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The impact of visualizing operational deviations on overall quality in assembly lines

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Abstract

A framework for data collection and visualization of operational deviation at a Volvo truck manufacturing plant implementing Volvo Group's production system, Volvo Production System (VPS), is presented. This includes visualisation of daily quality performance indicators to support decision making and improvement actions at the shop floor team level. The approach is evaluated in a qualitatively study using a survey instrument to collect responses from managers and team leaders, which acted as input for the actual use of the data and as validation of the framework. The results from this evaluation show that potentially operational deviations can be reduced, impacting positively quality performance indicators such as first-time through (FTT). This paper also provides a brief description of the VPS in connection with data analytics and visualization.

Keywords: Operational deviations; Quality performance; Volvo Production System

1. Introduction

A fierce market competition, along with increased customer expectations and customized requests, forces manufacturing companies to implement new technologies in their manufacturing systems [13]. In [14] it is argued that data is a key enabler for increasing operational competitiveness through prioritized, and well-informed, decision making. In addition, the increasing degree of digitalization has created a new means for collecting high quality data [12]. As discussed in [13], there is a possibility of reducing costs by utilizing real-time data visualization. Digitalization acts as an enabler for this improvement and one way for manufacturing companies to reap the benefits is through data analytics platforms.

Operational deviations during assembly result in additional actions required later in the process to handle the deviations. These additional corrective actions are necessary to secure that zero defect units are shipped to customers. Typical operational deviations include missing parts, product quality defects and incomplete assembly cycles. Operational deviations typically result in a decreased first-time-through (FTT), one of the quality key-performance-indicators (KPI) of production systems. FTT is described as the percentage of products that are assembled without any operational deviation being reported. Operational deviations during assembly contribute to large losses in both resources, time, and money. In [5] and [10] the authors propose that operational deviations also detrimentally affect customer satisfaction and thus operational deviations are important to understand and to identify the root-cause of the deviation so countermeasures can be taken.

Today, data collection and visualization processes of operational deviations are largely manual and reactive in terms of using the data to improve quality performance. Automatic quality driven data collection brings transparency about the operations, the materials utilized, the facility logistics, and the work team at the workstations. The application of data analytics and visualization, which refers to the use of statistics to discover and visualize distinct data characteristics and patterns to help the decision making process, is made possible by the use of automated or semi-automated data collection.

The main contributions of this paper are (i) a framework for visualization of operational data from a quality control system to support a better decision making by the shop floor teams at workstation level. (ii) a qualitatively study of the implementa-

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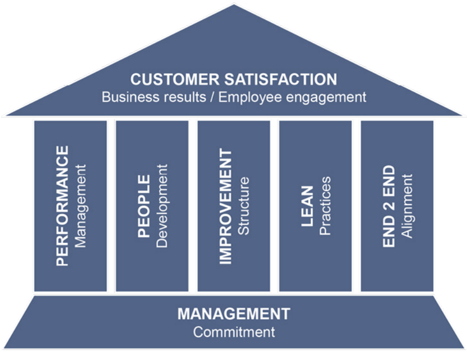


Fig. 1. Volvo Production System (VPS).

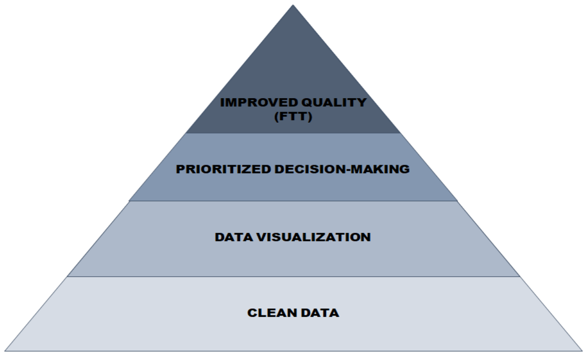


Fig. 2. Data analytics for FTT.

tion, and (iii) a brief introduction to the Volvo Production System (VPS).

2. Quality deviations and First-time-Through (FTT)

FTT is one of the quality KPIs of production systems which is defined as the percentage of products that are assembled without any operational deviation being reported and formally defined as

$$\mathrm{FTT} = \frac{\text{Units produced} - \text{Units with deviations reported}}{\text{Units produced}} \cdot 100\%.$$

Increased FTT implies higher product quality. Increased FTT is also an indication of delivery time improvement, waste elimination and corresponding cost reduction.

Assembly, the last link in the product-form process, is highly labor intensive and is a key link for determining product quality. Thus, understanding the deviations in terms of the source, magnitude and location on the product could potentially help identifying the root-cause of the deviation and if handled could result in improved FTT. Therefore, we argue that collecting the relevant quality deviation data and visualizing it is useful for the shop floor teams to define priorities and take decisions. Through visualization, the analysis is aided by the process of detecting patterns and trends in the data, something we as humans are very good at through our visual apparatus, leaving the complex computations behind the visualization to be performed by the computer, thus combining the strengths of humans and computers.

3. Current state

Volvo Production System (VPS) [11] was launched in 2007 as a continuous improvement effort. The VPS model, shown in Fig. 1, is a system that consists of several key elements (performance management, people development, management commitment, improvement structure, lean practices, and end 2 end alignment) necessary to drive an organization. The right interpretation and translation of the key elements into actions is expected to improve results. The actions are expected to result in increased customer satisfaction, increased business result and increased employee engagement. The *performance management* key element emphasize fact based analysis possibly supported by visualisation of data. Big data, data analytics, and real-time visualisation are thus important techniques in supporting performance management. The *people development* key element create conditions for the teams to collaborate and make the appropriate decisions based on data and fact analysis to improve the company performance. *Management commitment* means engaging leaders with necessary behaviors and management practices to support the organization to continuously improve and learn. Improvement structure is about developing a culture for daily problem solving analysis and standardization for sustainable improvements. The *lean practices* key element emphasize stability and predictability of the production process supported by flow thinking and built-in-quality with zero defects as the target. *End 2 end alignment* is about the alignment of different players in the organization in goals and targets, towards the company's goal.

This work is related to the performance and lean elements of VPS where the goal is to increase the built-in-quality (specifically the FTT) by using automated data collection and visualisations of operational deviations. In Fig. 2, the process to improve the FTT is presented. It starts with cleaning the data, then visualizing data. Clean data and visualization results in decision can be prioritized based on facts. This process potentially improve the FTT. The plant where this study was conducted has, as part of the quality improvement plan, a target of reaching a FTT of 100%.

3.1. Current efforts

The Volvo truck plant, where this case study was conducted, has a quality information system which collects all operational deviations as the truck moves along the workstations in the assembly line. This information is documented on a physical product specific document, called travel card. The operators, at each workstation, document all the deviations for the truck on the travel card. At the end of the line all the deviations on the travel card are registered into the digital quality information system (QULIS). The method for reporting deviations on the travel card is not standardized, thus the same type of deviation might be reported in different ways by different operators. This makes it difficult to search and find specific deviations to support a good root cause analysis. This has resulted in an inefficient problem-solving processes, where sometimes symptoms of problems are solved rather than the root cause. Therefore, there is a need to standardize the way of collecting and visualizing data to better support a fact based problem solving process.

3.2. Plant description

The manufacturing plant consists of six different production departments. There is a main line which consists of three assembly areas; base module (BM), final assembly 1 (FA1), and final assembly 2 (FA2). The main line is supported by three feeding lines that deliver axles, engines, and cabs in a fish-bone structure. The structure of each department is broken down into shop floor teams, which are responsible for specific processes. Every shop floor team is led by a team leader together with 10 to 15 operators whom are responsible to perform various operational tasks at each workstations (WS). All assembly areas have a main quality gate. These quality gates are located at the end of each assembly process to collect all deviations registered by the operators at each WS along the assembly process. These quality gates are named Q6, Q7 and Q8. Quality gate 6, Q6, is located at the end of the main line, Q7 is located after Q6, after adjustments have been made. Q8 is the final quality gate after final testing and further adjustments. After Q8, the trucks are ready to be delivered to the customers

4. Method

The research process consisted of three consecutive steps. The initial emphasis was on investigating the context. Later, data collection, and mock-up visualization models were developed, iterated and evaluated. After the data-collection process, the results were analyzed and a final framework for the data-collection process and a model for the visualization of quality deviations were developed. To improve the plant's data collection and visualization of operational deviations interviews and observations, as well as best practices in other plants of the organization was used. Furthermore, the collected information and knowledge were analyzed, which resulted in a framework for how the data-collection process of quality deviations can be improved as well as a model for visualizing these deviations at the shop floor team level.

4.1. Interviews and job observations

In order to get a complete view of the current state, structured and semi-structured interviews were conducted. Eighteen interviews were performed in a top-down approach, starting with semi-structured interviews with five managers. Conducting interviews in a semi-structured way allows for more flexibility to ask follow-up questions, hence this was deemed appropriate in the initial phase of the investigation to understand the plant's situation. The first interviews were conducted as pilot interviews, in order to continuously improve the interview questions to cover relevant information. During the pilot interviews, more holistic questions were asked in order to better grasp the situation. These questions were then adjusted to target and get more detailed information of the area investigated in this study. For example, a question such as "Could you describe how the data collection process of quality deviations takes place today?" asked during the pilot interviews, was later adjusted to focus on certain process steps instead. The initial interviews were followed up by interviewing three data analysts and three quality engineers to get more detailed information about the subject under investigation. Moreover, information and knowledge gathered from the semi-structured interviews were then guiding the authors in the right direction of where and with whom to conduct more detailed structured interviews on a team level. A total of seven team leaders from different departments were interviewed. The questions used for the interviews are described in [2]. To further deepen and complement the knowledge obtained from the interviews, observations were performed. The observations served as a mean to contrast the interview data, as well as to create a more holistic understanding of the operational practices and procedures. The observations covered different departments of the production line, mainly focused on how operators, team leaders, and control stations are collecting data of deviations.

5. Results of interviews and job observations

In this section we summarize the findings of interviews about how the data collection is carried out today and current use and expectation of visualisations of quality data.

5.1. Current data collection tools and problems

Apart from QULIS (one of the FTT data collection systems), the plant uses several other different systems that are connected to the quality area. PI is a system that collects and presents data of the main quality indicator, namely FTT. Another system is called PRODIFY, which handles all data related to line stops. For example, if a sensor detects an issue on the line, this is automatically reported into PRODIFY with alarm codes, time and duration. However, this still requires some manual reporting from team leaders to add comments about the different stops. Furthermore, regarding electronic control units, a system called PROSIT is used to find detailed information about particular error codes. One issue with all these systems, which several interviewees have mentioned, is that the systems do not speak very well with each other. For example, a system called PRAUDIT is used for collecting data about audit points, even though this is reported into QULIS as well. As Analyst A said: "There are a lot of isolated systems that do not integrate well with each other, and also systems that are doing similar things such as QULIS and PRAUDIT". There is also an overarching control system, named FCS, that contains general and specific information of all the trucks currently on the line. Once the trucks are complete, this system transfers the data to storage and is accessible through the system FCHS. One problem that several of the interviewees brought up is that quality deviations that are reported into QULIS are sometimes moved by team leaders since they do not agree that the problem occurred within their workstations.

5.2. Current visualization tools and problems

On a manager level, the use of digital tools is more prominent but certainly not prevalent. In general, at a manager level, whiteboards are still widely used for tracking the short- and long-term outcomes, but on a more holistic level than the ones used by the team leaders. The information provided by the team leaders is synthesized for each step in the hierarchy, but the analog visualization is more or less the same. As for the quality technicians and engineers, the analysis and visualization are solely done in Microsoft Excel. Some individual efforts have been put into visualizing the data through Microsoft Power BI, however, there exists no expertise within this area at the quality department of the plant. For the entire plant, Analyst C describes that there exist some visualization solutions based on Microsoft Power BI, however, these are holistic and high-level visualizations of overall daily performance, and not detailed at the shop floor team level. During the data-collection process, several managers have expressed the need for real-time visualizations of the quality outcome, which they believe could aid them in making more informed and faster decisions. To-date all FTT and data visualizations are developed in Microsoft Excel. The team leaders expressed that the daily preparations for reporting was a rather time-consuming activity.

All of the team leaders who were interviewed claimed that they spend between 10-20 minutes every morning, gathering and synthesizing the information from the different data sources as well as calculating specific KPIs that are to be visualized on the whiteboards. Team Leader A explicitly said that “I usually come in to work 15 min earlier, just to make sure that I have enough time to prepare everything”. Additionally, Team Leader B and C expressed enthusiasm for having all the relevant information in one place rather than checking and gather data manually from several different systems. Furthermore, the daily preparations are expressed to be complex, and not all team leaders have the knowledge of how to conduct it. Team Leader G was frustrated in relation to this and stated that “It is very cumbersome to switch between different systems that is often complex to deal with”.

6. A visualization framework for quality deviations

This section introduce a prototype implementation of visualisations of quality deviations. The implementation was done using Microsoft Power BI and visualize day-to-day performance as well as short and long-term trends of quality deviations. Departing from the importance of simplicity and clarity, argued by [4], the models have been developed with a strong emphasis on being user-friendly and with clear connection to what was requested by the team leaders, as they are ought to be the lead users of it. One of the prerequisites that the authors identified was the importance of valid visualization. To ensure this, the development process of the model consisted of three steps: prototype development, verification and validation of the model. The initial step was to develop a prototype using static data, the second step was the development of the model using dynamic data which was validated during the regular daily reporting routines. After validations of the model with dynamic data, the proposal is a factory-wide implementation. In addition, [9] explains the importance of acknowledging who the stakeholder and recipients are, what is the key message to convey, and how will the visual earn credibility. To ensure that the model earns credibility, it has been thoroughly validated during the development process, both through piloting and rigorous testing. The emphasis on the models being user-friendly further enhances the possibilities for earning credibility.

6.1. Day-to-Day shop floor team dashboard

The day-to-day dashboards were developed on premise to ease the daily preparation process by synthesizing all the information needed as well as to eliminate the risks of miscalculations due to human error. Succeeding with this, creates the potential to increase quality through streamlining and reducing waste. As argued by [6], visualization can be both an effective and non-effective way of communicating information, and it is thus of utter importance that the right information is visualized. The main dashboard, Fig. 3 contains the most important KPIs needed for the daily reporting, such as FTT, stop time, and audit points (Gårdagens Poäng). The metric “ÖP” describes how many of quality remarks that passes a quality gate without being resolved, where “Stängda” is quality remarks that has been closed before the quality gate. For the calculation of “FTT”, only the “ÖP” impacts the metric. Furthermore, the metric “Egenrapporterat” displays the number of quality remarks that is reported by the causer of the remark, for example, in Fig. 3, “Egenrapporterat” refers to quality remarks caused and reported by “Cab trim grupp 6 A”. On the opposite, “Kundrapporterat” refers to quality remarks reported by another team later on the line. “Andel Egenrapporterat” is the only metric not directly requested by the team leaders but is developed by the case study authors. This was done on the premise to increase the incentive for finding the own team’s errors and thus, decreasing the time lag between occurrence and finding of a quality deviation. For more detailed information about previous day’s quality remarks, it is possible to navigate to another tab, Fig. 4, where the remarks are ordered by their criticality and severe faults are highlighted. This tab includes all the relevant information about the remarks that are available from QULIS. Lastly, Fig. 5 contains more detailed information about previous day’s stop time, for example, which workstation responsible, during what times, and a chart showing the stop-time distribution. To some extent we could state that the developed dashboards may not spread information better than plain text, which was a justifiable bene-

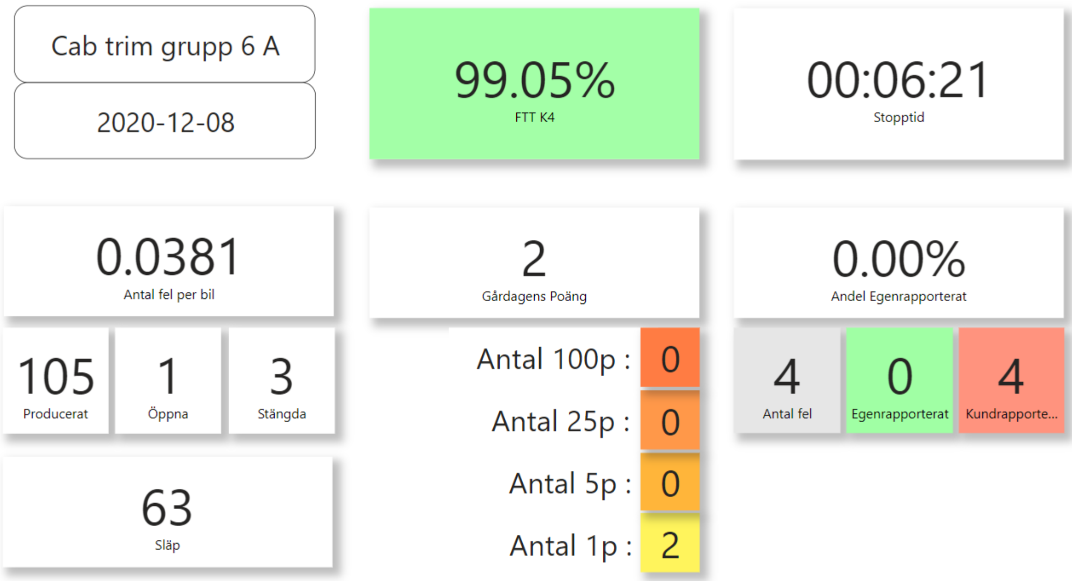
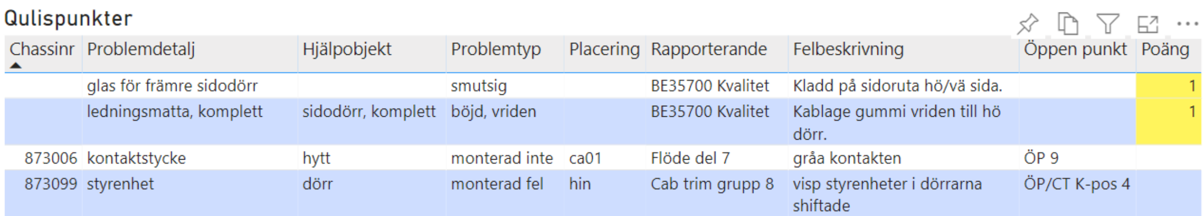


Fig. 3. Visualization of the main day-to-day dashboard used for daily reporting.



Qulispunkter

Chassinr	Problemdetalj	Hjälpobjekt	Problemtyp	Placering	Rapporterande	Felbeskrivning	Öppen punkt	Poäng
	glas för främre sidodörr		smutsig		BE35700 Kvalitet	Kladd på sidoruta hö/vä sida.		1
	ledningsmatta, komplett	sidodörr, komplett	böjd, vriden		BE35700 Kvalitet	Kablage gummi vriden till hö dörr.		1
873006	kontaktstycke	hytt	monterad inte	ca01	Flöde del 7	gråa kontakten	ÖP 9	
873099	styrenhet	dörr	monterad fel	hin	Cab trim grupp 8	visp styrenheter i dörrarna shiftade	ÖP/CT K-pos 4	

Fig. 4. Second dashboard in the day-to-day dashboard with detailed information of quality remarks.

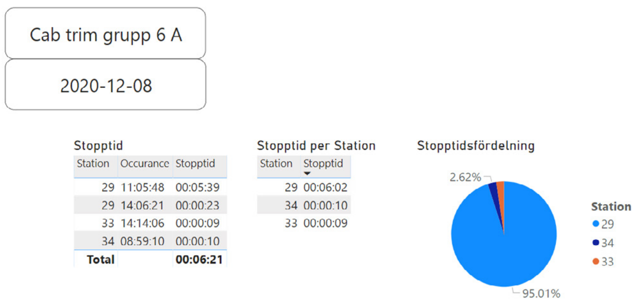


Fig. 5. Third dashboard in the day-to-day dashboard with detailed information about stop time.

fit of data visualization by [7]. The reason for these arguments is that the dashboards primarily consist of plain text, rather than graphs or sophisticated visualizations. However, as emphasized by [9], the goal of visualization is to transfer knowledge and convey a message. In addition, if the information is best communicated through plain text, the visualization should be kept simple and preferably expressed by a text box or similar. The work in [4] further strengthens this by proclaiming that information is effectively communicated when it is clear, visible, and simple to understand. The table in Fig. 5 has no significant borders, it highlights the paramount data, and utilizes transparency of colors. To decrease the cognitive load of the visual, efforts have been made to eliminate clutter and only include what is requested by the team leaders, thus adding value to the visual. Furthermore, in order to focusing attention to the most important attributes the visuals are structured by showing the most important KPIs, FTT and Stop time, at the top, as well as making them larger than the less important ones. In addition, dynamic color coding has been utilized to strengthen the intended message of the visual. Previously, many team leaders find the prioritization and selection process complicated and ambiguous. To counteract this, the dashboards aim at easing this selection process by visualizing both short- and long-term trends of different quality deviations. The dashboard for trends that is visualized in Fig. 6, Fig. 7, Fig. 8 are team-specific, but compared to the day-to-day dashboard, the user has the possibility to look at trends in a specific time period that meet their data requirement. Furthermore, the dashboard in Fig. 7 shows histograms of the most common problem types, problem details, and heatmaps of the most common locations of the deviations. All of these visuals are filtering each other, meaning that the results dynamically change if you choose a different time period or pressing a particular problem type or detail. This enables analysis of specific problems, where the team leaders can choose an appropriate time period and filter down on specific problem

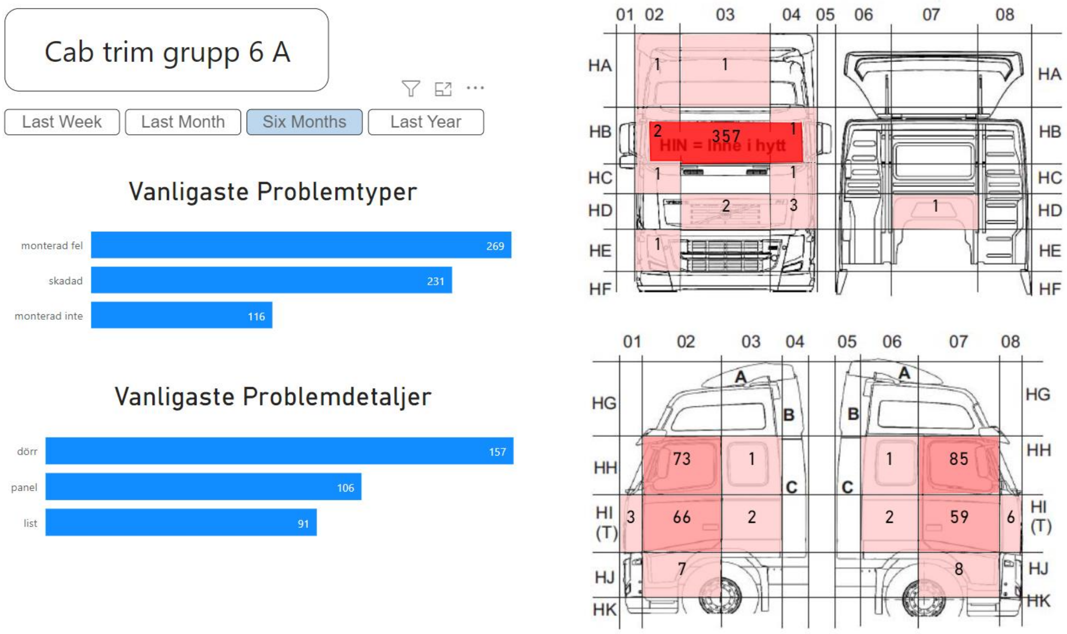


Fig. 6. Visualization of the trend dashboard of most common problems.

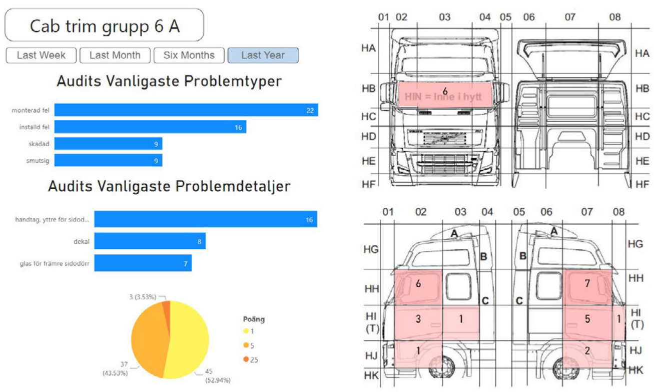


Fig. 7. Visualization of the trend dashboard of critical remarks.

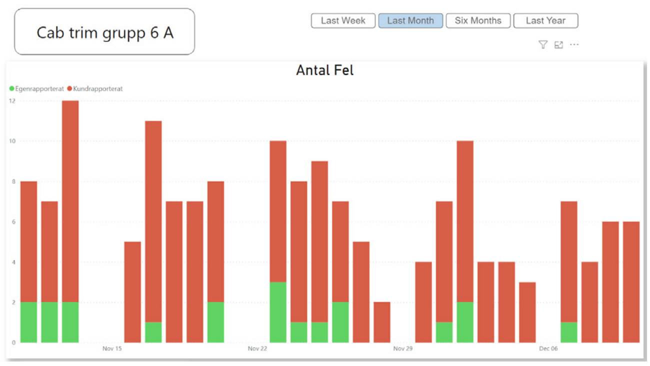


Fig. 8. Visualization of the trend and distribution of problems reported by your own team compared to problems reported by others.

types and problem details to see where on the truck the most deviations occur.

6.2. *Managing change within the organization*

The implementation of the dashboards requires no major disruption of today's procedures and practices, but rather an incremental improvement of internal processes. Furthermore, the implementation described above does not involve significant changes to any artifacts, values, or assumptions. However, it is still worth acknowledging that resistance might occur. As argued by [1], the lack of trust towards the visuals may create a reluctance behavior to incorporate the new practices. To counteract this, it is recommended to follow the proposals indicated by [8] to map out the different stakeholders and their attitude towards the change. This would create the possibility to direct attention and efforts to where it is needed. In addition, it can prove beneficial to acknowledge the informal networks among the recipients of the changes, namely, the team leaders. To gain credibility and acceptance, [3] express the importance of gaining it from people with large informal networks, since they have a strong influence over others' perception.

To ease the implementation process, it is thus recommended to identify key stakeholders and employees with large informal networks for pushing the change forward. For this investigation, eight team leaders were selected to pilot the visualizations on, based on their initial enthusiasm. These team leaders will then act as somewhat of a key user by spreading the word and creating a need among other team leaders. Doing it this way, it may be possible to create a bottom-up need for the visualizations, which in turn, could ease the implementation process.

7. Conclusions

Through visualizing operational deviations the possibilities to base decisions on facts increases. Moreover, this transparency can not only act as a catalyst for creativity, but also support data quality improvements, where the people involved get more direct feedback of their input to the information systems. However, in order to reap these benefits and increase the chances of improving the quality for a manufacturing company, prerequisites such as ensuring data quality, valid visualizations, and digital maturity are essential. To facilitate the visualization process, the data collection methods and procedures in a manufacturing company should be structured and suitable for the visualizations in mind. Reporting of quality deviations should be done as soon as possible after occurrence, to avoid time- and knowledge gaps. In order to mitigate data quality issues, it may prove beneficial for the interface of the information systems to be Poka-Yoke (error-proofing devices or processes), as well as including the right information fields that enable data analysis. Visualization of quality deviations opens up for possibilities to ease decision-making and hence, becoming a more data-driven organization. Well-developed visuals can provide an easier and more accessible way of transferring and absorbing information. Furthermore, automated visuals will free up time, which augments the decision-making process. Last but not least, this is highly correlated with the performance management and lean key elements of the Volvo Production System (VPS) which is the driving force of the continuous improvement process in Volvo Group Operations. From September 2021 the local management at the Volvo manufacturing site, at which this investigation was conducted, decided to expand the data collection and visualization model described in this paper. The overall product quality measured by FTT has improved from 31 percent in September 2021 to 44 percent in February 2022. It is difficult to correlate how much of this FTT improvement is due to the operational visualisation model described in this paper, but it is likely that some is related to the value of data analytics and better decision making facilitated by the visuals reported in this paper.

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