Traceability of Human Error Production Defects in Automotive Manufacturing

A Case Study on Quality Assurance Process Improvement for Error Logging

Bachelor of Science Thesis in Software Engineering and Management

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Chiara Lucatello

Bachelor Program Software Engineering and Management
Department of Computer Science and Engineering
Gothenburg, Sweden
guslucatma@student.gu.se

Chatchai Sornkarn

Bachelor Program Software Engineering and Management
Department of Computer Science and Engineering
Gothenburg, Sweden
gussorch@student.gu.se

Abstract— **Many global automotive industries have moved towards factory automation, yet several still rely on collecting manual data from the plant floor and manually inputting the data into the management quality system in the assembly line. In this case study research, the objective of our study was to observe how technology advancement can be supported for human error logging in the quality assurance process. The study was conducted over the course of 7 weeks where we analyzed the traceability of human error production defects in Volvo Cars AB located at Torslanda, Gothenburg. Triangulation from three data sources – interviews, observations, and artifacts – reveals that the process is done using paper and manually inputted into the system which leads to human errors and to possible delays. The solution that is perceived from existing literature and our findings suggest that factory automation is a foreseeable solution for the company and other manufacturing companies dealing with the same issues.**

Keywords— *error detection, in-and-out logging process, inputting process, technological frames, usability, traceability, process improvement, factory automation.*

I. INTRODUCTION

In global automotive industries, lean production is a standard for waste minimization and cost reduction without compromising productivity [1]. The philosophy focuses on eliminating the production of waste as the focus is shifted on customer value creation [2]. Lean manufacturing holds the seven common Muda – the Japanese term for waste [2]: inventory, over processing, overproduction, transportation, motion, waiting, and defects.

A *defect* is any error in a process that can lessen the value of the product for the customer, or that requires additional operations to correct the defect [1]. An error is an incorrect step, process, result, or a human action that produces an incorrect result [3]. These errors arise out of processes lacking standard procedures or poor control systems that impact both productivity and production costs [1, 2]. Waste of defects should be prevented where possible; better to prevent than to try to detect them. Nevertheless, not all defects can be prevented or detected early on during production. The process of effectively and efficiently tracking human error quality defects to the point of origin is vital as assembly line workers need to understand their error in their efforts to prevent the error from occurring again. One of the major issues of these

errors arise from the manual entry of data that results to inaccurate reporting and delayed cost reporting [4].

Similar to many companies, Volvo Cars AB based in Gothenburg, Sweden, utilizes paper *in-and-out logs* to collect data from assembly line workers which are then inputted manually into ATACQ (Answer To All Car Questions) – a yard management quality system in the assembly line. In our study, we will be focusing on the quality assurance process for the traceability of defect based on human error and evaluating the quality in use of the technology (software) involved in this process. Please see Appendix A for a visual representation of how work is conducted in the factory.

Since manually collected data entered into the system often results in inaccuracy and untimeliness, a generalized solution to this current problem is to automate work-flow labor data collection with existing Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) [9]. Automating plant floor data collection provides increased benefits in three key areas during production: management, productivity, and efficiency [8]. However, although potential benefits make such investment an attractive one, many companies are hesitant to employ its adoption due to certain obstacles [8]. The main impediment of such resistance is due to the uncertainty of the resulting benefits. Management is frequently hesitant to make the commitment to automate plant floor procedures unless there is a solid confirmation that the organization's required degree on their internal return on investment will be achieved [8]. Failure to seek and measure strategic benefits; vulnerability in adopting the technology; and absence of data and information regarding the potential advantages, are a few reasons why companies postpone investment in these technologies [8].

Considering that implementing plant floor automation "requires a long-term investment of financial resources and trained people", it is vital to seek out and evaluate current operations and practices [8]. By identifying problems and needs in current processing activities from various key groups within the organization, companies will be able to facilitate the adoption and integration of plant floor automation. Potential improvements can be made in technology introduction by supporting a step-by-step procedure for change initiatives that can meet identified needs in an efficient way.

Our study investigates how to support an advancement towards the adoption of plant floor automation. We utilize the

theory of technological frames to examine underlying assumptions, expectations and interpretations of technology, to identify a more efficient and smoother process for such a change initiative that can be incrementally planned [6]. Utilizing the theory of technological frames to examine underlying assumptions, expectations and interpretations of technology in the automotive industries can support efficient improvements towards the adoption of plant floor automation. The outcome of our study introduces a methodological guideline for establishing a process and climate for facilitating integration of new technologies in the manufacturing system [8]. In reference to technological frames, three domains are characterized as the: nature of technology, technology strategy, and technology in use [6], where the technology in use (the current system where data is manually inputted) will be analyzed through the evaluation of quality-in-use provided by the *MUSiC* framework for usability measurement [7, 10].

II. RELATED WORK

A. The Problem Domain and Potential Solution

Warren Wolfe's paper presents the current problems organizations have with manual-data entry and how failure to adopt new technology may result in loss in productivity, profits, and even competitive advantage in the market [5]. He outlines the problem domain by stating how companies have invested in manufacturing systems yet the data that steer these systems are paper-based and manually collected. The data derived from these papers are then manually entered into the system which results in a decrease in accuracy and efficiency [5]. This problem is outlined in Lubomir Lengyel's publication where he explains and emphasizes the rise of automation in production plants, however, plenty of companies still rely on operators manually entering data into a given system [11]. Since the major focus for companies is placed on improving the productivity and efficiency of its operations in order to maximize their production output while minimizing costs, an automated factory is the potential solution for a company's prospective future [11].

Mohsen Attaran addresses both the benefits and obstacles for adopting an automated plant floor data collection system in industries. He underlines the assumptions behind the resistance towards new technologies and creates some foundation by highlighting adaptation obstacles [8]. In his other work, he presents his study by providing case applications in the United Kingdom (UK) that have adopted computer-integrated manufacturing (CIM) or flexible manufacturing systems (FMS) in automotive industries [12]. He states the obstacles behind the adoption of an automated factory but capitalizes on the advantages of utilizing these technologies. These advantages present tangible benefits, of which a few are listed below:

- Reduction in labor costs: reducing direct and indirect labor in work, rework, and inspection [12].

- Reduction in time set-up: set-up times can be reduced before a production shift when utilizing different engineering methods [12].

- Improved product quality: better scheduling during production and lower defect-rate that is achieved by higher accuracy [12].

The intangible benefits include:

- Improved management control: predictability is improved in the stages of manufacturing and in operations, leading to better management control [12].

- Improved quality of work life: productivity is increased by the direct and indirect motivation behind a high-quality workforce [12].

III. RESEARCH METHODOLOGY

The objective of our study was to investigate how technology advancement towards plant floor automation could be supported, where our focus of research was on the quality assurance process for human error detection at Volvo Cars AB Torslanda and to define areas for process improvement. Based on this, we formulated our main research question presented below:

RQ1: How can technology advancement for enabling traceability for human error logging in the quality assurance process be supported?

The sub-research questions were derived from our main research question as follows:

RQ1.1: What perceptions do key groups in the organization have in understanding the role of the current technology for the traceability of human error logging?

RQ1.2: What are the relationships between the usability of the current technology with the artifacts derived from the process and technology?

RQ1.3: What factors influence the usability of the system?

RQ1.4: How can the process of traceability of human error product defects be improved?

A. Research Method and Company Site

We chose a case study as our suitable research method as it "is an empirical method aimed at investigating contemporary phenomena in their context" [13]. We wanted to obtain a high degree of realism in the real-world setting, meaning that we did not change the working environment or any factors surrounding it.

The research method conducted within our case study was designed as interviews where we collected standardized information from a specific population. Our selected group consisted of the entities from the Final Assembly line at the Volvo Cars AB Torslanda Plant and was derived from the evening and night shift working entities of Team 46C and 47C. We have approached our research as exploratory and improving since we were "finding out what was happening, seeking new insights, and generating ideas and hypotheses for new research" [13]; and seeking areas to improve certain aspects of the phenomenon we were studying. The case study conducted was based on qualitative data as this provides a richer and deeper description of the studied phenomenon. Per Runeson and Martin Höst states that a case study consists of

five major process steps which we have used in our study: (1) Design, (2) Preparation, (3) Collection, (4) Analysis, and (5) Reporting [13].

B. Preparation

Before interviewing our subjects, we presented our interviewees with a consent form outlining the anonymity of their responses to ensure confidentiality and a comfortable trust environment. Furthermore, we clarified our objectives and the case study and explained how the data will be used. Ten interviewees were selected based on their management levels to gather data from key groups within the organization to comprehend the bigger picture and correlate the findings to the study. Our interviewees consisted of:

One Middle Manager (MM) – "individuals who are typically responsible for translating goals set by top managers into specific details that lower-level managers will see get done" [14];

Three First Line Managers (FLM) – "individuals responsible for directing the day-to-day activities of Non-managerial employees" [14]. They are also referred to as team leaders;

Five Non-Managerial Workers/Assembly line workers (NMW) – "People who work directly on a job or task and have no responsibility for overseeing the work of others" [14], and;

One Technician – an individual responsible for supporting the ATACQ system at Volvo Cars AB.

All of the people who were interviewed utilizes the ATACQ system in different ways. For assembly line workers, the system provides a way to acknowledge their errors when assembling cars on the plant-floor. This vital for workers to receive this information as they must not let these errors re-occur during production.

First line managers utilizes the ATACQ system not only for the in-and-out log process, but also to directly and manually input errors as they occur during production. These errors can also be notified by previous teams in the production line in their efforts to warn about missing components, faults, or errors in assembly. The system allows for the first line manager to inform the team of errors during assembly.

The middle manager utilizes the system as an overview of the errors that are logged specifically for the balance that they are in charge of.

Prior to the actual interview questions, a set of introductory questions were first asked to get background information on the respondents. We prepared different questions for key groups we have interviewed in our efforts to attain critical information pertaining to the case we were studying. The interview questions were formulated as open questions, thus allowing our interviewees to invite a broad range of answers and issues pertaining to the study [13]. The interview was conducted as semi-structured, allowing us to seek improvisation and exploration of the study through a conversation-like approach with our interviewees [6]. Our subjects were interviewed separately in our efforts to minimize influenced responses and the interview time was limited to 15 minutes.

Case study research is a flexible research method where different data sources may be used in the efforts to limit an interpretation from a single source [13]. Triangulation allows the ability to use several data sources to extract information in order to form more concrete conclusions. In our study, we have collected our data source from three levels:

First degree - Interviews: we had direct contact with our subjects and collected data through interviews [13];

Second degree - Observations: we observed the case context without interacting with our subjects by collecting real-time data using the MUSiC framework while analyzing workers' interaction with the ATACQ system [13];

Third degree - Artifacts: we analyzed the work artifacts available from compiled data that was used in the process. These archival artifacts consist of the in-and-out logs that are inputted manually into the ATACQ system as well as the worker error log reports that are shown to workers displaying their errors.

TABLE 1: Data sources

First Degree	Second Degree	Third Degree
Interviews	Observations	Artifacts
1 Middle Manager	Team 46C Night Shift	Paper in-and-out logs
3 First Line Managers	Team 47C Night Shift	Human Error Log Reports
5 Non-managerial Workers	Team 46C Evening Shift	
1 Technician		
10 interviews	**Observations over the course of 11 days**	**78 data points**

- Interviews – lasting no more than 15 minutes
- Observations – 11 days approximating to 84 hours
- Data points – 78 in-and-out log sheets consisting of 1584 data entries

C. Data Collection Techniques

The interviews were structured to obtain interpretations from three domains derived from the theory of technological frames. The interview questions covered the nature of technology, technology strategy, and technology in use. By understanding our participant's perception of the ATACQ system through its capabilities and functionalities; by understanding the motivation behind the adoption of the ATACQ system; and by comprehending how the technology is utilized on a day-to-day basis covering both conditions and consequences associated to its use; we were able to group key

perceptions of the given technology [6]. Please refer to Appendix B for the interview questions.

In relation to comprehending the utilization of the ATACQ system based on its technology in use, the MUSiC approach was used to interpret the quality-in-use by providing a performance measurement method for analyzing the usability of the given system [6, 10]. The usability measurements are classified as: effectiveness, efficiency, and satisfaction.

In the context of our case study, effectiveness is measured by the formula:

$$Effectiveness = (Quantity, Quality);$$

where *quantity* is measured as "the proportion of the task goals represented in the output of a task which have been attempted" [10]. *Quality* is measured by the degree (correctness) to which an output has been achieved for the given task.

In order to calculate efficiency, we examined assembly line workers – those responsible for interacting with the ATACQ system – and calculated the effectiveness of their ability to complete their task by the amount of time it took for them to achieve an output of their given task. This is measured by:

$$UserEfficiency = (Effectiveness/TaskTime)$$

In our efforts to analyze user satisfaction for the ATACQ system, various questions were asked in our interviews that had been formulated to answer sub-research question RQ1.3 - "what factors influence the usability of the system?".

D. Data Analysis

Through the collection of interviews, observations and artifacts derived from our study, we were able to cross-reference and correlate our findings among all three data sources. Our modified case study analysis process aided in establishing an appropriate method to evaluate current operations and in establishing possible quality assurance process improvements pertaining to human error logging. According to our study, this laid down the foundation for support towards technological advancement. Figure 1 presents the structure of how the three data sources was analyzed and formed into cohesive conclusions for the study:
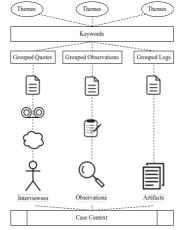

Figure 1: Modified case study process chain analysis based on various data sources [13].

Interviewees had perceptions based on their own experiences which were sound recorded, transcribed, and grouped into preliminary sets of code keywords. In order to reduce bias from our interviews, both researchers analyzed the interviews separately and the preliminary deductions were then merged into one common analysis.

Observations were conducted in the span of two weeks where notes were taken in regard to the MUSiC framework measuring both effectiveness and user efficiency.

Artifacts were collected and logged in parallel to our observations since the artifacts were used by assembly line workers during the course of our observations.

All three data sources were then outlined by code keywords which were then converted into major themes in our study that are outlined in our results. An example of this process is when we interviewed a worker and underlined key problems within process. After underlining these terms, the information was then cross-analyzed with the artifacts and the observations. An example is the time it took to manually input all the data into the ATACQ system which was mentioned in the interviews and re-affirmed during our observations.

E. Validity Threats

Validity indicates the reliability of the study which is vital for denoting unbiased results from a researcher's subjective standpoint [13]. Threats to the validity of the study are stated below.

Construct validity: The interview questions discussed with the subjects might be interpreted differently. Any misinterpretation of the question could result in skewed information being collected that does not fit the context of the question. This is mitigated by having a conversation-like interview to form a discussion based on the questions. When asking the interview questions, we prepared follow-up questions for our interviewee to aid in clarifying the answers they had presented us with. If there were any hesitation in comprehending the questions, we explained and extended the question until the respondent was fully aware of what we were asking and what information we needed.

Internal validity: Non-managerial workers might be influenced by group dynamics established in their team and might conform to having other worker's perceptions instead of their own. By guaranteeing that the interview is anonymous through signing a consent form and setting a comfortable environment for the interviewee, the threat to internal validity was avoided and/or decreased.

Triangulation allows for an increase in precision for our empirical research [13]. By attaining participants from two different working shifts, from two different teams, and from various levels within the organization, we were able to gather information and acknowledge whether our participants formed key conclusions regarding the current process of traceability of human error logging and their perceptions on the ATACQ system.

Reliability: As briefly stated in subsection-C of Research Methodology, both researchers separately analyzed the interview responses to form preliminary deductions that were then merged into one common analysis. By individually

examining the interview results, we were able to comprehend and analyze our perceptions to form unbiased insights of the research we had conducted.

IV. RESULTS

In this section, our results are presented in the context of the three data sources we have collected in our study.

A. In-and-Out Log Process

The results in this section help answer RQ1.1 because this theme refers to the perceptions key groups have on the current technology and the process. The time-sheet process theme emphasizes the standardized way of working in the assembly line. The discourse outlining the process describes the systematic way non-managerial workers must conduct their work starting from the point of manually logging themselves in at their station to the point of logging themselves out at each station in the assembly line.

Based on the interviews, all first line managers and non-managerial workers claim that there is a standardized way of working at Volvo Cars AB that all must follow in order to attain and maintain high-quality throughout the manufacturing process. Not all non-managerial workers follow the standardized way of working as multiple factors present themselves during the time of production. Some workers have developed their own working process that they feel more comfortable working with. Some workers simply forget to follow the standard or have small work-around depending on how light or heavy the production day is. One assembly line worker said:

"There are some occasions where the time I've been assigned to change before the line starts rolling, and which I don't have time to sign in before making my first car."

When asked what the standardized way of working is, the consensus of their interviews stated that the first thing workers must do at their station is that they must sign themselves in. One signs themselves in by writing the serial number of the car one starts with and stamps their identification number on the in-and-out log. Every car has a prefix number and a line number. Workers must follow standardized procedures and do the assigned tasks they are responsible for at their given station. When the signal for switching stations turns on, workers must sign out on their last car by writing the car number they last worked on and writing the next car number that their colleague will be working on.

B. Inputting Process

The results in this section help answer RQ1.1 and RQ1.2 because this theme refers to the first line managers and non-managerial workers' understanding on the current technology based on its quality-in-use. The inputting process occurs during production when a worker collects the in-and-out logs from the previous day. The worker responsible for interacting with the ATACQ system manually inputs the information from the handwritten in-and-out logs into the ATACQ system. This worker is responsible for inputting the car's serial number and the worker associated with the range he/she was responsible for at each station.

Assembly line workers responsible for manually inputting the in-and-out logs into the ATACQ system mentioned that the process is very time consuming and that multiple errors can be made. One worker has stated that:

"It takes time, and there is a lot of room for errors. So every time something is wrong with the car, you have to receive information approval that you have done something wrong. There is a way to be sure, but it takes a lot of time to check."

One top manager has also stated:

"It's a waste, it's a waste of time and paper and mostly time because it takes time to see what car one should log in and see the right car. Especially over at the door station when you have triple entries to log into the system. It's very hard and almost wrong inputs are made every day and in all shifts. After the 12 hours shifts on Sundays, it takes longer to input data into the system; it takes almost one and a half hours for some."

One first line manager stated:

"The logging process takes for about 45 minutes, but the reality isn't like that. For example, yesterday, just because of three or four people writing the wrong numbers in the in-and-out logs at the door station, it took a worker about two hours to do it. But just to say on the record we don't have so much of a problem here, but I know there are other groups in the factory that has a lot of issues with this process in the factory."

When asked how this process was conducted before the current system, two first line managers stated that there was less attention to detail where quality and traceability was almost at its minimum. With the current process, data from in-and-out logs are stored and accumulated in the system so overall traceability has improved.

The process for manually inputting data from the in-and-out logs into the ATACQ system begins with filling in required fields such as: factory, year, week, day, shift, team number, station number, and the car prefix. Once these fields are inputted, the worker begins with digitally logging in the data from the in-and-out logs. He/she is responsible for typing in an employee number and the range of the car's serial number associated to that specific individual at that current station.

Our observations – conducted over the course of 11 days regarding the amount of time it takes a worker to input all data from the in-and-out logs into the ATACQ system – are presented in Figure 2. Over the course of these days, two workers took turns to manually input all the in-and-out logs from the stations into the ATACQ system. During our observation period, the average time it took both workers to manually input data into the system approximately ranges between 30 minutes to 60 minutes.
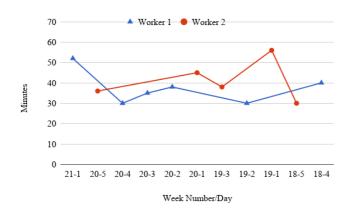
Figure 2: User efficiency measured by the amount of time it took the workers to achieve an output of manually inputting data into the ATACQ system.

Figure 3 presented down below depict the percentage of data that was inputted correctly the first time around without having it rechecked by the worker.
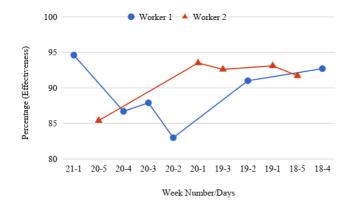

Figure 3: Effectiveness measured by the amount of correct inputs into the ATACQ system based the cross-analysis of observational data and artifacts of the in-and-out logs.

Effectiveness was measured by the following formula:

$$Effectiveness = (Quantity, Quality);$$

In association to Figure 2 and Figure 3, one first line manager commented that:

"Everybody has an ID number and after a while, the people who are responsible for manually logging the data into system know the ID numbers automatically. We have a list of employee stamps corresponding to their personal identification number… They input it into the system, they don't look at the paper with the list of identification numbers anymore, but they do wrong too as well. It is my responsibility to double-check every night and I look at the in-and-out logs and also the list of identification numbers. They put the numbers in and I check that they have done it right so errors do not go to the wrong people."

Please refer to Appendix C for the table showing the number of data entries in each in-and-out log observed over the course of 11 days.

C. Usability

The results in this section help answer RQ1.2 and RQ1.3 because this theme refers to the factors influencing the usability of the system based on users and their interactions with ATACQ. The relationship between the usability of the current technology and the artifacts derived in the whole process accentuates the perceptions from both the first line managers and assembly line workers. The code keyword in terms of usability refers to the satisfaction users have with the ATACQ system.

In relation to the inputting process and the measurements of user efficiency and effectiveness, workers have mentioned that learning the fundamentals of the system was not difficult but putting it into practice was a challenge. The day-to-day situations on how the in-and-out logs looked determined the difficulty of inputting the variables down into the ATACQ system. Examples of these situations occur when the writing on the in-and-out logs were illegible, if the stamps were scrambled, or if workers accidentally wrote the wrong car serial number down. The in-and-out logs could be difficult to read sometimes which makes it harder when inputting it into the ATACQ system. Workers responsible for manually inputting the in-and-out logs into the system constantly must keep their eyes on the screen and the paper in order to input the correct variables. There is a lot of unnecessary waste of paper and waste of time to log everything into the system. There is a lot of room for errors from both the manual transcriptions on the in-and-out logs as well as the action of manually entering data into the system. Double checking errors is time consuming but has to be done by both the worker the first time around as well as the first line manager once the numbers have been inputted into the system. Through the interviews, it is perceived that this process can be improved a great deal.

Both assembly workers and first line managers agree that the system is not user-friendly and can benefit from an update in the overall layout and functionality. One first line manager stated:

"From my point of view, the system is outdated. It feels old. I think the idea is good, but they didn't improve it… When you open the ATACQ system the interface is old, everything is old. Sometimes there is no logic. If I were to make my point, I believe it will be better to have pictures, but it doesn't take much you know like icons to navigate. Sometimes there is a term that teams know, but maybe an icon will tell you something more. Something like that would be helpful. All spots in the system can be improved a lot. I think they began with something and it just stuck."

The ATACQ technician – who has worked in the company for 32 years and has worked as a technician for the ATACQ system for three years – stated:

"I think it's good! But, I'm sitting with it all the time, it's the new ones who come that might comment on it. They're going to say what they think is wrong with the system. With those who have worked for a long time, they do not see what's is wrong with it."

D. Traceability

The results in this section help answer RQ1.1 because this theme refers to how errors are detected and traced in the process. An overview of the term traceability in our context refers to how efficient it is to track defects back to the worker responsible.

Interviews reveal that human errors are currently evident only after the in-and-out logs have been manually inputted into the system. At the end of the final assembly line, each car is checked for defects and that it achieves the quality standards the company demands before it reaches the customers. The process of effectively and efficiently tracking human error quality defects to the point of origin is vital as assembly line workers need to understand their error in their efforts to prevent the errors from occurring again.

One interviewee discusses how the traceability process does not happen in real time. One first line manager states:

"For the moment you cannot know the error the same day because it's not in real time. I don't think it is, I think that the ATACQ system works like that for the moment. You cannot get real time. I think it's because it's a progression line... when everything is finished you get the information back. So maybe it takes 24 hours."

Another first line manager states:

"Well, it depends on the mistake. If it has something to do with the software, it takes about half an hour until I get notice about it. The team after us, team 47C, is responsible for scanning with some type of software and they check the software and electronics if it is complete. But for example, if a piece of equipment is missing, it can take up to one day; the next day. For example, when we missed an equipment yesterday, I get notice about it now, for about one hour ago. The middle manager just told me."

Assembly line workers are worried that errors might be redirected to them although they were not responsible for them. This can be either from the mistakes made during manually writing in the in-and-out logs or mistakes occurring during input in the ATACQ system. Workers say:

- "Humans may make so many mistakes right. And I'm not sure if this system tells you about the mistakes every time. It doesn't get displayed to you."

- "I'm being assigned cars that someone else is stamping in for me in a PC. Which I don't find ok."

- "It depends also, you know the input is not automatic. They put it manually, if you typed wrong it will be wrong anyways. It's not bulletproof. There is some fault also."

- "The wrong issues mustn't come to the wrong people you know. Maybe he has done the car, but you get the blame for it just because of a worker typing two instead of three in the system, for example."

The ATACQ technician states:

"It would be pretty good not to write it by hand but then there must be scanners or things everywhere instead. Often if you're on the assembly-line and if you have to notify a fault sometimes they write it down by hand instead of going to the car scanning a barcode registering the fault, but no, some choose to write the car's serial number down to save the time. Then the wrong number could be written and then the wrong car will get registered into the system."

E. Process Improvements

The results in this section help answer RQ1.4 because this theme refers to interviewees' perceptions on how the process of traceability can be improved by gathering feedback from the individuals in the context of ATACQ, the overall work environment, and process.

First line managers discuss the ideas of tablets or having everything in digital form. They said:

- "The only thing you need is something like a tablet or you have a scanner, you can scan your id card."

- "I believe it will be better in digital form. It cannot be so difficult, I think maybe you have some kind of chip in your card and maybe you just swipe. Maybe you will have some kind of sensor when the car comes, the sensor knows which serial number it is or maybe like some kind of touch-pad."

Assembly line workers share the same perceptions that of the first line managers and that change improvements can be brought into the company especially in terms of the in-and-out log process and inputting process. Workers stated:

- "Everyone instead of a stamp should have a personal clicker. You just put it on the screen and then you sign in and everything. You don't need a pencil or anything else. The system should register the car. You see on the screen the car's serial number for example, 375. That's my car and I sign in and the system knows I am doing this car, and then I step out and the car gets registered to me."

- "If it is as easy I should arrive to the station, swipe the card or whatever and then swipe again when I have done my last car."

- "By the end of the day the system should know technically which cars we've been building during our shift since we stamp in and out at a specific time. So technically it should be a lot easier."

- "I think that you don't really need to write it down on the paper. You know there are digital systems right now, today. You can maybe change it to a digital system, I don't know. You should not need to do that, write it down on paper."

When asked why factory automation has not yet been adopted, the middle manager states how this has been discussed by higher management and the idea is currently on pause since there are a lot of proceedings and points to discuss. The middle manager believes that factory automation will be feasible in the future for the company.

I. DISCUSSION

How can technology *advancement* for enabling traceability for human error logging in the quality assurance process be *supported*?

In order to answer our main research question and formulating a set of feasible recommendations as a form of guideline to support the advancement of technology for enabling traceability in terms of error logging, the discussion has been broken down into three main sections.

A. Perceptions of the Current Technology

Regarding RQ1.1, on the perceptions key groups have in the organization in understanding the role of the current technology for the traceability of human error logging, it is perceived that groups relatively share the same perceptions. These perceptions reside in context of the nature of technology, technology strategy, and technology in use.

The results show that there is a standardized working process that workers are aware of, but do not always follow due to several reasons. These reasons are summarized below:

- Workers have developed their own process since it is easier for them to follow.

- Some workers simply forget the standard way of working especially when it is a difficult production day.

- There are occurrences during production where rotations take place prior before an assembly worker has the ability to finish their tasks on their supposed last car. This could be due to the production line stopping early or when the production line continues to roll regardless of the rotation.

In regard to the current technology – the ATACQ system – it is observed that the manual inputting process is very time-consuming, and errors can be made at various points in time during this process. Furthermore, a lot of paper is wasted due to this process. Restating what has already been presented in the results section, user efficiency based on the average time it takes a worker to manually input data into the system ranges anywhere between 30 minutes and 60 minutes in a working shift. These results are dependent on many factors during production. These factors are listed below:

- The amount of *andon* (a Japanese manufacturing term that is an element of Total Quality Control (TQC) "used for highlighting trouble areas within the production system" [15]) alarms rung for the need of assistance in the production line. The worker responsible for inputting data into the ATACQ system might need to stop his/her task and help the worker who rang the alarm if the first line manager is not present to help. This leads to delays in the inputting process.

- Problems and errors in the in-and-out logs due to illegibility of what was written, if the stamps were scrambled, or if workers accidentally wrote the wrong car serial number down. These factors affect the time it takes to manually input data into the ATACQ system.

- Inputting wrong information into the system due to the previous point mentioned or due to carelessness when inputting the data into the system without double-checking. This leads to delays as the data inputted has to be corrected.

Due to these factors, the effectiveness of correct inputs is also affected. Consistent quality cannot be guaranteed when inputting data manually into the system since double checking always needs to be ensured.

In terms of traceability with the current technology involved, results show that errors are currently evident only after the data from the in-and-out logs have been manually inputted into the system. Although traceability of errors has improved at Volvo Cars AB since the ATACQ system was adopted, it is perceived that the traceability process does not occur in real time and it takes approximately 24 hours for the error to be accounted for and linked back to the individual responsible for making such type error. Even through traceability is ensured by the process, the accuracy of error detection is not bulletproof. As stated by the interviewees, manually inputting incorrect data into both the in-and-out logs and/or the system may result in the fault being redirected to the wrong worker.

Their perceptions indicate that effectively and efficiently tracking human error quality defects to the point of origin has to be accurate and consistent.

In summary to answer RQ1.1; the workers, first line managers, middle manager, and technician seem to agree that the process has a lot of room for error, is time consuming, and a lot of paper is being wasted.

Concerning RQ1.2 on the relationship usability has with the current technology and the artifacts derived within this process, we can see patterns: mistakes in the artifact may also lead to mistakes made into the system. The term usability is defined as "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component" [3].

An example of this happened during our observation session (week 16-day 3) where it was noticed that one of the workers was spending over an hour and half inputting data into the ATACQ system. After conducting an interview with this worker and checking the artifact linked to this problem, it was revealed why this process was taking such a long time.

In the interview, the worker responsible for inputting the data for the previous day inputted the wrong prefix number (the number was off by one digit) during the shift due to a mistake written on the in-and-out logs. After manually inputting the data for three work stations, the worker realized the error and had to re-input all the data once again. This incident shows that mistakes will propagate longer than necessary and may lead to further delays which in turn affects the usability of the system.

B. Usability of the Current Technology

Regarding RQ1.3 on the factors which influence the usability of the system, the results show consistency of opinion among the first line managers and the assembly line workers. They recognize that the system is not user-friendly and can benefit from an update in the overall layout and functionality.

The technician who has been working at Volvo Cars AB for 32 years and has been working with the ATACQ system for three years gives a somewhat different opinion. He states that he does not see problems with the layout of the current system but he understands why newcomers might complain. This point of view is due to the technician's traditional way of working and his familiarity with the system.

The usability of the system is influenced by the overall process of how data is being manually inputted into the system. For example, the system does not validate the data that is being inputted into the system because it does not keep track of the production line (in terms of these in-and-out logs for traceability) in real time. As a result, the worker responsible for inputting data into the system has to double-check the data while he/she is working on this task. Furthermore, the first line manager also must check the data after the worker has completed his/her task.

C. Traceability of Human Error Defects

Regarding RQ1.4 on how the process for traceability of human error product defects can be improved, workers and first line managers have a number of concrete suggestions that are similar to one another.

Many of them suggest updating the technology to remove the paper aspect in the process as it is a waste, and have it replaced with a digital solution. Some of these suggestions include tablets to replace the paper in-and-out logs, key cards that have swiping functionality to register oneself at their station, or identification tags that can be machine read.

Additional suggestions discuss implementing a system where the cars are tracked in real-time and workers can be registered to their assigned cars in real-time. This will also help with the traceability of human error production defects as workers can be informed of their errors much faster as the human component has been removed from the system.

After interviewing the middle manager, it is clear that factory automation is achievable and is something that has been considered by Volvo Cars AB but has not yet left the discussion and planning phase since there is no timeline for when this will be adopted that we are currently aware of. Nevertheless, it is perceived that factory automation is something that will be beneficial for the workers, first line managers, middle managers, and the overall quality assurance process for error logging.

D. Supporting Technology Advancement

Our objective of our study aims to answer our research question of how technology advancement for enabling traceability for human error logging in the quality assurance process be supported.

As seen in the previous three sections, an issue has been detected in the quality assurance process for error logging in Volvo Cars AB. Key groups are in agreement that the current situation needs change as the process is time consuming, not environmentally friendly, and is prone to human errors. These current problems are also addressed in Warren Wolfe's paper where he outlines that manual data entry results in the loss of

productivity, profits, and even competitive advantage in the market [5].

The solution that has been also identified by these key groups is introducing new technology and automation on the plant-floor to remove the human element in the effort to solve this issue and to improve the quality assurance process.

Based on the perceptions of the assembly line workers, it can be stated that the current system does not provide them with all of the promised benefits of efficient error logging because these errors are reported with a delay (approximately 24-hours) and can be attributed to the wrong worker. Technology advancement – as mentioned in Section C – can improve this issue by providing real-time data and thus removing the delay caused by the current process.

As far as middle managers and first line managers are concerned, this technology improvement will help them achieve their objectives more efficiently. Middle managers will be able to oversee errors as they occur and first line managers will be able to point errors to their origin as soon as these errors are detected.

This solution is also supported by related work and presents the benefits of adopting factory automation. These include reduction in labor costs, improve product quality, improve quality of work life, and improved management control to name a few [12].

In the efforts towards the direction of future research and implementing the automated factory at Volvo Cars AB, we propose a guideline with a set of steps that can be followed and supported by existing work on the subject matter [8, 12]. These steps include:

1. Analyzing the current situation: this case study serves the role of completing this step and presenting the current situation based on the triangulation from three data source points. The perceptions of the key groups have been collected together with observations and artifacts that have been mentioned in the section titled *Perceptions of the Current Technology*. The results have been collected over the course of two weeks from the evening and night shift working entities from team 46C and 47C, but it is possible to form a generalization for all teams using the ATACQ system in regard to the in-and-out log process.
2. Establishing possible improvement techniques: the research conducted in this study also focuses on the perceptions of key groups and the improvements that can be made that are stated in the section titled *Usability of the Current Technology* and *Traceability of Human Error Defects*. The improvements are focused on the process and can be achieved by introducing new technology. The consensus formed from the interviews suggests that there must be a shift towards a real-time management system for assuring quality control in the process.

The next couple of steps are outside the scope of this case study, which was focused primarily on the quality assurance process for traceability of human error. The following steps are best left for future work and research which can be further

analyzed and investigated to adopt the new technologies involved, identified by our current study [4, 8, 12].

3. Understanding new technologies involved: this can be conducted through another study focused mainly on accurate costs and operating information. It is vital to understand what suppliers are involved and how competitors have solved this problem by introducing plant-floor automation.
4. Set new perspectives: Volvo Cars AB (based in Torslanda, Gothenburg) must re-analyze their traditional way of thinking in terms of manufacturing operations. Improvements and optimizations must be made for the entire process and not only for individual processes inside the factory. This requires management and industrial engineers to collaborate and share the vision of factory automation.
5. Involve the right people: to implement these changes towards factory automation, it is not only higher management that has to be involved. Everyone from the assembly line workers, suppliers and engineers have to be made part of this process to ensure their cooperation and to guarantee that the process fits within the work environment. The working culture at Volvo Cars AB already involves workers through their change initiatives as they play a vital role in the general manufacturing operations. We therefore perceive that Volvo Cars AB does not need to take any special initiative for this step as it is already an important component for their change initiative.
6. Automate in steps and keep track of changes and future improvements: automation has to be implemented in steps following a plan and implementing the most useful features first. Factory automation must begin at an origin yielding the least risk and greatest return. We believe that automating the in-and-out log process is a good place to start this process improvement towards adopting this new technology.

In our final effort to answer our main research question, we have answered our four sub-research questions. To summarize them, we have found out that key groups share the same perceptions of the system, errors appear in artifacts which impact the usability of the system, the usability of the system is mainly affected by the manual input process (both writing in the in-and-out logs and inputting this into the system), and improvements are desired by key groups – namely, factory automation. We can conclude that technology advancement begins with understanding the current situation in a company. Based on our theory of technological frames [6], having shared interpretations of the current technology and of the possible improvements shows that these can help in supporting technology advancement in an organization. Technology advancement can be further supported by the suggested guidelines that have been outlined in our discussion section.

V. CONCLUSION

This case study was conducted at Volvo Cars AB and was focused on studying the quality assurance process for error logging. The main research question investigated how technology advancement can support the traceability for human error logging. Three data sources were triangulated to form a cohesive set of results and interpretations. These data sources were interviews with key groups in the organization (middle manager, first line manager, non-managerial workers, and an ATACQ technician), two weeks of observations during the evening and night shift, and related artifacts derived from the process. Our findings indicate that the key groups share both the perceptions of the problem and possible solutions.

Technology advancement is seen as the solution to the problems faced by the working entities in the process. This can be supported by our findings and on existing literature on factory automation – which is the potential and feasible solution for the company. Our case study is meant to be a stepping-stone on which further research can be conducted in advancing the support of adopting full factory automation in Volvo Cars AB and in other manufacturing companies dealing with similar issues.

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Appendix A:
Plant Floor Visualization and Work Environment

Workers must be at their station when the production shift begins and are required to follow the standardized way of working at Volvo Cars AB. Workers are responsible for signing themselves into the in-and-out log sheets that are presented at each station on the balance before they begin their assigned tasks. They are required to write the serial number of the car they begin with and stamp their identification number on the same line. When the alarm rings – indicating a rotation shift – workers must sign out by writing the serial number of the last car that they have worked on and write the next car's serial number which his/her colleague will begin working with. Several andons are present in the balance for workers to ring in case they have any trouble during production.

During production, one worker is taken off the balance and replaced either by another worker available or the first line manager responsible for the team (e.g. first line manager from Team 46C). The worker taken off balance switches responsibility to work with the ATACQ system. The worker collects the in-and-out logs at each station from the previous day. Once all in-and-out logs from each station have been collected, the worker goes to the computer and opens the ATACQ system where he/she is responsible for transferring the written information from the in-and-out logs and manually inputs them in the ATACQ system for data to be registered.

Appendix B:
Interview Questions

The following questions presented below guided us during our Interviews. We used a semi-structured interview leading with open-ended questions that helped us in developing follow-up questions in order to draw out more information in regard to the candidate's assets. We aimed to have more of an open conversation with our candidates that allowed free discussions to be formed but still targeted our key concepts and questions pertaining to our main research question.

MAIN RESEARCH QUESTION: How can technology advancement for enabling traceability for human error logging in the quality assurance process be supported?

RESEARCH QUESTIONS	Middle Managers	First-Line Managers	Non-managerial workers / Assembly Workers	Technician
Introductory Questions	How long have you worked at Volvo Cars AB Final Assembly line as a middle manager? What was your position at Volvo Cars prior to being a middle manager?	How long have you worked at Volvo Cars Final Assembly line as a team leader? What was your position at Volvo Cars prior to being a team leader? Have you worked with other teams in the Volvo Cars Final Assembly line?	How long have you worked in your current team at Volvo Cars Final Assembly line? Have you worked with other teams before? Have you worked different shifts (day, evening, night) or at different balances?	How long have you been with Volvo Cars AB? How long have you worked with the ATACQ system? How long has the ATACQ system been used at Volvo Cars AB? Have there been any improvements in the ATACQ system over the course of the years you have worked with it? What do you think of automating this whole process in the factory plant? Many companies have factory automation, why hasn't Volvo adopted this yet?
RQ1.1: What perceptions do key groups in the organization have in understanding the role of the current technology for the traceability of human error logging?	What are the current activities performed to ensure that a defect is traced back to the individual responsible? How was this process done prior to the current one you	What are the current activities performed to ensure that a defect is traced back to the individual responsible? Are you responsible for	What is the standard way of working during your shift and reporting a possible error? Walk us through the process. Do you always follow	What is your role in regard to the ATACQ system? What are the benefits of using the ATACQ system and the current process involved with using this technology? (the

	have mentioned? Have you seen an improvement in terms of error detection from the prior process to the current process? What are the benefits of using the ATACQ system and the current process involved with using this technology? (the process of manually inputting information into the ATACQ system). What are the drawbacks? Are all errors detected and reported once the in-and-out logs have been inputted into the system? How accurate is the information reported? What do you think of automating this whole process in the factory plant? Many companies have factory automation, why hasn't Volvo adopted this yet?	inputting the in-and-out logs into the ATACQ system? Please elaborate your role in this process. How was this process done prior to the current one you have mentioned? Are all errors detected and reported once the in-and-out logs have been inputted into the system? How accurate is the information reported? How long does it take for an error to be reported back to the individual responsible? How are they made aware of their error? (If the person has worked with other teams) Is this the same process for other shifts? Other teams at the Final Assembly line? In regard to the ATACQ system, have you ever inputted anything wrong? Why is this so? How much time does it usually take for you to input the data into the system? What are the main issues you have with the current ATACQ system? What do you think of automating this whole process in the factory	this standard when working? Do you try following the steps you've mentioned daily at work? What are your responsibilities you have when working with ATACQ? Can you please walk us through the process? In regard to the ATACQ system, have you ever inputted anything wrong? Why is this so? What do you do when you realize that you have made a mistake? How much time does it usually take for you to input the data into the system? What are the main issues you have with the current ATACQ system?	process of manually inputting information into the ATACQ system). What are the drawbacks?

		plant? Many companies have factory automation, why hasn't Volvo adopted this yet?		
RQ1.2: What are the relationships between the usability of the current technology with the artifacts derived from the process and technology?	*Data sources were derived from an observational perspective and through artifacts during our case study.*			
RQ1.3: What factors influence the usability of the system?	*(We are not sure whether this question is necessary or applicable to higher management since they are not the ones using the system on a day-to-day basis) How do you find the layout of the system? The design? Is it easy to navigate through the system?	Was it difficult understanding and learning how to use the ATACQ system? How do you find the layout of the system? The design? Is it easy to navigate through the system? What do you find most frustrating or challenging regarding the system?	Was it difficult understanding and learning how to use the ATACQ system? How do you find the layout of the system? The design? Is it easy to navigate through the system? What do you find most frustrating or challenging regarding the system?	How do you find the layout of the system? The design? Is it easy to navigate through the system?
RQ1.4: How can the process of traceability of human error product defects be improved?	If you can change something about this overall process, what would you change? And why? And what can be improved?	If you can change something about this overall process, what would you change? And why? And what can be improved?	If you can change something about this overall process, what would you change? And why? And what can be improved?	If you could change something about the ATACQ system, what would you change? And why? And what can be improved?

Appendix C:
Number of Data Entries in Each In-and-Out Log at each Station per Day

Station/Week	18/4	18/5	19/1	19/2	19/3	20/1	20/2	20/3	20/4	20/5	21/1
Dörr höger	33	33	63	33	33	60	30	27	30	33	54
Dörr vänster	33	33	63	33	33	60	30	27	30	33	54
Balja	11	10	19	10	11	15	11	10	9	11	19
Avplock	11	11	22	11	12	20	10	9	12	11	19
Påkoppling	12	11	22	12	12	20	10	9	12	12	19
X-man	12	11	21	10	10	20	10	9	10	11	18
Centerstack	11	12	21	12	11	20	11	9	10	12	20

The table presented above indicates the amount of data points presented at each in-and-out log sheet during the course of 11 days. Days are organized as week number followed by the index of the working day; starting from Sunday (1) to Friday (5). More data points are visible for Sundays because the shifts are approximately 10-12 hours compared to usual shifts that are 5.5-6 hours.