

DEVELOPING AN OEE PROTOTYPE

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ABSTRACT

The OEE metric, which is a machine production efficiency evaluation method, has been widely used in many industrial organizations. Since more and more manufacturing companies use MES (Manufacturing Execution System) to control their production line, the multitudinous services supported by an MES are according to different purposes, and the OEE metric is one of the services among them. It enables the manufacturers to view and check the machine working statement, for better machine maintenance and production efficiency.

The purpose of this thesis is to explore how to develop an OEE prototype, which will be used as a module in an MES, and to show the prototype's usability. It was inspired during an internship at Productionsoftware, a company located in Lahti, Finland.

As a result, this thesis gives a detailed solution of how to create an OEE prototype and explains its usefulness in brief.

Keywords: oee, prototype, development process, possibility, usability

ABBREVIATIONS

EIS	Execution Information System
ER	Entity Relationship
IS	Information System
MES	Manufacturing Execution System
OEE	Overall Equipment Effectiveness
TPM	Total Productive Maintenance
UML	Unified Modeling Language

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1. INTRODUCTION

1.1 Background

Manufacturers have been putting effort into exploring solutions for better quality, lower costs and more efficient delivery, since the external environment is changing all the time and becoming more and more competitive with the development of organizations. There is no doubt that machines play a significant role in production. However, finding ways to take advantage of this in order to achieve higher levels of effectiveness and efficiency in a production process is a problem. Because of this, good management systems are in high demand. (Wudhikam 2013.)

Total Productive Maintenance (TPM) is a widely used concept in various management philosophies. The aim is for the whole organization to work together to improve equipment effectiveness. The concept was first introduced by Nakajima in 1950s, and it is a method for maximizing machine effectiveness, involving all departments of the organization, from the top managers to the frontline employees, planning, using and maintaining the equipment. (Pomorski 2004.)

The heart of the TPM concept is the Overall Equipment Effectiveness (OEE) metrics. It is a widely spread methodology used in factories, which was initiated when the TPM philosophy was first introduced by Nakajima. The aim of the OEE metrics is to ensure the continuous efficiency of equipment. The metric is also a calculation covering the availability, performance and quality of the manufacturing process. (Almström et al. 2016.)

1.2 Motivation of the Research

In the summer 2016, the author of this thesis had an opportunity to work at Productionsoftware Oy, an IT company based in Lahti, Finland. The company has created a product called SMARTMES®, which is a manufacturing execution system for industrial use. The

author was given a task to create an OEE programme because the company's clients had been asking for one.

When conducting the study, the author found out that most of the earlier research on OEE applications focused on exploring algorithmic logic and problems or combining the OEE with other management philosophies. There were no existing studies on how to create an OEE application or prototype.

1.3 Thesis Structure

In addition to the present chapter, the thesis includes six chapters. Chapter 2 illustrates the research design, especially the research question. Chapter 3 describes the knowledge base underlying the research question of this study. In addition, chapter 3 discusses the related concepts, theoretical background and methodology. Chapter 4 gives the important illustrations for the research question and chapter 5 shows and proves the usability of the artifact. Finally, chapter 6 and 7 concludes and discusses the research separately.

2. RESEARCH DESIGN

2.1 Research Question and Purpose

This thesis focuses on discussing the Overall Equipment Effectiveness (OEE) and aims to answer how to create a web-based OEE prototype by using the Microsoft Visual Studio 2015 community edition. Moreover, the aim is to prove that it is possible to create a useful prototype of an OEE application.

While implementing a research study, the research question is the initial barrier. In any research project, the research question is vital. It provides focus for the whole research project and indicates the direction researchers should take. (O'Leary 2004, 76-77). Finding a research direction is partly based on previous studies. Most of the previous studies on the OEE focus on one specific case, mostly from the perspective of evaluation, or explore the OEE methodology. These studies rarely mention how an OEE prototype should be

developed. Therefore, the research question of this study differs from the previous ones.

In short, the thesis aims to answer the following research question:

How to develop an OEE prototype to be used as a module in a Manufacturing Execution System (MES)?

2.2 Research Method

Since this thesis project is prototype construction, the employed research method will be different.

IT artifacts are broadly defined as constructs (vocabulary and symbols), models (abstractions and representations), methods (algorithms and practices), and instantiations (implemented and prototype systems). These are concrete prescriptions that enable IT researchers and practitioners to understand and address the problems inherent in developing and successfully implementing information systems within organizations. (Hevner & Chatterjee 2010, 271.)

In this study, the IT artifact is the OEE prototype regarded as an instantiation according to the definition above. The employed research method and data analysis plan will be described in detail in this chapter.

2.1.1 Information Systems Research Methodology

Since this study commits to the topic of building an OEE calculation prototype, the paradigm of design science will be employed in this research project. One of the main purposes of the design science methodology is executive information systems (EISs) development, and this method covers the construction, methods and instantiations of IT artifacts.

In addition to design science, information systems research often employs behavioral science-based research methods. These usually aim to apply theory to explain phenomena in organizational contexts. Design science, on the other hand, enable researchers to profoundly understand a solution or approach while developing a given system.

Therefore, a design science based research question focuses on problem solving and is related to designing a system. (Hevner et al. 2004, 79.)

This study applies the design science method to illustrate the process of planning and building the OEE prototype application, which can be customized in the further implementation. So there will be no necessity for comprehensive reconstruct according to different factories' conditions. Since different factories have different working patterns, which will result in the complex of OEE calculation and algorithm.

In this study, the author employs the information system research framework as illustrated by Hevner et al. (2004, 80) in figure 1 below:

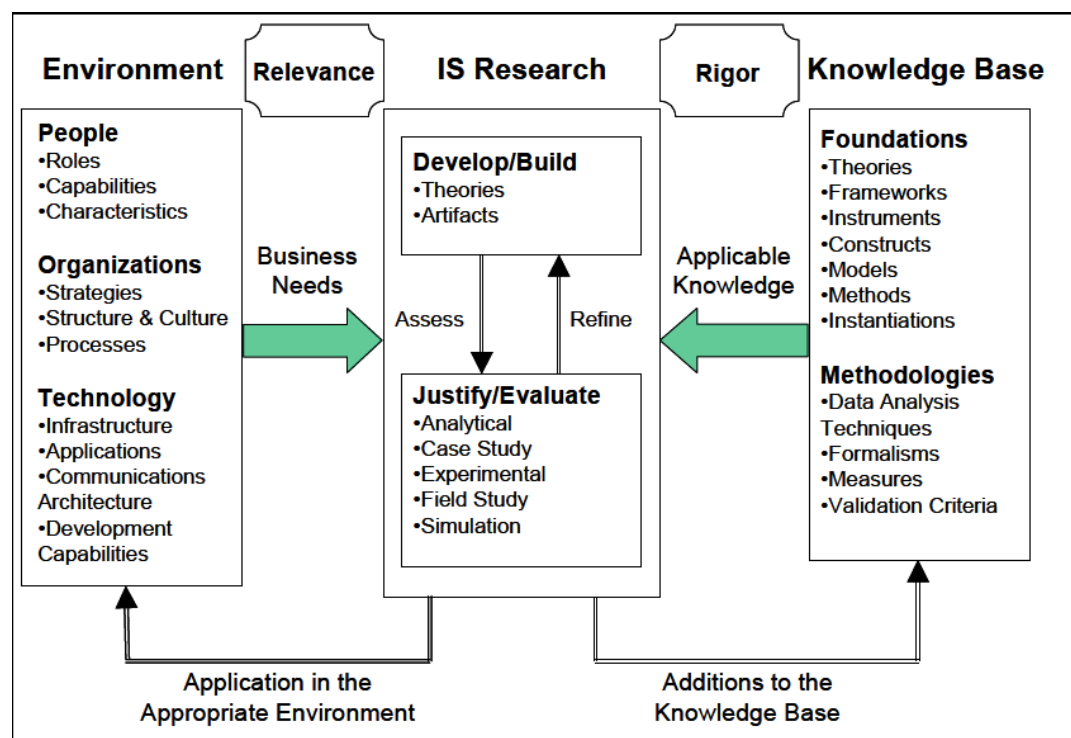


Figure 1: Information Systems Criteria (Hevner et al. 2004)

The above figure implies the basic research framework of this study in developing an OEE prototype. The knowledge base, based on certain foundations and methodologies, supports creating the artifact, the OEE prototype.

In this study, the knowledge base is based on the several key

concepts. These key concepts include the following: the OEE, the OEE calculation equation, prototyping in information systems development, and database design. In short, the knowledge base includes all the knowledge obtained and used in this study. This will be described in more detail in later chapters.

The environment in design science methodology is associated with the people, organizations and technology. In this study, the environment is related to Productionsoftware's clients, their demands for having an OEE service, their roles, their organizational backgrounds, and the technology they use. The term "people" here refers to the users who will be using the OEE prototype. Their user roles can be divided into two: managers and frontline employees. The term "organizations" implies the possible case organizations in research. However, since the OEE application is only a prototype, this study does not focus on a particular case company. Finally, the term "technology" here refers to the Microsoft Visual Studio 2015 community edition, the operating environment for the prototype. However, this can be different in future depending on the servers or facilities used in different companies.

With regards to IS research, this study addresses the research problem by creating an OEE prototype. This is done based on the information in the knowledge base and the needs of Productionsoftware's clients. The development process of the prototype will be described in detail in chapter 4.

2.1.2 Qualitative Research

Qualitative and quantitative research approaches are frequently used in research projects. Qualitative research aims at understanding a social or group problem by exploring various theories. The purpose of qualitative research contains solution procedures. In qualitative research, data is collected through observation and interviews, and from documents and texts. In contrast, quantitative research focuses on testing an existing theory according to different variables. The aim

is to collect and analyze data to support a theory. (Creswell 2014, 11-14.) Rather than aiming to test a theory, as the research question suggests, this study focuses on problem solving, and the provided solution is based on existing theories. Therefore, this study adopts a qualitative research method.

2.3 Data Collection and Analysis

There are numerous types of the data collection methods such as questionnaires, interviews, tests, observation, and secondary data. Unquestionably, data collection results from the research question, educated experience and overall findings. (Merriam & Tisdell 2016, 17.) The below table summarizes the techniques of data collection in qualitative research.

Table 1: Data Collection Techniques (Creswell 2014)

Data Collection Techniques	Types	Advantages
Observations	<ol style="list-style-type: none"> 1. Complete participant 2. Observer as participant 3. Participant as observer 4. Complete observer 	<ol style="list-style-type: none"> 1. Researcher has a firsthand experience with participant. 2. Research can record information as it occurs 3. Unusual aspects can be noticed during observation. 4. Useful in exploring topics that may be uncomfortable for participants to discuss
Interviews	<ol style="list-style-type: none"> 1. Face-to-face interview 2. Telephone interview 3. Focus Group 4. E-mail Internet Interview 	<ol style="list-style-type: none"> 1. Useful when participants cannot be directly observed 2. Participants can provide historical information 3. Allows researcher control over the line of questioning.
Documents	<ol style="list-style-type: none"> 1. Public Documents 2. Private Documents 	<ol style="list-style-type: none"> 1. Enables a researcher to obtain the language and words of participants 2. As written evidence, it saves a researcher the time and expense of transcribing.
Audio-Visual Materials	<ol style="list-style-type: none"> 1. Photographs 2. Videotapes 3. Art objects 4. Computer messages 5. Sounds 6. Film 	<ol style="list-style-type: none"> 1. Provides an opportunity for participants to directly share their reality. 2. It is creative in that it captures attention visually

In order to answer the research question (how to develop an OEE prototype) and to prove its usefulness, the thesis collects data through face-to-face interviews. In addition, data is collected through observation. The author will observe a usability test session of the OEE prototype.

There are numerous different procedures in qualitative data analysis,

but analyzing data cannot leave out three keys: person, processes and presentation (Grbich 2013, 15-16). In this study, data collection is based on observation and an interview. The steps to analyze the data are the following:

- Transcription

This step includes transferring the conversation or interview into a document formatted in order to have clear notes (Grbich 2013, 20). In this study, the author will record the interview and transcribe it into table format.
- Preliminary data analysis

This step follows transcription and involves ensuring, tracking and analyzing the collected data. Normally, this step leads the researchers to better understand the research question. (Grbich 2013, 21-22.) For this study, the author analyses the interview data and observes a usability test of the OEE prototype.

3. KNOWLEDGE BASE

3.1 Overview of Overall Equipment Effectiveness (OEE)

The OEE was put forward initially by Seiichi Nakajima when he defined the TPM in 1980s, and it was regarded as the core measurement within the TPM philosophy. The OEE can be utilized to evaluate production processes and locate potential problems that affect the operation of equipment. As a widely employed yardstick in measuring machine performance, the equation was created according to the six big losses behind the manufacturing process, and it was associated with three main elements: availability, performance and quality, which will be explained in detail in later subchapters. According to Nakajima (1982), the OEE equation is:

$$OEE = A (Availability) * P (Performance) * Q(Quality)$$

However, the essence of calculating OEE is the proportion of Fully Productive Time and Planned Production Time. The diagram below displays the three elements of OEE as well as the statement behind them:

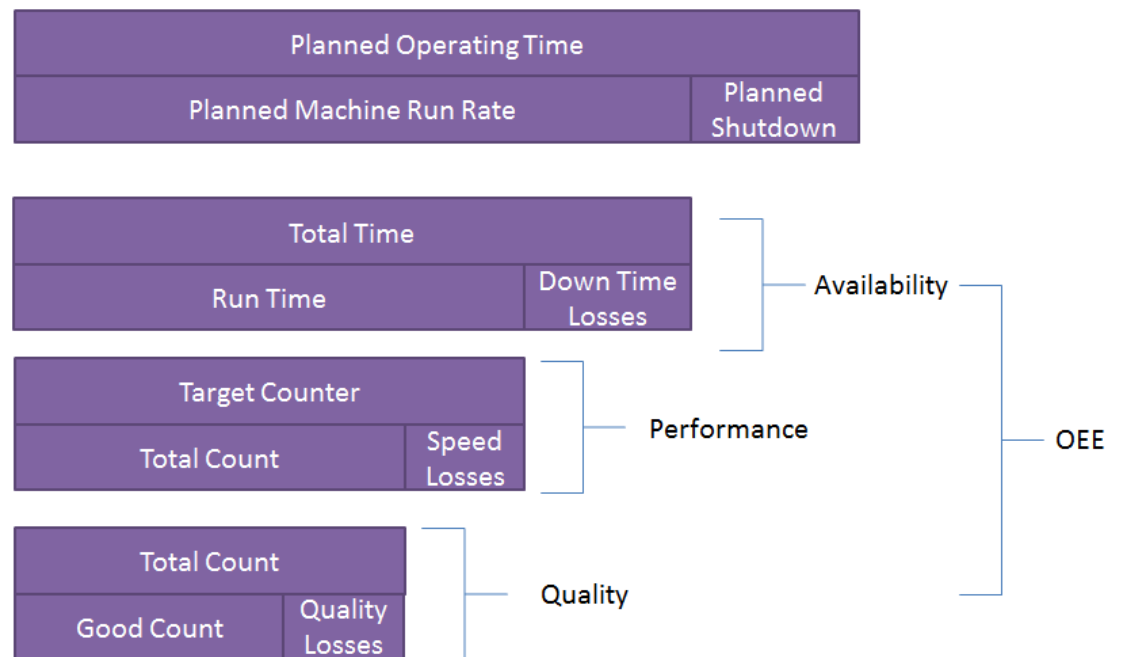


Figure 2: The related statement behind OEE concept (Wudhikam 2013; Naidu et al. 2013; Kaing 2015.)

In the figure above, the main content is the associated components behind the availability, performance and quality. Since the OEE is the measurement for evaluating equipment effectiveness and is the ratio of Fully Productive Time and Planned Production Time, the data of scheduled production time and real production time are significant. The “Planned Machine Run Rate” is the Planned Production Time, combining it with the planned shutdown period of the machine results the “Planned Operating Time”. The “Run Time” is the time record of the machine actual running period. When it is add to “Down Time Losses”, which is the real or unscheduled down time of the facility, the result will be the “Total Time”. When Implementing the OEE method, managers have to set up the “Target Counter”, which is the Ideal Cycle Time of the machine. Frontline workers have to record the “Total Count” and “Speed Losses” at the end of the production cycle, which is related to the calculation of performance. The total count consists of a “Good count” (i.e. flawless products) and “Quality losses” (i.e. damaged products or products that need to be reproduced). Those will be calculated for the quality rate.

One trigger behind the popularity of the OEE metric is its simple calculation method and widespread impact on efficiency of production (Almström et al. 2016). However, when its used in different industrial settings, putting the equation into practice might be quite complicated (Naidu et al. 2013). Although the OEE is used in different manufacturing companies and often customized to meet particular requirements at factories, the fundamental idea is based on the original OEE concept. This study focuses on creating a prototype, not to apply the OEE at any specific factory, and the prototype will not be implemented immediately.

3.2 The Six Big Losses

When thinking about the manufacturing process, the first image that often comes to mind is the operation of a machine accompanied by an employee. The process often has problems such as unexpected interruptions. These problems cause various kinds of waste. Nakajima described as the “six big losses” and categorized them to three main themes: downtime losses, speed losses, and quality losses. (Magnus & Patrik 1999.) These losses reduce the effectiveness of the manufacturing process. The below table illustrates the six big losses and the categories they belong to:

Table 2: The Six Big Losses behind OEE Metric (Magnus & Patrik 1999; Wudhikam 2013)

Three Factors	OEE Losses Category	Six Big Losses
Availability Rate	Downtime Losses	1. Equipment failure/Breakdown 2. Set up and adjustment
Performance Efficiency	Speed Losses	3. Idling and minor stoppage 4. Reduced speed

Quality Rate	Quality Losses	5.Defects and reworks in process 5.Start-up losses/reduced yield
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To more specific explanation, the “six big losses” is described as following:

Downtime Losses:

1) Equipment failure/ breakdown:

The breakdown of the machine belongs to the downtime losses because machine failure will result in the product quantity losses and will have a bad influence on productivity.

2) Set up and adjustment:

The set up and adjustment means the losses because of the breakdown or faulty products that were produced when the equipment stopped the on-going assembly and adjusted or set up itself to manufacture another item. During this process, time losses may occur.

Speed Losses:

3) Idling and minor stoppage:

The production process might be disturbed by an accidental or temporary stoppage error, or if the equipment is idle.

4) Reduced speed:

Losses occur is the speed of the machine is slower than planned. In other words, there is disparity between planned speed and the real running speed.

Quality Losses:

5) Defects and reworks in process:

This refers to the imperfect and flawed items in the manufacturing process, which should be dropped off or reworked. This might be caused by malfunctioning

production equipment or the adjustment of machines. These losses result in time losses or financial losses because of wasted time on rework and product downgrading.

6) Start-up losses/reduced yield:

Start-up refers to powering a machine on. Start-up and reduced yield relate to the period between a machine start up and its stable operation.

(Wudhikam 2013; Almström et al. 2016.)

The availability rate is based on the downtime losses. When evaluating performance efficiency, the speed losses play a key role. Quality rate will be determined by the quality losses. These three loss categories realize in varied ways during the real manufacturing process because different companies have different production processes.

3.3 OEE Calculation

The OEE calculation result aims at giving information about significant losses, helping factories evaluate the situation production process problems. The diagram below demonstrates the OEE calculation based on the figure 2.

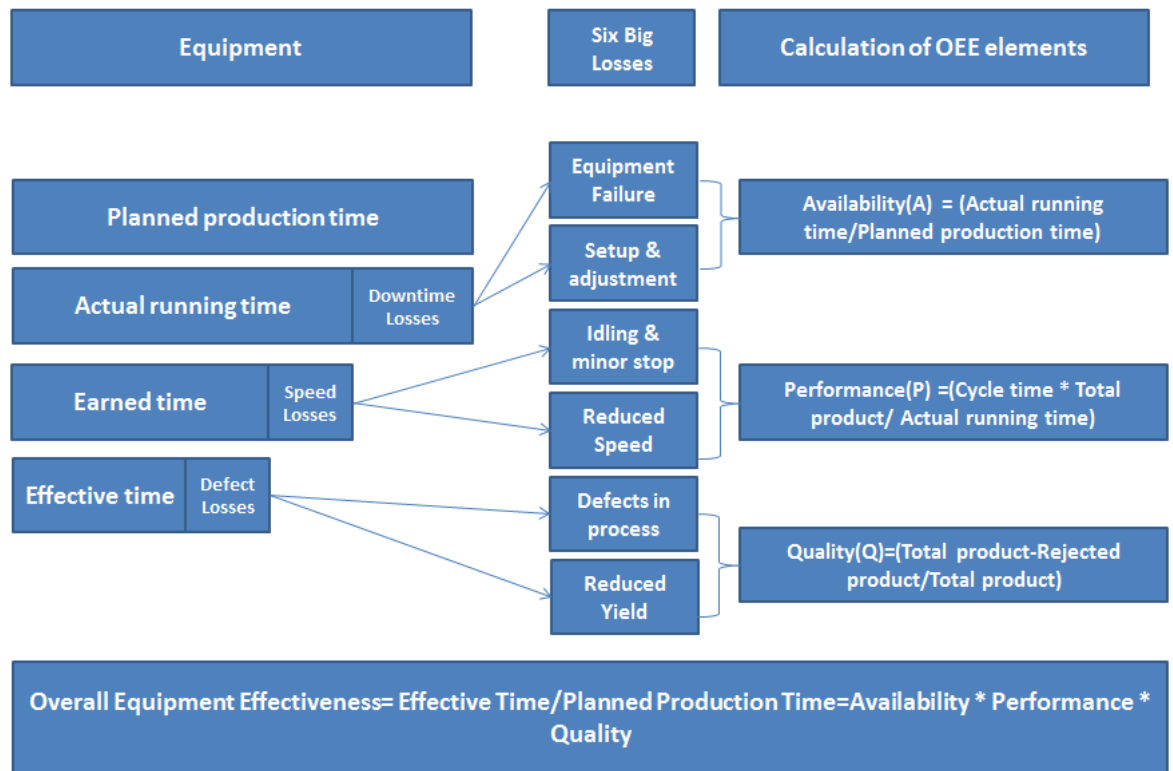


Figure 3: Brief OEE Calculation (Eswaramurthi & Mohanram 2013)

Moreover, many researchers have tried to define an optimal OEE score. Nakajima (1982) suggested the following:

If Availability is > 0.90, Performance is >0.95 and Quality is > 0.99, this results to an OEE score of over 0.84, which is world-class level. However, the optimal OEE score is constantly being debated. Below is an example of OEE scores:

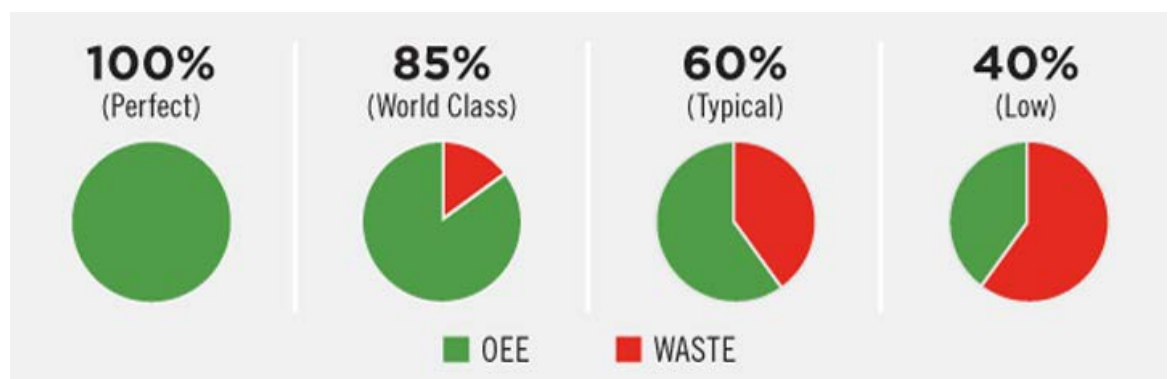


Figure 4: OEE scores (Leanproduction 2016)

3.3.1 Availability

Availability in the manufacturing process implies all the occurrences

that break or prohibit the planned production period, and take the consideration of planned as well as unplanned breakdown. It detects the utilization ratio of the operating machine. Typically, it takes few minutes, includes the small stop, breakdown, the reason that preventive maintenance, set up times, and the lack of operators. It is the ratio of actual running time and planned production time.

Availability formula below:

$$\text{Availability} = \text{Run Time} / \text{Planned Production Time}$$

Sometimes, the actual running time of the machine is the difference of planned production time and downtime together of the facilities.

$$\text{Run Time} = \text{Planned Production Time} - \text{Stop Time}$$

(Naidu et al. 2013, 1630.)

3.3.2 Performance

In accordance with the figure 3, the performance is related to the speed loss, which means that the comparison between the running speed and the maximum capability. It takes into account the desirable speed, actual speed of the facilities operating, the products amount, and the running time. In the equation below, the Ideal Cycle Time is the desirable speed, which means the speed of producing one part, that using minimum time. The Total Count indicates the quantity of the produced pieces including the defected products. The Ideal Cycle Time multiplies the Total Count come out the result of Net Run Time, which is the speed of producing a product.

$$\text{Performance} = (\text{Ideal Cycle Time} * \text{Total Count}) / (\text{Run Time})$$

Another calculating method is taking into account the Ideal Run Rate, which is the inverse of Ideal Cycle Time:

$$\text{Performance} = (\text{Total Count} \div \text{Run Time}) \div \text{Ideal Run Rate}$$

(Naidu et al. 2013, 1630.)

3.3.3 Quality

Quality in OEE is measuring the examination of good pieces rate, or in other words, quality losses. Therefore, it is the portion of good products amount (can be used, sold or meet the requirements) and the total amount of the parts produced. Quality usually involves good pieces amount, total pieces amount and the quantity of defected pieces. The following is its formula:

$$\text{Quality} = \text{Good Count} \div \text{Total Count}$$

Usually, when there is a large amount of work in factories, the amount of good pieces is huge. Thus, the Good Count will be calculated as following:

$$\text{Good Count} = \text{Total Count} - \text{Defected Count}$$

(Naidu et al. 2013, 1630.)

3.4 Software Prototyping

In the past, software prototyping was regarded as an expensive, long-time building method for the ultimate result of the software. However, with the development of various software tools, the cost and time period of developing a prototype has been reduced. Thus, constructing a prototype for the software has been a popular trend in many IT companies. (Avison & Fitzgerald 2006, 123.)

Prototyping is a solution model of software development. Compared with the traditional system developing, which the first version is the final implementation one, the prototype model resolve the problems occurred of the traditional method that the trouble of making changes after the whole software has been implemented. Prototyping reduces the risk of project rejection, such as misunderstanding of customers' requirements, the features that users do not want and so on. Thus, prototyping pays the emphasis more on customers' needs while the traditional measurement solely for developing software. A prototype construction make the program has lots of spaces to change and improve, and easily satisfied the demand of users. (Avison & Fitzgerald 2006, 126.) In this research, under the circumstance of

different factories have different work model and machines, the OEE calculation will be a little bit diverse. Therefore, the OEE program will be developed as a prototype in order to meet customers' need when it is implemented in reality.

3.5 Prototyping process

There are two mainstream philosophy of prototype:

1. Throwaway prototype

This approach usually is for quickly user interfaces building in graphical extent, as well as basic functionality. In other words, it is utilized in the conditions such as no specific requirement, some required functions' performance, complicated to joint with other systems, poorly documented and so on. The emphasis of this approach typically is on the requirement clarification over and over again, in order to reduce the risk of the project. It will be thrown away immediately after evaluation of the information system, which will be not utilized for further development of the system. (Avison & Fitzgerald 2006.) The figure 5 displays the process of throwaway approach:

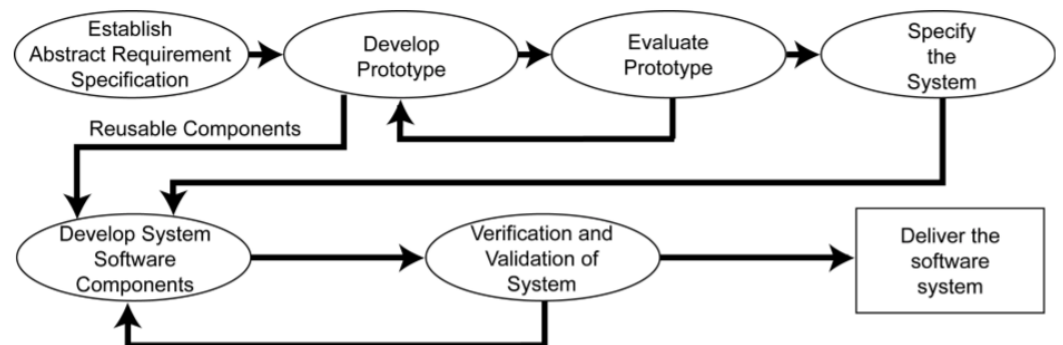


Figure 5: Throwaway Prototype Process (Helm 2017, 6)

2. Evolutionary prototype

This methodology usually is regarded as a perfect method for developing an artifact that already existed, not starting with totally blank. It will help with the difficulty of software specification. The crucial point of this method is utilizing various techniques that allowing for the further development of the program, for example,

using high level programming language and various tools for the development process, because it requires the ability of the prototype, that can be operated or even effectively. The figure 6 demonstrates the process of evolutionary prototype method as following:

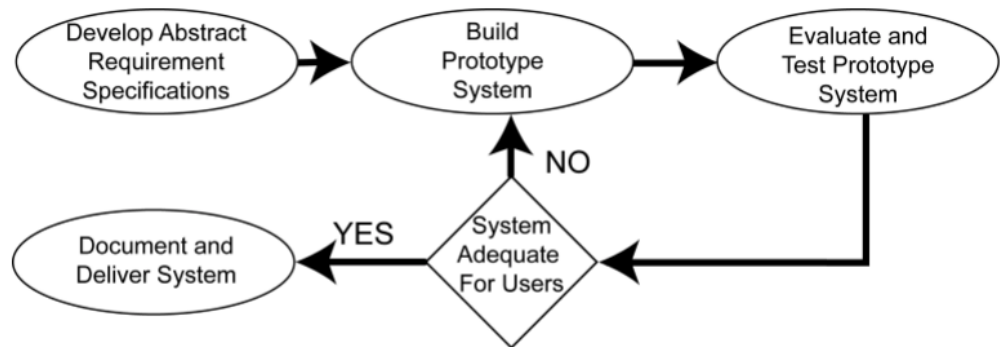


Figure 6: Evolutionary Prototype Process (Helm 2017, 5)

The distinction between throwaway and evolutionary approach is that an evolutionary prototype can be utilized for the further development. Apart from that, there is no need for the developers that rewrite the coding, make big change of the user interface, or rebuild the whole program. Creators can improve it all the time to meet different requirements from the customers. To the contrary, the throwaway method refers to the software specification, which means it focus on requirements and specification from the users. Generally, this approach is for satisfying customers' need immediately, to make sure about what they want, but not for further software expanded, and the final version may be totally different than the prototype. (Avison & Fitzgerald 2006, 124.)

In this case, the development of OEE prototype program will apply evolutionary prototype methodology, due to its purpose of creating a program to end-users while throwaway prototype is validating the system requirements, as well as the features of evolutionary approach the needless reconstruction, can be used for further development.

3.6 Database Design

Database has been ubiquitous in any organization, system, and everyday life for three decades with the development of technology. A database is the collection of correlative data that stored in a system or organization in order to satisfy the demands from users. Since the database technology development has been promoted in recent years, there are many tools, approaches and concept surround the database. (Lightstone et al. 2006, 1.) To construct the OEE prototype, the data of the facilities and workers cannot be avoided, and a large amount of data has the necessity to be recorded so that OEE figure can be calculated. Therefore, database design and implementation plays a significant role in the constructing process.

3.7 Database Life Cycle

A database life cycle provides a general procedure for database design, enable designing a logical database. In addition, the life cycle can be followed and utilized even when the database is implemented. The figure below demonstrates the steps of database life cycle. (Lightstone et al. 2006, 4.)

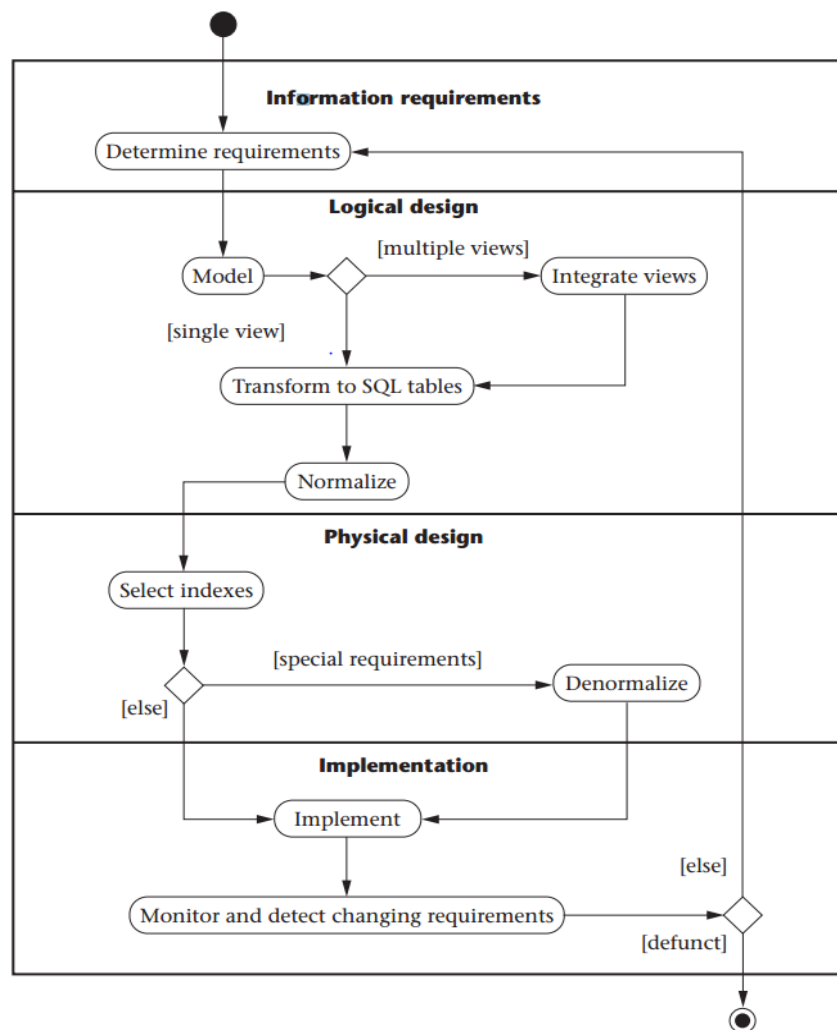


Figure 7: Database Life Cycle Procedure (Lightstone et al. 2006, 4)

- Requirements analysis

A formal requirement specification can be built by collecting the information through the interview of producer and users. It involves the required data orientation, the data relationship, and the software platform that support database construction. (Lightstone et al. 2006, 3.)

- Logical design

In order to design a logical database, the common approaches are Entity Relationship (ER) model and Unified Modeling Language (UML) diagram (Lightstone et al. 2006, 3-6), which will be introduced in Chapter 5.2 and 5.3.

- Physical design

The process of physical design contains the selection of

indexes, the segmentation and gathering of the data. This step aims at improving more detailed and accurate data combination into reality. It is more useful during the implementation of the database, to check, review and update the data relations. (Lightstone et al. 2006, 6-7.)

- Database Implementation and modification

The database can be implemented by using data definition language (DDL) in the platform of database management systems (DBMS). The data manipulation language (DML) can be employed to query for the purpose of database modification. A widely used language is SQL. During this process, the requirements from users should be satisfied and update if needed according to the discussion. (Lightstone et al. 2006, 8.)

3.8 The Entity-Relationship (ER) Model

The ER model comprises three main aspects: entities, relationships and attributes. Entities imply the data objects that need to be collected, typically points to a person, place, thing or event. Relationships is the association among the entities that designer defined. In ER model, the relationship usually is the three types of lines connecting the entities: one-to-one, one-to-many and many-to-one. An attribute refers to the detailed information of an entity. For instance, a worker entity may have the attribute of worker-id, worker name, worker address, working time, etc. The picture below displays instances of ER model entity connection concept.

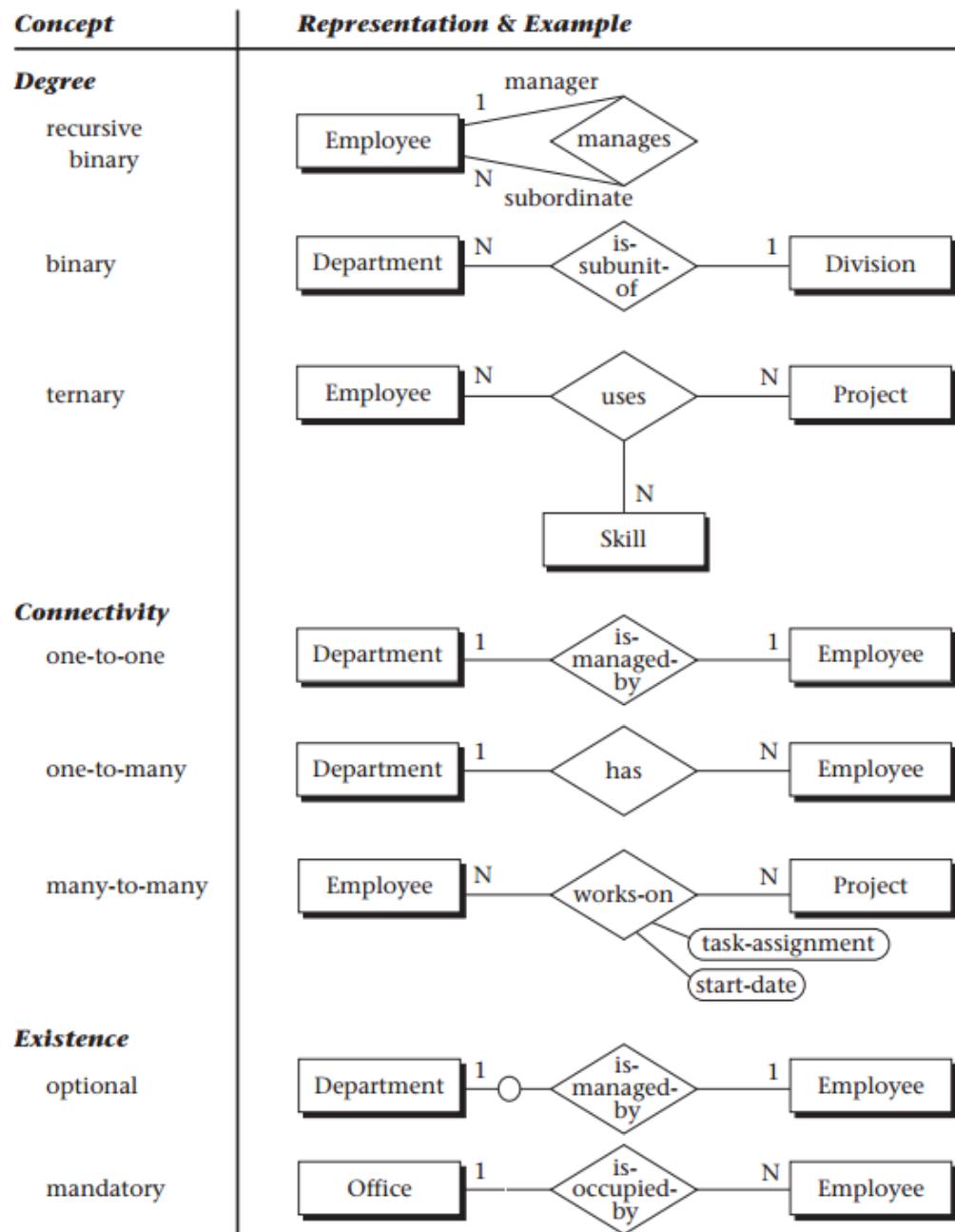


Figure 8: The basic concept of ER model (Lightstone et al. 2006, 17)

The ER model support the developer locating the objective data and its properties, ensuring what data should be taken into account and the basic relationship among them.

(Lightstone et al. 2006, 13-20.)

3.9 The Unified Modeling Language (UML)

The UML is an approach not only for database design, but also for the design of software development before coding. There are various

UML diagrams methodology for different software and database design. A widely spread structure of the diagram serve the database design evolves class and activity model. The distinction between class diagram and activity diagram is that class diagram emphasis on the structure design while activity diagram put the interest on dynamic process of designing a database. (Lightstone et al. 2006, 33.) For this study, the author will utilize the class diagram to deal with database design issues, to give a logical structure of the database element.

The UML class diagram has the similarity with ER model, its creation is influenced by the ER model. The diagram below shows the relationship and connection aspect of UML model, and the audience can compare it with Figure No. to view the difference between ER model and UML method easily. (Lightstone et al. 2006, 38.)

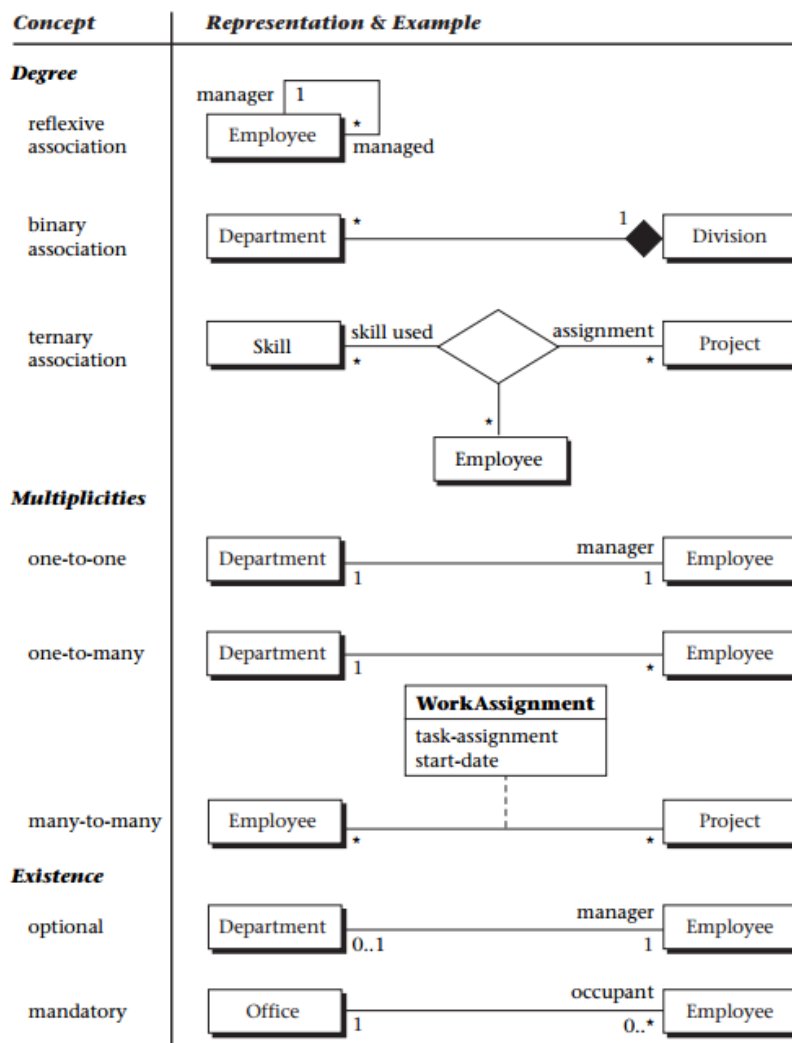


Figure 9: The Connection concept in UML diagram (Lightstone et al. 2006, 38)

In database design and construction, primary key is an important concept within it. It refers to the attribute in a class diagram, and a given data of the attribute pinpoint a specific class. Here is the example of primary key in UML diagram:

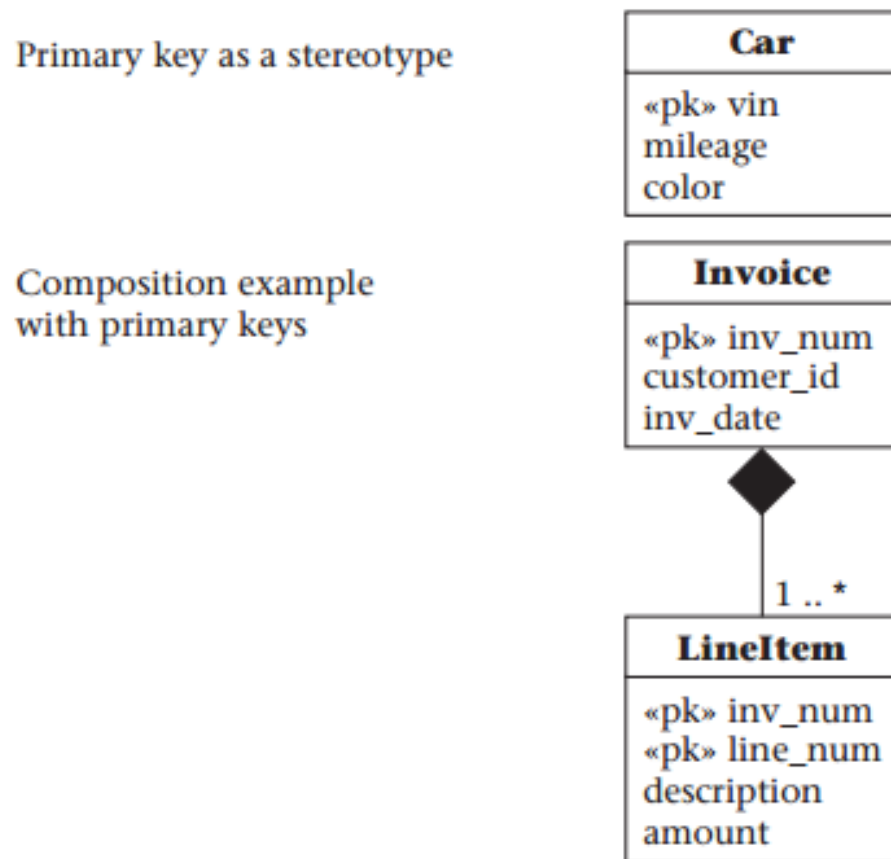


Figure 10: Basic Example of UML model (Lightstone et al. 2006, 42)

In the figure above, the primary key in the class of “Car” is “vin”. It means each “vin” points to a specific “car”, and each “car” has a unique “vin”.

4. IS RESEARCH: DEVELOPMENT PROCESS OF OEE PROTOTYPE

In this chapter, the author will describe the process of constructing the OEE prototype in details. The main process that described in this part is consistent with the evolutionary approach, but focus on the software requirement specification and building process. From writing the initial specification, it will shape the first image of thinking how to create this prototype, what this program work for, and the main initial

function acknowledge, which will contribute to the next step of the process: construction. The web design, database design and the coding behind derived from the requirement specification.

4.1 Development Team

When constructing the OEE prototype, the team consisted of four members. The CEO of Productionsoftware was the leader of the team and gave the team systems requirements. The prototype will be implemented in further in the future as part of the company's SMARTMES® software. The author was the developer focusing on coding, database creating, UI implementation and documents writer. The other team mate was the UI designer, gave the image and discuss with the author in every meeting, so that the author could change and improve the user interface. Another student came and participated in this project later as the beginning of his internship training, he helped with checking and improving the code.

4.2 Writing the Software Requirements Specification

4.2.1 Purpose

This document is the software requirements specification for OEE calculation program on the basis of existed SMARTMES® software. The aim of this document is to consider in advance that the requirements and overall image of the OEE calculation program, in order to give readers an initial image and logic behind of this prototype, because there is a demand from more and more customers that their industries need to calculate the OEE for better data analysis and the improvement of production efficiency. At the same time, the requirement specification will help with implementing the prototype smoothly in some level. This document is associated to the initial design or plan of the prototype. The product will become the part or module of the SMARTMES® software in the future, and it will include four main parts: Availability Calculation, Performance Calculation, Quality calculation and OEE calculation. All the results of them have to be displayed to the users. Therefore, the related

database, together with the relationship of the tables is the important designing aspect of this prototype.

4.2.2 Intended Audience and Reading Suggestions

The intended audience will be developers, project managers, workers such as UI designers, testers and documentation writers, users, among which, the users will consist 2 groups: Managers of the companies and workers in the factories. The former will utilize this prototype for analyzing the production efficiency of industries as well as setting up some data to the database, the later will be mainly for inputting the specific data and viewing or checking the calculation result, they will be the main group for operating or using the module.

4.2.3 Product Scope

The final product will be implemented further based on the existed software: SMARTMES®, which belongs to the Productionsoftware. However, in this case, how to develop a prototype of the product is the first step. The main functions of the program are to calculate not only OEE but also three aspect of it: Availability, Performance, and Quality, which will help managers with the efficiency of the whole production process and consider which element, should be improved no matter daily, weekly, monthly or yearly. It will benefit for analyzing machine, workers in order to make better production process analyze. Also combine those data with other modules in the SMARTMES® software. Therefore, the OEE calculation will act as the analyze tool, for the utilization of the companies' business strategies such as prediction, assessment, and summary.

4.2.4 Product Perspective

Rather than being a replacement of certain existing systems, OEE program is a follow-on member of SMARTMES® information system, its operation will be based on the operation of the SMARTMES®. SMARTMES® is created by Productionsoftware Oy that helps with

intelligent industrial management. It offers different modules for various specific area of the factories management, and makes customization successful depending on different demands of customers. Under this circumstance, OEE program will become a module and a function for SMARTMES® because almost every customer needs OEE calculation nowadays. Therefore, OEE and SMARTMES® actually will run on the same server. A simple diagram shows the major process of the overall system and interconnections with OEE program in following:

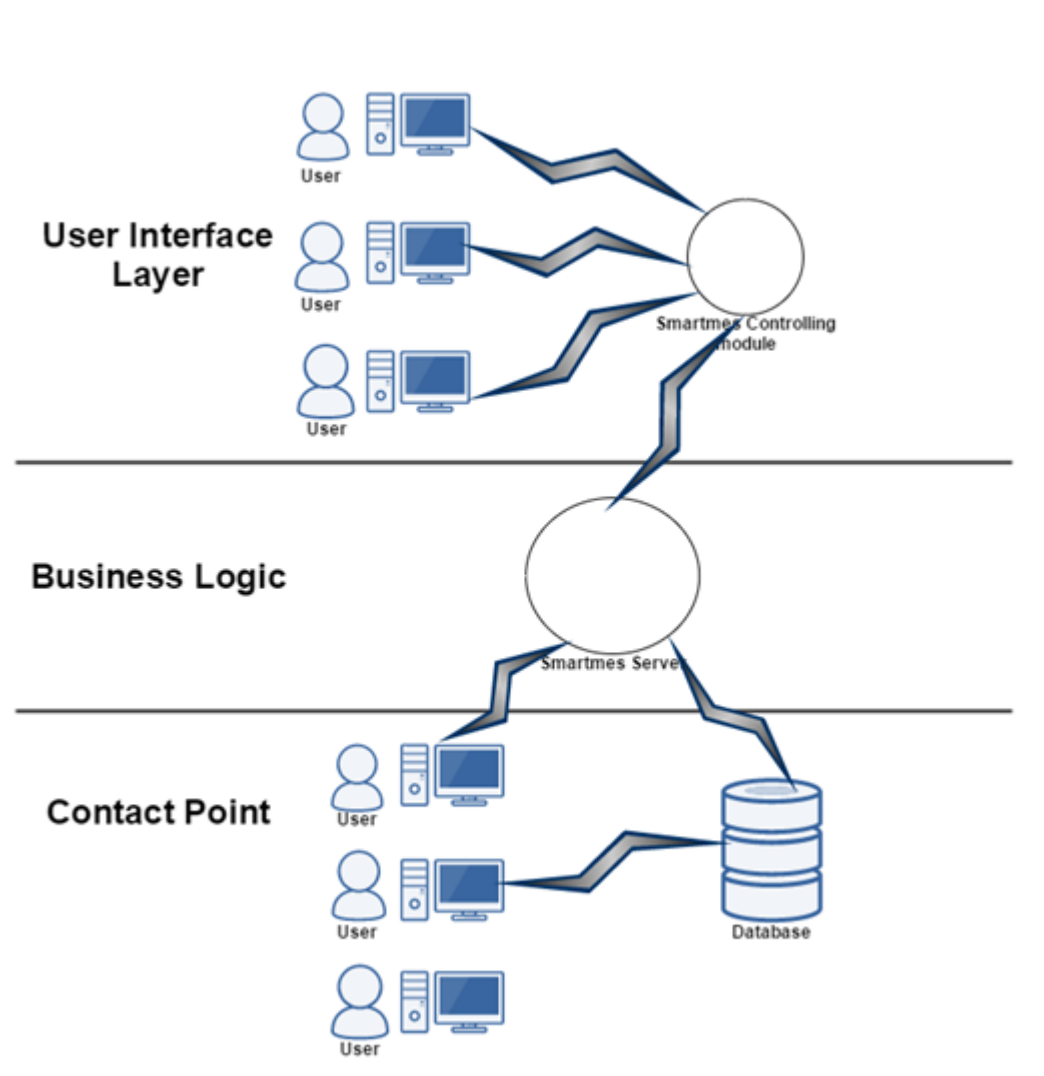


Figure 11: Major Connection Process of OEE program

4.2.5 Product Functions

The major functions of the OEE program will be: Availability calculation, Performance calculation, Quality calculation, OEE

calculation, and necessary data inputting. All those mentioned before except the input data are using formula to calculate in order to express machines' operating efficiency and production efficiency. What the program must perform is using the figures from the database to calculate and display the result. While for the users, the program must let them input the data that saved and recorded in the database. The diagram below is the use case of the OEE prototype, which demonstrates more clearly of the functions entity and its relationship.

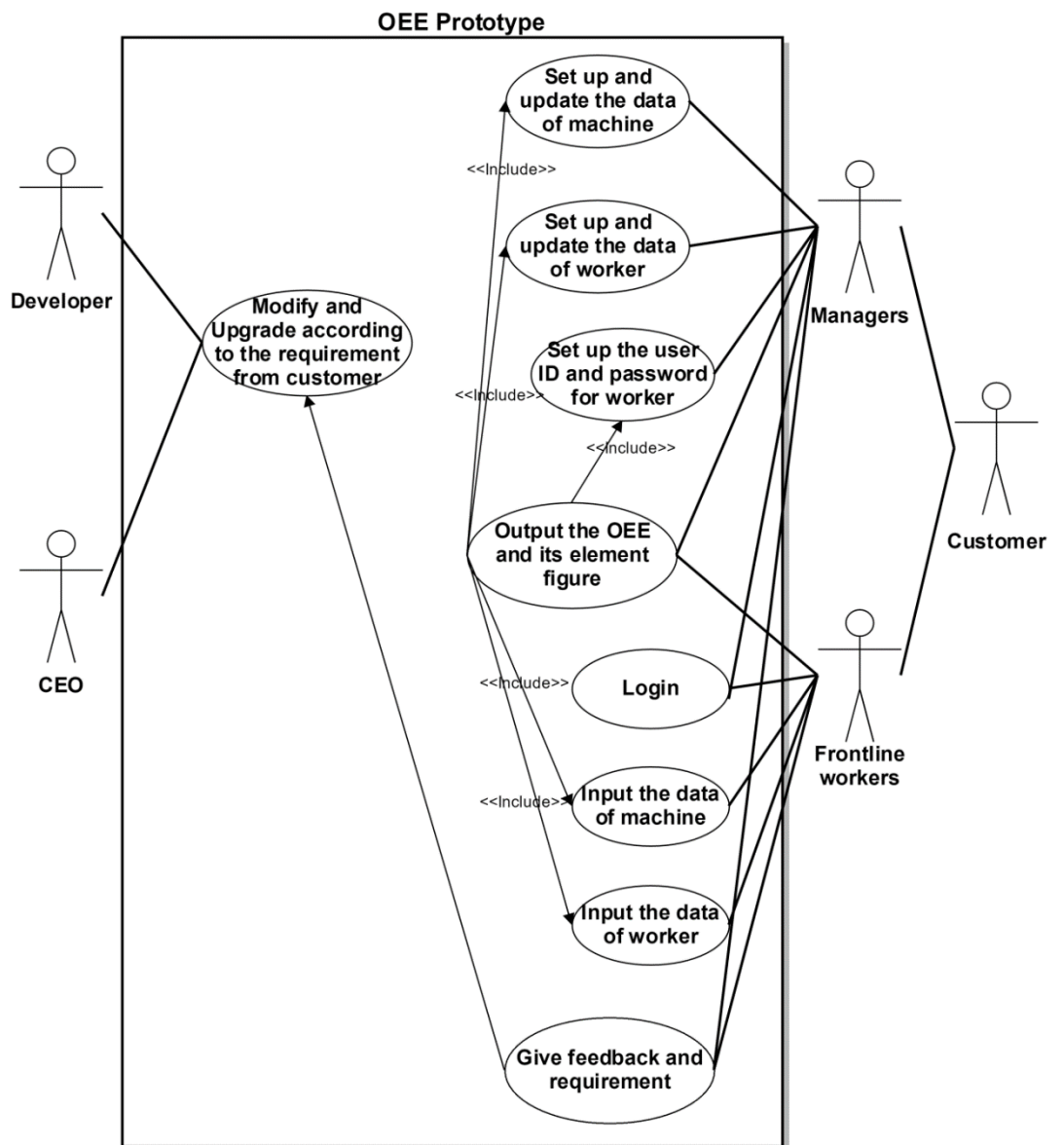


Figure 12: Use Case of OEE prototype

The user classes will contain project managers, developer, customers (managers and frontline workers). The developer who creates this program as well as the project manager need to use it as testing and upgrading purpose through the process of managers set up the data, workers input the data and the calculation logic.

4.2.7 Operating Environment

In fact, the OEE prototype is a web-based application and developed by the platform of Microsoft Visual Studio 2015 edition and Azure. Therefore, the operating environment at the moment is Visual Studio and Azure. However, in the further development, it needs the environment of SMARTMES® operation. Once using SMARTMES® software, customers can choose the OEE module to input data that calculating and viewing the result. Basically for the hardware, it needs computers or access to internet, together with server machines.

4.2.8 User Documentation

There will be a user manual including online help and tutorials. The manual will offer courses, lessons and guidelines to help users to learn how to use the program. The user manual will be available online at: www.psacademy.fi

4.2.9 Assumptions and Dependencies

The software will be implemented by Microsoft's programming tools. The further sight is that it will be a part of existed bigger software: SMARTMES®. The software could run on all machines with using Microsoft Windows operating system version of Win7 or later, or Windows Server operating system version 2012 or later.

4.2.10 Hardware Interfaces

There is no specific hardware interfaces contained within this system. The only significant interface is for operating the system, which means it will require a terminal for its operations.

4.2.11 Software Interfaces

OEE calculation program will act as a component of the SMARTMES® software, which will be developed in order to increase the function of SMARTMES® as well as add competitiveness to it. Since it will become a module of the SMARTMES® software, it might connect to other modules. However, as being the process of the initial designing part, it is implemented independently at first and test whether it will run properly, so there will be two websites that one of them is showing the result and the other one is ask users to input data and test the program. It will be added into the SMARTMES® software finally, but during this starting moment, it will be developed out of the SMARTMES® software at first.

4.3 UI Design

When the author started the OEE project in Productionsoftware company, the UI designer and author had the meeting regularly and small discussion by using online working tool: Slack, for UI design and its' implementation. The picture below is the initial UI image given by the team member, which is the main page of displaying OEE and its' factors result. The author decided to follow this UI image to create the web page.

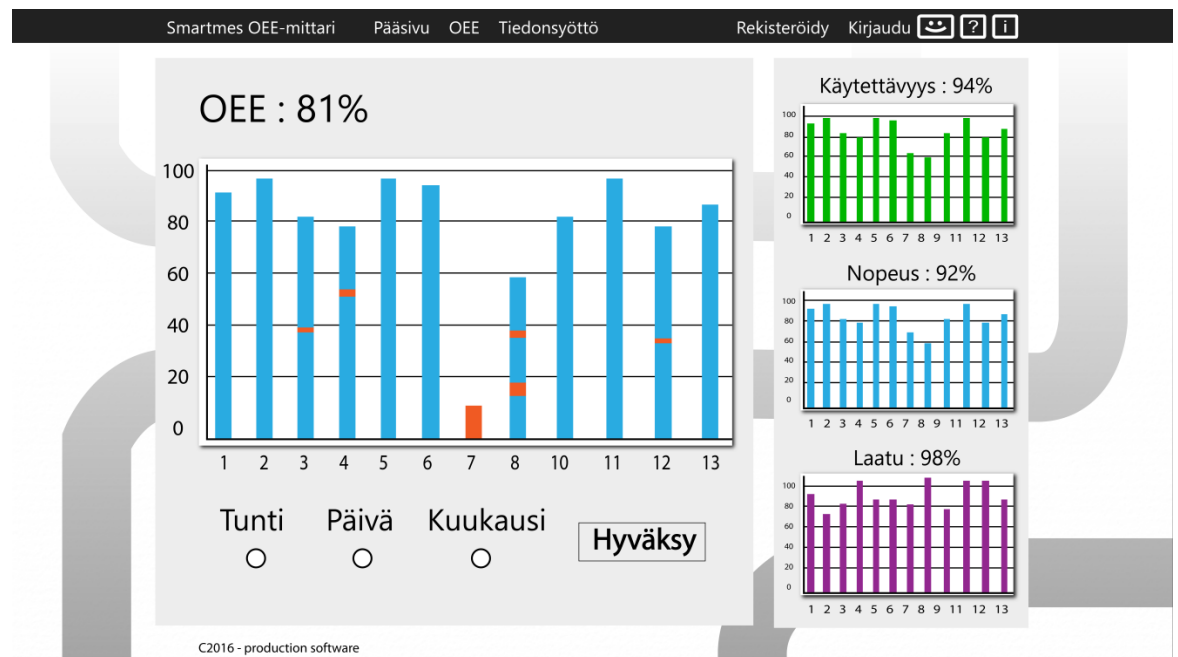


Figure 13: Initial User Interface Design Result

The image is the initial main page and result page of the OEE prototype. It pursuits the layout as concise as possible, and has the features inherited from SMARTMES® software in order to make it operate in SMARTMES® in the future. The main features of the OEE result page are:

- Displaying availability figure
- Displaying performance figure
- Displaying quality figure
- Displaying OEE figure
- Enable users to view all those figures by hourly, daily, and monthly by choosing and clicking the button
- Enable users to compare the figures directly from the chart

4.4 Constructing the Database Design

The database plays a significant role in the OEE prototype construction process. What is the necessary data that to be collected? How to identify the data? What are the relationships among those data? They are the basic abstract issues when designing the database. According to the concept described in chapter 5, the developer will follow the database life cycle but emphasis on the

requirement analysis process and logical design process, using the methodology of ER model and UML diagram.

4.4.1 Requirements

To design a database for OEE prototype, the first requirement comes from the working flow of the industries, since the OEE philosophy contains the participation of equipment, workshop employees, and managers. Therefore, the basic sets of data come from those three positions. Then, the second requirement can be inspired through OEE calculation, for instance, the total count and good count that produced by machine will result in quality rate, thus, the data of total count, rejected count and good count should be recorded in the database. By this analogy, the data that support the performance and availability result can be identified. The initial relationship among those data sets will be explained during the process of ER model design.

Besides, in this constructing process, the environment of developing database will be the Microsoft Visual Studio 2015 community that connected with Azure account.

4.4.2 The ER Model

The initial ER model is showed as following.

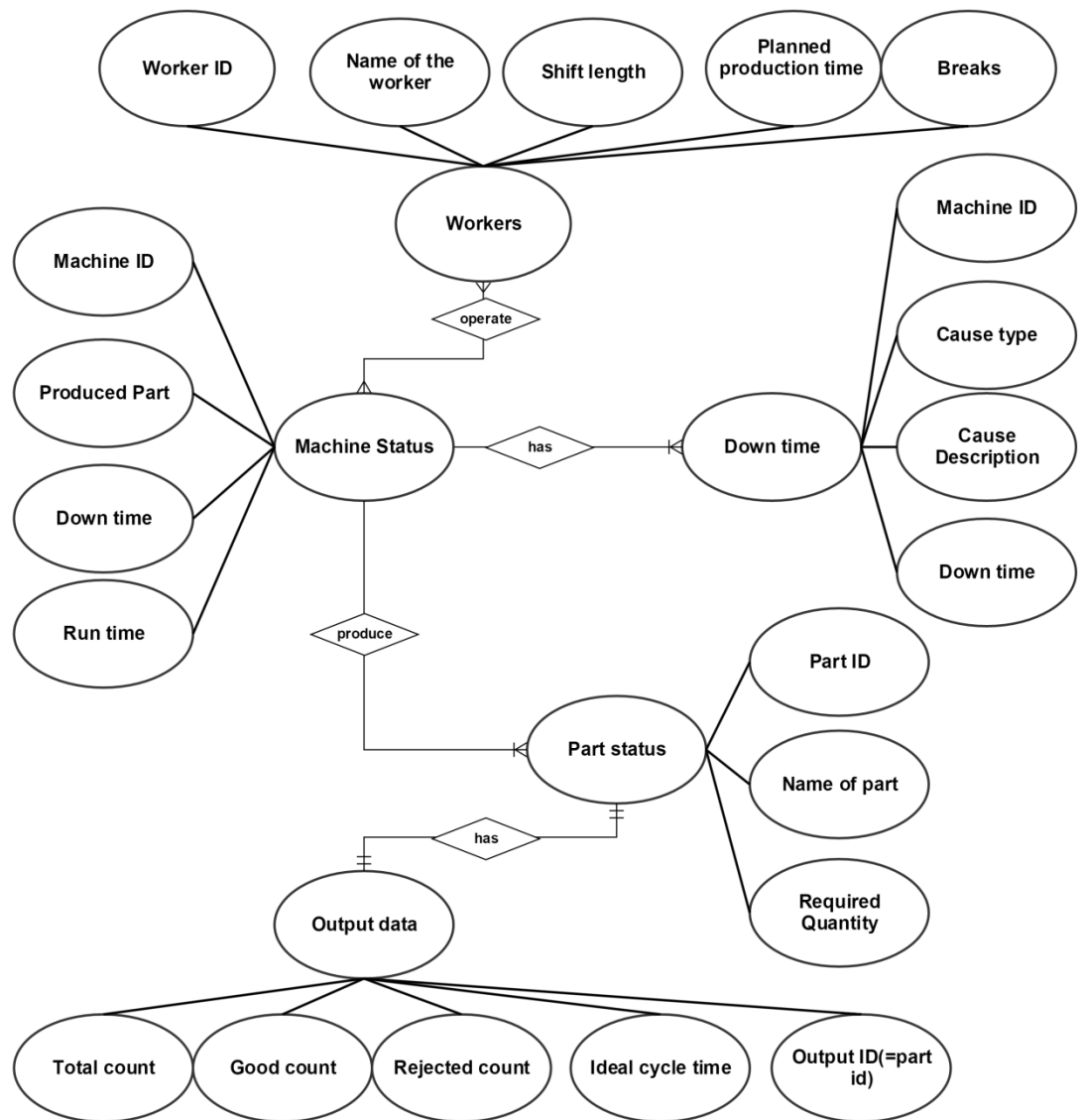


Figure 14: ER model of OEE Prototype

From the figure above, the basic identification of data set are “Machine Status”, “Workers”, “Part Status”, “Down Time” and “Output Data”. It was based on the situation that if the industry need workers to operate machine running. The relationship between machine and worker is many to many, since a worker can operate not one machine, and machine can be operated by multiple workers. Besides, the connection between machine and its downtime is one to many, because one equipment can occur several times of downtime, while the various downtime periods only points to a specific machine. Similarity situation between machine and pieces it produces, one machine may produce many parts, but those parts point to the specific facility. Moreover, the combination of parts status and output

data is that a produced part has its amount, and the output data only result from one produced piece. Therefore, the relationship is one to one.

Since the ER model is an initial consideration result, with the thinking deeper and combining the UI design, a more specific database design structure will be demonstrated though the UML diagram.

4.4.3 The UML diagram

The UML diagram for OEE prototype is displayed as bellow, it contains class name, the attribute, identifies which is the primary key, and the type that used in database implementation. The relationship construction is based on the primary key among the classes.

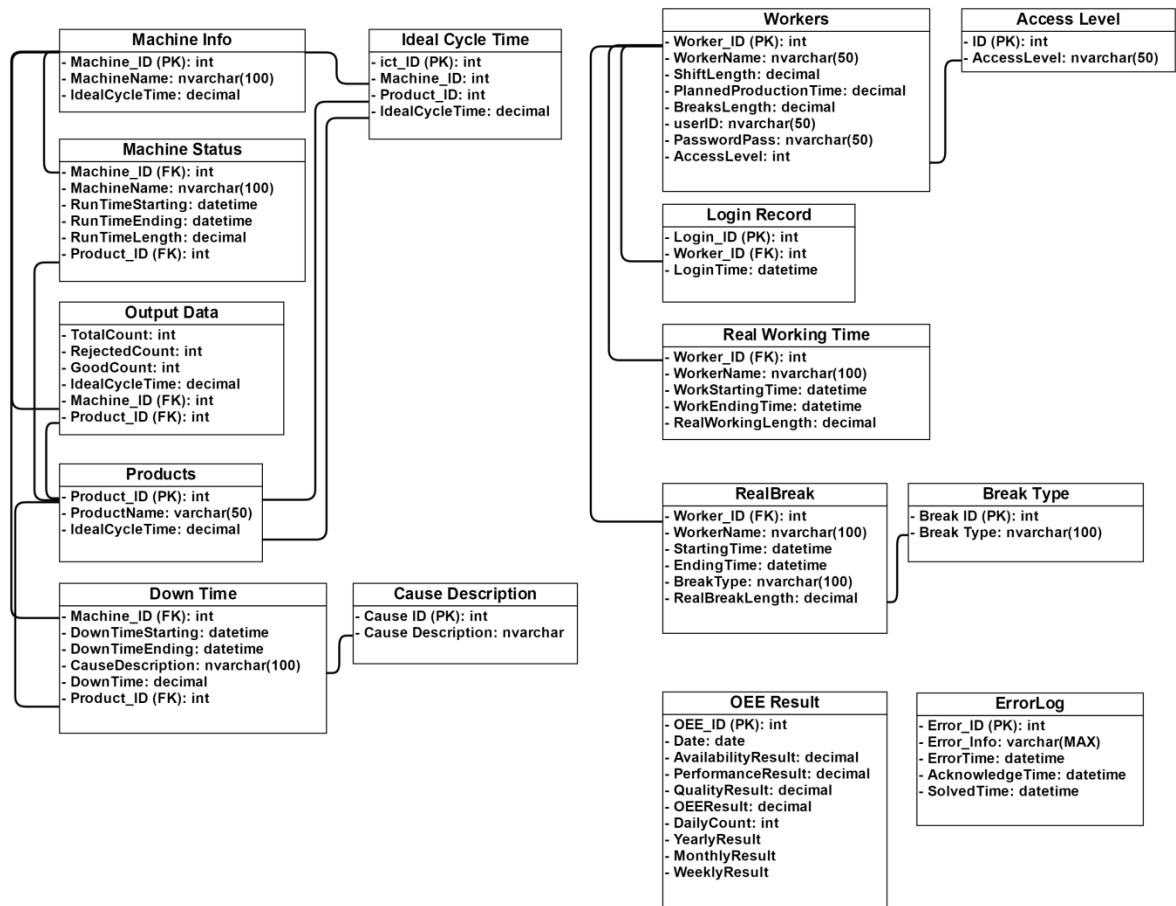


Figure 15: UML Diagram of OEE Prototype

In this UML diagram, there are two basic categories: machine and worker. The “machine info” will serve the users who create and input the ID, name and ideal cycle time of the machine, so that workers

could select the machine to input more data of its production condition. Thus, the table of “machine status” is conducted. For the class of “Products”, it will serve the managers as well that input the planned produced product or pieces information, so that enable worker to know what pieces the machine will produce. “Ideal cycle time” is also for managers to set up the machines’ ideal cycle time. Basically, the data of “machine info”, “ideal cycle time”, “products”, “cause description”, “workers” and “break type” derived from managers. The rest of them come from workshop employees who record the real operation condition data of equipment, their real shift condition.

4.4.4 Physical database construction in Visual Studio

Microsoft Visual Studio 2015 community edition impels the clear and easy database construction, which in this case, connected with Azure. Initially typing the name of tables and attributes, it will automatically conduct the database without inputting any SQL sentences.

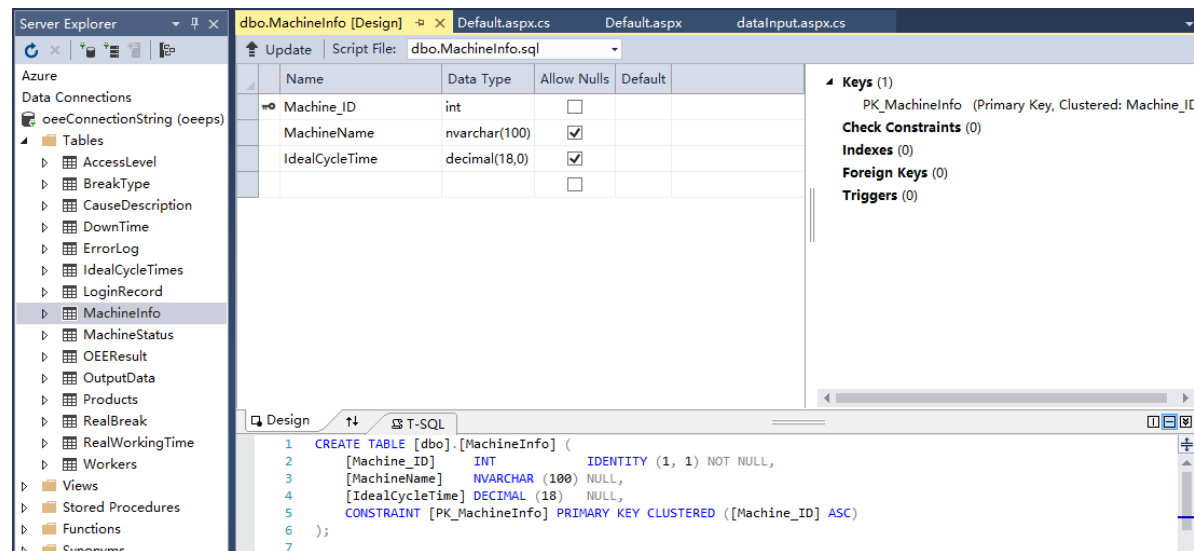


Figure 16: Database Construction in Microsoft Visual Studio

4.5 Web Achievement

The main page UI designing inspired the author to create the web page for the whole structure of OEE application. To achieve it, the developer created ASP.NET web application based on Microsoft Azure platform in Visual Studio 2015 Community version based on

visual C#. It provides template, and supports toolbox that having various items for web application development.

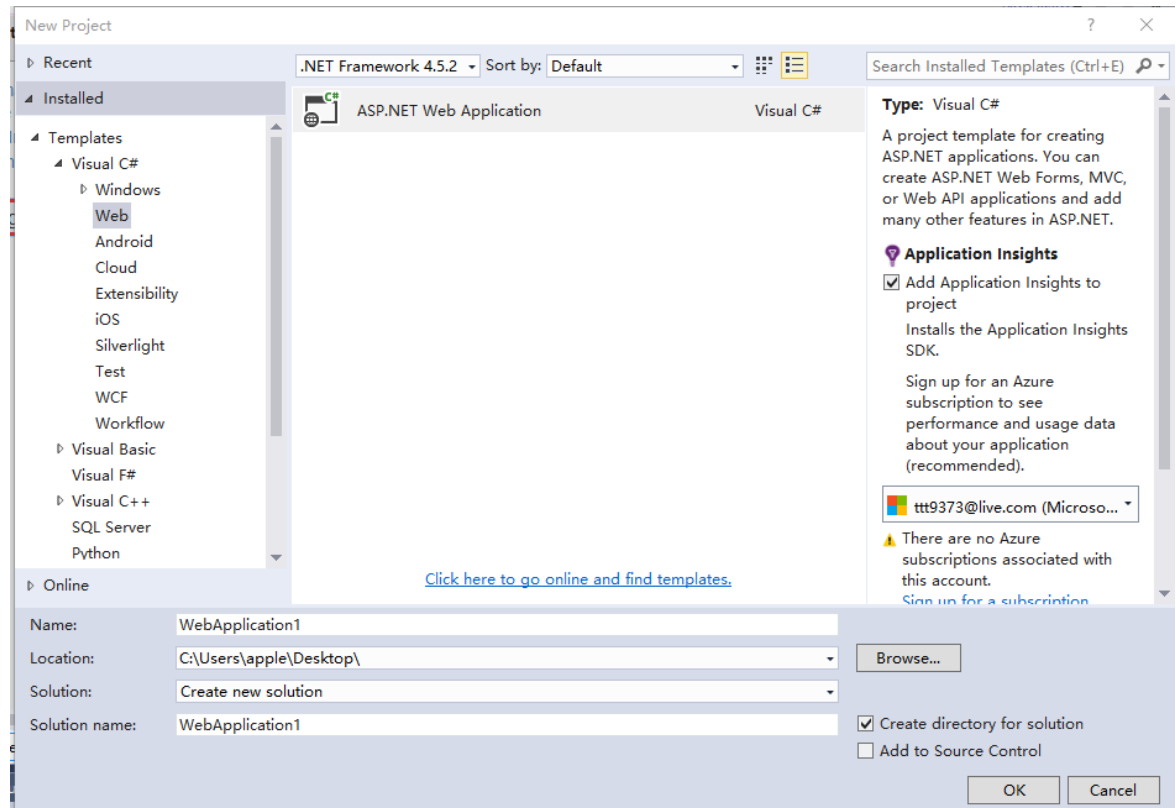


Figure 17: Creating A Web-based Prototype by Using Microsoft Visual Studio

According to the UI design, the final main page of the OEE was achieved as following:



Figure 18: The Result Displaying Page of OEE Prototype

The final solution compared with the initial one, lack of the button, since the author decided to simplify the page and allow the figures displayed according to the click of choices rather than one more button that clicking twice. Besides, the CEO required that “hourly” is too frequent for industries, so the choices changed to “Daily”, “Weekly”, “Monthly” and “Yearly”.

Except the main page, the developer constructed the login page, admin page and the page of data input for work shop employees. The login page will be the first sight while the users open this prototype. Since OEE philosophy combines not only for facilities maintenance, but also need participation from workers and managers, the data input page operates to collect data of the machines and frontline workers, and the admin page is for managers to set up the data of worker and machine.

- Login page

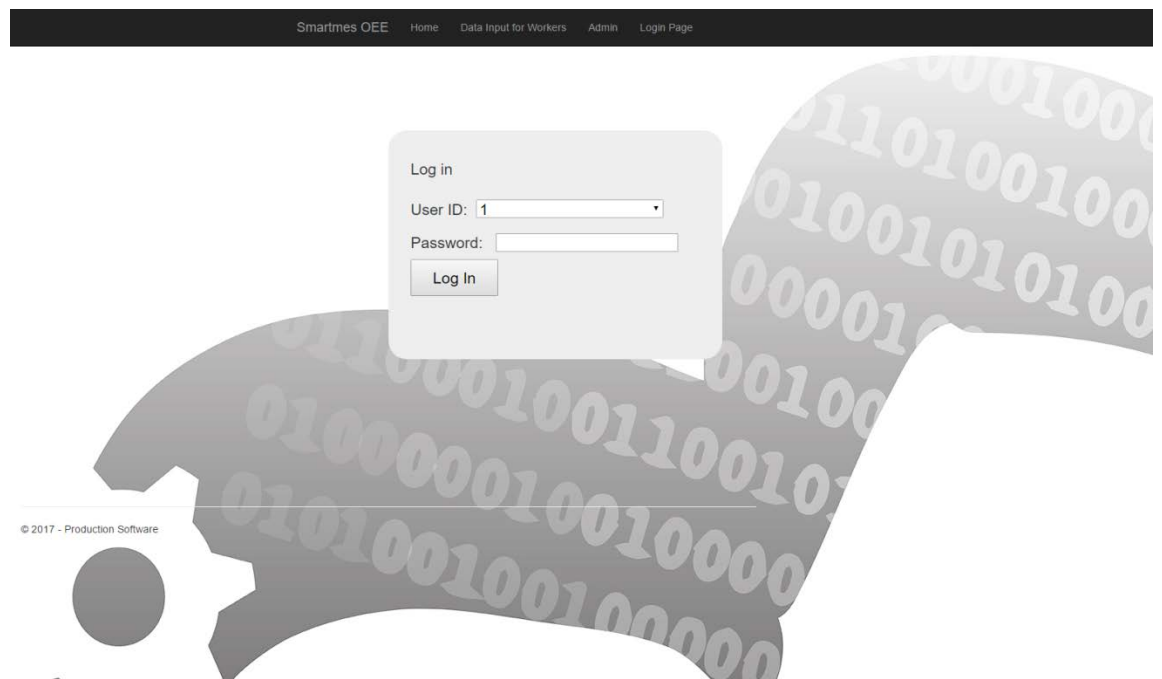


Figure 19: The Login Page

The login function will insure the security of the factories to some degree, and the database will also record the login data.

- Data input page

Smartmes OEE Home Data Input for Workers Admin **Log Out**

Data Input Page

Machine Info

Select Machine:
metal

Select Product:

Starting Time:

Ending Time:

Down Time Starting:

Down Time Ending:

Cause Description:
Explosion

Total Count:

Rejected Count:

Worker Info

Select Worker:
Jane

Working Start Time:

Working End Time:

Break Starting Time:

Break Ending Time:

Break Type:
lunch time

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Figure 20: Data Input Page for Frontline Workers

This function is help with collecting data and saving them into database, in order to calculate OEE. In the block of Machine Info, users could select equipment, which is input to the database from admin page, the product or pieces it will manufacture as well. Enter the time to record the machine real run time, and the down time period accompany with the reason, in order to save the data for availability and performance calculation. Moreover, the information recorded of the total count and rejected count is for calculating quality rate of the production. When it comes to the block of Worker Info, is the workshop employee record their shift length, in case of some companies need workers to operate the equipment, as well as for supervision.

- Admin page

can use this application to record the machine information.

Since the Microsoft provides the template of web page, small changes of layout occurred when developing the web pages. Regardless of that, the rest can be achieved by drag and drop. The developer only modifies a little bit in Site.css file and HTML file. For instance, the figures below are the illustrations of layout construction in CSS and HTML. The figure 22 shows the code of “body” in Site.css file, and figure 23 showing that utilizing it in html file, which is for all the pages’ basic layout.

```

6  body {
7  /*padding-top: 50px;
8  padding-bottom: 20px;*/
9  background-image:url('../Picture/oee2tausta.jpg');
10 background-size:cover;
11 height: 320px;
12 margin: 0;
13 padding: 0;
14 }
```

Figure 22: Example of CSS

```

18 <body class="body">
19   <form runat="server">
20     <asp:ScriptManager runat="server">
21       <Scripts>
```

Figure 23: Example of Related HTML

4.6 Database Connection Setting

The available visual tools in Microsoft Visual Studio support the property that connecting to the database. After setting up, the developer can write the code to the database connection.

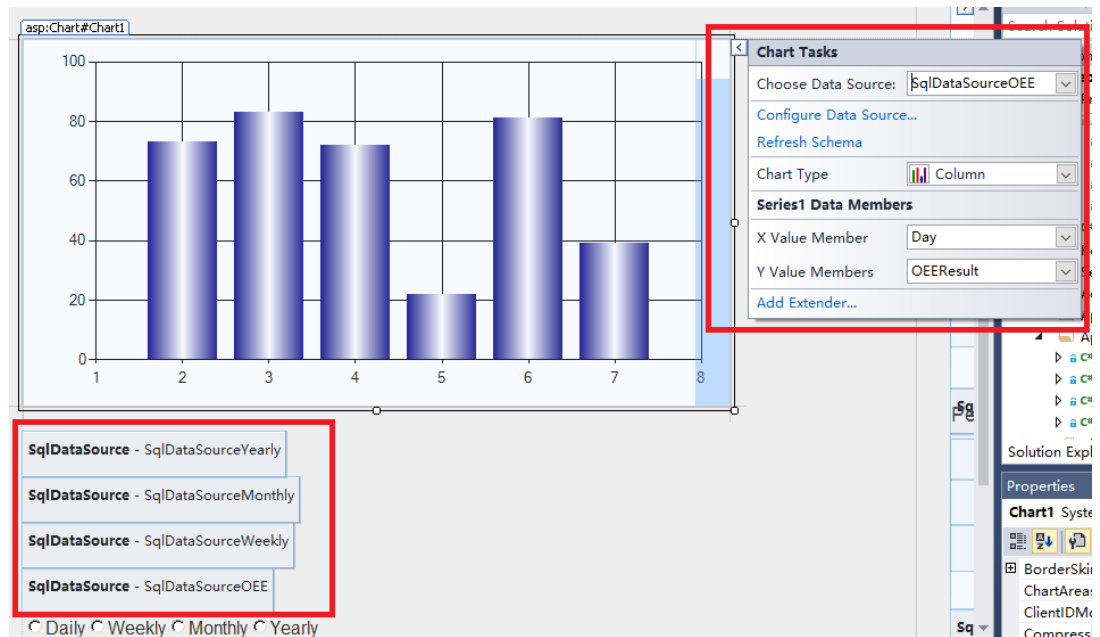


Figure 24: Achieving the Database Connection in Visual Studio

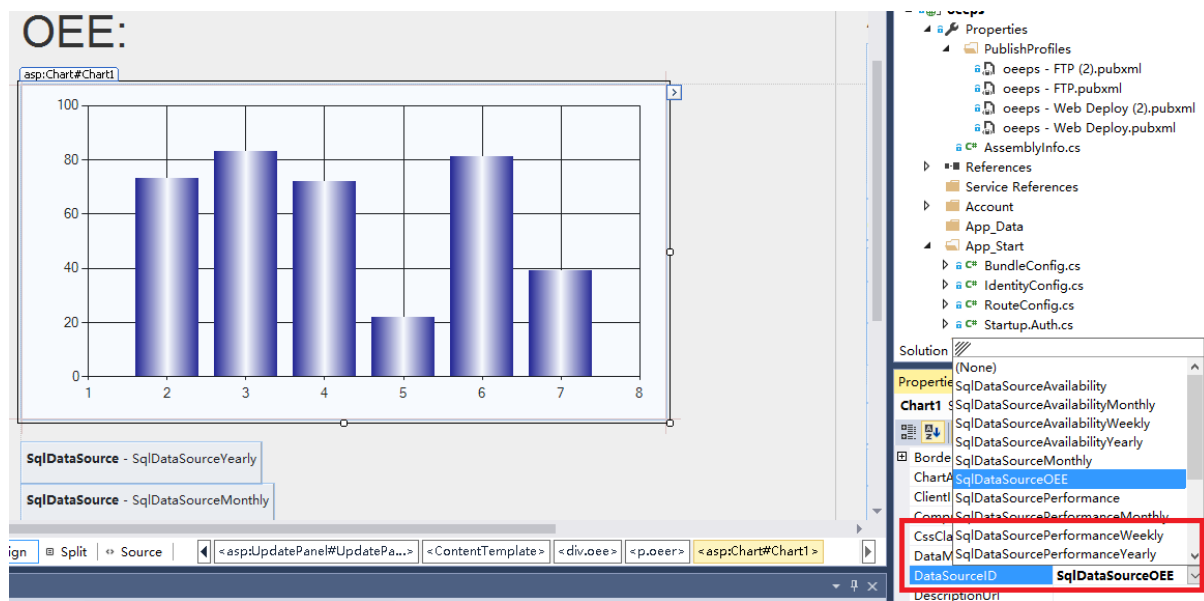


Figure 25: Achieving the Database Connection in Properties

In the figures above, the chart can be customized to the connection of database and decide the X and Y value from the attribute of a table. Developer can configure the data source and give a name to it. In the main page, each chart is connected to the database table according to daily, weekly, monthly and yearly.

Besides, not only chart, but also drop down list item can be connected to the database tables. To illustrate, the picture below

displays the drop down list that used in login page, is connected to the SQL database named as “SqlDataSourceUserID”. The text displayed is the userID from the table of “Workers”, and the value of it is the worker_ID from the same table. Under this circumstance, the function can be achieved as enabling users to select the user id. The drop down list tools used in other pages was achieved in the same method.

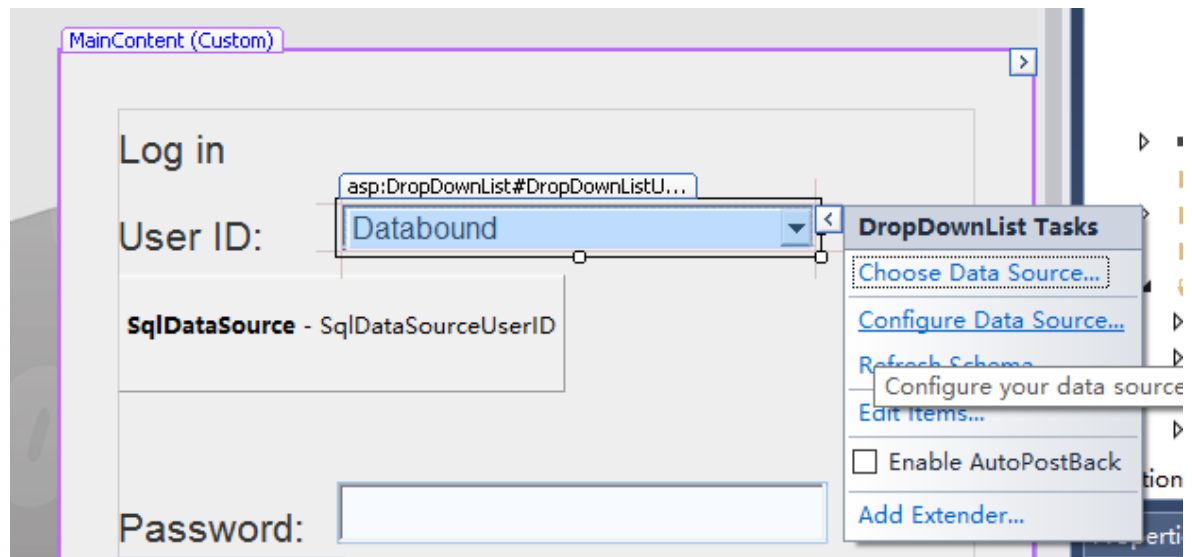


Figure 26: Connecting to the Database for Drop Down Menu

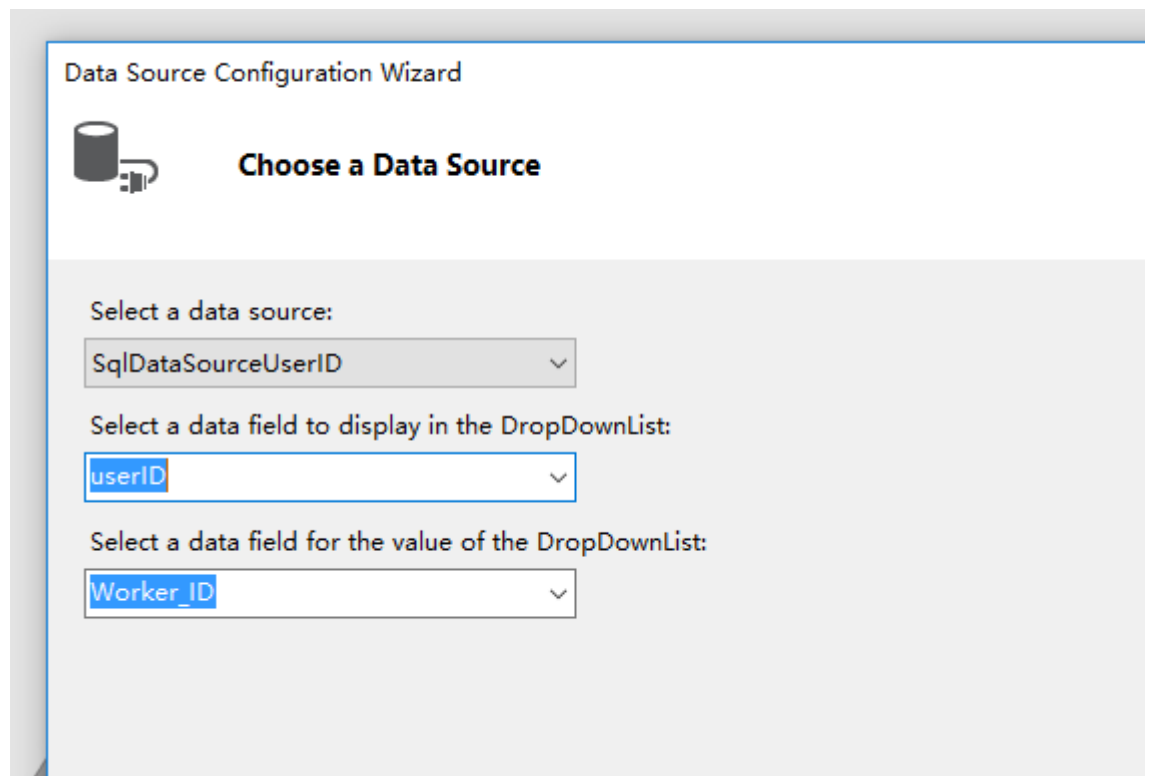


Figure 27: Choosing the Data Source

4.7 C# coding to achieve functions operation

In this chapter, the author will describe the code construction behind this OEE prototype. For the programming language, the developer utilized C# programming language since it was the main programming language learned in the university. Besides, the object-oriented programming will be revealed in this application since there were lots of repeated commands and sentences. Building classes and its methods are constructive approach to achieve the concise code. The writer will divide the code description into five parts according to the classes' implementation. Here is the picture that showing the classes of the OEE prototype.

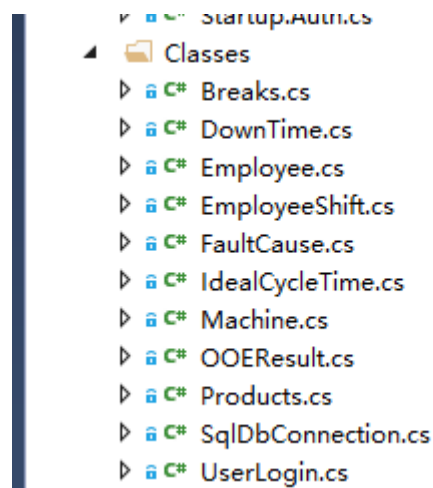


Figure 28: The Tables of Database in OEE Prototype

4.7.1 Description of UserLogin Class

The figure below shows the class name, attributes, and methods.

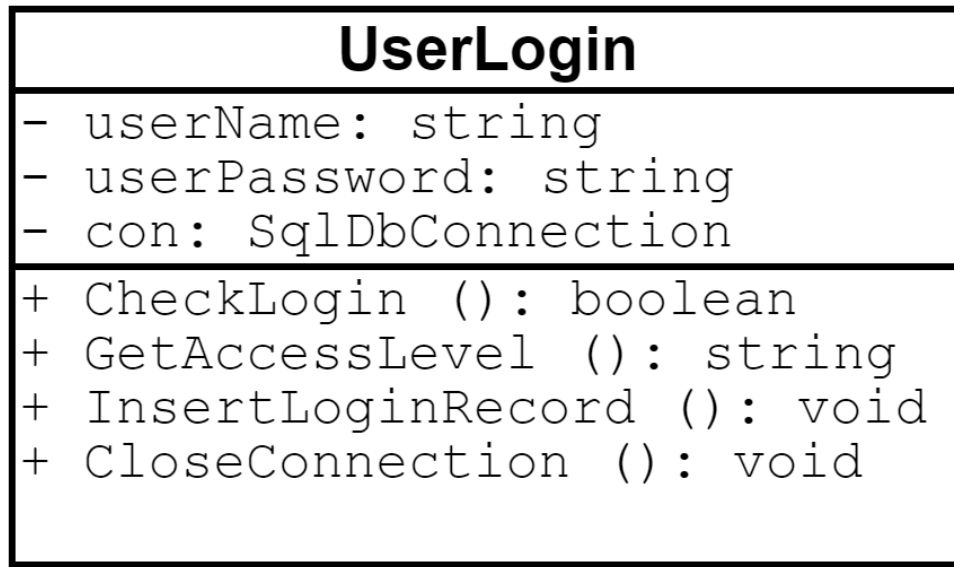


Figure 29: The Class of UserLogin

From the diagram above, it can be seen clearly that the main functions are checking login, getting access level, recording the login in to database and close the database connection. In this OEE prototype, each class has the function that closing the database connection in order to enable developer to use it when utilizing each class.

The main code for login page aims at achieving the functions that checking if the user ID and password is correct, if it is correct, the time of login will be recorded into the database, accompany with getting the access level that if it is manager, the admin page will be directly loaded after user login. Whereas, worker level will lead to the data input page straightly. The picture below is the code that utilizing the class and method of "UserLogin" to achieve the mentioned functions.

```
else
{
    UserLogin login = new UserLogin(DropDownListUserNames.SelectedItem.Text, tbxPassword.Text);

    if (login.CheckLogin())
    {
        Session["username"] = DropDownListUserNames.SelectedItem.Text;
        Session["accessLevel"] = login.GetAccessLevel();
        login.InsertLoginRecord();
        login.CloseConnection();
        Response.Redirect("/default");
    }
    else
    {
        LabelLoginFail.Text = "Password did not match user ID. Login Failed!";
        //tbxPassword.Text = "";
        if (IsPostBack)
        {
            tbxPassword.Text = "";
        }
    }
}
```

Figure 30: Example of C# Programming for Login Page

4.7.2 Description of Machine, DownTime, FaultCause, Products and IdealCycleTime Classes

The basic class UML diagram of them is demonstrated as following:

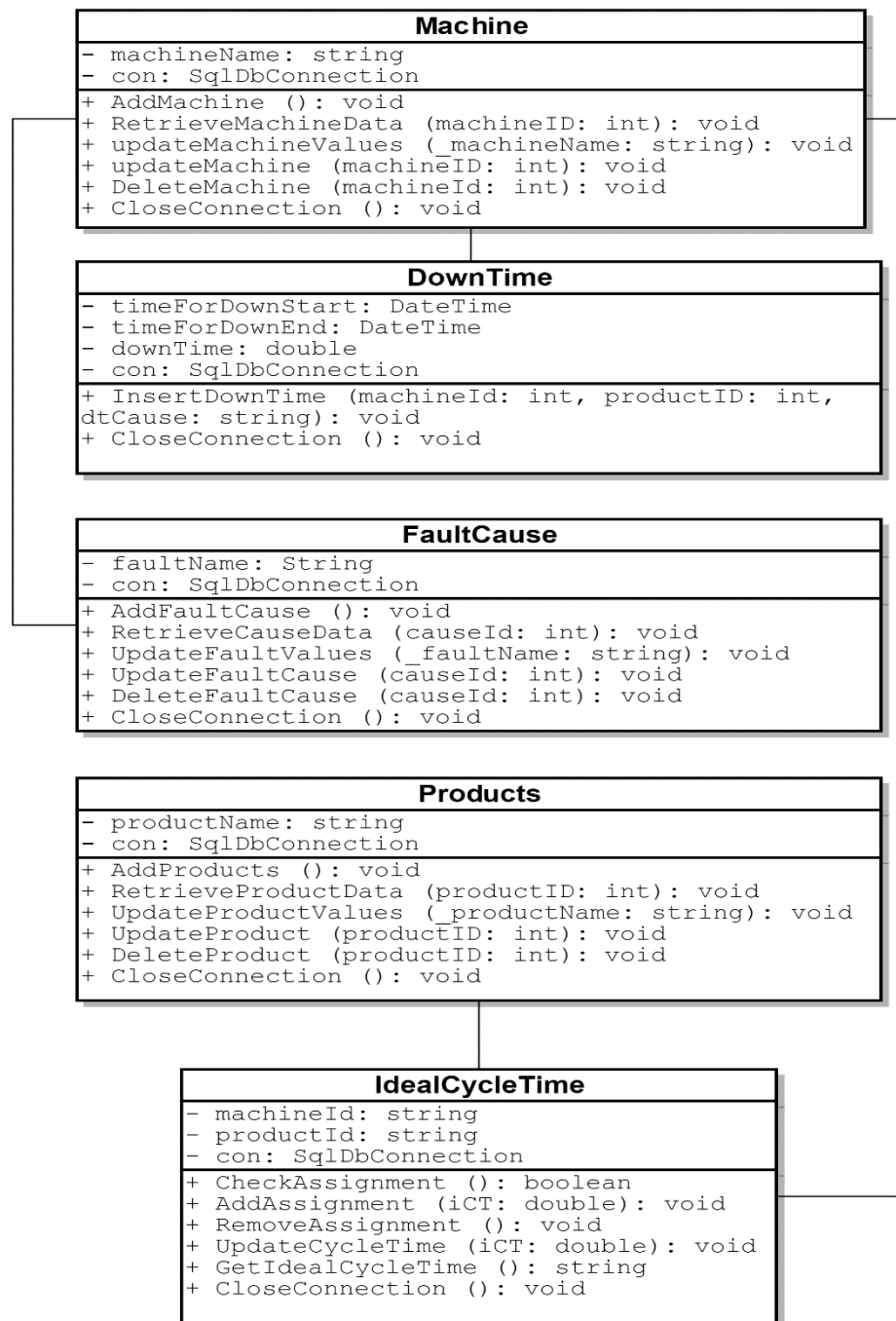


Figure 31: The Classes of Machine, DownTime, FaultCause, Products and IdealCycleTime

In general, the class of “Machine”, “Products”, “IdealCycleTime” and “FaultCause” serve managers level that enable them adding, deleting, and updating the information of machine, planned produced products and ideal cycle time in database. Under this circumstance, frontline workers can view and select those information visually through the coding that retrieving those data from database. The class of “DownTime” supports employees that record and input the down time

information of the machine operation into database. The figures below are the illustrations of creating objects of the class and use “AddMachine”, “CloseConnection” methods that supports users adding machine information. Figure 33 is the corresponding code of “AddMachine” method.

```
try
{
    Machine machine = new Machine(txbMachineNameInput.Text);
    machine.AddMachine();
    machine.CloseConnection();
    LabelErrorManager.Text = "Machine added successfully";
    LabelErrorManager.ForeColor = Color.Green;
}
```

Figure 32: Utilizing the method of AddMachine from Machine Class

```
public void AddMachine() //adds new machine type to database
{
    con.SetCommand("Insert into MachineInfo (MachineName) Values(@MachineName)");
    con.com.Parameters.AddWithValue("@MachineName", machineName);
    con.NonQueryEx();
}
```

Figure 33: The Method of Adding Machine into Database

4.7.3 Description of Employee, EmployeeShift and Breaks Classes

The class of “Employee” and “Breaks” enable managers managing their worker information. Managers can add, update and delete the data of worker and the type of breaks into or from the database.

While the class of “EmployeeShift” mainly for frontline workers that input their real working period. The class UML below includes all the attributes and functions of these aspects.

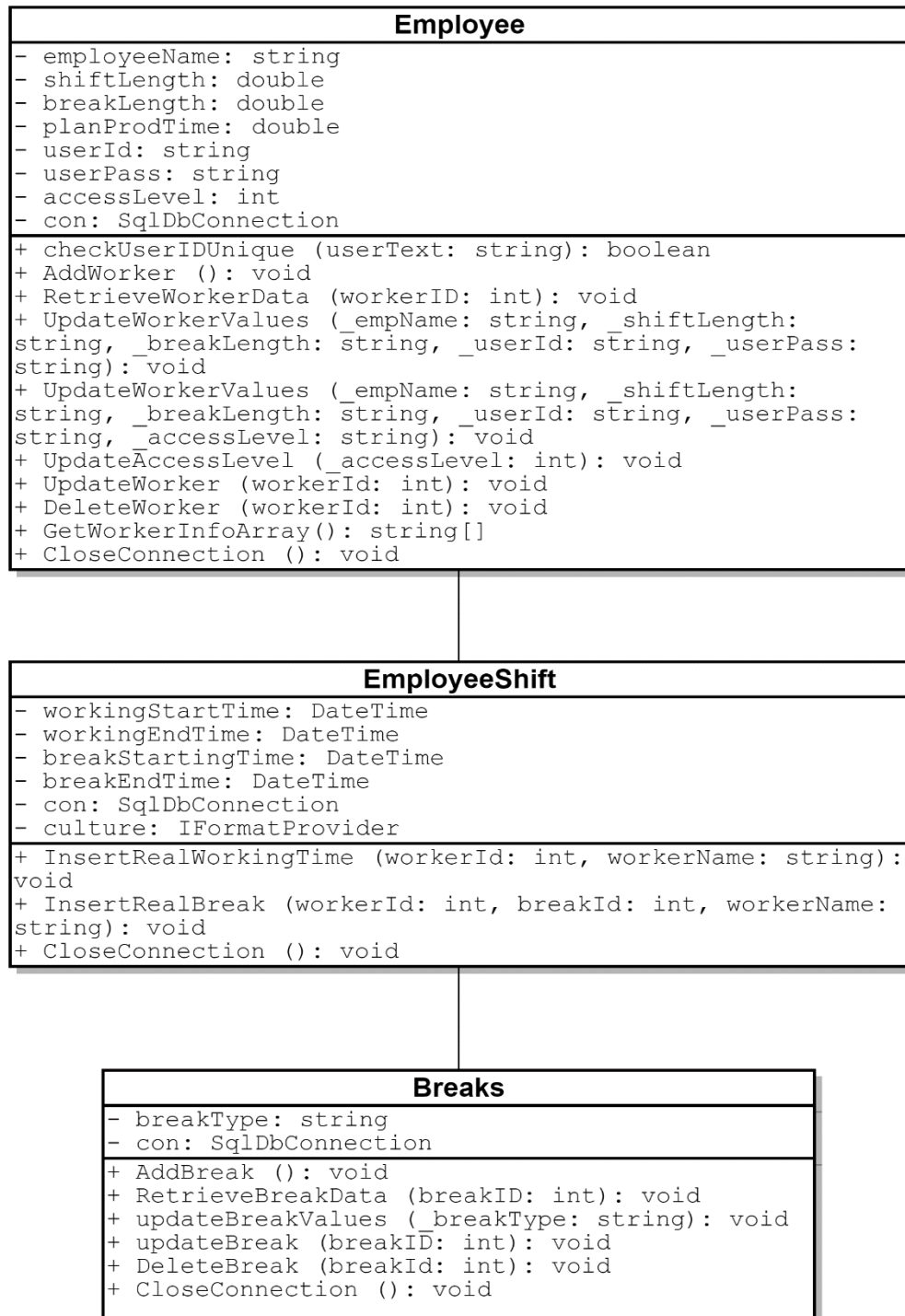


Figure 34: The Classes of Employee, EmployeeShift and Breaks

4.7.4 Description of SqlConnection Class

Since the largest effort to be put forward in this OEE prototype is the database, the code and work of database connection and the SQL sentences are significant. Thus, the developer built a class of “SqlConnection” that could be utilized in main coding part.

SqlDbConnection
<pre> - _con: SqlDbConnection - _com: SqlCommand - daAd: SqlDataAdapter - dt: DataTable - reader: SqlDataReader </pre>
<pre> + SetCommand (query: string): void + IntScalar (): int + DoubleScalar (): double + StringScalarAsync (): string + NonQueryEx (): void + NonQueryEx (_com: SqlCommand): void + ExecuteDataReader (_com: SqlCommand): SqlDataReader + ExecuteDataReader (): SqlDataReader + CloseCon (): void + CloseReader (): void + FillDataTable (): DataTable + Hae (sql: string): DataTable + SEH (title: string, info: string): void + ErrorAcknowledge (errorID: int, timeAck: DateTime): void + ErrorSolved (errorID: int, timeSol: DateTime): void </pre>

Figure 35: The Class of SqlDbConnection

4.7.5 Description of OEEResult Class

The main functions in this class is the OEE calculation and input them into database, which is described clearly in following class diagram.

OEEResult
<pre> - con: SqlDbConnection - availability: double - performance: double - quality: double - oeeR: double - startTime: DateTime - endTime: DateTime - runTime: double </pre>
<pre> + CalculateAvailability (machineId: int): void + CalculateQuality (totalCount: double, rejectedCount: double): void + CalculatePerformance (machineId: int, productId: int, totalCount: double): void + InsertMachineStatus (machineId: int, machineName: string, productId: int): void + InsertOutputData (machineId: int, totalCount: double, rejectedCount: double, productId: int): void + GetDailyCount (): int + UpdateOEE (dailyCount: int): void + InsertOeeData (): void + CloseConnection (): void </pre>

Figure 36: The Class of OEEResult

Except from the database plays the magnificent role in this OEE prototype, the OEE calculation is the key point in this program. Separately, the pictures below illustrate the C# coding that calculating availability, performance and quality.

```

public void CalculateAvailability(int machineId)
{
    con.SetCommand("SELECT SUM(DownTime) FROM DownTime WHERE DownTimeStarting > @rs AND DownTimeStarting < @re AND Machine_ID = @id");
    con.com.Parameters.AddWithValue("@rs", startTime);
    con.com.Parameters.AddWithValue("@re", endTime);
    con.com.Parameters.AddWithValue("@id", machineId);
    string tempString = con.StringScalar();
    double downTime;
    if (tempString == "")
    {
        downTime = 0;
    }
    else
    {
        downTime = double.Parse(tempString);
    }
    runTime = (endTime - startTime).TotalMinutes;
    availability = (runTime - downTime) / runTime;
}

```

Figure 37: The Process of Calculating Availability and Save into Database

```

public void CalculatePerformance(int machineId, int productId, double totalCount)
{
    con.SetCommand("Select IdealCycleTime From IdealCycleTimes Where Machine_ID = @mid AND Product_ID = @pid");
    con.com.Parameters.AddWithValue("@mid", machineId);
    con.com.Parameters.AddWithValue("@pid", productId);

    double ICT = con.DoubleScalar();

    performance = (ICT * totalCount) / runTime;
}

```

Figure 38: The Process of Calculating Performance and Input into Database

```

46 public void CalculateQuality(double totalCount, double rejectedCount)
47 {
48     double goodCount = totalCount - rejectedCount;
49     quality = goodCount / totalCount;
50 }
51

```

Figure 39: The Process of Calculating Quality and Save into Database

5. THE USABILITY OF OEE PROTOTYPE

With reference to chapter 2.1, apart from giving the solution of how to develop an OEE prototype, the second purpose of this study is to show the prototype's usability, which means demonstrating that the OEE prototype is useful. To achieve that, the author will be the observer to test this OEE prototype. Since the main operation of the OEE prototype is collecting the data into database, and utilizing them to calculate OEE result, the main observation will focus on the database reaction to the database itself and to the displays of the pages.

In addition, the author conducted a face-to-face interview with the CEO of Productionsoftware Oy, who participated in this OEE

prototype development process, to evaluate the prototype's usability.

5.1 Database Reaction

To illustrate an instance of data reaction, the block of "Worker Info" in admin page will be typed into information as the figure shown below:

The screenshot shows a web form titled "Worker Info". It has several input fields: "Worker Name" with the value "Tang Tiantian", "Shift Length" with "9", "Break Hours" with "2", "User ID" with "Tangtian", and "Password" with "111111". There is a dropdown menu for "Access Level" set to "Worker". To the right of the dropdown is a checkbox labeled "Check to update". At the bottom left is an "Add" button.

Figure 40: Adding Worker Data into Database

After clicking "Add" button, the data that input as the figure shows above saved successfully into the related data table: "Workers".

Worker_ID	WorkerName	ShiftLength	PlannedProd...	BreaksLength	userID	PasswordPass	AccessLevel
1	Jane	8	7	1	1	1	1
2	kate	8	7	1	1234	banana	3
3	John	9	7	2	elephant7	apple	3
4	Watson	9	8	1	8910	test	3
10	Jason	10	8	2	1988	1	2
12	Steve	10	8	2	1999	1	1
13	Bob	11	9	2	admin	password	NULL
15	Tang Tiantian	9	7	2	Tangtian	111111	3
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 41: Saving the Data Successfully

Login "Tangtian" as the user ID. Its related workerID is 15, and the time of login will be recorded and saved in the "LoginRecord" database.

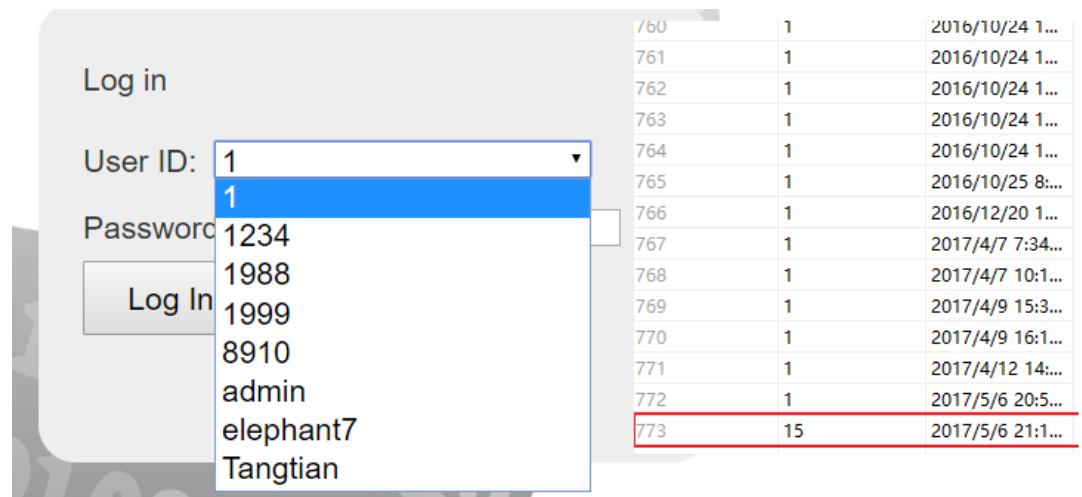


Figure 42: Login Recording Test

Here is the picture of previous records of testing the calculation result and save it into the database of “OEEResult”, after inputting all the related information into the pages:

OEEID	Day	AvailabilityRe...	Performance...	QualityResult	OEEResult	DailyCount	ResultYear
28	2016/8/17	0.7677	0.9012	0.0440	0.0304	1	2016
30	2016/9/7	0.7500	0.3333	0.9231	0.2308	1	2016
31	2016/8/18	0.8900	0.5000	0.7800	0.3471	1	2016
32	2016/8/19	0.7800	0.6800	0.7600	0.4031	1	2016
33	2016/8/20	0.6800	0.6700	0.7400	0.3371	1	2016
34	2016/8/21	0.8900	0.7000	0.5000	0.3115	1	2016
35	2016/8/22	0.5600	0.7000	0.3000	0.1176	1	2016
36	2016/8/23	0.8900	0.5000	0.8000	0.3560	1	2016
37	2016/8/24	0.9800	0.5000	0.9900	0.4851	1	2016
38	2016/8/25	0.8000	0.1000	0.1000	0.0080	1	2016
39	2016/8/26	0.7100	0.8000	0.8900	0.5055	1	2016
40	2016/8/27	0.7000	0.6000	0.7800	0.3276	1	2016
41	2016/8/28	0.7000	0.7000	0.6700	0.3283	1	2016
42	2016/8/29	0.8500	0.9000	0.1200	0.0918	1	2016
43	2016/8/30	0.8700	0.9900	0.8900	0.7666	1	2016
44	2016/8/31	0.7600	1.0000	0.7800	0.5928	1	2016
45	2016/9/1	0.6700	0.4500	0.6700	0.2020	1	2016
46	2016/9/2	0.5600	0.6500	0.7800	0.2839	1	2016
47	2016/9/3	0.6900	0.7800	0.6700	0.3606	1	2016
48	2016/9/4	0.8900	0.7800	0.6700	0.4651	1	2016
49	2016/9/5	0.5600	0.5600	0.8900	0.2791	1	2016
50	2016/9/8	0.6500	0.8700	0.8900	0.5033	1	2016
52	2015/9/8	0.8000	0.7900	0.9900	0.9900	1	2015
53	2014/6/5	0.7800	0.6700	0.7600	0.8800	2	2014

Figure 43: Records of OEE Result

5.2 The Review and Analysis of Interview

With the limitation of unrealizable implementation of this OEE prototype into real industries at the moment, there is only one interviewee for this research. Regardless of that, the author designed

seven questions to the interview person: the CEO of the Productionsoftware Oy, who has long experience in software development and understands the OEE concept, knows the process of prototype operation. Since the OEE prototype will be developed further and implemented as a module in SMARTMES®, the CEO of Productionsoftware Oy is a suitable and reasonable interviewee to evaluate the OEE prototype usability. The following illustrates the interview in a table format with all the interview questions, associated replying, as well as the findings according to the responses.

Table 3: Interviewee's Opinions and Data Analysis Findings

Questions	Responses	Preliminary data analysis (findings)
1. Does your target market actually have a need for this OEE service?	“Yes, before there are companies that asked for this service to checking their machines’ production efficiency. At the moment, one customer find that data collection is useful, the prototype will be applied to them quite soon. That company will be the first one to use the OEE prototype.”	Business needs for the OEE prototype is significant. To evaluate the OEE prototype, from the angle of the environment (according to the framework of Design Science Methodology) will be the good method to prove the prototype’s usability or value.
2. Is this OEE prototype being developed correctly? Is it	“Definitely useful and correct even though there are some features to be	The OEE prototype was developed in a correct way.

useful?	improved or changed to meet specific customers' needs."	
3. Will you utilize it for further development? Or will you apply it to SMARTMES®?	"Yes, will implement further development soon and make it as a module in SMARTMES® for customers who use this software."	One of the usability of prototype in software is its' value of further development.
4. Do you think this OEE prototype is innovative and in which aspect?	"It is different from others, easy to use and easy to change, which is important for updating in the future."	The usability of OEE prototype will also be proved by its' easy-customized.
5. How well did the prototype work?	"The OEE prototype work as it should be."	The functions of the prototype work well.
6. Did the prototype produce or contribute to the intended outcomes in the short, medium and long term?	"Yes, it is now can calculate OEE result and its element figures, and data connection is okay. Now it's near the future, and will be used by companies."	The main functions of the prototype: OEE calculation and database reaction contribute to the intended outcomes, and is possible for long-term development.
7. What are the drawbacks of this prototype (In which aspect or features you think	"For example, the first customer who wants to use this prototype only interested in quality	The drawback is that, maybe the changes will be really big. The calculation method,

<p>this OEE prototype should improve)</p>	<p>and availability part, but for performance, they don't have related data. Therefore, big changes may happen when implementing it into real use. Since different customers or factories have different needs and data. The features of the prototype will be changed and maybe related equation, I mean the OEE algorithm will be totally changed. Anyway, it is a good start."</p>	<p>the algorithm may be totally different compared with that in the current prototype.</p>
---	---	--

According to the table above, accompany with the observation by author, it can be seen clearly that although there may be some changes or become totally different in the further development, this OEE prototype works smoothly, and functions operates well. It is easy to use and customized, which will be the biggest value in terms of a prototype.

6. CONCLUSIONS

The aim of this study was to examine how to develop an OEE prototype and study its usability. The topic arose during a practical training period at Productionsoftware Oy when the CEO introduced the OEE project to the author. The author then studied the concept of OEE and some related theories, and also found out how to create

application prototypes. As a result, the author designed and created an OEE prototype based on the Microsoft Visual Studio 2015 community edition.

Chapter 3 discussed the theories related to the OEE, defined the concept of the prototype and explained various approaches to create prototypes. The chapter also discussed database design techniques. This chapter provided the theoretical background and methods for the developer before creating the OEE prototype.

The underlying research question was the following: how to develop an OEE prototype? The following steps can be understood to answer this.

- Understanding OEE metrics

To create an OEE prototype, it is important to understand the philosophies, calculation methods and equation underlying the OEE.

- Choosing a prototype construction approach

Two main approaches are available for creating prototypes: the throw-away approach and the evolutionary approach. These were described in chapter 4. This study applied the evolutionary approach since the created OEE prototype will be eventually implemented as part of a larger system, the SMARTMES® software. This implies need for further development

- Specifying abstract requirements for an OEE prototype

Since the prototype was created by applying the evolutionary method, it was important to summarize requirements (see figure 6 on page 21).

- User-Interface design

A user interface provides a virtual conception of the prototype, of its functions and appearance. It is usually created based on given requirements and discussions with a project client.

- Database design and construction
As explained in chapter 5, the ER model and UML diagram design method were regarded as the two main methods to be used to design the database. Because the OEE prototype will collect a large amount of data and calculations, the logic behind the database and its construction are critical.
- A web-based prototype
Based on the UI and requirements, a web-based OEE prototype was created using Microsoft Visual Studio 2015, HTML and CSS in this study.
- Coding to create functions
Finally, coding is needed to support the operations of the required functions: logging in; connecting to the database; showing the retrieved data on the web page; saving, and updating and deleting information.

7. DISCUSSION

7.1 Limitations

As suggested in the evolutionary prototype approach, the processes of specifying abstract requirements and building a prototype system were described in detail to this study. However, the process of evaluating and testing the prototype system was insufficient. This OEE prototype was tested only by the members of the development teams, and there is only one interviewee who evaluated its usability. Therefore, lack of testing and evaluating is the first limitation to this study. In addition, lacking the documentation and system delivery process is another limitation.

The prototype was developed using Microsoft Visual Studio, used C# programming language, HTML, CSS and SQL. The tools are a limitation to a degree because there are various tools and methods that can be used to create OEE prototypes nowadays.

Despite these limitations, this study managed to introduce an OEE prototype development process, and gave a clear and logical indication.

7.2 Reliability and Validity

In qualitative research, the term “reliability” is used more often than the term “dependability”. Validity, then again, refers to the tools and techniques used in a particular research project. (Golafshani 2003) The OEE equation applied in creating OEE prototype was retrieved from the theoretical sources used in this study. The OEE equation in this study combines the view of the OEE founder: Nakajima (1950s), and other newest research result of the OEE equation, for instance, Naidu et al. (2013) conducted a research on the evaluation of OEE by implementing it in a specific company, and describe the OEE equation clearly, few differences with the original of the OEE calculation. Thus, the basic OEE calculation method is reliable in this research. The tools used to create the prototype such as Microsoft Visual Studio, Azure, C# languages, etc are common and widely used. Therefore, the web-based OEE prototype in technological extent (tools) is valid. Thus, the solution of research question is reliable and this study is valid.

7.3 Further Study

Future study could relate to testing and evaluating the prototype among users from different fields of industry. This would help in checking if there are any functions that need improvement. Moreover, the process that joint OEE application into SMARTMES® software package can also be taken into account, or connect it with a specific industries to make research on the accuracy of the OEE results. Therefore, future research could put more emphasis on actual implementation of the OEE prototype. This study mainly focused on the development process.

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APPENDIX

Interview questions for evaluating OEE prototype.

Interview duration: Around 15 minutes.

Location: Niemenkatu 73, 15140, Lahti.

Table 4: Interviewee personal information

Jari Kukkonen	Male	CEO	Productionsoftware Oy
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Interview Questions:

1. Does your target market actually have a need for this OEE prototype?
2. Is this OEE prototype being developed correctly? Is it useful?
3. Will you utilize it for further development? Or will you apply it into SMARTMES®?
4. Do you think this OEE prototype is innovative and in which aspect?
5. How well did the prototype work?
6. Did the prototype produce or contribute to the intended outcomes in the short, medium and long term?
7. What are the drawbacks of this prototype (In which aspect or features you think this OEE prototype should improve?)