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Design of tool life estimation system in the turning process

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Abstract

The cutting tools have a critical wear limit. Its life is essential for machining data for usage and tool replacement planning. One of the challenges in planning is the difficulty of real-time tool life estimation before and after usage. Real-time estimation of tool life before and after use is expected to assist the Production Planning and Control (PPC) department in selecting tools based on their remaining life, estimating the number of machined products, and planning timely tool replacements. A system has been designed to estimate tool life before and after usage to address this issue. The outcome of this research is the conceptual design of the tool life estimation system and the interface design illustrating the results. The tool life estimation system consists of five pages with several essential features. Firstly, the login page for user authentication and authority control. Secondly, the main page presents two menu options, namely insert registration, and insert list. Thirdly, the insert registration page is used to register the usage of a new tool based on the tool's identity, machining process, and machining parameters. Fourthly, the insert list page displays a list of registered tools, the estimation of new tool life based on the Taylor equation, and the estimation of remaining tool life. Lastly, the new project and insert history page is used to estimate the number of workpieces that can be processed by the selected tool, estimate the remaining tool life after usage, and display the tool usage history.

Keywords: Taylor equation, tool life, tool wear

1. Introduction

A cutting tool insert is one of the tools that must be considered in the turning process. The interaction between the workpiece and the tool occurs during the turning process [1]. When cutting the workpiece material, the cutting tools will experience repeated friction and pressure [2]. If the cutting tools are used beyond their capacity, they can experience unexpected wear and damage, thereby disrupting the efficiency of the production process [3]. One of the factors that influences tool wear is the tool usage time [4]. Tool usage time is the duration or length of time the tool is used. To prevent tool wear from occurring suddenly, planning tool use is needed [5]. Some solutions that can be applied are selecting a tool with sufficient remaining life and estimating the number of workpieces that can be turned based on specific parameters. To implement this solution, it is necessary to estimate the tool life before use and the cutting time required by each product. Another common problem in the metal machining industry is the difficulty in predicting tool replacement time due to wear reaching a critical condition [6]. Tool change times can positively impact the efficiency and yield of the production process. The production process must be stopped or suspended to replace worn tools, resulting in decreased working time that should be used for production. The solution to this problem is to plan tool replacement times. Tool life is defined as the duration of time required for the tool to reach the wear limit [4]. Tool life is one of the essential machining data in planning the use and timing of tool replacement. Data on tool life before use can help parts Production Planning and Control (PPC) to plan tool use, such as selecting a tool with a service life that best suits your needs and estimating the number of workpieces that can be turned based on specific parameters [7].

Based on the previous paragraph, a system is needed to estimate tool life before and after use to overcome problems related to turning tool life. The system is designed to estimate the life of a new tool until it reaches a critical wear limit. The new tool life estimation is obtained theoretically using the Taylor equation. In addition, the system is designed to estimate the remaining tool life after use based on previous tool life estimates, cutting time, and the number of products to be machined. The system will record, store, and display the history of tool use, including estimated tool life, both before and after use. With the tool life estimation system, it is hoped that it will make it easier for users to find out the age of the tool before and after use so that planning the service and timing of tool replacement runs more efficiently. This research aims to (1) design a tool life estimation system in the turning process, (2) evaluate the design of the tool life estimation system in the turning process that has been created, and (3) create an interface design for the tool life estimation system design in the turning process.

2. Methods

This research discusses designing a tool life estimation system in the turning process. The research stage begins with a literature study to collect relevant data and information to determine system boundaries. Next, a system's thinking flow was created to guide the concept of a tool life estimation system. The research stages can be represented as a flow diagram, as shown in Figure 1. This research focused on designing a tool life estimation system. The system has been designed for cutting tool inserts with fixed process parameters (cutting speed, feed rate, and depth of cut) and in dry-cutting conditions. The research results can help plan effective and efficient use and replacement of cutting tool inserts.

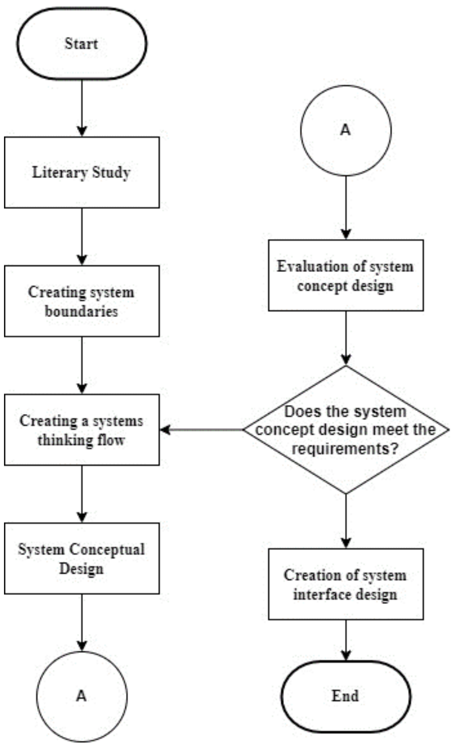

Figure 1. Research stage diagram

Identification of tools before use is carried out by estimating the life of the new tool. New tool life estimation can be done using two methods, namely theoretically based on the F.W. Taylor equation: 〖V.T〗^n=C and empirically by conducting direct tests on the turning process to determine tool life until it reaches the maximum wear limit [8]. In this research, the system uses theoretical tools for life estimates. To use the Taylor equation, the exponent value n and the constant C are needed [9]. The n and C values were obtained through turning experiments using various tools, workpiece materials, and process parameters [8]. The flow diagram of the new tool life estimation process can be seen in Figure 2. Apart from estimating the life of a new tool, this research also aims to estimate the remaining life of the cutting tool inserts after use. On the other hand, methods for determining the remaining life of a tool after use tend to take a lot of work to implement. However, a simple approach that can be used to estimate the remaining tool life is to know the estimated tool life before use, cutting time (cutting time), and the number of products or workpieces (product quantity).

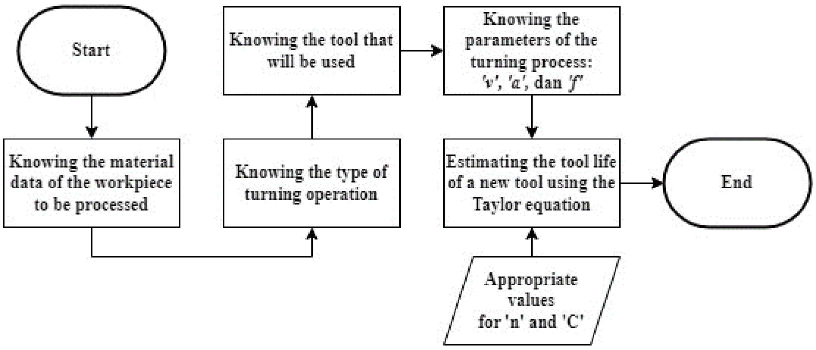

Figure 2. Flowchart of the new tool life estimation process

The next step is to provide identity to tools and cutting edges to distinguish similar tools and cutting edges. This identity is usually given through a unique code of numbers or letters that reflect the turning tool's type, size, and characteristics. In addition, additional identification, such as using particular colors or markings, can also be provided on cutting tools to facilitate recognition of similar tools. One of the aspects discussed in this research is giving identity to the insert box, insert, and each cutting edge of the insert. Providing identity makes it easier for users to distinguish which insert and cutting edge are used.

It is also essential to provide an ID on the toolbox of cutting tool inserts. The purpose of giving identity to the insert toolbox is to differentiate one toolbox from another to ensure that each tool is placed correctly without any mistakes. In this research, three brands with several different types of inserts were taken as examples of giving an insert box identity. Insert box ID is the identification of the insert box. If the brand and insert type consisting of insert shape, insert size, chip breaker, and grades are different, then the insert box ID will be other too. For example, the Lamina toolbox containing insert with type CNMG 120408 NN LT 10 has insertbox ID A-1. The letter "A" indicates that the box includes an insert with the Lamina brand with type CNMG 120408 NN LT 10, while the first strip demonstrates that this is the first toolbox to accommodate a tool with the Lamina brand and type CNMG 120408 NN LT 10—example of providing identity on the box. An example of the toolbox can be seen in Figure 3 (left).

Identity through color is used to make it easier to identify inserts that are small in size. Each tool in one box is given a different color, and each divider in the insert box is also provided with a color that matches the color of the insert placed in it. Apart from that, stickers with numbers written on them are used as clear numbering on each insert divider. Color is used as a visual method to depict insert identity numbers, with red being the first insert, blue being the second insert, and so on. This method will make identifying the inserts easier and finding suitable partitions based on similar colors. Based on the description above, insert management will become more efficient, and identifying similar tools will become easier. Insert ID is the identification for each insert in the insert box. A relationship exists between color and insert numbering, each representing a specific insert identity number. The identity of the inserts with color can be seen in Figure 3 (right).

Figure 3. Providing identity to the insert box (left) and insert (right)

To distinguish each cutting edge on the insert, it is necessary to give an identity to each cutting edge. Users can easily recognize and differentiate each cutting edge used on the insert tool by providing an identity. Three forms of inserts were taken to provide examples of giving identity to inserts—firstly, an S-shaped insert. If the S-shaped insert is positive, then the number of cutting edges is 4. However, if the insert is negative, the number of cutting edges is 8. The identity of the cutting edge on an S-shaped insert can be seen in Figure 4 (left). On an S-shaped insert, there are two surfaces: surface 1 (face 1) and surface 2 (face 2).

The following form is the W-shaped insert. If the W-shaped tool is positive, then the number of cutting edges is 3. However, if the tool is negative, the number of cutting edges is 6. The identity of the cutting edge on the W-shaped insert tool can be seen in Figure 4 (right). On a W shape insert, there are two surfaces: surface 1 (face 1) and surface 2 (face 2). Surface 1 has a red mark on the right side as inside ID and facing upwards.

The last form is an insert tool with a C shape. If the insert with a C shape is positive, then the number of cutting edges is 2. However, if the tool is negative, the number of cutting edges is 4. The identity of the cutting edge on an insert tool with a C shape can be seen in Figure 5. On a C-shaped insert, there are two surfaces, namely surface 1 (face 1) and surface 2 (face 2). Surface 1 has a red mark on the right side as insert ID and facing upwards.

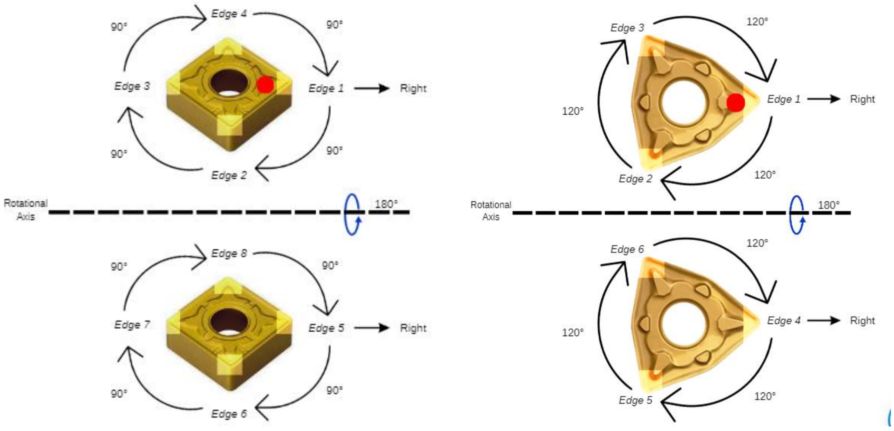

Figure 4. Identity of the cutting edge of an S-shape insert (left) and a W insert cutting edge (right)

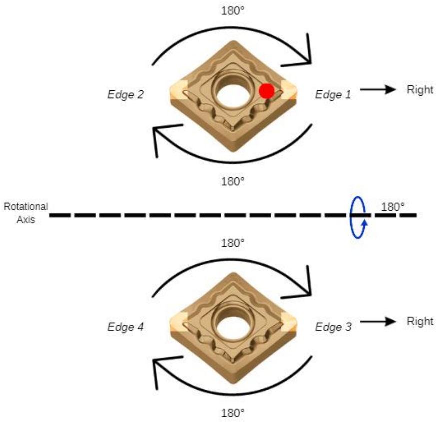

Figure 5. Identity of the cutting edge of insert C

3. Design of a Tool Life Estimation System

Planning system estimation age insert requires steps to be taken. These steps will help design the system concept effectively. The following are the steps taken in this research:

a) Determine the purpose of the tool life estimation system.
b) Know and adapt to user needs.
c) Determine design requirements from the tool life estimation system.
d) Determine the features that a tool life estimation system must have.
e) Design a thinking line for each element of the tool life estimation system.
f) Create wireframes from the design of the tool life estimation system.
g) Build a database according to needs.
h) Evaluate the concept design of the tool life estimation system.
i) Create an interface design for the tool life estimation system design.

A wireframe is a framework or black-and-white sketch display that guides the arranging of elements in an application system [10]. In a wireframe, there are various visible elements, such as text, images, and placement of items on the application page [10]. The tool life estimation system in the turning process consists of five pages: the login page, main page, insert registration page, insert list page, and new project and insert history pages. The activity diagram of the tool life estimation system in the turning process is divided into five parts according to the system's features: Page Login, Main Page, Insert Page Registration, Page Insert List, and New Project and Insert History Page. The wireframe of the Login Page can be seen in Figure 6 (left). The login validation activity diagram can be seen in Figure 6 (right). The Main Page can be seen in Figure 7 (left) and the main menu selection flow diagram can be seen in Figure 7 (right).

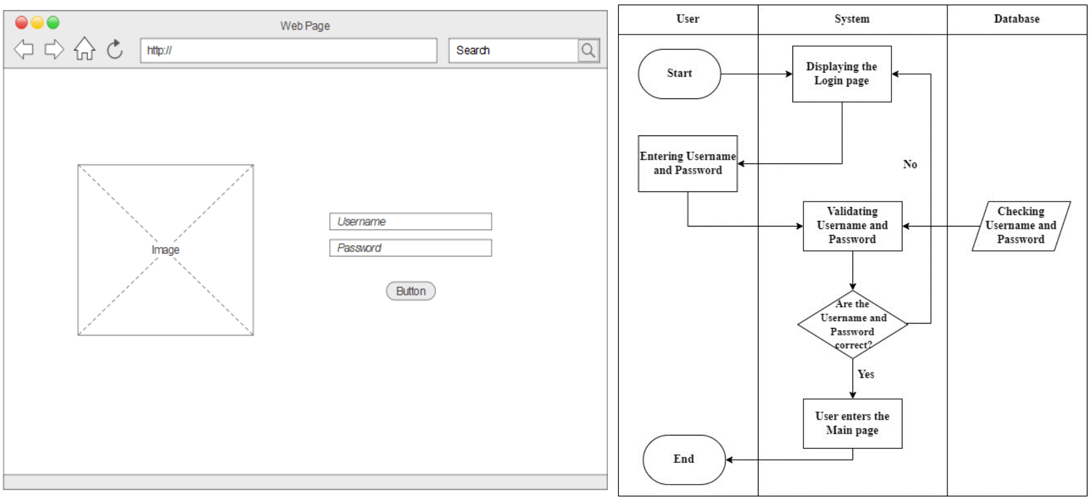

Figure 6. Wireframe Page Login (left) and login validation activity diagram (right)

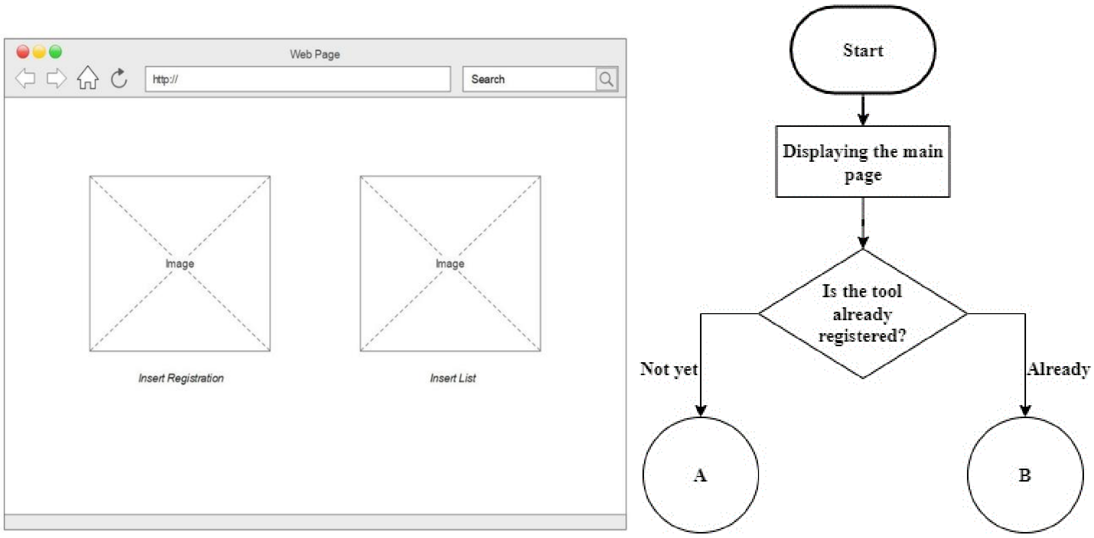

Figure 7. Wireframe Home Page (left) and Main Menu Selection Flow Diagram (right)

On the insert registration page, the user must fill in some of the necessary information, such as insert selection or enter data on the insert tool to be used (brand, insert shape code, insert shape and size, chip breaker, grade, insert box ID, insert ID, and cutting edge ID), machining process which consists of the classification of the workpiece material to be turned (workpiece material) and the type of machining operation (operation type), as well as machining parameters which consist of cutting speed, cutting depth and feed motion to be used. The purpose of insert registration is to store tool data used in working on a project with specific parameters in an organized manner so that users can easily access and manage information related to the tool. The wireframe of the insert registration page can be seen in Figure 8 (left), and the insert registration process activity diagram can be seen in Figure 8 (right).

The insert list page contains information regarding the parameters used when using the tool, estimates of new tool life based on Taylor's insert life, and estimates of remaining tool life (remaining insert life), which is updated automatically by the system based on the last project, which is executed. To indicate that a tool is almost at the end of its life and needs to be replaced, the system will give a particular sign in the form of red on the remaining insert life section when the remaining tool life is less than the safety factor multiplied by Taylor's insert life. If the user selects the "use" option in one of the tool options, they will be redirected to the new project and insert a history page to continue using the tool and view its usage history. The insert list page helps users find the information needed for planning tools' use and replacement time. For example, when the user chooses the tool that will be used to work on a project, the user can select the tool with the remaining life that best suits their needs. In addition, tools with almost no remaining life can be monitored through the system to plan when to replace the tool. The wireframe of the insert list page can be seen in Figure 9 (left), and the insert selection activity diagram can be seen in Figure 9 (right).

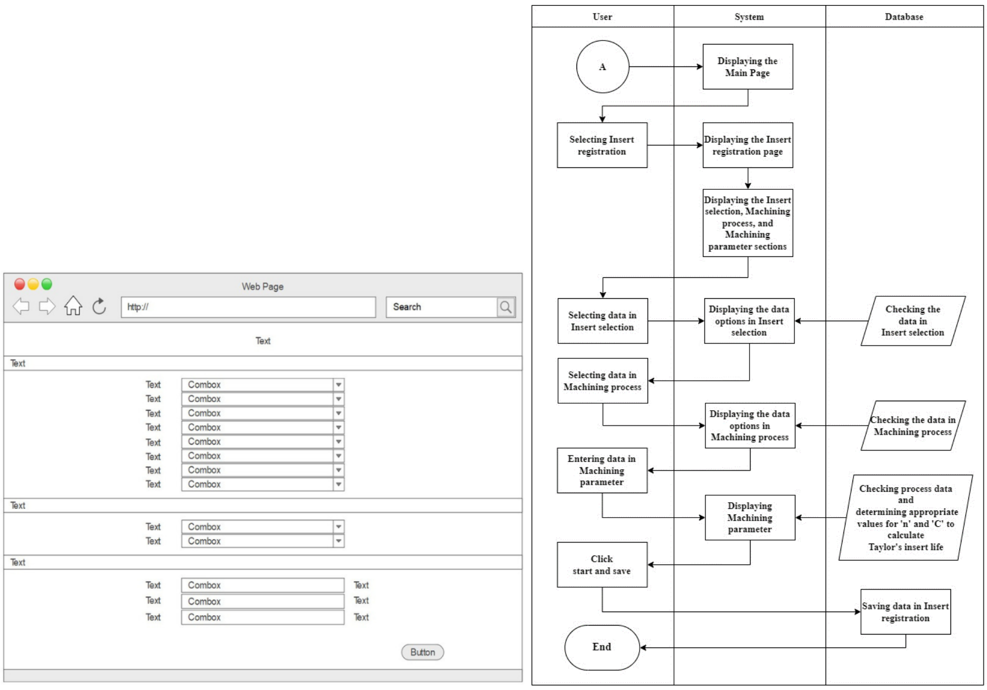

Figure 8. Insert Registration Page Wireframe (left) and Insert Registration Process Activity Diagram (right)

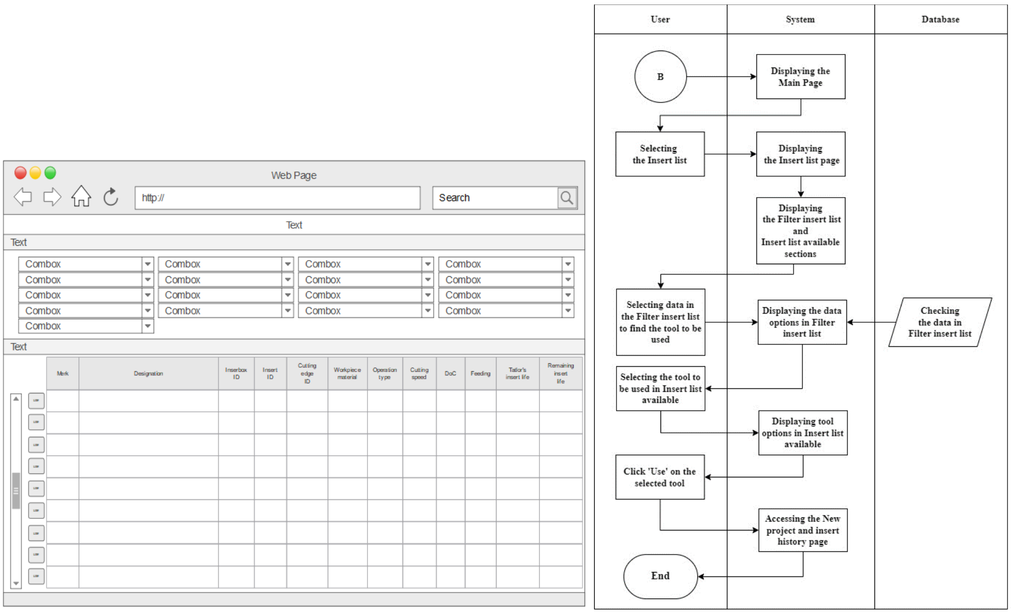

Figure 9. Insert List Page Wireframe (left) and Insert Selection Activity Diagram (right)

The new project and insert history page are used to register new projects to estimate the number of workpieces or products that can be turned, estimate the remaining tool life after use (remaining tool life), and save and display the history of tool use. In the first step, the user fills in the required information, such as product ID, cutting time, and quantity. When filling in the product quantity, the system will provide information regarding the maximum number of products that can be turned. The maximum number of products that can be turned is obtained based on the tool life before use (current insert life) divided by the cutting time for each product (cutting time). The wireframe of the new project and insert history page and activity diagram can be seen in Figure 10.

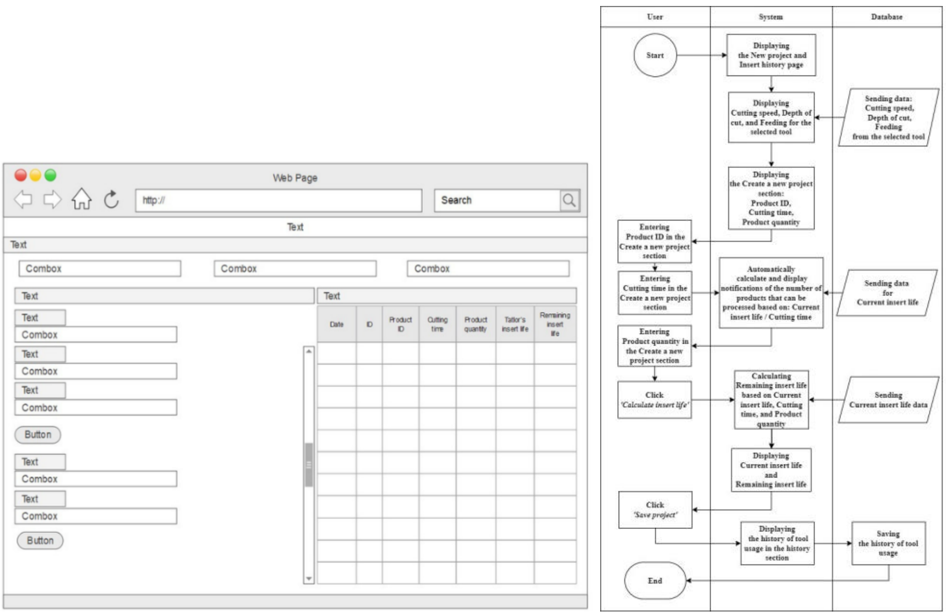

Figure 10. New Project and Insert History Page Wireframe (left) and Activity Diagram for Estimated Number of Products and Remaining Tool Life (right)

Database modelling is essential in supporting the implementation of the system so that it can function well. The Entity Relationship Diagram (ERD) concept is used to create a structured database model. ERD makes explaining the data model created easy and helps design the database structure well. The database model used in this research is shown in Figure 11.

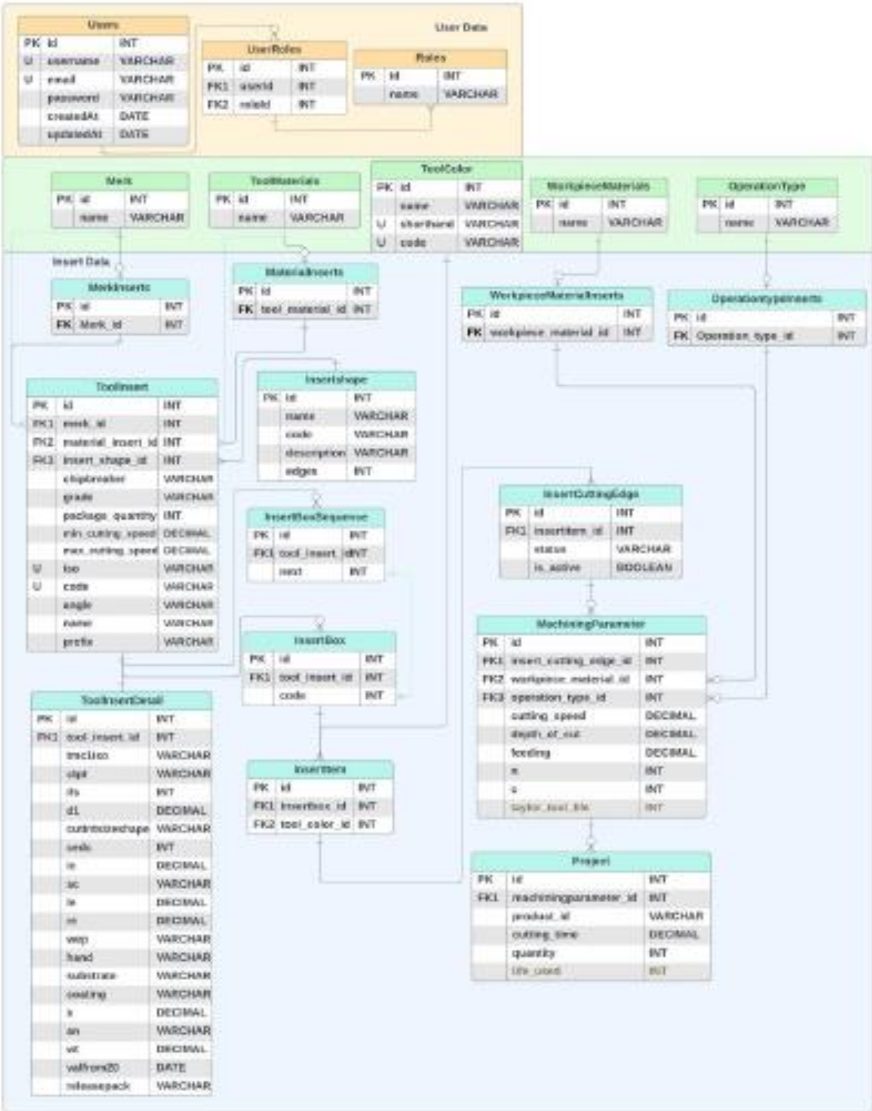

Figure 11. Tool Life Estimation System Data Modelling

Before using the tool life estimation system, the production planning and control (PPC) department already has data on the workpiece material, type of machining operation, type of insert, machining process parameters to be used, and the cutting time required to turn each workpiece. The planning tool used in this research was carried out by selecting the tool to be used and estimating the maximum number of products that would be turned by the chosen tool based on the remaining life of the tool before use. The flow diagram for planning tool use using a tool life estimation system can be seen in Figure 12.

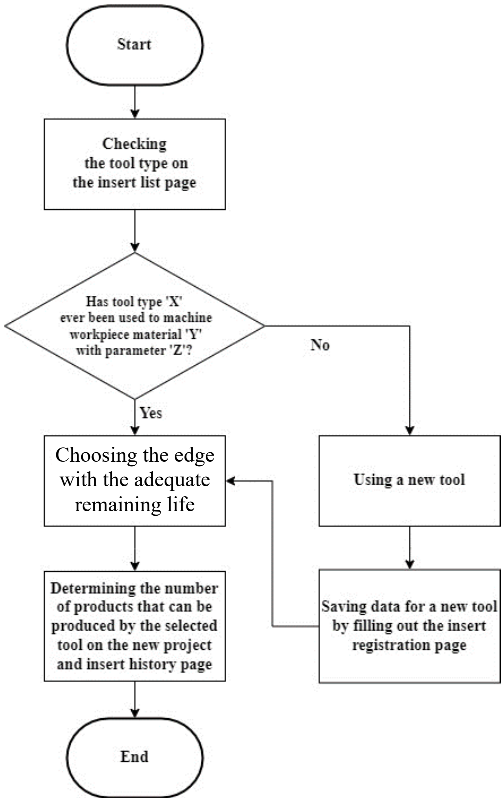

Figure 12. Flowchart of the Tool Use Planning Process

Planning tool replacement time using a tool life estimation system is based on the remaining tool life after use. Considering the estimated remaining tool life, tool replacement can be done on time before the tool is entirely ineffective. It is to avoid the risk of sudden wear that can disrupt the machining process. The flow diagram for planning tool replacement times using the tool life estimation system can be seen in Figure 13.

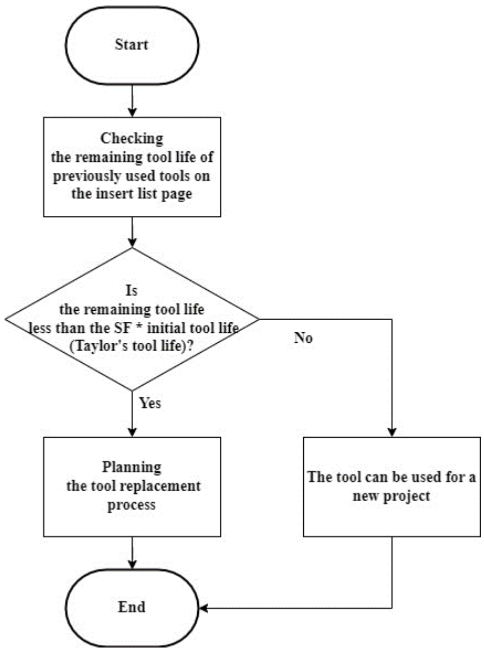

Figure 13. Flowchart of the Tool Replacement Time Planning Process

4. Result and Discussion

Evaluation of the design of the tool life estimation system concept in the turning process will help understand the consequences, impacts, and need to implement the idea. Evaluation considerations consist of several important points, namely as follows:

1. Results and implications of implementation, namely production efficiency and product quality.
2. Effect of other systems, namely monitoring systems and availability of sensors and technology.
3. Impact on costs, namely cost savings and initial investment.
4. Implementation requirements, namely data readiness and interface design.

After designing the tool life estimation system concept, the next step is to create an interface design from the concept design. Creating an interface design can be used as a guide for developers in implementing a tool life estimation system. Interface design displays of the concept design of the tool life estimation system in the machining process are Page Login, Main Page, Page Insert Registration, Page Insert List, and Page New Project & Insert History.

Page Login is the first display a user faces when using the system. The page login must enter the username and password correctly to enter the main page. The design of this interface is shown in Figure 14.

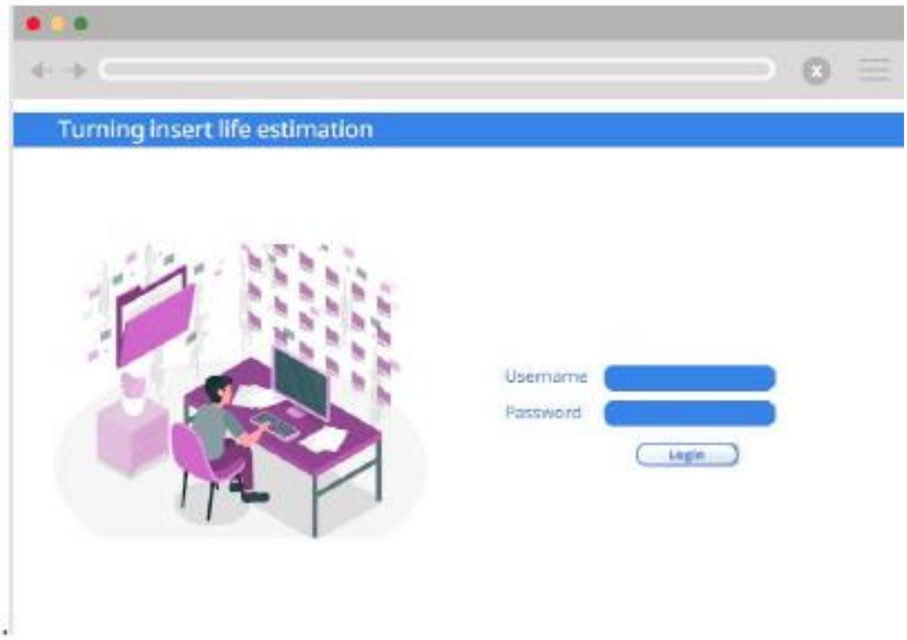

Figure 14. Page View Login

After successfully completing the activity login, the user will be redirected to the main page. The main page presents two main menus: insert tool registration (insert registration) and the insert tool list (insert list). The main page interface design of the tool life estimation system in the turning process can be seen in Figure 15.

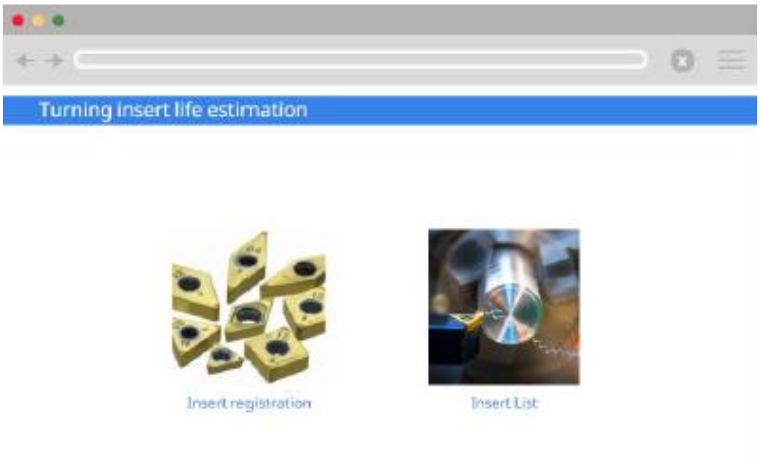

Figure 15. System Main Page Display Tool Life Estimation

Page Insert registration serves to register the tool to be used. Users can fill in some of the information needed when working on a particular project on this page. The system will use the data entered by the user to calculate tool life based on the Taylor equation. The system will display the results of the new tool life estimation calculation using the Taylor equation on the page insert list. Page interface design display insert registration from the tool life estimation system in the turning process can be seen in Figure 16.

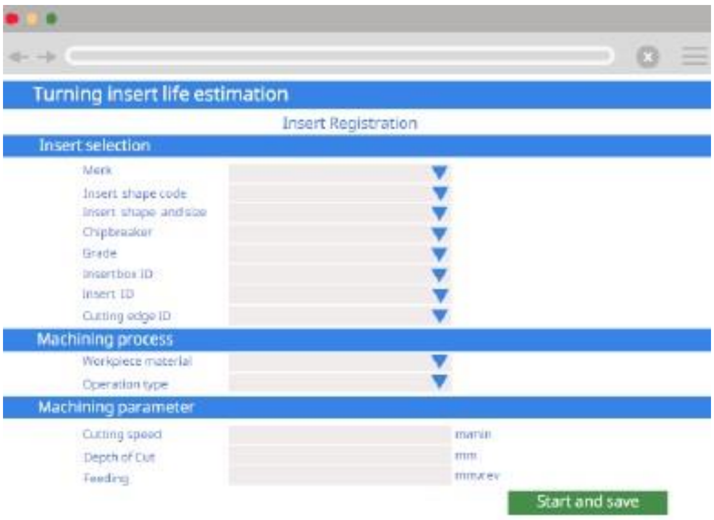

Figure 16. Page View Insert Registration

The insert list page functions to display a list of tools the user registers on the insert registration page. On the insert list page, there is information regarding the parameters used when using the tool, estimated tool life until it reaches the wear limit based on Taylor's insert life equation, as well as estimated remaining tool life (remaining insert life), which is updated automatically by the system. Based on the last project executed. If the user selects the "use" option in one of the tool options, they will be directed to the new project and insert a history page to create a new project using existing parameter data as a reference or basis and view the tool usage history based on projects that have been run. The interface design display for the insert list page of the tool life estimation system in the turning process can be seen in Figure 17.

Figure 17. Page View Insert List

On the New Project and Insert History page, users can register a new project, estimate the number of products that can be machined by the selected tool, estimate the remaining tool life after use based on unique project data, and view the history of previous tool usage. The display of the new project and insert history page interface design for the tool life estimation system in the turning process can be seen in Figure 18.

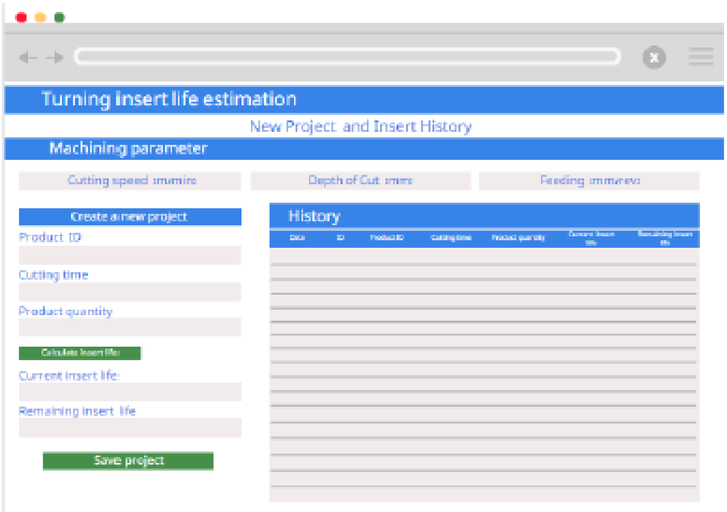

Figure 18. Page View New Project and Insert History

5. Conclusion

Based on the research that has been carried out, the concept of a tool life estimation system for the turning process has been successfully designed. The system can help plan tool usage and replacement times with the ability to estimate tool life before and after use. The interface design of the concept design for the tool life estimation system in the turning process has been created. The tool life estimation system consists of five pages: login, main page, page insert registration, page insert list, and page new project and insert history.

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