Usage Data Analytics for Human-Machine Interactions with Flexible Manufacturing Systems: Opportunities and Challenges

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Abstract. *Analyzing data from complex production systems and processes can be used in improving existing products, processes, and services, and innovating novel offerings. We report the findings from a six-month case study with a company developing flexible manufacturing systems. During a collaborative development process of a data analytics and visualization tool, our goal was to identify potential metrics, business opportunities, and challenges when utilizing logged data of end-users' human-machine interactions in development activities. Our key contributions include a characterization of the potential usage data metrics to be logged and visualized, identification of opportunities this data entails for business, and discussion about the challenges related to usage data logging in the studied context. Finally, we propose topics that should be considered in the organization before investing in usage data logging in the context of flexible manufacturing systems.*

Usage data logging; visual data analytics; human-machine interaction; flexible manufacturing systems; multi-dimensional in-depth long-term case study

I. INTRODUCTION

Suppliers of complex industrial systems in metals and engineering industry are increasingly interested in using various types of log data from systems after their deployment on the market. Industrial information systems record and store data about the status and how end-users use and interact with the complex underlying production systems and processes. In the context of this paper, logged usage data means data logged from system use based on end-user interactions. This includes the system features and functionalities used by end-users along with the associated metadata (e.g., time, data input, and automation state). Although some analytics and visualization solutions exist on the market for companies to use on their own manufacturing data, such as Bosch's manufacturing analytics solutions [1], commercial analysis suites for supporting the business operations and development of supplier companies themselves, who provide manufacturing software and solutions for their customers, are rare or non-existent. One of the challenges is that the data to be collected and used has to be identified to be relevant to the product and business development in the supplier company. This calls for understanding the relevant information, usage goals, and the potential users of the analytics and visualization tools to support the development of useful tools.

Little previous research exists specifically in the domain of exploratory user interaction analysis of complex industrial systems, particularly regarding the expectations supplier companies have for using such data. We contribute to this research topic with empirical findings by exploring 1) which usage metrics should be logged and analysed, 2) what potential business opportunities usage data logging enables, and 3) what are the challenges and obstacles related to usage data logging in the context of manufacturing automation? These questions were studied over a case study during which we developed a visual analytics software framework for a company developing industrial manufacturing automation systems for the metal industry. In addition to describing our study method and the visual analytics tool, we will discuss and compare the results with related studies and propose a set of questions to be addressed in companies before investing in usage data logging. Although it presents significant challenges in terms of data acquisition and analysis, utilizing logged usage data was considered a promising avenue for improving both the manufacturing system supplier's and customers' production processes.

II. RELATED WORK

Visualizing temporal patterns is an active area in the domain of visual data analytics. The process encompasses both the extraction of patterns and presentation of the results. For example, Fails *et al.* [2] demonstrated a system that allows the user to create visual pattern queries by interactively defining sequences of an arbitrary number of events and the interleaved timespans. Results are visualized in a two-dimensional table with matches on rows and time on the horizontal axis. Discovered patterns are represented in ball (event) and chain (timespan) fashion. In the LifeFlow interface [3] the focus is more on presenting an effective overview of all possible event sequences and the temporal spacing of events within the sequences. Multiple interactive features allow for a viewing of details to drill into the constituent events. The DataJewel architecture [4] integrates

the database component (linking multiple data sources), algorithmic component (provide access to temporal data mining algorithms), and visualization component – a technique called CalendarView, which leverages users' familiarity with common visualizations such as calendars and histograms. With the interface, users can interactively map attributes to colors to explore hypotheses and apply their knowledge of the data domain, or utilize temporal mining algorithms to create the mappings based on discovered event patterns. Frequence [5] seeks to simplify the process of mining temporal patterns from real-world data. A modified Sankey layout is used to represent patterns as a sequence of nodes (events) and edges (subsequences of the events). Thickness of edges is used to represent pattern frequency and color the relationship of the pattern to an outcome variable of interest. Prominent subsequences can be inferred from the thickness of combined multiple edges across events. Patterns of interest can be dynamically defined by clicking on multiple nodes and the patterns can also be filtered and viewed at multiple levels of detail to account for the hierarchical nature of event data.

Relatively few examples exist in research where visual analytics tools are specifically applied to the analysis of logged user interactions in complex industrial manufacturing systems. Holzmann *et al.* [6] studied the acquisition and visualization of user interaction data from a touch screen based robot controller to find cost-efficient solutions for the usability evaluation of handheld terminals in the automation industry. The goal was to help developers to identify possible problems in users' workflow (e.g. navigation problems or unused functions) based on user interface interactions. Navigation path analysis and usage intensity were identified as the most important topics for data logging, based on interviews with a programmer and two project managers in automation industry enterprises.

Grossauer *et al.* [7] created a prototype for automation industry to visualize navigation flows through an application. After applying the visualization tool to multiple datasets, they recommend such tools should include 1) a wide variety of filters and 2) views that show the whole navigation data and allow the inspection of individual sequences. Further, Kandel *et al.* [8] highlight opportunities in supporting visual analytics workflows in enterprise settings, related to the discovery, management and profiling of data. Such opportunities include being able to do early-stage analysis on partially structured data (such as log files), utilizing existing data warehouses without a need for explicit data migration across systems, and providing direct manipulation interfaces for data acquisition and management.

One of the main challenges of data processing and analysis is to facilitate analysts' tasks. Experts can be working on challenging problems to which no direct answer is available, and they participate in inventing, innovating or discovering activities [9]. Tools designed for these activities should support human performance, error-free use, creative exploration, hypothesis building, and history keeping, as well as collaboration and dissemination to others [9]. One of the aims of producing such tools can be thought of as increasing the analytics literacy of the development team [10]. Interactive data analysis should not only help improve the productivity of technically proficient users but also be accessible to users with limited programming skills [10]. Several different types of enterprise data analysts exist, from proficient programmers to users of dedicated analysis applications [11], and these different user groups with varying skills need to be taken into account and identified as potential users of data analytics and visualization tools.

In big data analytics, a domain that our research context resembles, the analysis tasks are exploratory and happen on-demand, the results are aimed at audiences with little background in data science, and with the need to produce reproducible and reliable results [12]. In effect these tasks fall within a continuum that spans activities focusing on producing known, low impact insights (e.g., static reports) to activities that aim to uncover high impact, previously unknown insights (e.g., real-time alerts, predictions, and recognition of patterns) [13].

Work related to data logging in information security context may also provide insights from the product development perspective. For example, SANS [14] and OWASP Foundation [15] have suggested activities to be logged by critical systems from a security standpoint.

A common approach to acquiring usage data is to instrument software applications to log user interaction events. A straightforward but laborious way is to add logging instructions directly into source code, although this approach may introduce new complexity into the system [16]. As an alternative, many instrumentation frameworks aim to reduce the burden on the application developer by semi-automatically logging relevant interactions, e.g., [16, 17] and several Web analytics frameworks such as Google Analytics. The complexity and level of abstraction of the instrumentation varies by its purpose, but when implementing instrumentation and analysis techniques, one should consider the levels of abstraction of the captured events, how higher level interactions are composed of lower level events, and how to capture contextual information [18].

In our case, we focus specifically on the analysis and visualization of end-user interactions with the production system. The use of interactive systems can be logged as a part of usability and user experience (UX) research with the aim of identifying potential problems and issues affecting the experience as in our case. Such logging can address multiple needs within the product development organization. UX measurement can include the use of device functions, access of features by different user groups, or identification of changes in user behavior [19].

Prior research has identified company needs on data analytics and visualization in the domain of metals and engineering industry [20]. The identified needs for data types are: 1) usage combinations, such as the customer's production type and in what mode they use the system, 2) patterns of use, 3) types of user groups and profiles that can be found, 4) summarizations of the system use based on logged data (logs of events, system status, user actions, interactions etc.), 5) identifying problem or fault situations (individual and possible patterns), and 6) changes in use (such as features) over weeks or months.

III. CASE STUDY

Our case study had three interrelated aims that focus on understanding the use of logged usage data. First, we wanted to understand what kind of logged usage data from the customers' systems are relevant to the supplier in manufacturing industry. This information can support the developers of data analytics and visualization tools in what kind of visualizations are required in the context of FMS to present the desired data.

Second, to justify any investment of resources in usage data logging we needed to understand what business opportunities it can provide in the context of FMS. With this, we can better evaluate the value of usage data logging for different stakeholders.

Third, by identifying challenges specific to usage data logging in FMS context, future research can focus on tackling these obstacles.

Based on our experiences we propose a set of questions for stakeholders in manufacturing system supplier companies interested in utilizing usage data logging in practice to support their business.

A. Method

The methodological approach of the case study was based on collecting usage data and participant feedback during an agile development process of a data analytics tool in collaboration with a company developing flexible manufacturing systems. The analytics tool development process was inspired by Shneiderman *et al*. [7 9] multi-dimensional in-depth long-term case studies (MILC) approach. The MILC approach combines field studies, with participant observation, interviews, surveys and automated logging of user activity. In this paper, we focus on the qualitative results of user observation and interview sessions. While the exact interview questions developed during the study period, the main themes we discuss in this paper were:

- Which usage data should be logged and/or visualized?
- What are the potential business opportunities enabled by usage data logging?
- What challenges are related to usage data logging in industrial context?

B. Study context

Our study took place in the context of industrial manufacturing automation systems called flexible manufacturing systems (FMS). FMS are typically used in metal industry for manufacturing parts by using different metal operations [21]. In FMS, the production is typically conveyed on pallets [22], on which the parts are attached for machining. FMS is used to automate pallet-based machining for manufacturing small batches of different types of products. Goal is to flexibly change the manufactured product without a need for changing the whole factory layout [21]. In FMS, software and hardware are combined to provide a manufacturing company an easily modifiable, dynamic manufacturing system.

FMS is operated via a combination of graphical user interfaces (used e.g. to enter new manufacturing programs, control the program parameters and modify system status) and physical or software coded buttons for pallet control. In this study, our primary focus is on user interactions by the human operators on the workshop floor with the FMS elements of the manufacturing system.

The case study company was interested in collecting and analyzing usage data of their FMS systems after they had been supplied to the customers. Usage data was expected to benefit the company's R&D, customer support, and service business in the future. While the FMS systems already logged data of their behavior, it was mainly used for on-demand maintenance. The log data portraying users' interactions with the system provided a new channel to study the product usage.

C. Participants

A purposive sample of six participants working in the case study company participated in the study. Table I presents the participants' roles, responsibilities and familiarity with analytics tools. For data analytics and visualization purposes, four of the participants used MS Excel. One developer also used unspecified data base tools. One developer (ID6) left the study midway, but his responses until then were included in the analysis.

D. Data analytics and visualization tool

Next, we describe the developed data analytics tool, "UX-sensors", at the end of the study period. The user front end of UX-sensors is an interactive web application. It consists of a data selection view and the main data browsing view with timelines and analysis tools. The main data browsing view consists of six main elements that are numbered in Fig. 1. The elements are: 1) overview panel, 2) overview timeline, 3) detail timeline, 4) additional filters, 5) tabs, and 6) main filters.

The overview panel contains general information about the selected observation window e.g., the number of found events, most frequent events by value, the average usage session length, the average number of operations per session and the number of error events. Events are split into sessions

TABLE I. THE CASE STUDY PARTICIPANTS' ROLES AND FAMILIARITY WITH DATA ANALYTICS TOOLS.

ID	Role	Main responsibilities	Use frequency of data analytics and visualization tools?
1	Director	Manages research and innovation development	Weekly
5	Product manager	Manages product life cycle service offerings	Monthly
4	Team leader	Manages technical customer support team	Weekly
2	Team leader	Manages software development team	Not at all
3	Software developer	Front-end & back-end development	Less than once a month
6	Software developer	Front-end development	Less than once a month

Figure 1. Main data browsing and analysis view. The elements are: 1) overview panel, 2) overview timeline, 3) detail timeline, 4) additional filters, 5) tabs, and 6) main filters.

based on maximum time duration between successive events. The default value is five minutes and it can be changed in settings. The overview timeline displays the overall number of events by the hour and works as a filter where the user can restrict the further analysis to a shorter observation window. The detailed timeline displays the individual events within the observation window. By hovering over an event, detailed information is displayed. The user can also add additional notes directly to the timeline. The additional filters element can filter the event set further. In our study setup, six main filters were available: factory, observation window (if multiple windows selected), system, user, level and feature.

The tab elements display processed information about the selected events and provide tools for further exploration of the data. Used features tab displays a line graph of feature use over time and a complete list of features and feature-value pairs with count and percentage of total events. The data table can be sorted by each column and filtered by search. Errors and recovery tab provides a list of the most common errors, average recovery time and user interaction sequences during error recovery. Error recovery time is estimated as the duration between the last successive error event and the first following user interaction (i.e., event that is not an error or warning). Frequent sequences tab is used to calculate and display the most frequently occurring sequences. This is done by splitting the events into sessions and then looking for similarities in the event sequences within the sessions. Through the search tab single events or sequences of events can be searched by defining key-value pairs consisting of e.g., feature and value. Data entry tab is for exploring events indicating user data entry and user interaction sequences during data entry. Lastly, the main filters element can contain up to two filter panels on the right side of the timelines.

E. Procedure

Before the first group meeting we conducted a background survey, where we asked for what purposes the participants would like to use logged usage data. Five iterations were made to the data analytics tool during the six-month study period. We had two group discussion sessions and three individual observation sessions with each participant. In the observation sessions, participants could freely use the updated tool for exploring the available log data. During the session, the researcher encouraged the participant with questions such as ”what are you thinking now?” The session ended with an interview. Each session was recorded with a video camera and lasted approximately one hour.

F. Analysis

The written notes from the sessions were updated based on the videos and transcribed interviews. The interview data were analyzed by coding responses to descriptive categories.

The main categories included benefits, challenges and future opportunities for usage data logging. Finally, the number of comments in total and by separate respondents for each code were summarized to identify the most discussed topics.

IV. RESULTS

The background survey results (n=6) suggest, that the respondents would like to use logged usage data to a) increase knowledge about customers (4 responses), b) increase knowledge about end-users (4), c) improve remote customer support (4), d) support maintenance (3), e) support training and development of training material (3) and f) develop their service business (3). In addition, usage data could be used to compare how customers' different work teams use the product.

A. Usage metrics to collect and visualize

Table II lists the usage metrics and related data types that at least two respondents were interested in to collect and/or see visualized. Next, we will discuss the most often mentioned topics in more detail.

Frequency of system feature use seemed to represent a core data for understanding the system use. The director (ID1) commented that feature usage can help in making development decisions: focusing on popular features and studying the reasons behind unused features. There were also some new features in the system that the supplier had no usage information about. Use frequency of features also acted as a stepping stone towards why-questions, that may require direct contact with end-users. For example, one of the developers (ID3) could not figure out a reason for an unusually occasional use of a specific feature. The product manager (ID5) also proposed that the knowledge of feature use could work as a reference for new customers in sales or marketing when showcasing the most popular features. Finally, feature use frequency might inform user interface (UI) developers optimizing the UI.

A possibility to **combine different logs** from various systems on one site or between several factories around the world for visualization purposes was considered valuable for the supplier's management and customers in supporting fleet management. Per the director (ID1), combining usage data with other key indicators, such as **utilization ratio of the system**, could provide more information about events leading to system downtime periods.

User actions before and after events could help customer support to understand what users did before a specific error event and how they tried to solve the problem. A quote from the customer support team leader:

…it would be interesting to know… what kind of operations the user has done to recover from this error… when one needs to use the system in a way that differentiates from everyday use, what do they do then? Do they leave it or will they try something? (ID4)

Inspecting the **long-term statistics** of usage data could reveal repeated usage patterns that are inefficient, suggesting a need for user training or UI redesign. The product manager proposed that a combined long-term data (e.g., over a 3-month period) from several customers showing similar usability issues could convince stakeholders of the need to improve the shop floor UI. Furthermore, **event sequences** that show repeated usage patterns with specific users and systems may reveal possible problems in the UI design, such as navigation issues.

TABLE II. STAKEHOLDERS' INTERESTS FOR USAGE METRICS TO BE COLLECTED AND/OR VISUALIZED.

Interests of stakeholders	Respondents
Use frequency of features	5
Combining different logs	5
User actions before / after event	5
System usage ratio	4
Long-term statistics	4
Event sequences	3
Log data from specific user	3
Log data from specific machine / app.	2
Remote customer support activities	2
Use frequency of UI elements (e.g. buttons)	2
User navigation in UI	2
Frequency of same error over time	2
Differences between users	2
Usage of new features	2

Although **collecting log data from a specific user** entails legal and privacy issues that should first be resolved, the respondents considered this as an opportunity to offer tailored training services. One of the software developers (ID2) suggested that if a user seems to be making repeated systematic errors in the handling of the system, training could be offered for this precise use case.

B. Business opportunities for logged usage data

Discussions with the stakeholders revealed five business opportunities supported or enabled by usage data logging.

Continuous user interface development. A systematic approach to collect and analyze usage data from the manufacturing systems used by customers could offer developers and UI designers a direct channel to understand how their products are used from the start to the end of their life-cycle. For example, when new systems are installed in a customer's factory, developers may get very limited or even misleading information about the daily usage patterns:

Our knowledge from the users' way of using this is mainly guesswork. Yes, we see it when the system is being implemented, but there is so much fuss going on that it maybe does not represent routine day and routine use. (ID3)

Major software updates were seen as fruitful instances for collecting log data to inform developers:

There is a good chance for learning, since usually something changes in the update. A) does it work although the bugs should have been noticed before… and B) how the users use the new version, are they taking advantage of the new features at all or were they waste of time? Can the users find them, has the training been successful or were they trained at all? (ID3)

Logged usage data can help developers understand how users navigate in the UI, how features and UI elements are

used, and what usage patterns emerge. For example, if users repeatedly use long navigation paths or rarely use UI elements that are on the main view, this can decrease use performance and may require changes in the UI. After identifying interesting usage patterns from log data, the emerging why-questions can be studied with qualitative user research methods such as interviews or user observations.

Improve the quality of customer support services. The customer support team uses log data on a daily basis when inspecting what events led to a problem and what events followed. Especially during complex error events, customer support and developers browse and compare text logs from various machines and related services to get the overall picture of the chain of events. Usage data would provide one more source for this investigation process. An easy way to browse and visualize the users' actions and system events on the same timeline could support the inspection process, resulting in more detailed solutions and instructions for the customer to avoid similar problems in the future.

While end-users may have difficulties in recalling the detailed chains of events and exact time when an error occurred, usage data logs show without doubt when and what really happened. This can save time, especially when preparing for maintenance visits at the customer's site.

New opportunities for customer training offers. New service business opportunities can be found by identifying inefficient use or repeated error situations of the customer's system based on usage data. These findings can be used to support e.g. an offer for a tailored training package for the customer's workshop floor personnel or even individuals if usage data allows recognition on this level:

...we could log the usage to see if the user tries to take many actions that are not allowed, so if this happens often then it could indicate that there is a need for additional training. (ID2)

The director (ID1) proposed that training offers could also be planned based on the most and least used features.

Customer reports that provide additional value. Customer reports are currently manually compiled based on ad hoc requests. The product manager suggested that periodic reporting of the status of the customer's systems might be useful to the customer and that the developed analytics tool could provide data for such reports in the future. Reporting logged usage data over longer time periods, such as months or years, could provide value for customers.

The customer support team leader was intrigued about the possibility of creating automatic reports from the logged usage data that could easily be modified and shared with customers. Such reports should be well prepared summaries, since factory managers usually have little time to spare. Clear visualizations of the data should help in skimming through reports intended for executives.

Evidence for accidents. The respondent from customer support (ID4) noted that log data acts as an evidence in case of any accidents at customer's factory when using the FMS. When discussing the liability for damage, log data may provide evidence of user actions and whether the system was working correctly. For example, log data may show that users had turned off some automated safety functions before the accident. As the price of material damages can be very high, the effective use of log data could result in significant monetary savings for the supplier company.

C. Challenges related to usage data logging

In this section, we present the challenges and obstacles related to the usage data logging in FMS context that at least three of the respondents mentioned during the interviews.

Analytics skills and context knowledge. The main challenge that all respondents brought up was that interpreting logged usage data requires specific knowledge of the system and the context at the customer's factory. As one of the developers commented:

...it requires a lot of interpretation and knowledge of how the system works and is built. I assume that the project manager did not get much out from this. I am so much more familiar with this stuff, so that when I see this sequence here, I see those dialogs and buttons in my mind. (ID2)

If usage data is intended to provide additional value for the customer e.g. in the form of periodical reports, the "raw" usage log data should first be analyzed by the supplier:

Perhaps this could be somewhat useful for customer's people in production and maintenance, but the data should first be well refined: what to do and what are the recommended actions. As such, it is not valuable for them. It must be in more natural language. (ID4)

Missing data types. Practitioners in different roles were interested in some data types that the FMS did not currently log or that were not imported to the UX-sensors tool:

It would be nice to have the error code that could be used for searching. It is not always available in our system. (ID4)

...what device were they using at this moment? It should also be somehow added to this data. However, this is probably not available in the logs. (ID3)

One of the developers had the impression that logging is commonly added late when problems start to emerge or when there is a need to know something.

Data quantity. The sheer amount of available log data distributed across log files from several sources underlined the need for efficient searching and filtering functions:

Going through logs is challenging as there are thousands of lines of data and it can easily take half an hour to even find the correct time. We do compare different logs at the same time. (ID4)

A data analytics tool with easy to use timeline visualizations and recognizable codes for different types of events might support the searching of specific events. Over the time, users might learn to read the visualizations and specific patterns that help pinpoint the beginning of interesting events.

Access to log data. The director noted that agreements with customers should be made regarding the use of log data to be able to utilize the data efficiently and avoid any disputes over access in the future. If the data are used for business purposes, customers should receive in exchange something that provides value for their operations:

...if we use it (data) for doing business then primarily the customer wants something in exchange. It could be, for

example, reports or propositions to develop their operations. Even mobile user interfaces. Things that create value. (ID1)

To summarize, manufacturing companies should create systematic processes for accessing, collecting and transferring log data from the customers' systems to better utilize the data for analysis.

V. DISCUSSION

The identified potential usage metrics to be logged and visualized in our study were in line with the overall data and information needs identified in [20]. When logging user interaction with the system in this context, the most relevant themes to start with seem to be finding specific events and user actions around them. A specific need highlighted by our study was the combination of logs from different services in the same analysis tool, for example by visualizing all events created by human-machine interactions and by different digital services on the same timeline. This would reduce the need for alternating between different log files and searching correct timestamps when following the chain of events. Adopting an architecture similar to DataJewel [4] could reduce the complexity of managing separate datasets originating from different modules of the manufacturing system. On the visualization side, an approach similar to LifeFlow [3] could be adapted to interleave events of interest from multiple systems into a single timeline and allow digging deeper into the data on demand.

The proposed business opportunities in our study reflect the expected benefits identified in [20]. Both studies highlight the log data potential to 1) support product development and customer support (teleservice) activities, and 2) provide novel opportunities to offer customized training to customers. Practitioners in supplier companies expect that log data related to tracking the production and efficiency of system use could provide value for customers (ibid.). In our case study, the proposed medium for communicating these data to the customer was a periodical report that the customer could get in exchange for the data or as an additional service.

One interesting finding in our study was using the log data as an evidence during accidents or dangerous situations, where it is important to inspect if the system has functioned correctly, as this can settle who is responsible for the damage. Utilization of information logging standards [e.g., 14] can support both the supplier and customer in preparing for such situations. As a related concern, visualizations that visually encode the temporal properties of the event sequences (e.g., [2, 3]) could assist in assessing the nature of usage patterns preceding faults; for example, whether the pattern is an isolated issue (e.g., erroneous commands carried out by a user) or a more systematic issue that recurs periodically and could indicate a system level problem.

Knowledge of how the FMS is built was considered as a requirement to get full advantage of the logged usage data. Still, an analytics tool should provide an easy access to the key usage metrics, such as the most and least used features, which interest the majority of stakeholders. As the analytics literacy of the team improves over time, more people might take advantage of such tools in the future [8 10].

As suggested by one respondent, logging capabilities may be implemented afterwards only when need arises. Logging requirements should be discussed during the early stages of the industrial system's development process, as this could potentially solve some of the challenges we identified: accessing logged usage data and lacking the log data of specific features. Reflecting on our experiences and the identified challenges during this study, we propose stakeholders in manufacturing companies consider the following questions before embarking on usage data logging:

- **Possibilities**: What type of usage data and related data from the system and context can be logged?
- **Goals**: What do we want to learn from these data? What value can these data provide and for whom?
- **Data analysis**: Who has the requisite skills and context knowledge to analyze the log data?
- **Data access and security**: How can the log data be accessed? Who owns the data? How will the data be transferred and stored? How do we ensure security?
- **Tools and data wrangling**: Which data analytics and visualization tools are suitable for the needs of different stakeholders? How much data wrangling is required to import the raw log data to these tools?

While not an exhaustive list of all questions regarding data logging, we argue that discussing these topics with stakeholders representing different roles in the company will ensure that their needs are acknowledged, leading to the more versatile utilization of logged usage data. Stakeholders from management, product development, design, customer support and marketing should be consulted, as well as customer's representatives, before deciding which data to capture. A systematic process in place for effortlessly logging and importing usage data into an easy to use analytics tool should also motivate those stakeholders who are less familiar with analytics. The proposed questions can serve practitioners working also in other contexts, including different web-based services, mobile systems or industrial systems that enable the logging of end-user interactions.

Limitations and future work. Our case study results reflect only the views of a small sample of different stakeholder roles. Future research should inspect the views from marketing, sales, user training and customers. Another interesting question relates to data ownership and the value proposition for customers in sharing logged usage data with the supplier. Understanding how end-users react towards the logging of their actions will be critical for the viability of data analytics in the industrial context.

VI. CONCLUSIONS

In this paper, we present potential usage metrics and identify business opportunities and challenges for usage data logging in the context of flexible manufacturing systems (FMS). We propose a set of questions to support practitioners planning to utilize usage data logging in their product development activities.

Data were gathered during a six-month collaborative development project of a visual analytics tool prototype with six practitioners from a FMS supplier company. We

identified a need for combining usage data and system event logs in the same visualization timeline to support the analysis of error situations. Logged usage data were seen beneficial in user interface development, solving error situations and as evidence in accidents. User training offers and periodic reporting based on usage data could provide value for customers. Required analytics skills, data quantity, and accessing data owned by customers were the key challenges in utilizing log data. In future, empirical studies regarding the realization of the opportunities or ways to overcome the identified challenges would be valuable for practitioners in FMS and related industrial contexts.

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REFERENCES

[1] Bosch Software Innovations, https://www.bosch-si.com/solutions/manufacturing/data-analytics/manufacturing-analytics.html

[2] J. A. Fails, A. Karslon, L. Shahamat, and B. Shneiderman, "A visual interface for multivariate temporal data: Finding patterns of events across multiple histories," Proc. IEEE Symp. On Visual Analytics Science And Technology (VAST), IEEE Computer Society, 2006, pp. 167-174.

[3] K. Wongsuphasawat, J. A. Guerra Gómez, C. Plaisant, T. D. Wang, M. Taieb-Maimon, and B. Shneiderman, "LifeFlow: visualizing an overview of event sequences," Proc. SIGCHI Conference on Human Factors in Computing Systems (CHI 11), ACM, May 2011, pp. 1747-1756, doi:10.1145/1978942.1979196.

[4] M. Ankerst, A. Kao, R. Tjoelker, and C. Wang, "DataJewel: Integrating visualization with temporal data mining," in Visual Data Mining: Theory, Techniques and Tools for Visual Analytics, S. Simoff, M. Böhlen and A. Mazeika, Eds. LNCS 4404, 2008, pp. 312-330.

[5] A. Perer and E. Wang, "Frequence: interactive mining and visualization of temporal frequent event sequences," Proc. 19th international conference on Intelligent User Interfaces (IUI 14), ACM, Feb. 2014, pp. 153-162, doi:10.1145/2557500.2557508.

[6] C. Holzmann, F. Lettner, C. Grossauer, W. Wetzlinger, P. Latzelsperger, and C. Augdopler, "Logging and Visualization of Touch Interactions on Teach Pendants," Proc. 16th international conference on Human-computer interaction with mobile devices & services (MobileHCI 14), ACM, Sept. 2014, pp. 619-624, doi:10.1145/2628363.2628429.

[7] C. Grossauer, C. Holzmann, D. Steiner, and A. Guetz, "Interaction visualization and analysis in automation industry," Proc. 14th International Conference on Mobile and Ubiquitous Multimedia (MUM 15), ACM, 2015, pp. 407-411, doi:10.1145/2836041.2841218.

[8] S. Kandel, A. Paepcke, J. M. Hellerstein, and J. Heer, "Enterprise data analysis and visualization: An interview study," IEEE Transactions on Visualization and Computer Graphics, vol. 18, Dec. 2012, pp. 2917-2926, doi:10.1109/TVCG.2012.219.

[9] B. Shneiderman and C. Plaisant, (2006). "Strategies for evaluating information visualization tools: multi-dimensional in-depth long-term case studies," Proc. 2006 AVI workshop on BEyond time and errors: novel evaluation methods for information visualization, ACM, May 2006, pp. 1-7, doi:10.1145/1168149.1168158.

[10] B. Medler, M. John, and J. Lane, (2011). "Data cracker: developing a visual game analytic tool for analyzing online gameplay," Proc. SIGCHI Conference on Human Factors in Computing Systems (CHI 11), ACM, May 2011, pp. 2365-2374, doi:10.1145/1978942.1979288.

[11] J. Heer and S. Kandel, "Interactive analysis of big data," XRDS, vol. 19, Sept. 2012, pp. 50-54, doi:10.1145/2331042.2331058.

[12] D. Fisher, R. DeLine, M. Czerwinski, and S. Drucker, "Interactions with big data analytics," Interactions, vol. 19, May 2012, pp. 50-59, doi:10.1145/2168931.2168943.

[13] Q. Liu, M. Vorvoreanu, K. P. C. Madhavan, and A. F. McKenna, "Designing discovery experience for big data interaction: a case of web-based knowledge mining and interactive visualization platform," Proc. Second international conference on Design, User Experience, and Usability: web, mobile, and product design - Volume Part IV (DUXU 13), A. Marcus, Ed. Springer-Verlag, vol. Part IV, July 2013, pp. 543-552, doi:10.1007/978-3-642-39253-5_60.

[14] SANS Information Logging Standard, https://www.sans.org/security-resources/policies/server-security/pdf/information-logging-standard

[15] OWASP Foundation, https://www.owasp.org/index.php/Logging_Cheat_Sheet

[16] S. Bateman, C. Gutwin, N. Osgood, and G. McCalla, "Interactive usability instrumentation," Proc. 1st ACM SIGCHI Symp. on Engineering interactive computing systems (EICS 09), ACM Press, 2009, pp. 45-54, doi:10.1145/1570433.1570443.

[17] R. Atterer and A. Schmidt, "Tracking the interaction of users with AJAX applications for usability testing," Proc. SIGCHI Conference on Human Factors in Computing Systems (CHI 07), ACM, 2007, pp. 1347-1350, doi:10.1145/1240624.1240828.

[18] D. M. Hilbert and D. F. Redmiles, "Extracting usability information from user interface events," ACM Computing Surveys, vol. 32, Dec. 2000, pp. 384-421, doi:10.1145/371578.371593.

[19] P. Ketola and V. Roto, "On User Experience Measurement Needs - Case Nokia," International Journal on Technology and Human Interaction (IJTHI), vol. 5, 2009, pp.78-89, doi:10.4018/jthi.2009070104.

[20] H. Väätäjä and 9 others, "Opportunities and needs for logged usage data analytics of complex industrial systems," Proc. Twenty-Fourth European Conference on Information Systems (ECIS), AIS, 2016.

[21] T. Sheridan, Human and automation: system design and research issues. New York, NY: John Wiley & Sons, Inc., July 2002.

[22] H. A. ElMaraghy, "Flexible and reconfigurable manufacturing systems paradigms," Int J Flex Manuf Sys, vol. 17, Oct. 2006, pp. 261-276, doi:10.1007/s10696-006-9028-7