REAL-TIME ALERT NOTIFICATION SYSTEM FOR OPTIMIZING MANUFACTURING PRODUCTION LINE VIA MOBILE APPLICATION

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ABSTRACT: The existing system employed by Konica Minolta for handling emergency text alerts is ineffective and lacks reliability. The company, which specializes in business and industrial imaging solutions, relies on email notifications for daily emergencies. This approach has several drawbacks, as notifications are sent to all employees simultaneously, leading to irrelevant alerts for those not involved in the specific projects. Additionally, the visibility of these notifications raises concerns about confidentiality and privacy, potentially compromising sensitive information. As the volume of notifications increases, tracking and analyzing content becomes increasingly challenging. The objective of the Mobile Alert Notification System for Manufacturing Production Lines (MANSMPL) is to provide targeted alerts tailored by incorporating the role-based access control (RBAC) method specifically for manufacturing environments. To validate the identified problems, unstructured interviews and surveys with domain experts were conducted. The findings from the interviews and surveys were instrumental in designing MANSMPL. The developed application effectively streamlines the notification process, ensuring that alerts are relevant to the intended recipients. MANSMPL offers a novel solution that is tailored to a manufacturing environment that restricts alerts to intended recipients while maintaining the confidentiality and privacy of sensitive information.

KEYWORDS: *alert notification systems; manufacturing production line; RBAC, emergency alerts; mobile applications.*

1.0 INTRODUCTION

It is essential for manufacturing management to promptly address product defects and processing errors as disruptions or breakdowns in a production line can negatively impact the manufacturer's profitability and reputation if orders are delayed [1]. Disruptions are regarded as the fundamental cause of manufacturing inefficiency. Consequently, real-time monitoring of machine or production status has become a mission-critical function in numerous manufacturing sectors.

Failure to address production line disruptions promptly can have several significant consequences for businesses. Production delays can lead to increased costs, including higher expenses for expedited shipping, sourcing materials from alternative suppliers and potential overtime pay for workers. A previous study revelaed that supply chain disruptions can result in a 3%-5% increase in expenses and a 7% decrease in sales [2]. Delays in product availability can frustrate customers, leading to decreased satisfaction and loyalty. Negative experiences can damage a company's reputation, making it difficult to regain customer trust once it has been lost [1]. Song and Cheng [1] highlighted the importance of understanding the impact of disruption on the manufacturing assembly line in terms of daily output and disruption duration, indicating the importance of prompt actions against the disruptions. Maharjan and Kato [2] recommended strategies to address the manufacturing disruptions caused by COVID-19 in Japan.

Disruptions in the production line can be regarded as an emergency due to their undesirable effects on manufacturing. One method to address the emergency is through alert or notification systems.

Emergency alerts in production lines are critical for ensuring safety and efficient response during various incidents, such as equipment failures, accidents, and severe weather conditions. For manufacturing companies, notifications are crucial to warn employees of any production line issues and disruptions. Whenever an emergency occurs, employees need to be informed so that immediate actions can be taken. Another urgent situation is to notify employees of changes to production line details. Notifications are also serve as a communication channel to update employees on corporate events and achievements.

Therefore, to closely observe a real alert notification system implementation in the manufacturing domain, Konica Minolta which is located in Melaka, Malaysia was chosen. Konica Minolta is a Japanese multinational technology corporation based in Tokyo, operates in 49 countries around the globe. The company specializes in manufacturing business and industrial imaging products, which include copiers, laser printers, multi-functional peripherals (MFPs), and digital printing systems tailored for the production printing sector [3]. Emergency alerts within Konica Minolta's production line are essential for ensuring safety and maintaining operational efficiency. Even though the company utilizes sophisticated systems to oversee production processes and effectively respond to emergencies, there is still room for improvement. Figure 1 shows an assembly line station for printers in Konica Minolta that is part of the alert monitoring subject.

Figure 1: An assembly line station in Konica Minolta [4].

Sending alert notifications to personal devices in the workplace, particularly in a manufacturing setting, offers several compelling advantages over traditional signaling methods like buzzers and bells. Personal devices ensure that alerts reach employees instantly, regardless their location on the production floor. Unlike stationary buzzers which may not be heard by all workers, mobile notifications can be received directly on smartphones, allowing for quicker responses to emergencies or disruptions. The integration of mobile alerts and notifications in manufacturing has become increasingly significant in enhancing operational efficiency, safety, and communication among employees. The use of mobile devices is a part of the fundamental principles of Industry 4.0 that fall under technical assistance [5],[6],[7].

There are recent developments and implementations of mobile-based monitoring systems within the manufacturing context. In a study by Jumde, Kolhe, and Talawdekar [8], SMS alerts were used to enhance industrial operations through real-time monitoring of critical parameters (e.g. temperature, pressure, humidity, and gas concentration). Mobile applications also have been used for continuous natural gas (NG) pressure monitoring of pneumatic pressure-sensitive machinery where IoT sensors are integrated into the system [9]. Email notifications have been used in temperature and humidity monitoring systems for factory electrical panel rooms [10]. Nevertheless, one significant issue is the potential for information overload. As numerous alerts are being generated, employees may struggle to prioritize and respond effectively. Additionally, the reliance on internet connectivity can pose challenges in environments with limited access, leading to delays in notifications.

A study by Maulana, Aminah, and Nugraha [11] utilized Industrial Internet of Things (IIoT) technology through a mobile application to oversee production processes, report outcomes, evaluate machine performance using the Overall Equipment Effectiveness (OEE) method, and issue maintenance alerts based on scheduled maintenance. The use of IoT in real-time monitoring also can be referred to the previous studies by Liu et al. [12], and Afreen and Bajwa [13]. Chen et. al [14] proposed low-cost communication technology through the use of Rasberry Pi utilizing Bluetooth Low Energy (BLE) and Wi-Fi wireless to enhance real-time communications as a part of the smart manufacturing Data Hub Project. Other applications of mobile alerts include the security domain for unauthorized entry or intrusion detection through sensors [15], health monitoring [16], and water industry monitoring [17]. The usage of alert types is also applied based on the levels of risks. Public alerts such as buzzers and bells are usually for high-risk alerts involving severe hazards in the manufacturing environment for immediate responses. The levels of risks namely lower, middle, and high have been defined for alert mechanism planning [1]. As such, personalized alerts can complement the public alarms for middle and lower-risk alerts.

Previous studies have shown that mobile applications are necessary for modern manufacturing as they enable real-time monitoring and control of production processes while ensuring safety. However, there are significant gaps that need to be addressed for future advancements. For instance, many existing systems have integration challenges in harmonizing various technologies and platforms, which can hinder data flow and responsiveness. Additionally, excessive notifications can lead to alert fatigue among users, reducing the effectiveness of alert systems. A study by Yang and Chiao [18] emphasized the importance of utilizing user-specific alerts targeted at employees responsible for the particular task. Nevertheless, no practical implementation reported.

In addition, the use of Role-Based Access Control (RBAC) has limited coverage within alert monitoring systems in the manufacturing context. Integrating a RBAC model into a manufacturing alert system can enhance operational efficiency, enabling user-specific alerts. RBAC is a method for managing access to resources based on the users' roles within an organization, ensuring only the particular employees have access to the specific information necessary for their job functions [19].

Thus, this situation calls for mobile-based alerts that are both user-specific and secure, which need to be tailored to specific environments including manufacturing. The question that arises is what are the requirements for an efficient alert notification system in the production line? This paper aimed to investigate the current alert notification system implemented in a manufacturing domain. The objective of this study is to provide a unique and novel targeted alert system that is tailored specifically for manufacturing environments. To achieve the objective, the problems of the current alert notification systems must be identified and validated. Thus, the scope of this paper focuses on the problem formulation and validation that will serve as the foundation for the complete MANSMPL.

2.0 METHODOLOGY

This section describes the method of developing the mobile alert notification system and also the method of validating the problems in the current alert notification system. Although a standard development method has been adopted, the present study provides novel elements in terms of addressing personalized and targeted alert notifications that incorporate RBAC method which are lacking in the current manufacturing practices that include the utilization of buzzers, bells, and emails.

2.1 Development Method

Konica Minolta at present, already has an alert and notification system but with some limitations. To develop the enhanced system, database Life Cycle (DBLC) methodology was chosen as the development methodology for the proposed system.

Figure 2 illustrates the DBLC stages. The six phases in the DBLC consisted of database initial study, database design, implementation and loading, training and evaluation, operation, and maintenance and evaluation. In this paper, the results of the first and the second stages of the proposed system namely database initial study and database design are presented. System architecture design, system navigation design, and user interface design that are not visible in the DBLC will also be presented in Section 3.3.

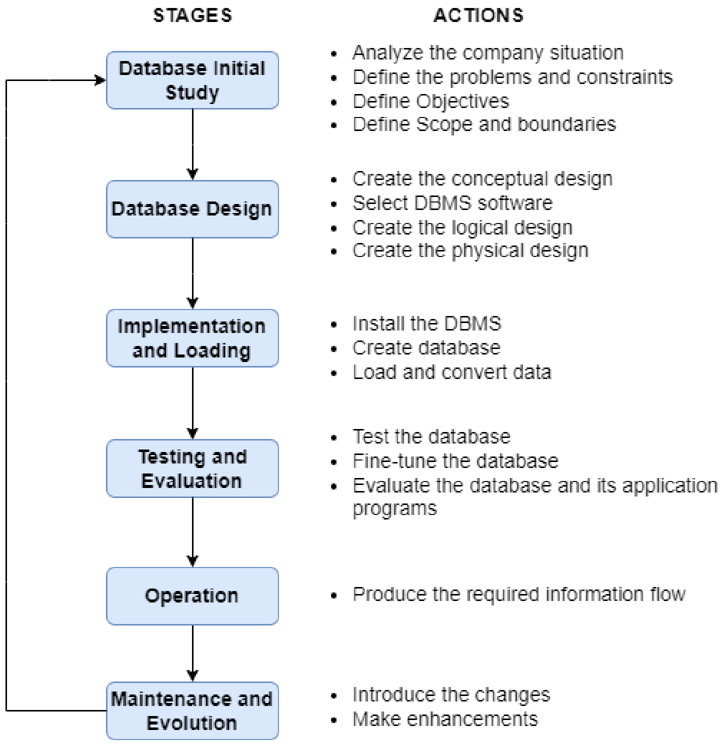


Figure 2: DBLC Stages (Adapted from [20])

Descriptions of the stages are as follows:

I. *Database initial study*: In this stage, the current system was observed and analyzed. An unstructured interview with the production line managers was performed to understand the current flow of the alert notification system in Konica Minolta. Unstructured interviews can serve as a valuable exploratory research method. Characterized by its informal and flexible nature, it often elicits engaging responses from participants. Based on the interview, the problems and constraints of the current system were determined. To validate the problems that were raised during the interview and to quantitatively analyze them, a survey was conducted among the production line managers. The details of the survey are explained in Section 3.2.

II. *Database design*: This phase focused on the database model's data requirements that supported the system operations and objectives. This phase consisted of four sub-phases (conceptual design, DBMS software selection, logical design, and physical design). In conceptual design, an entity-relationship diagram (ERD) was created and a database normalization process was performed. DBMS software that would be used was also decided in this stage. Microsoft SQL Server DBMS was selected based on the recommendation made by Konica Minolta's team.

III. *Implementation and loading*: In this phase, SQL Server Management Studio was installed as the DBMS management software. The programming languages used to develop the system were JAVA and PHP.

IV. *Testing and evaluation*: During this phase, three sub-phases of testing were implemented namely testing the database, fine-tuning the database, as well as evaluating the database and its application program functionality. The objective of this phase was to ensure integrity, security, performance, backup functions, and recovery of the database are well set. The results of the functionality test are presented in Section 3.3.

V. *Operation*: After the testing stage, the system was finalised and became fully operational. The users of the system began to operate the system to facilitate the required information flow such as loading data, managing data, and reading reports.

VI. *Maintenance and evolution*: At this stage, the system was implemented in the practical use to discover problems and errors that were not detected in the earlier stages. Consequently, maintenance included fixing errors, enhancing system features, and streamlining system performance.

2.2 Survey and Analysis Method

A survey was conducted to validate the problems raised during the interview in the database initial study phase and to collect quantitative data for analysis. Ten production managers in Konica Minolta working closely with the existing alert and notification system participated in the survey. Usually, managerial roles in the factory are tightly restricted in number. These managers are considered domain experts, possessing specialized knowledge and experiences in a specific industry or field. Despite the small number of participants, the use of in-depth interviews provided rich, detailed data, allowing for a comprehensive understanding of participants' experiences with the current system. USE (Usefulness, Satisfaction, and Ease of Use) questionnaire developed by Lund in 2001 was adopted in this study. The questionnaire is widely used for measuring the subjective usability of a product or service [21], [22]. An online questionnaire that consisted of four sections namely usefulness, ease of use, ease of learning, and satisfaction was distributed among the respondents. The sections consisted of Likert-scale questions with 1 (strongly disagree) to 7 (strongly agree) options, with a total of 30 questions. The reliability of the questionnaires was measured following the Cronbach alpha internal consistency using the SPSS tool. The questionnaire also consisted of an open-ended questions section asking about the negative and positive aspects of the existing system that can be accessed through the URL: https://garyperlman.com/quest/quest.cgi?form=USE.

Structured analysis using Data Flow Diagrams (DFDs) was adopted to explain the processes in the proposed system graphically. A context diagram was implemented to provide a comprehensive overview of an entire system through a single Data Flow Diagram (DFD) where the element of RBAC was incorporated.

2.3 System Analysis and Design

An improvement of the current alert and notification system was proposed by adopting the mobile-based systems integrated with RBAC. Mobile-based systems refer to software applications and technologies designed for mobile devices such as smartphones and tablets. These systems utilize wireless communication and are characterized by their ability to provide users with specific functionalities while on the move.

The development of MANSMPL requires analysis of the enhanced processes before the system can be designed and developed. As mentioned in Section 2.2, structured analysis using Data Flow Diagrams (DFDs) was adopted to explain the processes in the proposed system graphically. Figure 3 shows the context diagram of MANSMPL. Context diagram gives the bird’s eye view or high-level visual of a system. For simplicity, other DFD levels were excluded from this section. Based on the context diagram, two external entities interact with the system namely Administrator and Employee. The diagram illustrates the data that the system receives from the external entities, and also the data that are sent to the external entities from the system. Note that, the RBAC method is incorporated within MANSMPL where user roles become the input that will verify user access.

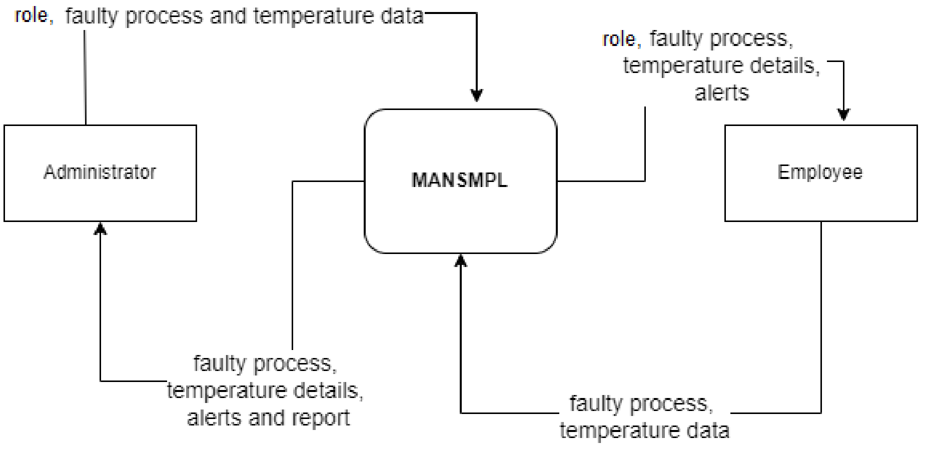


Figure 3: Context Diagram of MANSMPL with RBAC method

2.4 System Architecture Design

The architecture of this system was designed as an Android-based mobile application. It can be accessed on devices running Android 6.0 Marshmallow or later. This application must first be installed on the target device before it can be used. The mobile-based system approach was selected as the architectural framework because of high adoption rate of smartphones among employees at the client company. This platform offers great flexibility and serves as an efficient mobile communication tool for reporting and tracking production line issues. Furthermore, the application can be utilized immediately after the APK file is installed on the employees' devices. Figure 4 illustrates the three main components of the system architecture consisting of the Client (Android Mobile App), the Web Server with WAMP and PHP with JAVA as the programming language, and the Database Server (Microsoft SQL Server). The RBAC modules are executed for each login session.

The key components of RBAC are roles, permissions, and users [19]. Roles are defined based on job functions and responsibilities, while permissions define access rights assigned to roles. Users are individuals assigned to specific roles. When a user attempts to access a resource, the system checks their assigned role and grants or denies access based on the predefined permissions associated with that role.

The roles in MANSMPL include administrator, line manager, and also operator. Both manager and operator belong to the Employee group.

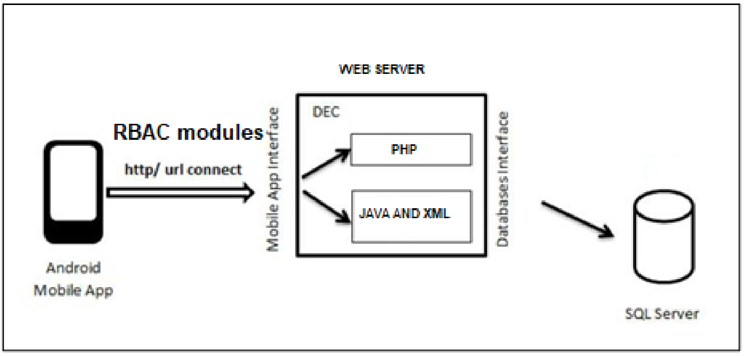


Figure 4: Data Exchange Component (DEC) Architecture with RBAC-based Mobile Application (Adapted from [16])

2.5 Conceptual Database Design

The conceptual design was validated to verify each entity is related to another entity to form an Entity Relationship Diagram (ERD) in Figure 5. Each entity has non-key attributes, primary key, foreign key as well as relationship with other tables. Note that the role table was added for RBAC implementation.

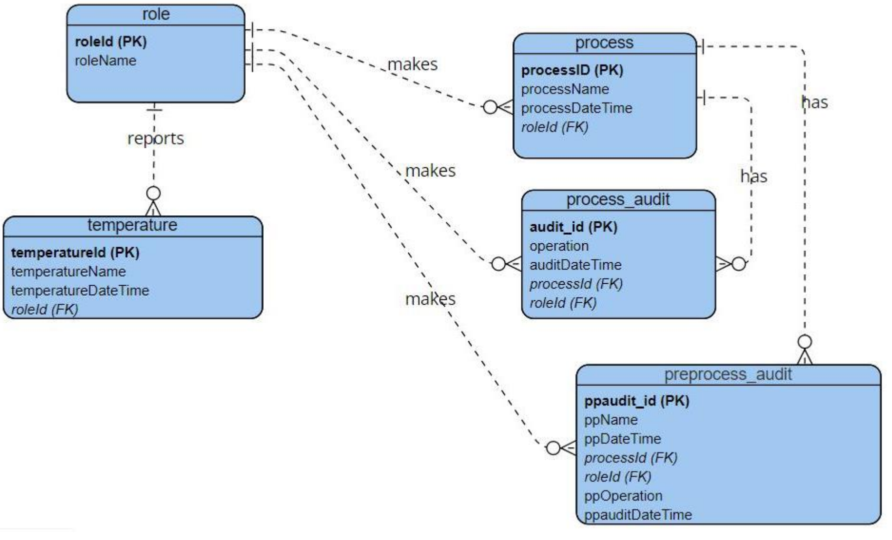


Figure 5: ERD of MANSMPL

2.6 System Navigation and User Interface Design

System navigation design refers to the process of creating and structuring the pathways through which users interact with a website or application. Figure 6 illustrates the MANSMPL Navigation design.

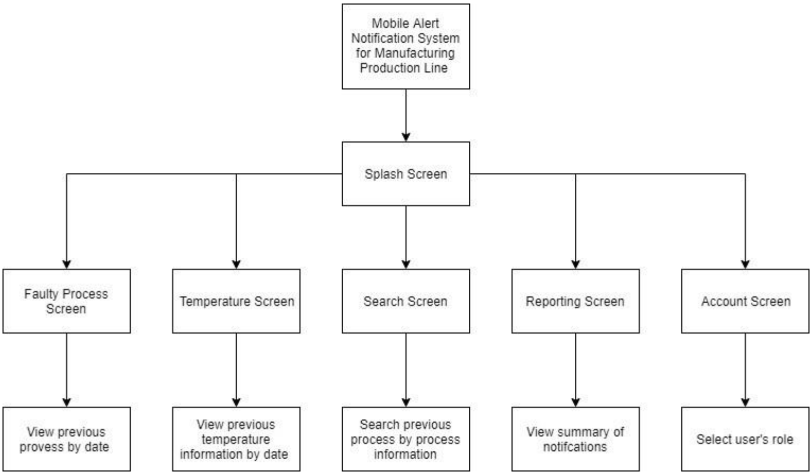
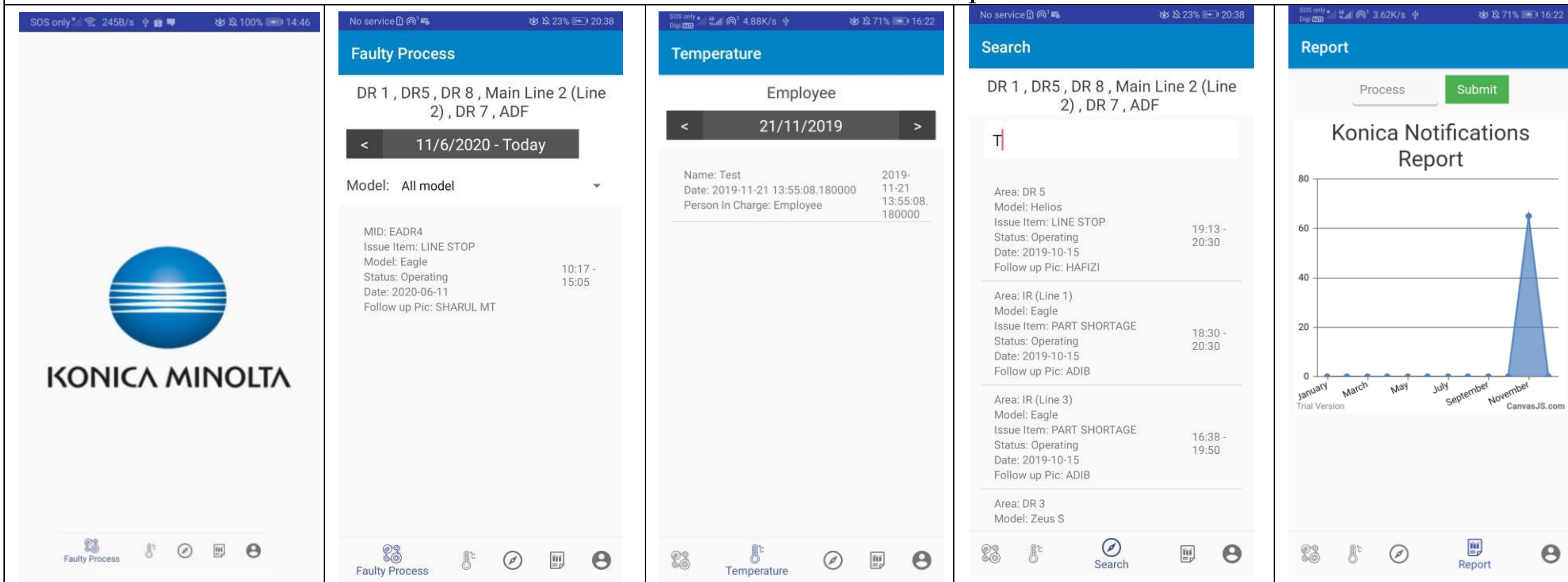


Figure 6: MANSMPL Navigation Design

Figure 7 depicts the user interface design of MANSMPL mobile application screens together with the descriptions. The accessibility of these screens will be based on the navigation design of the system as shown in Figure 5. The Splash screen in Figure 7(a) is the landing screen of MANSMPL where access to all other screens is provided in the screen. Figure 7(b) is the screen that displays previous notifications of faulty processes, Figure 7 (c) displays previous notifications of abnormal temperature, Figure 7 (d) shows the function of searching for previous information, and finally Figure 7 (e) shows a summary report of the notifications monthly.

User Interface Screens and Descriptions



(a) (b) (c) (d) (e)

Figure 7: MANSMPL User Interface Design

3.0 FINDINGS, RESULTS AND DISCUSSION

3.1 Unstructured Interview Findings

Based on the unstructured interview conducted, several key findings have been discovered regarding the limitations of the current alert and notification system. The current system generates notifications through email which is inefficient and easily overlooked. Another issue is the difficulty in locating previous notifications, as employees frequently receive numerous emails daily, contributing to an overwhelming volume of alerts. The notification system also lacks confidentiality as notifications are sent to all employees broadly and simultaneously, without filtering based on roles and privileges. This raises a concern, as confidential company information and private conversations can be viewed by unauthorised employees.

The problems can be summarised as the following:

I. *Notification is inefficient and less noticeable*: Email-based alert notifications are often less effective and may go unnoticed by the intended employees.
II. *Notification lacks privileges for sorting*: All notifications are distributed to all employees simultaneously, without being categorised by roles and privileges. Consequently, all notifications are accessible to everyone, potentially leading to the exposure of confidential information to unauthorized individuals.
III. *Tracking sent notifications is challenging*: Tracking and analysing email-based notifications becomes increasingly difficult as the volume of notifications increases.

3.2 Survey Results

Figure 8 shows the results of the survey which covered four sections namely usefulness, ease of use, ease of learning, and satisfaction. Based on the figure, satisfaction had the highest average score which was 4.83 and the lowest score was usefulness with 4.33. Overall, the managers were not completely satisfied with the current system. The results also indicated that the system was not very user-friendly and required additional training. To analyse further, Figure 9 illustrates the scores in terms of percentage values. The results revealed that all variables examined were below 70%, indicating significantly lower than expected for an efficient system. This supports the findings from the interview conducted prior to the survey, emphasizing the requirement for an improved alert and notification system for Konica Minolta.

The results of the open-ended questions also indicated the need for an improved system. Among the responses were "The notification should be sent to the intended recipient/related pic only", "Too many notifications leading to the information to be overlooked", and "Some phones such as Huawei does not support the system".

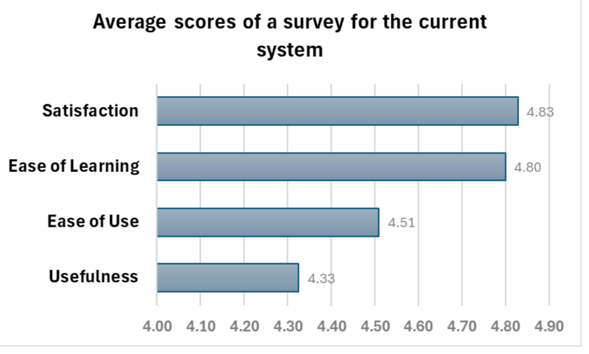


Figure 8: Average scores of a survey for the current system across four criteria.

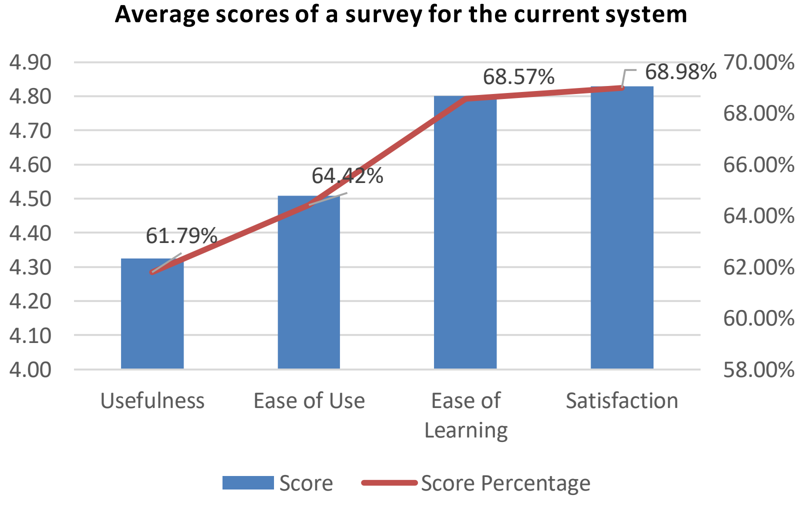


Figure 9: Average scores and the percentage of a survey for the current system across four criteria.

Table 1 displays the reliability test results for the questionnaires addressing the investigated factors. The overall Cronbach's alpha scores for internal reliability of usefulness, ease of use, ease of learning, and satisfaction were 0.97, 0.95, 0.93, and 0.83, respectively. The scores with more than 0.70 were considered high reliability [23] for all factors used in the questionnaires.

Table 1: Reliability of questionnaires

Items	**Factor**	**Cronbach's alpha**
1-8	Usefulness	0.97
9-19	Ease of use	0.95
20-23	Ease of learning	0.93
24-30	Satisfaction	0.83

3.3 Functionality testing

This section presents the results of functionality testing of MANSMPL. The app was tested to ensure its effectiveness in monitoring faults within the factory equipment. The primary focus was on the functionality aspect and the runtime/response time. Other aspects like memory and energy consumption were also used as the testing criteria [24] although were not covered in this paper. In mobile app testing, the number of test iterations can vary significantly based on the specific goals of the testing process. However, a common practice involves executing multiple iterations to ensure comprehensive coverage and reliability of results [25].

In this study, each test case was iterated five times. The test cases used are shown in Table 2. The device used was a Samsung Galaxy J1 with Android 6.0 Marshmallow operating system. 11 test cases were implemented following the common functionality of mobile apps which were adapted from [25] to suit factory/manufacturing settings. The testing involved two stations in the assembly line. Based on the results, the passing rate was 9/11 (81%), where the fastest average response time was 0.9 seconds (Real-Time Dashboard Update); and the longest average response time was 8.9 seconds (Report Generation (Complex Report)). Further improvement needs to be made on query rewriting that may cause delays in report generation and report sharing.

TABLE 2: Functionality Testing Results

Test Cases	**Function**	**Expected Response Time (in seconds)**	**Average Actual Response Time (in seconds)**	**Status (Pass/Fail)**
Fault Detection (Station A)	Fault detection and alert generation	≤ 2	1.8	Pass
Fault Detection (Station B)	Fault detection and alert generation	≤ 2	1.5	
Real-Time Dashboard Update	Updating machine status	≤ 1	0.9	
Push Notification for Critical Alerts	Push notification delivery	≤ 2	1.7	
Role-Based Alert Delivery (Operator)	Deliver alert to the relevant user	≤ 3	2.5	
Role-Based Alert Delivery (Manager station A)	Deliver alert to the relevant user	≤ 3	2.4	
Role-Based Alert Delivery (Manager station B)	Deliver alert to the relevant user	≤ 3	2.3	
Role-Based Alert Delivery (Administrator)	Deliver alert to the relevant user	≤ 3	2.7	
Data Loading on App Startup	Load dashboard after login	≤ 3	2.9	
Report Generation (Complex Report)	Generate detailed reports on faults	≤ 7	8. 9	Fail
Report Sharing to Manager	Share generated reports via the app	≤ 5	5.7	Fail

4.0 CONCLUSION

In conclusion, the MANSMPL addressed the challenges faced by Konica Minolta in the current alert notification system for production lines. These challenges include the inefficiency and unreliability of email-based emergency notifications, the indiscriminate broadcast of notifications to all employees, potential breaches of confidentiality and privacy, and the difficulty in tracking and analyzing notifications. The development of MANSMPL incorporates the role-based access control (RBAC) method, introducing innovative alert notifications system for manufacturing production lines. The results of surveys and observations validated the identified problems, and the design and development of MANSMPL demonstrated its potential to improve notification efficiency and confidentiality. This system will not only benefit Konica Minolta but also other manufacturing domains facing similar issues. Future research should include benchmarking MANSMPL with a similar mobile-based alert system.

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AUTHOR CONTRIBUTIONS

The contributions of the authors are as follows:

N. A. Emran: Writing- Original Draft Preparation.

N. Harum and C. Y. Yu: Validation, Writing-Reviewing and Editing, Mobile app design and development.

M. M. Ridzuan and A. J. AlQubaisi: Validation, Writing-Reviewing, and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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