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Production quality control through a user-oriented and characteristic-based quality visualization model

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Abstract

This paper presents a quality visualization model as a method for user-oriented quality visualization. Existing models show the lack of sufficient visualization, monitoring and evaluation of the quality situation regarding different requirements of manufacturers for quality control. In this model, the quality of an object is represented through a layer via the object-specific quality characteristics. Enriched through tolerance limits, this method leads to a simple visualization of quality as well as enables cluster analysis and benchmark analysis. Moreover, the application opportunities in vehicle assembly are shown. The main benefit of this method is to increase the level of production efficiency.

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Keywords: Quality Model; Quality Assurance; Optimization; Assembly; Quality Control

1. Introduction

1.1. Demand for quality visualization in vehicle assembly

The visualization of quality is indispensable for monitoring, evaluating and controlling the quality situation [1-3]. Especially the automotive industry, whose production quality and product quality embody elementary competitive factors [4, 5], has both a strong interest and a necessary need for adequate quality visualization based on characteristics [6]. Industrial observations in the automotive industry show that despite all common quality tools and visualization methods for quality control, the proportion of defects and rework as well as the resulting rework costs remain constant and in some cases disproportionately high [7-9]. Although there are already various methods, diagrams and models for the visualization of quality, which only create qualitative added value through intensive analyses by quality engineers. An immediate influence on the production process is not possible in this way. Therefore, a method is required which not only provides a relevant added value for quality engineers, but also for workers, supporters, reworkers and quality inspectors in the cycle-bound process.

1.2. Contribution of this method

The method in this paper fills the gap of the missing adequate quality visualization through a generic model. It enables (1) visualization and quality monitoring of an object on the basis of its quality characteristics and inspection characteristics, (2) its quantification and evaluation, (3) quality control of the object, to avoid defects in the long term, and (4) reduction of quality costs with increased production efficiency. Thus, this model can be categorized as a new quality tool.

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Table 1. Approaches for quality monitoring.

Legend	Requirements											
u focus k ability but inept a no ability	generic	homomorphous	object-independent	multi-objective	hierarchical	analytical	graphical	tolerance-based	quantifiable	characteristic-based	asymmetrical	user-independent
Fundamental quality tools												
Check sheet	u	k	u	u	u	u	a	u	u	u	u	u
Histogram	u	u	u	u	u	u	u	k	u	u	u	u
Pareto chart	u	u	u	u	k	u	u	k	u	u	u	a
Ishikawa diagram	u	a	u	u	u	u	u	a	a	k	a	u
Correlation analysis	u	k	u	u	k	u	u	a	u	k	k	a
Control chart	k	k	u	u	a	u	u	u	u	k	u	u
Radar chart	u	u	u	u	u	u	u	k	u	u	u	u
Boxplot chart	a	a	u	u	a	u	u	u	u	a	u	a

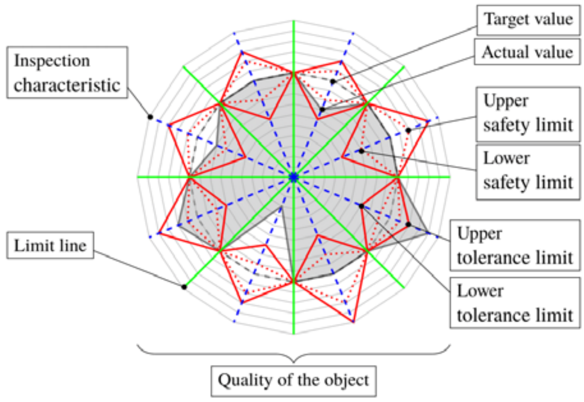

Fig. 1. Quality Visualization Model.

2. State of the art

2.1. Basic methods for quality visualization

In order for quality-related activities to be carried out efficiently and to contribute to the quality objectives, quality management must use various methods of cause analysis, data compression and visualization [10]. Quality visualization tools established in science and industry are easy to use [11] and mainly work with numbers [12], but less with graphical representation elements. Table 1 gives an overview of the best-known quality tools [13] and a subjective evaluation based on various criteria given from industrial manufacturers.

The evaluation points out that the histogram, the control chart and the radar chart are close to fulfill all requirements. However, both industrial opinions and the evaluation of the existing quality tools show a necessary need for an appropriate method, which holistically fulfills the above-mentioned criteria in a user-oriented manner.

2.2. Method of the QVM

An adequate method for vehicle assembly is the *Quality Visualization Model* (QVM) by Gewohn et al. [1]. The quality of an object or a combination of several objects is described here by quality characteristics and quality characteristics in turn are quantified by inspection characteristics. They show a graphical model based on the radar chart and the control chart. The relative actual values of the inspection characteristics of an object are displayed in a coordinate system via graphical vectors. To avoid mutual influence of the inspection characteristics, additional limit vectors with the length 1 are added after each inspection characteristic vector – every second line thus represents a quality-relevant characteristic. The line ends span a common layer and a polygon is created depending on the actual values of the inspection characteristics. The shape of the polygon represents both graphically and quantitatively the quality of the object.

To homogenize the different inspection characteristics with their different sizes, dimensions and units, the QVM considers the target achievement rates and normalizes the target values of inspection characteristics to the unit vector (value 1). This ensures homomorphism, creates comparability of all inspection characteristics and enables a common adequate visualization via one model [14]. Fig. 1 shows the structure of the QVM.

2.3. Open issues for research

The QVM gives a statement about quality for any object at a point in time by specifying a quality value. A quality statement over a period of time with several quality values within various clusters is still unsolved on a graphical basis. Furthermore, it is not possible to directly compare the quality situation of several objects within a model using a benchmark. In addition, the users of the model must be clarified for an industrial application. It also remains open how information must be fed back into production for quality control and what an application in automotive production might look like.

3. Extension of the method

3.1. Clustering of instance values

The QVM enables to classify characteristic values into defined quality groups using the safety limits (SL) and tolerance limits (TL). Following clusters exist in this model:

- **Cluster C+:** Actual value > Upper TL
- **Cluster B+:** Upper SL ≤ Actual value ≤ Upper TL
- **Cluster A:** Lower SL < Actual value < Upper SL
- **Cluster B-:** Lower TL ≤ Actual value ≤ Upper SL
- **Cluster C-:** Actual value < Lower TL

The aim is to position the actual value within cluster A, but at least within clusters B±. Fig. 2 shows an inspection characteristic within a layer with the five colored clusters.

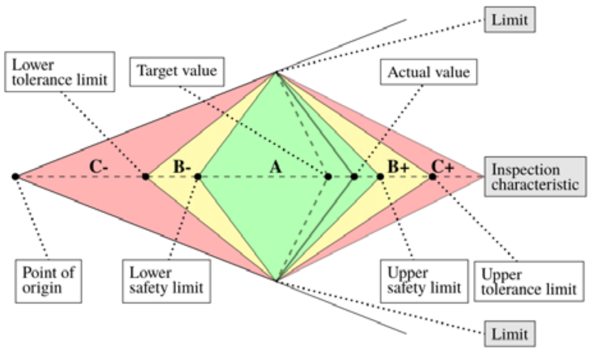

Fig. 2. Cluster analysis of characteristic values.

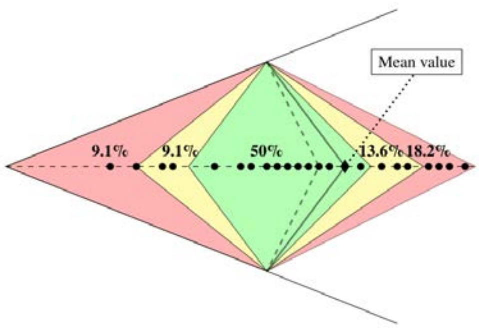

Fig. 3. Visualization as single values, cluster values and mean value.

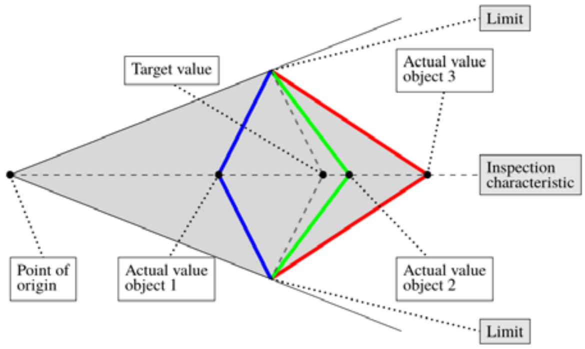

Fig. 4. Benchmark with equal objects.

The QVM makes it possible to consider both a point in time and a period of time. By *consideration a point in time*, it is assumed that there is only one value for each characteristic at one point in time. A special situation, however, is the *consideration of a period of time*. There are three ways of visualizing the characteristic values in the QVM:

- Visualization as mean value
- Visualization as single value
- Visualization as cluster value

The *visualization as mean value* is carried out via the arithmetic mean. There is only one value for all values for the characteristic in question within the period.

A *visualization as single values* displays the single values of the characteristic within a layer in the QVM. However, a layer with a large number of characteristic values carries a high risk of non-transparency and poor representability [1]. The visualization e.g. of the quality rate per day of a large series model production would comprise several hundred characteristics. Here, the representability suffers accordingly.

Due to the lack of detail by reason of the mean value and the risk of the lacking representability of all individual values, the *visualization as cluster values* offers a compromise. The five clusters will be enriched with relative share values. In this way, the user can determine directly which portion of the objects is within the respective cluster with regard to the inspection characteristic within the period of time.

A combination consisting of the visualization of the single values or cluster values and the visualization of the mean value can also take place in order to provide the user with more information. Here, the application can be selected arbitrarily as required due to the generic property of the QVM. Fig. 3 shows a visualization as single values, cluster values and mean value.

3.2. Benchmarking of objects

A special feature is the application of the QVM for an object-related comparative analysis of several objects based on the same criteria. This is done by overlapping several layers with their corresponding characteristic values and creates the basis for a comparative analysis. Fig. 4 shows an area of an inspection characteristic of a layer with three comparable actual values in blue, green and red.

One concrete application is the comparability of the production of a certain vehicle model at different production plants of an automobile manufacturer. A layer represents a combination of two objects consisting of the selected model (e.g. model 123) and production plants (e.g. Germany, China and USA). This creates an internal comparison of production plants regarding the quality of this specific vehicle model. Fig. 5 shows an application example of a benchmark. A layer represents a vehicle model, the vectors correspondingly the subordinate assembly groups. The actual value represents the quality rate. The quality rates of three production plants are displayed (blue, green and red). By determining the quantitative quality value, a statement can therefore be made about the achievement of the targets of the individual production plants with regard to the vehicle model.

A further application of the benchmark can also be in the area of production quality. This makes it possible to compare individual areas of an assembly system (e.g. the assembly stations) with regard to the quality characteristics of production quality [4]. The actual value represents the quality rate of the quality characteristic. The quality rate per layer can then be determined and compared. Fig. 6 shows an application example from the field of production quality with three assembly stations (red, green and blue) and an individual weighting of the quality characteristics.

3.3. Information content of the visualization

The QVM provides a *binary quality evaluation* by implementing the individual safety and tolerance limits. It is possible to determine directly whether an inspection characteristic lies within its tolerance ranges and whether the

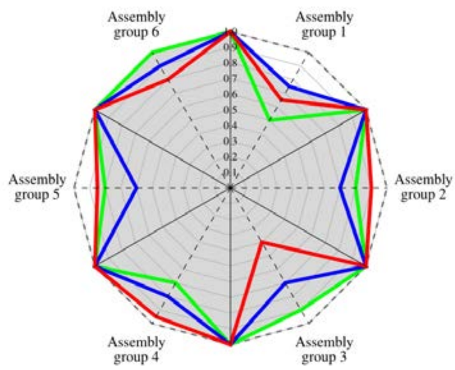

Fig. 5. Application example of a benchmark for product quality.

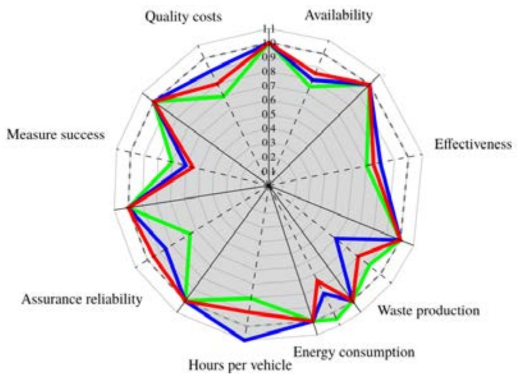

Fig. 6. Application example of a benchmark for production quality.

quality requirements are fulfilled for this inspection characteristic, quality characteristic and object.

By applying safety and tolerance limits, the process behavior can be visualized and monitored. The goals are to determine whether and in which direction the production process changes significantly [15] and to identify systematic quality deviations. The user of the QVM receives a methodological instrument with which a confirmation of the quality and a monitoring of the process behavior is possible.

A *quantitative quality evaluation* can also be carried out and visualized by the QVM. By connecting the line ends, it is possible to calculate the quantitative quality value over the spanned area. This can be determined for an inspection characteristic, for a quality characteristic or for the object.

3.4. User of this method

A special requirement is the simple visualization of the quality situation of an object. It is not sufficient that only quality managers and quality engineers can work with (visual) quality tools and derive improvement measures from them. The goal of an adequate quality tool shall be that every employee involved in value and quality creation can derive quality information from the visualization simply, quickly and reliably and can develop – in combination with his individual expertise – efficient measures [16-18]. This promotes a human-system collaboration in an assembly line which is necessary for high production efficiency.

Although the users of the QVM are primarily quality managers and quality engineers, the model is also suitable for workers, supporters, reworkers and quality inspectors to derive quality information due to its simple design. Depending on the application, a) the product quality e.g. can be displayed within a rework station for each individual vehicle with a limited number of inspection characteristics or b) the production quality e.g. can be displayed within a quality gate for efficiency with defined quality characteristics. The model is therefore user-independent.

3.5. Feedback to production

Feedback of information into the hybrid quality control system is required fundamentally for quality control. Concrete measures for quality control must be derived from the findings, forwarded and implemented. The decisive factor here is the human being. The users of the QVM act as controllers for cascaded quality control [19-22]. The QVM provides them an informative added value with regard to the general quality situation, systematic quality deviations and other quality-related key aspects of an individually selected object with its quality and inspection characteristics. Consequently, the personal skills of the QVM users are used for feedback. The QVM can be used by the user as an assisting quality tool for problem and cause analysis.

4. Industrial application

Due to its generic and object-independent properties, the QVM can represent any object. The QVM first requires the selection of the type of quality to be considered -- the production quality or the product quality. Then, the object can be selected as an instance. For an alternative hierarchical view, the object can be divided into further levels, consisting of the underlying objects. In the field of vehicle assembly, the following organizational systems are suitable [23, 24]:

- Production plant
- Assembly section
- Assembly line
- Assembly area
- Assembly station

4.1. Visualization of production quality

To visualize the production quality, the object must first be selected. The assembly system is suitable for this at high management level, while for an assembly foreman it makes sense to visualize the assembly area. Furthermore, the user has to select two view variants:

- Isolated view
- Organizational view

An *isolated view* of the production quality shows the user the selected object (e.g. an assembly section) with its specific quality characteristics. The actual length of the quality characteristic vector results from the calculation of the respective key figure. Depending on the application, the quality characteristics can be equally weighted or individually weighted. However, the requirement of the full angle[1] must be fulfilled. Depending on the quality situation or significance of the quality characteristics, the safety and tolerance limits can be defined. This leads to an individual or isolated view of the production quality for the selected object with focus on the specific quality characteristics. Fig. 7 shows an isolated view of production quality for an assembly system with individually weighted quality characteristics.

[1] the weighting is based on a full angle with 360° [1].

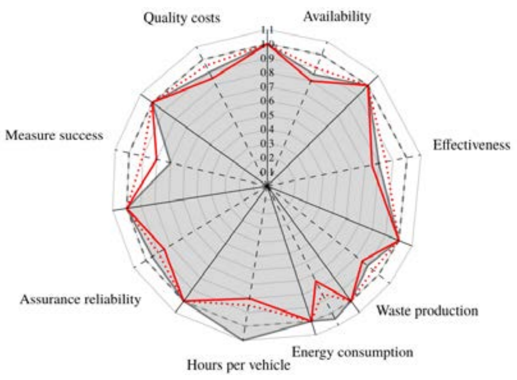

Fig. 7. Isolated view of production quality.

An *organizational view* of the production quality shows the user the selected object (e.g. an assembly area) as a layer with the underlying objects (e.g. the associated assembly stations) as vectors. In the case of an assembly area with n assembly stations, the layer has correspondingly n quality characteristic vectors. The actual length of the quality characteristic vector results from the quality rate of the corresponding object. A weighting can also be made as in the isolated view. Through the organizational view it is possible for the user to determine the degree of target achievement of production quality with focus on the organizational units or object-specific locations. Fig. 8 shows an organizational view of production quality for an assembly area with equally weighted assembly stations.

Characteristic of both approaches is the lack of upper safety and tolerance limits. The production quality represents in quantitative form a degree of target achievement whose definition range is between 0 and 1 or rather 0% and 100%. Consequently, an upper safety and tolerance limit is obsolete.

Subsequently, the quality information on production quality can be made available to different persons (e.g. a quality engineer or an assembly foreman) or locations (e.g. on a digital information board of an assembly station or a quality gate). In this way, information on assembly-specific production quality can be reported back to the user.

4.2. Visualization of product quality

Another area of application is the presentation of product quality. An object can be a component or an assembly group as well as a specific vehicle or a vehicle model. At the level of a rework station, the visualization of a reworked component is suitable as a layer, whereas the display of an assembly group

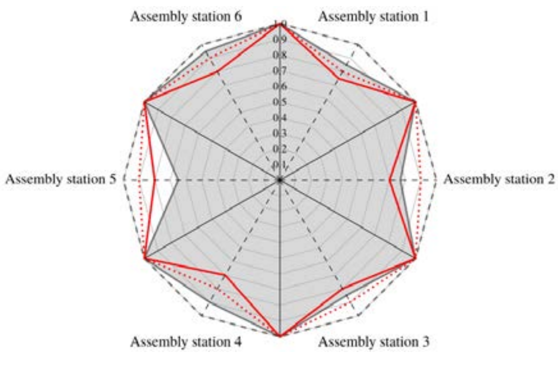

Fig. 8. Organizational view of production quality.

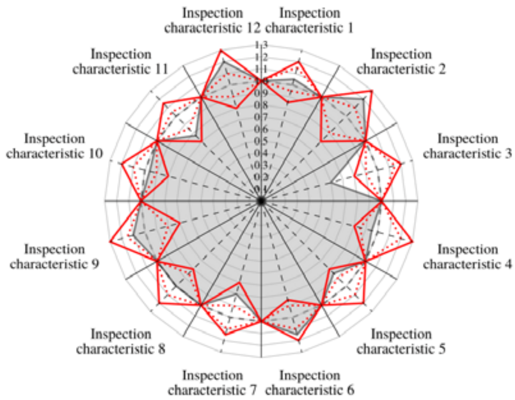

Fig. 9. Isolated view of product quality.

to be inspected is suitable for a quality gate.

The display of an object with many characteristics (e.g. a vehicle model or a specific vehicle) as a layer is only useful for a selection of quality and inspection characteristics, since a large number would negatively affect the representability of the QVM due to the vectorial design. A visualization on vehicle level would be suitable e.g. for clearance inspection of the vehicle body, since the number of relevant clearance inspection points is countably small and can thus be visualized via vectors. In the field of application of product quality, the user has to choose between three view variants:

- Isolated view
- Object view
- Organizational view

An *isolated view* of the product quality shows the user the selected object (e.g. a fender) with its individual quality and inspection characteristics on one layer. The inspection characteristics are displayed in a known form using the vectors. The representation of the product quality of an object via the QVM can be provided to the vehicle as digital meta-information during its assembly process. At relevant locations (e.g. a quality gate or a rework station), the quality information can be displayed according to the situation. Fig. 9 shows an isolated view of the product quality for a component with equally weighted inspection characteristics.

An *object view* of the product quality shows the user the selected object (e.g. an assembly group) as a layer with the underlying objects (e.g. the associated components) as vectors. In the case of a representation based on the quality rate, this is displayed over the actual length of the vectors. As with the visualization of production quality, there are no upper safety and tolerance limits, since only a value between 0 and 1 or 0% and 100% can be achieved. The weighting of a quality characteristic can be either equally weighted or individually weighted. Then the area calculation of the individual quality characteristics can take place, in which a maximum target area achievement is to be aimed for. By selecting the quality characteristic with the smallest actual area, the underlying level is visualized with the corresponding objects. This procedure can be carried out iteratively down to component level. Finally, the component with the highest negative quality fulfillment and the highest priority to control

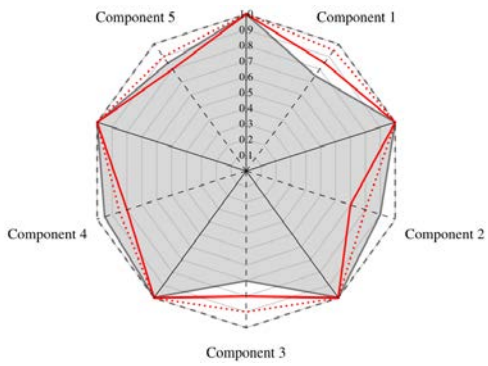

Fig. 10. Object view of product quality.

can be analyzed. Fig. 10 shows an object view of the product quality on the basis of the quality rate for an assembly.

An *organizational view* of the product quality shows the user the selected object (e.g. an assembly section) as a layer with the underlying objects (e.g. the associated assembly areas) via quality characteristics as vectors. A representation on the basis of the quality rate within the organizational view takes place analogously to the object view. The actual length of the vectors represents the quality rate of a characteristic with missing upper safety and tolerance limits.

The industrial application of QVM in vehicle assembly shows the generic property and the high versatility of QVM as well as the object independence with which each object or a combination of several objects (e.g. vehicle model A and production plant II) can be mapped on a characteristic basis.

5. Conclusion

This paper has shown a method for user-oriented visualization of the quality situation of any object or a combination of several objects based on the individual quality and inspection characteristics. The *Quality Visualization Model* (QVM) combines the graphical radar model with the analytical quality control chart methodology and thus allows the consideration of safety and tolerance limits. The actual values of the inspection characteristics are designed homomorphistically to the relative degree of target achievement and can therefore be displayed in a common model despite different dimensions, sizes and units. Due to its simple visualization, the QVM is independent of the user and application and can be used in various ways to control both product quality and production quality. The encompassment of both views is a prerequisite for a future integrated quality monitoring and control, especially in order to run methods for machine learning and artificial intelligence. The generic structure enables visualization and monitoring as well as evaluation and control of different qualitative issues. A hierarchical structure over several layers of an object is also possible. The QVM enables the user in a simple and fast way to make a binary and a quantitative statement to the quality situation and to generate necessary measures from it. Hence, the QVM is one solution of choice which fulfills the required properties for adequate visualization of the quality situation.

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