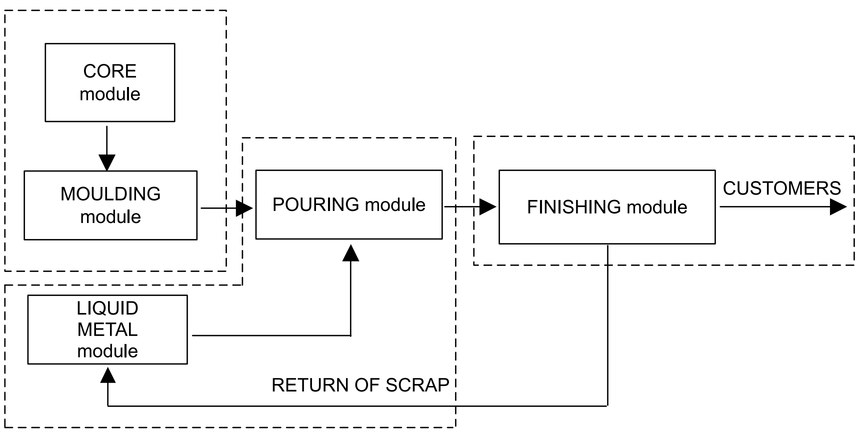

Figure 1.
An integrated model (with five modules) for quality improvement in foundries, on a simplified form

(1) The *core and moulding quality* sub-system, including the quality modules “core preparation” and “moulding preparation”. As an example, the latter is shown in Figure 2 in a developed form.
(2) The *liquid metal preparation* a sub-system that contains two quality modules: “liquid metal preparation” and “metal pouring”.
(3) The *finishing quality* sub-system, including the module “castings’ finishing”, and the process operations “packing and expedition” and “customer complaints”.

In each of the five modules a thorough analysis of the relevant quality controls, as well as the non-functional effects resulting from the failure of these controls are made. The IMQIF is the result of the integration of these modules. All five modules were developed according to the involved operations, as the “moulding preparation module” shown in Figure 2. This module includes six process operations represented in Figure 2, as “circles”. In the same figure, the “rectangular” items mean quality control operations for each process operation. For the other four modules, the procedures are similar.

Classification of defects in foundries

The ICFTA (1974) (International Committee of the Foundry Technical Association) establishes the nomenclature and graphical description of 110 types of defects, classified in 24 groups, and divided in 7 classes – metallic projections, cavities, discontinuities, surface defects, incomplete castings, incorrect dimensions/shape, inclusions and structural anomalies. In our case, we codified all defects with a four-digit code, where the first represents the defect class, the second one refers to the

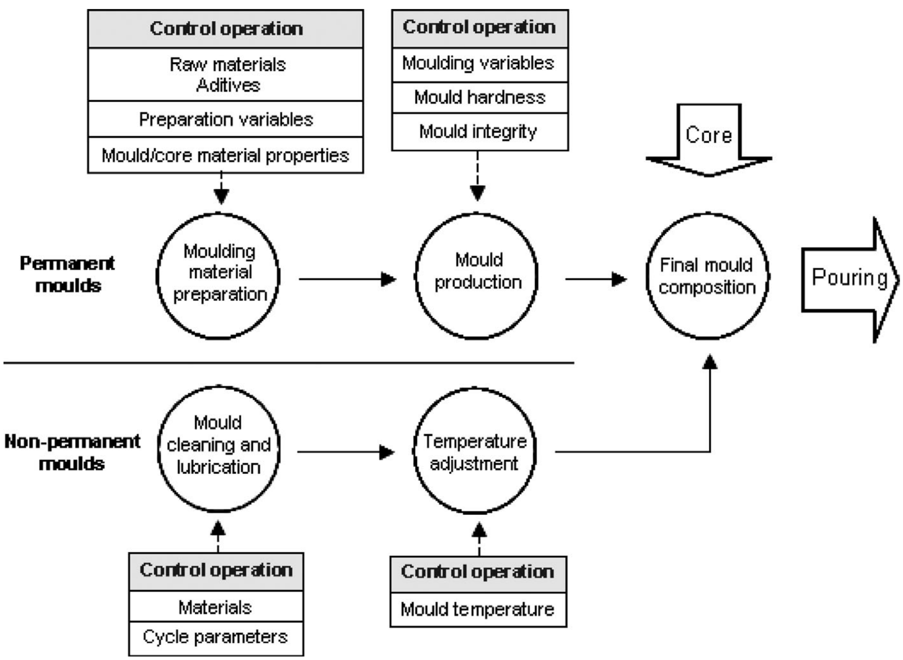

Figure 2.
Schematic representation of the “moulding preparation” module

defect group, and the last two digits refer to the type of defect. Each defect can have its origin in a single cause, or be a combination of several causes, that may reach 50 or 60 different ones (Cech, 1990). If all types of defects were considered, the total number of causes could reach 1,000-2,000 (Ransing *et al.*, 1995), and its handling and analysis should be almost impossible without some sort of numerical/informatics aid.

Most of the casting defects have their origin in the moulding process and in the metal preparation and handling, where dozens of different parameters play a significant role. In what concerns the mould and core operations, the characteristics of the base sand and additives, the sand preparation variables, the moulding sand mechanical properties, the moulding parameters like temperature and pressure, the patterns characteristics (pattern material and surface finishing, its geometrical and dimensional accuracy, adequate pattern plate design, accurate pouring and feeding systems calculation) and the quality of the moulding boxes are the most relevant factors affecting the casting quality. The quality factors involved in mould production can still be increased if sand recycling is performed, for instance, or if the foundry production cycle differs from day to day, by using different time gaps between moulding and pouring.

Metal melting and handling can also contribute with many different non-conformity factors, where the heterogeneity of the melting stocks and additives, the deoxidising, degassing and overall melting and refining procedure, overheating parameters, pouring ladle characteristics (geometry, size, insulating material and temperature), pouring temperature and accuracy are the most relevant ones.

Additionally, it should be noticed that the inspection procedure is the result of many individual factors, which also demand a strict quality control. The IMQIF model takes this into consideration. The model is also useful in the finishing and final production phases. It includes procedures and controls that take into account heating treatments, destructive and non-destructive tests, as well as packing, expedition and customer complaints. The integration of all these sub-systems in a single model guarantees that all aspects are important and taken into consideration in the aim of the quality control in a foundry.

Characteristics of the developed modular tool – "Qualifound"

The casting process, rich in experience and accumulated knowledge, is a good vehicle for the application of expert systems. Several authors (Creese, 1998; Roshen, 1989; Ransing *et al.*, 1995) developed such systems for the analysis of castings' defects. In these systems, uncertainty can be successfully handled through "certainty factors" (Phelps, 1989) as those employed in MYCIN, one of the older and more commercially successful expert systems (Sortcliff, 1976). The expert systems currently in use, identify a single defect in the castings and diagnose the cause(s) of that single defect. However, in foundries' practise, more than one defect per casting often occur, and, typically, in the casting process, the number of convergent defects can be very high (Cech, 1990).

For quality control, it is essential to use a uniform nomenclature to identify and describe defects in foundries. Hence, the nomenclature and graphical description provided by the ICFTA was used to establish a database of defects, as mentioned above. In this database, each defect is individually described and illustrated with drawings. The integrated model with five modules, shown in Figure 1, was then conceived as an expert system, called Qualifound, which can interact with the database. Qualifound enables the association of the defects with the relevant process operations and identifies their possible causes. It also suggests the implementation of actions to eliminate or reduce their occurrence. This is the qualitative analysis mode of the system. The quantitative analysis mode deals with the number of castings produced and rejected and the calculation of the non-quality costs. Figure 3 shows a simplified structure of the Qualifound, where the integrated model with their five modules is included (Santos, 1999).

Other configurations and filtration functionalities were added in the above structure, such as, the "customers' selection" (for the analysis of chronological or temporary reports), or the "start and end" function (for the period to be analysed). The model is versatile, as it allows either the introduction of new necessary data or the deletion of unnecessary one.

Structure and analysis of requisites

The graphical interface of the qualitative analysis mode of Qualifound is composed of 12 protocols that make the correspondence between processes and defects, as well as between defects and processes. The graphical interface of the quantitative analysis mode is composed of 13 protocols, namely "the parts' report", "the parts' defect report", the "where and how report", the "defects for casting report" and the "correspondence of defects to orders". These protocols and reports allow the analysis of the production per casting or selection of castings, or per order(s), month(s) or year(s). They provide data on the number of castings produced or rejected, rejection ratios and non-quality costs. It is also possible to perform a Pareto analysis, showing the percentages of the most frequent production defects per (or selected) casting, or per order(s) day, month(s) or year(s).

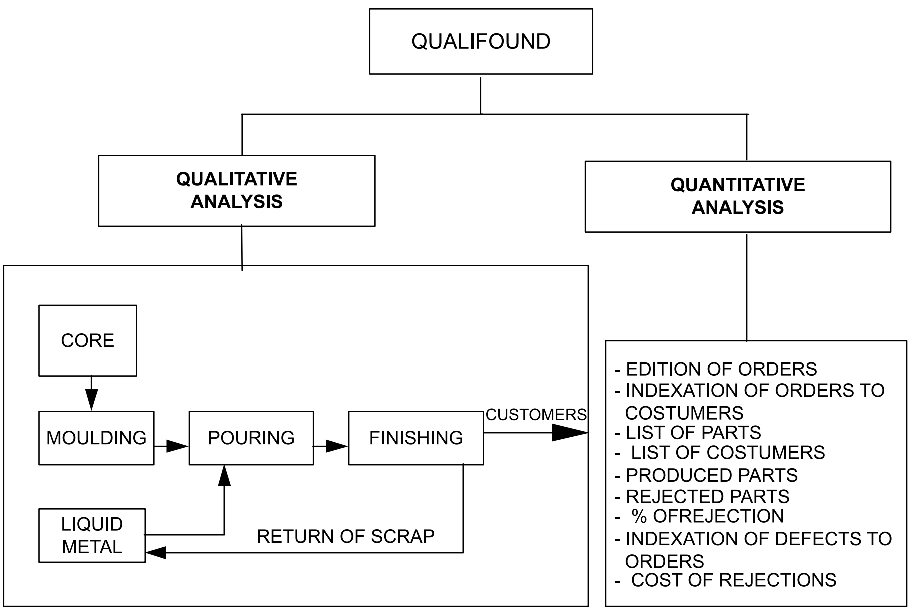

Figure 3. Simplified structure of the Qualifound including the integrated model

The defects were codified to make the qualitative analysis easier. As the codes shown in the quantitative (Pareto) analysis are the same, they can be identified either in the qualitative or in the quantitative analysis modes. The code of the models and protocols was developed in C++, for MS Windows 32 bits platforms. The final result is an executable file that can be configured automatically by an installation program. The "Paradox" mechanism was chosen for the database. The data model is completely dynamic. For each sub-system of the qualitative analysis, and for each protocol of the quantitative analysis, numerical data, graphics or figures can be visualised, edited, erased or added. The Qualifound program also contains a help file, where the main helping steps for users are described.

Data model

To be able to single out and analyse the structure and data relations of a very complex system, independently from the process that is carried out, it is often necessary to use a model for the data. In fact, this is particularly relevant when the system's model is to be used by the technical staff in foundries. They are interested in obtaining data that may help, not only to identify the different types of defects and the connections between them, but also the way they affect the customers orders.

The entity-relations (E-R) diagram shown in Figure 4, is a model that describes the data storage chart of a system at a high abstraction level (Yourdon, 1989). It differs from a flux gram, which simply formulates the functions that the system can carry out. In an E-R diagram, such as the one shown in Figure 5, the association, for example, between defects and processes, or between orders and defects, must be done with

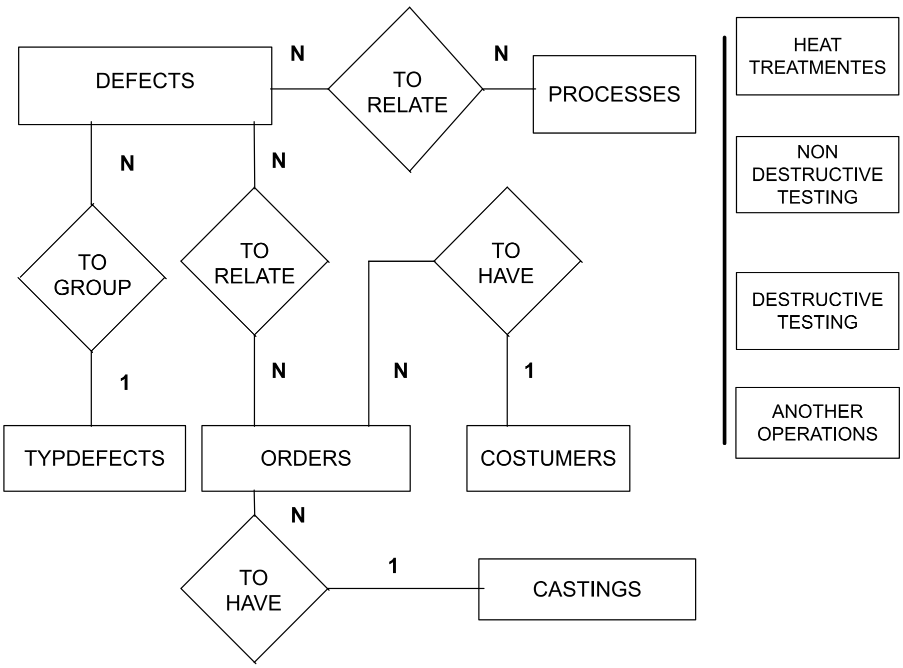

Figure 4.
E-R diagram

strong verbs in the infinitive form (Yourdon, 1989), such as, in the present case, to have, to group or to relate. In the diagram, processes such as heat treatments, non destructive and destructive testing, are also represented. In the qualitative analysis mode of Qualifound, the following relations are established between "processes/operations" and defects (Figure 4):

- one process/operation can cause more than one defect (N);
- one defect can have its origin in various processes/operations (N);
- (N) defects can be related with (N) processes; and
- one type of defects can be grouped with another (N) defects.

In the same way, in the quantitative analysis mode of the Qualifound, the following relation is established between the "customers and orders" or between "orders and defects" (Figure 5):

- one customer can have (N) orders; and
- (N) orders can have (N) defects.

Hence, the basic functionality of these modes can be summarised in the following way:

- it enables the foundry workers to identify which defects are associated with each process/operation in IMQIF; and
- if a defect is selected, it enables the identification of all processes/operations where it may have originated.

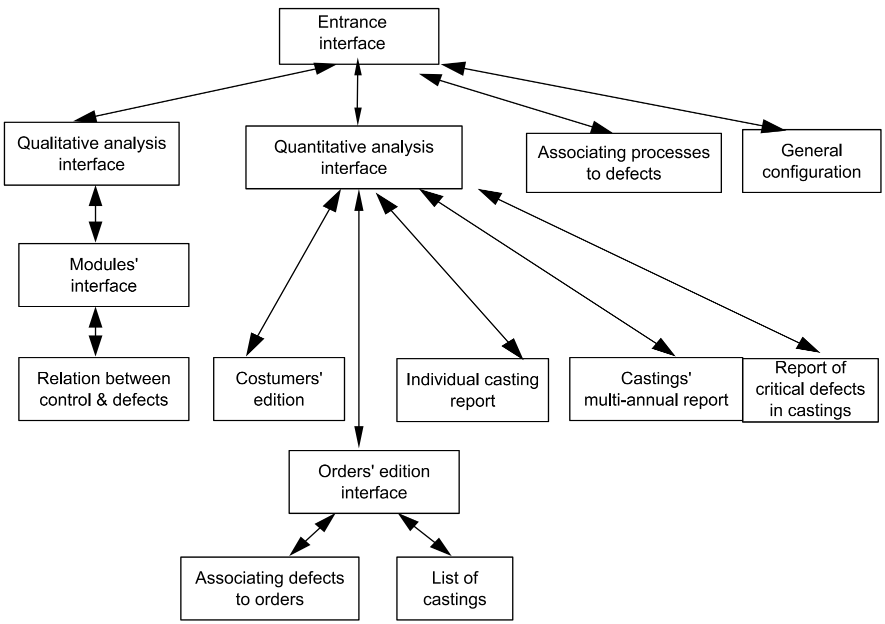

Figure 5.
Structure of the interface of Qualifound

Structure of the Qualifound interface

The basic structure of the interface of the Qualifound is composed by 14 protocols. The most relevant of which are the interfaces for the entrance, and for the qualitative and quantitative analysis (Figure 5). The qualitative analysis interface includes seven protocols, five of which identify the five modules that make up the integrated model (IMQIF) that was shown in Figure 1.

The main interface of the qualitative analysis mode is shown in Figure 6. Each of the five modules contains another interface that relates control and defects, totalling 21 protocols. Besides these, there are two more protocols, one linking defects and operations and the other aimed to the general configuration. All the new data corresponding to defects not considered in the ICFTA classification (see section "Data model") can be introduced in the latter.

The basic interface for quantitative analysis has another four protocols, the most relevant of which are "customers' edition" and "orders' edition". The "orders' edition" protocol is associated to two others, "associating defects to orders" and "list of castings". Finally, other protocols are used to produce reports corresponding to "individual castings", "multi-annual" (up to five years), and "critical defects" (maximum of six defects). The Qualifound considers as critical defects, those that are most common in the orders and, consequently, that contribute more to the rejection index.

Analysis of defects in foundries with Qualifound

In a foundry, the technical staffs usually classifies the defective parts in 10 or 12 defect types, and considers the others as a single residual class ("others"). The number of types of defects chosen depends on the conditions prevailing locally. Hence, in the present work, the correspondence between the 24 groups of defects in the ICFTA classification and the types of defects used in the industry had to be established after careful examination. On the other hand, the classification system used in some

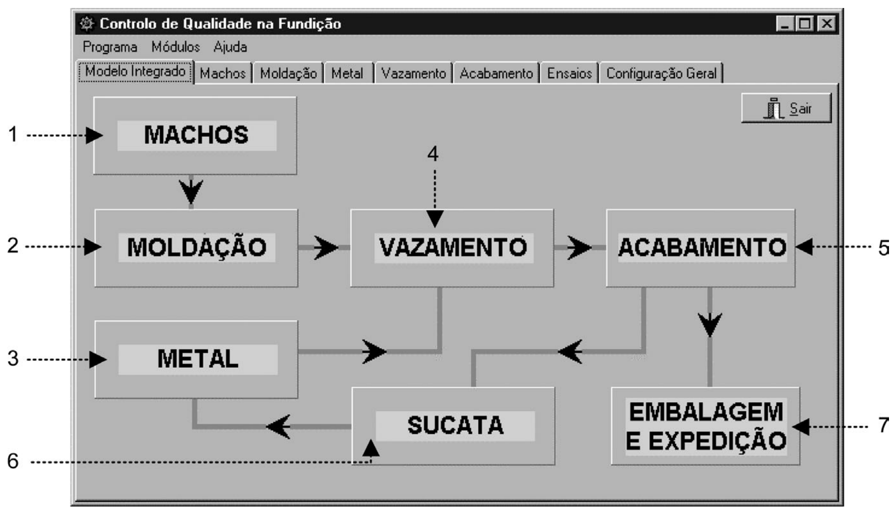

Figure 6.
Main interface of the qualitative analysis mode (key: 1 – core; 2 – moulding; 3 – liquid metal; 4 – pouring; 5 – finishing; 6 – scrap; 7 – packing and expedition)

foundries may contain certain types of defects not described in the IC-FTA classification. Those will be called "defects defined by the system", and are included by Qualifound in an eighth class, named "defects defined by the system". Most of the foundries visited do not collect data about the quantity of castings both rejected or accepted, before or after machining. The use of Qualifound allows that data to be routinely collected and treated statistically. This is a clear added value for quality control.

The studies of several authors (BCIRA, 1991; Wootton and Knight, 1989; Comins, 1987) involving a large quantity of data collected from the analysis of defective castings, showed that a great proportion (50-80 per cent) of them always had the same two or three types of defects. On the other hand, other types of defects were rarely or almost never found in those castings. In other words, some defects are responsible for only a small fraction of defective parts in a given order. This information is important to establish the relation between defects and the factors that cause them. For instance, they allow these factors to be disregarded when they also intervene in the causal chain leading to the types of defect that occur more frequently.

One important feature of the Qualifound programme is the capacity to recognize the defects that are more common and those that rarely occur. The software offers the possibility of representing in a Pareto diagram (Figure 7) the proportion of defective parts, showing the code of the pertinent defect in the same image.

Qualifound was installed and tested in 1998 on Portuguese medium sized aluminium foundry. In the following example, 10528 selected castings/products were analysed. The percentages correspond to rejected castings and the numbers to the codes of the main types of defects that caused the rejections. Figure 8 shows the cost of non-conformities, for the same batch of castings.

By using Qualifound, among many other functions, it is possible to know, at any moment, which are the most relevant defects in total scrapped parts, in which operation, procedure or parameter is their origin, which is its cost during a certain period of time or for a specific order or customer, which is the most relevant operation/parameter responsible for a given non-conformity or even to characterize the

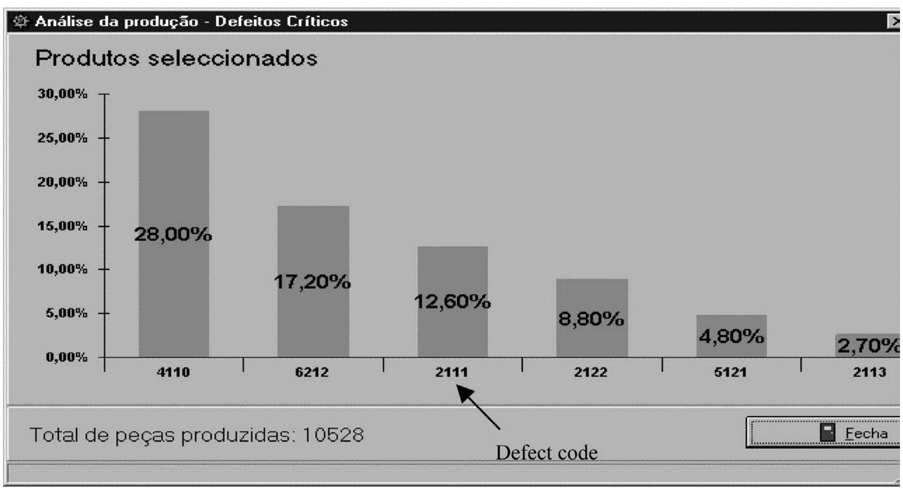

Figure 7.
Pareto diagram of the main defects detected in the analysis of 10528 castings

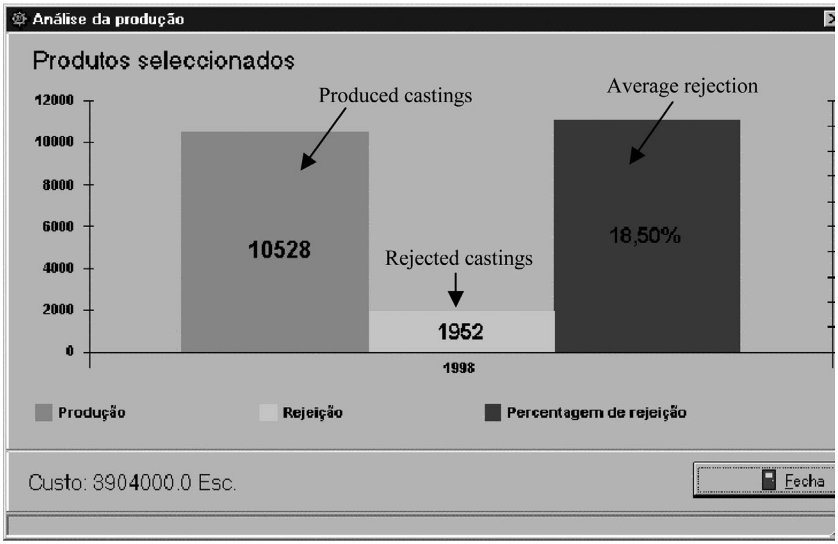

Figure 8.
Total cost of non-conformities for the same 10528 castings

contribution of a certain factor (operation, parameter, . . .) for the total rejected castings produced by the foundry (Figure 9).

Five years after Qualifound was installed in the so referred company, an analysis was made concerning the sales and non-conformities cost evolution during the last five years. Results are shown graphically on Figure 10. Available data indicates that the cost related with non-conformities increased in the year corresponding to the software installation (1998), which was due to a more precise and accurate identification and characterization of real rejection costs. After 1998, measures were taken to decrease

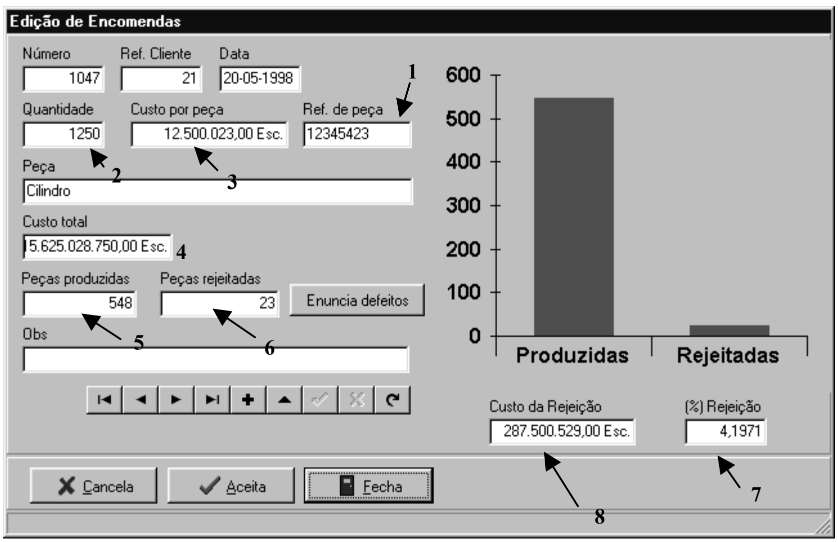

Figure 9.
Analysis of a batch of castings – key: 1 – part reference; 2 – coast/part; 3 – order quantity; 4 – order total cost; 5 – produced parts; 6 – reject parts; 7 – rejction (per cent); 8 – rejection cost; 9 – defects menu (link)

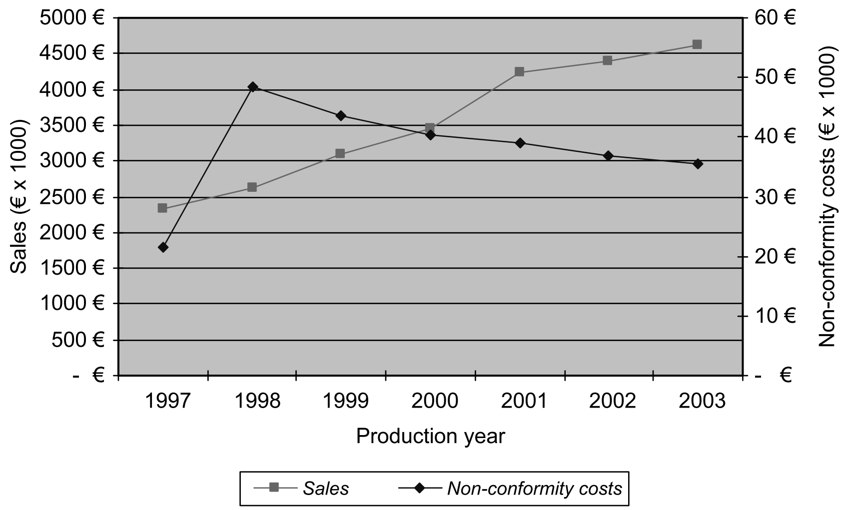

Figure 10.
Evolution of sales and non-conformity costs on the period 1997-2003

non-conformities, and as a consequence of that, the rejections cost has been decreasing every year, followed by a significant increase in the castings sales. This behaviour suggests an important contribute of Qualifound in the analysis and decisions that were taken, and that are in the base of the significant increase on the company's competitiveness.

Expansion and validation of the modular tool "Qualifound"

In the Qualifound new entries can be added to the global list of defects through the interface "management protocol of defects as a function of process". Whenever a new defect is filed, a text of comments, or even an image, can be added to that file. The image transfer can be done from any image editor, always using a transfer area. The images should have 190 × 150 (points). The defects codified in Qualifound are protected and should not be altered. New defects can only be added in the already mentioned eighth class ("defects defined by the system"). Whenever new defects are added, the software automatically gives them a new code.

The validation of Qualifound was carried out in a Portuguese foundry, whose quality system had been certified according to the ISO 9000 standards. The Qualifound was used in all areas involved in the management of that foundry. It was concluded that the programme had the required technological requisites to provide the necessary information for the foundry management to improve process quality. The results of this exercise, to be published later, constitute an interesting case study on how to promote quality in foundries.

Conclusions

The system developed in the present work has various important aspects. First, it is a very useful support of knowledge for the existing know-how in castings' production. Second, the value of the rejected castings can be quantified in economical terms, in an integrated way. Third, the causes of the rejections, as well as their consequences, can be analysed with the help of the Qualifound. Fourth, the tool can be applied successfully to the management and processing of technical and production data. Finally, the Qualifound allows the integration of some quality analysis that normally are used separately in foundries and thus, to improve production, especially in what quality is concerned.

This tool can be developed, upgraded or adapted according to the characteristics, needs and objectives of a specific foundry. That representation is general, and, hence, can be applied with the necessary adaptation to other production processes.

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