Feasibility study of using Time Blocks at Volvo Cars for time data management

Master’s thesis in Department of Technology Management and Economics

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ABSTRACT

In manufacturing, Time Data Management (TDM) refers to the process of establishing, maintaining, and utilizing time bases for various operations. These time bases can be used for tasks such as estimating costs, planning processes, and improving operations. However, with the introduction of new electric models at Volvo Cars, changes to existing assembly operations will require significant effort, time, and resources to establish and maintain new time bases. To address this issue, this thesis explores the feasibility of using time blocks with variables, as proposed by the research project TIMEBLY, to streamline TDM. The study focuses on the tunnel assembly line at Volvo Cars, analyzing all manual operations and identifying constants and variables to build time blocks. These time blocks are organized in a framework library, allowing for the determination of time bases by entering variable values. The accuracy of these time bases was compared to those determined by predetermined time systems, and the feasibility of using time blocks for TDM was validated based on its coverage, accuracy, and effectiveness. Ultimately, using time blocks with variables proved to be a highly feasible and effective approach to reduce the time, resources, and effort required for TDM.

Keywords: Time Blocks, Time Data Management, Time Bases, Complex assembly, Predetermined Time.

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Yashwanth Hedathale Pashupathi, Md Nahid Hasan, Gothenburg, 2023

Contents

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BMT	Basic Motion Time Study
MODAPTS	Modular Arrangement of Predetermined Time Systems
MOST	Maynard Operation Sequence Technique
MTM	Method Time Measurement
PII	Process Inspection Instruction
PMTS	Predetermined Motion Time System
PTS	Predetermined Time System
SAM	Sequence-based Activity and Method analysis
SWAG	Scientific Wild Ass Guess
TDM	Time Data Management
TMU	Time Measuring Unit (1 TMU = 0.036 Seconds)
VCC	Volvo Cars Corporation
VCT	Volvo Cars Torslanda

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Introduction

This report outlines the initial concept and brief overview of the Master thesis project "Feasibility study of using time blocks for time data management". The project was carried out at the Manufacturing Engineering department of Volvo Car Corporation and presented at Chalmers University of Technology. This report covers the background of the topic, main objectives, scope, findings, and discussions.

1.1 Background

Time Data Management (TDM) is the term used for the determination, application and administration or maintenance of time bases of operations (Hedman & Almström, 2017). These time data, named time bases, can have various applications like investment planning, workplace design, cost estimation, process planning, continuous improvement and many more across different departments (Hedman & Almström, 2017). Determining the time bases for all the operations involved in manufacturing and maintaining these time bases are crucial tasks within the Industrial and Manufacturing Engineering departments in every organization.

Despite enough emphasis on digitalization and automation in manufacturing industries, manual assembly is still the most cost-effective approach, where product varieties are higher(Hedman & Almström, 2017). Generally, assembly operations account for around 50 percent of production time and about 20 percent of production costs (Hedman & Almström, 2017). The manual assembly operation times are not static but dynamic because it is performed by different manpower at different time (Hedman & Almström, 2017). The cycle time for performing manual assemblies varies depending on aspects like learning period and skill set (Wiltshire, 2010). The operation time might vary depending on the familiarity of the variant and especially when there is a change in product and process design in manual assembly (Hedman & Almström, 2017). The manufacturing companies often believe these variations will be terminated after a learning period once the production stabilizes (Wiltshire, 2010). However, these variations will exist longer and remain within the system (Wiltshire, 2010). This will create a difference between the actual operation times and operation times used in the planning system (Almström & Winroth, 2010).

This gap between actual operation times and times used in the planning system can impose challenges at the strategic level by creating issues with product and manufacturing costs (Almström & Winroth, 2010). This can also have various adverse effects on resource utilization, affecting delivery lead times (Hedman & Almström, 2017). In most cases, the decisions on improvements and investments are based on the time data within the planning system. Hence, having accurate operation times within the system is critical for any manufacturing industry. It is often believed that conducting a stopwatch study by direct observation is the solution. However, it is a resource and time-consuming option and is not viable for the upcoming new range of products whose production has yet started. Conducting direct observation studies for a non-existent range of products is impossible. However, the requirement of operations times for these products for various activities like costing, production or resource planning, and rough balancing is still needed (Razmi & Shakhs-Niyaee, 2008).

Few companies establish time standards for all manual assembly operations using Predetermined Motion Time Systems (PMTS) to handle this issue(Hedman & Almström, 2017). These PMTS methods can determine the operation times using preset time standards for various motions before these operations are performed (Razmi & Shakhs-Niyaee, 2008). Many PMTS methods are available, for example MTM, MOST, MODAPTS and MTM-SAM. These methods are distinguished based on the level of detail, motions classification, time units used and application of the time data (Razmi & Shakhs-Niyaee, 2008). The MTM-USA being the commonly used PMTS methods; many Swedish manufacturing companies use MTM-based Sequence-based Activity and Method Analysis (MTM/ SAM) (Almström & Winroth, 2010).

Though the above-mentioned methods efficiently cover the gap between accurate operation times and operation times used in planning systems, it consumes a lot of resources and time. The ratio between work content and effort to determine time varies with the PMTS method adopted (Almström & Winroth, 2010). The traditional MTM-1 has a ratio of 1:200, and 1:25 for MTM-SAM (Hedman & Almström, 2017). However, the accuracy of the determined time might also vary with the PMTS methods (Hedman & Almström, 2017). It also demands effort when these time data need to be updated when there are changes in the assembly process to update and maintain the TDM systems.

Volvo Car Corporation is a well-known multinational luxury vehicle manufacturer headquartered in Gothenburg, Sweden. It was established in 1927 and has been known for safety, quality and innovation in automobiles since then. Geely Holding, based in China, currently own the company. Volvo Cars have grown exponentially and have operations and manufacturing facilities across continents. The company announced it will be a fully electric car manufacturing company by 2030. To achieve this goal, the company plans to leave behind the current internal combustion engines to move towards electrification (Cars, 2021).

The electrification strategy to transform into a fully electric car company will demand significant changes in the existing systems' design, development and assembly (Cars, 2021). This will demand significant changes in the assembly operations, especially the manual assembly operations performed to assemble a car. In addition, the introduction of an electric hybrid version of all existing models and upcoming fully electric models has ramped up the pace than before. Hence, these things will affect the manual assembly operations performed and the time bases for these operations. The time bases for these new and changed operations must be determined and updated at an increased pace to accommodate crucial business activities like costing, rough balancing and planning by using TDM. Though the current SAM method provides the required time bases with the desired accuracy, this can consume more effort, time and resources than before.

The ongoing research project TIMEBLY aims to explore and develop new concepts to efficiently determine and maintain the time bases for manual assembly operations, moving towards TDM automation for manual assembly (Vinnova, 2021). The concept of 'Time Blocks' with constants and variables can be used to determine time bases for the TDM. These time blocks have the potential to drastically lower the effort and time to determine and maintain the time bases for manual assembly operations. The feasibility of using this method to determine time bases for manual assembly operations at Volvo Cars is evaluated and verified through this Master thesis project.

1.2 Aim

The thesis project aims to study the feasibility of using time blocks for the manual assembly operations performed in Volvo Cars. The feasibility checking will evolve around the tunnel assembly area of the car. Tunnel assembly is a sub-assembly area of the entire car assembly unit. Upon completion of the project, a library of time blocks will be created for the specific assembly area operations. This library will include constants and variables, where operations with similar tasks will be considered constants and operations with slightly different tasks will combined. Thus, in future, during preparing the time settings for PII (Process Inspection Instructions), these blocks can be used from the library to reduce resources, effort and time required to set times using the predetermined time system. In addition, recommendations will be prepared to guide the future time block preparation from current SAM (Sequence-based Activity and Method analysis) data. Finally, we will find the benefits of using Time Blocks for the complex manual assembly process. It will sample the efficiency of Time Blocs for Time Data Management.

1.3 Delimitation

The scope of the thesis was delimited at two levels explained below. The library and time data are considered from this limited area of operations.

Firstly, in the assembly area of Volvo Cars, there are two types of assembly time. One is value-added time, and another is non-value-added time. Value-added time determines the time of an operation which adds end-customer value to the product during manufacturing. Also, the Manufacturing Engineering department analyses and owns the value-added time, where we will conduct our thesis project. On the other hand, non-value-added times are analyzed and calculated at the plant. So, the scope is delimited to value-added times of manual assembly operations.

Secondly, the application and validation of time blocks are delimited to tunnel assembly of the final assembly area only. This tunnel pre-assembly consists of complex manual assembly operations, including an end-of-line quality inspection. Operators handle cables, polymer components, metallic components, and parts with fabric at this sub-assembly area. Moreover, different kinds of compelling assembly notions are present at that sub-assembly line, i,e using rotating fixtures, kitting, and pick-by-light. Considering the complexity and procedures involved, this tunnel sub-assembly could represent the complete assembly process.

1.4 Research questions

During executing of this thesis project, we tried to find the answers to the question below. However, the project was not limited to these questions only.

- How can Time Blocks be formulated for the complex assembly?
- What value will it bring to the time-setting process compared to the current methods?

2

Methods

The thesis project is divided into two stages. The initial stage is to conduct a detailed literature review to get insights into the background and understand the processes involved in setting standards for time bases of various operations in a complex multi-model manual assembly environment.

In addition, It is crucial to set the knowledge basis, terminology, relationship, measures and theories to design the activities consciously (Hubka & Eder, 1996). We consciously organised the design science based on this complete knowledge. Both qualitative and quantitative data analysis has been done for this project. Quantitative data from interviews and written feedback in the form of emails were collected from stakeholders to understand the outcomes (Denscombe, 2014). This activity was done at the project's beginning and end. This was done to discover the current underlying challenges, interactive quantitative data analysis, alternative ideas and project openness.

During this thesis project, a general research methodology has been used along with the methodology for standard data development in the book Maynard's industrial engineering handbook (Maynard et al., 2001b). We followed the steps below sequentially.

2.1 Organization of work

The organizational structure of the manufacturing engineering division at Volvo Cars was studied to understand the stakeholders of Time Data Management (TDM). The areas that would be covered within the project's scope were identified. The top-down approach was used to identify the level of users who will use the time blocks. The standards and procedures for the current predetermined time systems used were studied. Further, the following questions were identified to be answered to determine the project's scope.

- What is the organization's structure and functions used in the current assembly arrangement?
- Which are the models and variants of the products produced in the concerned manufacturing facility?
- Are there any common assembly operations used in the facility?
- How often do changes occur within these operations due to changes in the product's design, processes and layout?

- What data are available on the current predetermined time system used, which would facilitate the building of time blocks?

After answering these questions, the project's scope was partially determined, and the probable stakeholders of the time blocks were identified.

2.2 Activity analysis

The discussion sessions were held with the Time Specialist, who determines the time bases for the manual assembly operations using predetermined time systems by understanding the assembly process. Processes involved in establishing time bases and the flow of information between different stakeholders were analyzed. The possible advantages of using time blocks to replace the existing method of setting time for manual operations were identified. The project's purpose aligning with the scope was established at this stage, and the project's scope was further delimited to specific assembly operations within the tunnel assembly section. Finally, the desired benefits of using time blocks for establishing time bases for manual assembly operations were established, through which the feasibility of using them at Volvo Cars can be studied.

2.3 Application analysis

The approach of the time blocks was moulded to suit the company and area of application. The rough structure for collecting the available data was prepared based on the data required for building time blocks. The benefits the company can derive from using the time blocks were well-defined and displayed. Through this step, the deliverable upon complication of the project was specified. The application of the time bases was defined at this stage so that the details, level and accuracy for the time blocks to be achieved were set. The efforts and resources utilized with the existing system, expected to reduce, were defined. Finally, a rough structure was planned and decided on how the final time blocks and equation should be.

2.4 Standard data analysis

The structure for collecting data prepared in the previous stage is filled with the available time data. Time bases were divided based on the existing system's Process Inspection Instruction (PII). This was accumulated into the working data sheet created from all PIIs related to the tunnel assembly area operations. These data were separated based on the products and variants involved within the products assembled in the facility. Further, these data were divided into the respective workstations where these operations are performed. A bottom-up approach was used to analyze these operations by studying the activities used to perform these operations. The activities were physically observed in the workstations and compared with the activity breakdown of those in the existing standard data. Further, these activities were analyzed by grouping them with similar operations performed.

2.5 Standard data development

The top-down approach was followed during this project step. The identified common operations formed the basic level of standard building blocks in the library. These operations with similar cycle times and activities were considered constants with a known name. A combination of constants and variables covered the operations with slightly different activities. The user could enter the variable value and retrieve the building block for the operation. Finally, unique operations were identified, and building blocks were added to the library. The library was divided based on manual assembly, screwing, material handling and inspection operations.

2.6 Validation

The primary purpose of this step was to check the accuracy, coverage and effectiveness of the built time blocks and equations. Firstly, the coverage is most important to check if all the operations currently performed in the tunnel assembly area are covered and if those operations are in the library. This was checked by randomly selecting the PII and performing PMTS using a library of time blocks. The operations that were missing were identified and added to the library further. Secondly, the accuracy of the time blocks is checked. The critical aspect of adopting any new method or standard is the accuracy of the new method. The accuracy was checked by comparing the PII time set with the existing PMTS and using the new time block library. When the PII was picked for checking the coverage, the time was set using the time block library, and this was compared with previous PMTS time bases, and the difference was calculated. Since the operations and activities in the time block library are constructed based on the existing PMTS data, the time blocks can be compared with this for accuracy rather than the actual clocking of the operation. Finally, the time and effort for setting time for complete new PIIs were compared between existing PMTS and the time blocks' library to determine whether the time blocks reduce the time and effort put upon setting time for operations. This is done by using a stopwatch for the process using both methods and effort rations are calculated and compared with existing and new systems. Further, feedback was taken from Time Specialists regarding the structure of the time blocks, correctness and usability, and changes were made per the feedback.

2.7 Application and maintenance

The practical implementation of the time block principle at Volvo Cars was outside this project's scope. However, detailed documentation involving the steps during the development stage and difficulties faced during development was presented. The validation results through different aspects formed a solid base for establishing feasibility. Further, these aspects, working procedures, and validation results were used to generalize the ideas of time blocks and their future maintenance guideline.

3

Theory

In the following sections explains in brief the different theory related to pre-determined time system and bases of time blocks.

3.1 Time Data Management

Generally, Time Data Management (TDM) is defined as the process that involves the determination, pre-processing, application and administration of time data (Kuhlang, Erohin, Krebs, Deuse, & Sihn, 2014). The TDM in industries plays an essential role in strategic-operative planning and decision-making. The time data within the TDM has applications across different departments throughout the process of the emergence of the product. It starts with modelling, simulation for the design of the workplace, production system analysis and setup, balancing of stations, lead time planning, material planning, costing and many more. The time data are determined and used across all the steps in the product emergence process and further during production improvements. Despite the importance and relevance of determining and maintaining the time data, companies assess the process as time, resource and cost-consuming (Kuhlang et al., 2014). Hence, TDM-related processes are often neglected, and products are produced without a well-maintained TDM system (Kuhlang et al., 2014). As a result, there is only a little active research within the TDM field and relatively fewer publications (Kuhlang et al., 2014). However, the need for having well-maintained time data is often observed across research communities and industries; it is preserved as the data already exists. The author mentions that, though the importance of having a TDM has decreased, the accuracy and intensity of utilization of time data increases across product emergence processes (Kuhlang et al., 2014).

Peter Almström and Mats Winroth further describe the implications of an inefficient TDM system. The Productivity Potential Assessment (PPA) studies conducted by authors identify a significant difference between the operation time in reality with the operation times used for planning and other central activities (Almström & Winroth, 2010). Utilization of resources is a critical part of building a sustainable production system and continuous improvement; due to the existing gap in operation times, the improvement measures would not yield significant results. The production planning and scheduling activities might need excess efforts to avoid the negative impacts of the gap, which would increase the losses and inefficiencies across the system. This might impact the manufacturing companies at the strategic and business level as the cost of products is usually conducted based on the available data within TDM.

3.1.1 Gap within TDM

Almström and Winroth (2010) identified three main reasons for the gap between operation times (Almström & Winroth, 2010). The first reason is that operation times need to be correctly determined. Often cycle times are retrieved from the Computer Aided Manufacturing (CAM) tools, which neglect operations like loading or unloading, setup times, quality control or inspection and many more. The competence to perform time studies to determine accurate times is missing in most industries(Almström & Winroth, 2010). Also, the process is challenging and time-consuming (Almström & Winroth, 2010). The second reason is that temporary allowance time becomes permanent (Almström & Winroth, 2010). The allowance time would be added to the operation times to handle planned and unplanned disturbances, and these allowances are never removed from the system. The third is that the time data need to be updated regularly (Almström & Winroth, 2010). The authors mentioned that only 25 per cent of studied industries updated their TDM based on accurate operation time data (Almström & Winroth, 2010). Though most companies have manual or automatic systems to report the actual cycle or operation times, they are rarely updated into the TDM (Almström & Winroth, 2010). The final reason is the root cause, where the production manager oversees the problems (Almström & Winroth, 2010). The improvement initiatives and projects are often regularly performed on the shop floor and need to be reflected in the TDM system.

3.1.2 Morphology of TDM

To address the issue, the Kuhlang et al. (2014) suggests a set of guidelines with characteristics and attributes for TDM systems through a morphology which can potentially be structured for company-specific TDM systems. First, the general aspects of TDM are defined using aspects of the type of products representing the assembly processes involved and the repetition of the operations. The competence of companies in TDM where the expertise and qualification of employees to handle the activities within TDM. The time unit used and level of time category where the units used for time and the level of details in terms of operations necessary for the company. The transferability of time data depends on the useability of time data across different purposes. The accuracy rate required for time data where the correctness of data is considered might depend on the data's application fields and further the accuracy review on how often the data needs to be revised for correctness (Kuhlang et al., 2014).

The attributes defining the determination stage of time data for the TDM would be the area of determination, the phase of production during the determination, and methods used to determine the time and effort required for determining the time data (Kuhlang et al., 2014). The area where the time is being determined might be necessary if the operations are assembly-related, maintenance-related, or logistics-related (Kuhlang et al., 2014). The stage of production during which the time is being determined would be a key aspect, where the product is still in the testing and pre-production stage, or the total fledge production of the product has started. The method used to determine is also a key aspect, which would also depend on the production stage. For example, the PMTS methods might be used for products at the pre-production level, or other time study methods would be used (Hedman & Almström, 2017) (Kuhlang et al., 2014). This would again influence the accuracy of the time data, where the time data estimates the exact value. The efforts required for determining is also an important attribute that varies based on the methods adopted for the process. Kuhlang defines it as the ratio of work content and effort to determine the time data (Hedman & Almström, 2017) (Kuhlang et al., 2014).

Further, the attributes that define the pre-processing stage of time data for the TDM are the type of times used in TDM, time influencing factor and presentation of time data (Kuhlang et al., 2014). The type of time being determined plays an important role, whether the time being determined is target times or actual times. The actual times are usually determined using different methods (PMTS methods, estimation from experience and previous time data or direct observation), and the target times can be further calculated using this data (Hedman & Almström, 2017) (Kuhlang et al., 2014). Various factors can influence the time, and these factors vary between the methods used for the time determination. The presentation of the data is linked with the users of the TDM, where the data must be presented in a structure depending on the use case of the data. The time data might need to be separated as value-added and non-value-added operations or even further with the types of operations like manual assembly, screwing, machine operations and many more (Hedman & Almström, 2017).

The attributes that define the application stage of time data for the TDM are application level and purpose and the accuracy requirements (Kuhlang et al., 2014). The time data application level might vary between companies where at the strategic level for activities like investment planning, tactical level for work system design and operational level for order monitoring (Kuhlang et al., 2014). The accuracy of time data varies between these levels of applications. The accuracy level required for activities like renumeration would be very high compared to accuracy requirements for mayor buy decisions and long-term capacity planning (Kuhlang et al., 2014).

The attributes that define the administration of TDM are the storage and level of integration (Kuhlang et al., 2014). The time data can be stored in a centralized system which increases the efficiency of usage and availability for the long term. However, the data can also be stored in a decentralized system (Kuhlang et al., 2014). The integration of the TDM plays an essential role in exchanging data with different systems within the company. In contrast, in fully integrated systems, the determination, pre-processing, application and administration would happen in a single IT system (Kuhlang et al., 2014).

The suggested morphology of TDM according to Kuhlang et al. (2014) provides a unique and comprehensive overview of the attributes and characteristics of an efficient TDM system (Kuhlang et al., 2014). The problems faced by current manufacturing industries in time data and gaps between actual times and times in planning systems can be rectified by having an efficient TDM system. An efficient and transparent TDM system can obtain quick and robust sights of the operating conditions of the assembly operations (Kuhlang et al., 2014). Efficient and data-centric decisions on operations, planning, control and improvements can be made with the help of the TDM system. Further, the data quality can be immensely improved by integrating users who affect the time data, including product designers, production engineers, planners and operators through TDM-IT (Hedman & Almström, 2017)

3.2 Measurement of work

It is commonly preserved as standards that provide an essential piece of information necessary for operations within any organization. The main activities like production scheduling, staff planning, line balancing, material requirement planning, remuneration for workers, simulation of the production systems, costing and evaluation of employees are highly dependent on standard time data (Maynard et al., 2001a). The standard time data can be defined as the time the operator works at an average pace to complete a task using predetermined methods, allowing some personal time for personal needs (Maynard et al., 2001a). It is considered that the operation is performed by an average skilled operator for standard-time data establishment. The average skilled operator is considered to be neither slow nor fast, and neither the best nor the worst performing operator, who can perform the operations consistently throughout (Maynard et al., 2001a). The objectives of establishing these time standards for all the operations would be widely spread across different levels of the organization. The direct users might use these standards for daily production planning and scheduling activities, and at a higher level, improvement ideas might be evaluated, and activities like method improvements are performed using these time standards (Niebel & Freivalds, 2003a). These can have an impact on the safety and well-being of employees and the quality of the products assembled and manufactured.

Further, these standard data can have multiple levels of refinement based on motion, element and task performed (Niebel & Freivalds, 2003b). The motion-based standard time data have critical applications, but it consumes longer time and skills to develop them (Niebel & Freivalds, 2003b). The element-based standard time data have many uses and can be developed much faster (Niebel & Freivalds, 2003b). Finally, these standard data have to be structured and stored for later uses, and when these operations repeat, established standards need to be used, and no efforts should be put into determining time-related data for such operations or tasks (Niebel & Freivalds, 2003b).

3.2.1 Methods for time measurement

The standards related to time are traditionally developed and established using one of the three methods, which are as follows.

3.2.1.1 Estimation of time

Estimation of time data can be done in two ways. The first is based on the knowledge about the tasks and operations being performed (Maynard et al., 2001a). The time required is initially provided using the SWAG (Simple wild-ass guess) method. This will be examined by the engineer who knows the process or activity being performed (Maynard et al., 2001a). The engineer will determine if the task or operation can be performed within the specified time. This will sometimes be right and sometimes wrong, where sometimes the particulate step in the production might be a bottleneck (Maynard et al., 2001a). This might be due to improper determination of time, which might lead to potential risk in planning and scheduling (Maynard et al., 2001a). The second is based on the estimation from previous or historical data. The time data within the organization are examined and compared with the new operations, and similar or the closest operation's time is used ((Maynard et al., 2001a). The potential problem arises when the new operations are entirely different, and no such operations exist—the quality and credibility of the current time data. If the historical time data is inaccurate and has deviations from them, then the new estimated time might also be deviated or inaccurate. This might create discrepancies with the quality of the method used for time determination. In addition, the Parkinson's law applicable to engineers might be an added risk with these methods (Maynard et al., 2001a).

3.2.1.2 Direct observation

Direct observation of the time data is measured by observing the operations performed directly. This type of measurement of time data can be done in three different methods (Maynard et al., 2001a).

The first method is called work sampling. In this method, the individual conducting the study will record and note many observations at various and random intervals (Maynard et al., 2001a). The condition of the performed activity is noted, and the state of the objects and various things involved in the activity is observed and noted. Further, these conditions and states of the activities while performing them are divided and separated as the categories of that particular activity (Maynard et al., 2001a). The insights about the activity are drawn from these separate categories, observations are made for that particular activity, and time data are determined and finalized (Maynard et al., 2001a). Though the method is expected to give standard time data at the required accuracy level, it is time-consuming as continuous observations must be carried out. This could demand time, resources, and time consumed during calculations and establishing the time data after observations. The major hinder to using this method would be that this can be carried out only when full-fledged production starts. If the product is still in development and assembly design steps, it is impossible to determine and establish the time standards.

The second method is the direct measurement of work performed by physiological means. The method is based on the general idea that work is equal to force times the distance and performing any work needs energy (Maynard et al., 2001a). When an operator or worker performs any physical work, it will always change many human-related aspects like temperature, heart rate, oxygen levels and lactic acid concentration in the blood (Maynard et al., 2001a). A direct relation exists between these aspects of the human body and the physical work performed by the human body (Maynard et al., 2001a). These relations are utilized to measure the physiological cost of work being performed (Maynard et al., 2001a). However, the main concern for using this method is the differences and variables involved within these aspects between different individuals. For example, the method might indicate higher physiological costs for a beginner attempting to work at an average pace (Maynard et al., 2001a). Hence, this method is preferred when the cost of performing varying tasks needs to be calculated (Maynard et al., 2001a).

The stopwatch time study is the third and most common method in direct observation. It is a procedure to measure an average skilled operator's time to complete a task by working at an average pace following a specified method (Maynard et al., 2001c). This method includes the method study, where the engineer performing the time study will observe the methods used to operate (Maynard et al., 2001a). So, this method will help recognize and quantify the time-related losses and inefficient methods used to complete the operation (Butterworth-Heinemann, 2020). This method will provide acceptable results for highly repetitive operations with short cycle time (Butterworth-Heinemann, 2020) (Maynard et al., 2001a). The time is measured by directly observing the operations performed using a stopwatch or time study watch. Different devices like decimal-minute or decimal-hour mechanical watches, split hand stopwatches, and digital stopwatches can be used with time study form and stationary to perform the time study. Once the times are noted, a few minimal basic calculations can be made to determine the time taken to operate (Butterworth-Heinemann, 2020) (Maynard et al., 2001a). The primary concern for using this method to establish time standards would be the quality of the data captured. The errors associated with time-measuring devices and human errors involved would be of concern.

Further, the variations involved between different operators or workers performing the tasks based on familiarity with the operations and experience of the operator performing the operations would add variations. This method demands more effort on observation to capture the data and further efforts whenever changes are made within the product and processes. The primary concern is that the stopwatch study can be used only when the products are in the production phase and not during the pre-production stages. It would require adopting a different method if the requirement of operation times exists before the production stages.

3.2.1.3 Standard data system

It is a collection of all the elements involved in performing a particular operations class with time values for each element (Maynard et al., 2001a). Here the time data are determined for a group of motions rather than every single motion of the operator (Maynard et al., 2001a). The significant advantage of this type is that standard times can be determined for a new operation without requiring those operations to be performed (Maynard et al., 2001a). On the other hand, knowing how particular operations are performed will make an individual select the time data from compiled tables, graphs or formulas (Maynard et al., 2001a). Currently, certain established systems are called predetermined time systems (PTS) through which this process is possible. This will be further explained in the upcoming chapters.

3.3 Predetermined Time Systems (PTS)

The PTS is a method used to define the time required to perform a particular operation by deriving from the existing established standards of the time (Razmi & Shakhs-Niyaee, 2008). The main pre-requisite for using this method is that the task for which time needs to be determined must be defined in terms of dynamic movements of the human body (Maynard et al., 2001a). When the movements or motions involved in the tasks are defined, the time required to perform those motions is calculated from the respective database of that particular method (Maynard et al., 2001a). The major drawback of estimation and stopwatch methods is eliminated in this method. Initially, the method analysis is performed to identify each motion involved through which risks, inefficiencies and problems are identified at the PEP phase. The requirement of an analyst to perform performance rating can be eliminated (Maynard et al., 2001a). The main advantage is that the time for the tasks and operations can be determined without the operation being performed physically at a higher accuracy level. However, the disadvantage of using this method would be when operations depend on machine times, and it requires significant training to gain competence to use any of the PTS available (Maynard et al., 2001a).

The PTS method is mainly classified as object-related and behaviour-related, where the characteristics of the parts involved in operations and workplace design are considered in the object-related systems (Maynard et al., 2001a). In behaviour-related systems, the human motions involved during the operations are emphasized and the motions are classified according to the observer's perspective (Maynard et al., 2001a). The PTS can be further differentiated as motion-based, action-based and activity-based predetermined time systems (Maynard et al., 2001a). The motion-based systems comprise the time elements of the small human movements involved during operations (Maynard et al., 2001a). The action-based systems consist of time elements consisting of a combination of basic movements involved for actions (Maynard et al., 2001a). Finally, the activity-based system combines basic movements and actions in a sequence representing a complete activity (Maynard et al., 2001a). The organizations select the PTS methods based on the accuracy requirements of the time standard and the application areas of these established time bases and sometimes adopt them based on the use case of these PTS systems.

The most famous PTS is MTM (Method Time Measurement), developed by Lowry, Maynard and Stegemerten. It is based on performance, skill, effort and consistency required to complete certain operations (Maynard et al., 2001a). This was developed by continuous observation at the micro level of individual motions to establish elements and standard times for those elements ((Maynard et al., 2001a). Since this was available from early times, most of the frequently used systems are based on MTM (Maynard et al., 2001a).

The operation is broken down into the most basic motions: reach, move, turn, position, grasp, release, disengage, eye times, and body motions (Maynard et al., 2001a). The standard time for these motions is predetermined in the MTM system, and they are added together to determine the time required to perform that particular operation using the MTM method. There are various other methods also which can be used to determine the time for these motions, like BMT (Basic Motion Time Study), WF (Work Factor) system, MODAPTS, and many more, which are classified under motion-based predetermined time systems (measurement of work, my book). Though these methods efficiently provide accurate time standards for the operation, the time consumed for the determination is relatively high. All the motions involved need to be analyzed, which demands efforts to determine time. The issue would be when a small lot of products need to be produced. To overcome these issues, various methods were developed basing the action. Few motions were combined into actions which would reduce the division of operations. These methods, like GSD (General Sewing Data), MTM-MEK, MTM-2 and MTM-3, were based on this principle (Maynard et al., 2001a).

3.4 Time Blocks

Time data management (TDM) is a crucial process in any manufacturing company as it helps determine, utilize, and maintain time bases for critical activities. Such activities may include cost estimation, process planning, flow simulation, and continuous improvement. To enhance the efficiency of TDM, the TIMEBLY research project (Vinnova, 2021) is exploring a new concept called Time Blocks.

Time Blocks are an extension of the existing Predetermined Motion Time System (PMTS) and involve identifying constant operation steps or tasks that can be used as building blocks. The identification process requires the identification of variables that play a role in various operation stations, products, or steps. Correlations between these variables and constants are then determined by examining similar operations within the organization. These correlations are referred to as time equations and can be stored in a library for easy use.

The concept of Time Blocks aims to reduce the repetitive use of resources and time by creating a standardized set of operations that can be used across different products, stations, and steps. By identifying constant operation steps, Time Blocks can help reduce the need for repetitive planning and estimation of time and resources. Moreover, the use of Time Blocks can help manufacturing companies save time and resources while improving data quality and consistency.

In conclusion, the concept of Time Blocks is an innovative approach to time data management that has the potential to revolutionize the manufacturing industry. By identifying constant operation steps and creating a standardized set of operations, Time Blocks can help reduce the repetitive use of resources and time while improving data quality and consistency.

4

Case Description

This chapter provides information on how the Volvo Car Corporation (VCC) is structured and how time-setting processes are conducted. It explains the flow between different steps and how time bases are established and maintained using the Time Data Management (TDM) system. Our knowledge of the current working structure is based on interviews, discussions, and internal documents found on the Volvo Cars intranet. Please be aware that these processes and structures may change in the future.

4.1 Time Data Management and Time Bases

Teamcenter is a sophisticated PLM software that acts as a central storage for all information related to a product and its processes. From the initial design stage to the final assembly process, every step of the product development procedure is accurately recorded and managed in this software. A diverse group of stakeholders work with the data contained in Teamcenter.

To keep track of assembly and production processes for specific components, the software uses a structured format called Process Inspection Instruction (PII). These PIIs contain important information such as part numbers, assembly operations, time bases (Volvo-SAM), and tools used for each operation. The data needed for production processes is gathered from manufacturing plants and inputted into local software.

To ensure smooth operations, it is essential to have the correct information available at the right PII and at the appropriate time. Manufacturing engineers are responsible for owning the PIIs and ensuring that all relevant information is added to the correct location in a timely manner. PIIs are created early based on the components and processes involved when a new product model is introduced. Information is added gradually at each step by various departments and teams.

Below, we provide a detailed explanation and demonstration of the various processes involved in handling time data, aimed at giving a comprehensive understanding of these complex operations.

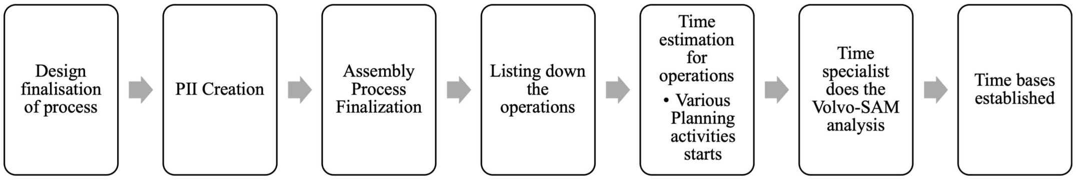


Figure 4.1: Process steps of handling time data through PLM software - generalised

When introducing a new product, it is essential to follow certain critical steps during the product emergence phase. Firstly, all components need to be carefully designed, tested, and perfected to guarantee optimum quality and functionality. Next, the process planning phase commences, during which a detailed list of Process Inspection Instructions (PIIs) is created, based on the components needed for assembly in the new model.

The components and assembly processes are thoroughly assessed and evaluated to determine the most efficient and effective way to bring the product to fruition. This involves generating a final set of operations, where the PII engineers or owners list the assembly operations for each PII. The times required to perform these operations are analyzed based on previous data, as well as the experience and knowledge of the PII owners.

Each operation is carefully considered individually and compared to existing similar operations to estimate the time required. The experience of the operators and PII owners is considered, and time data for current operations is used to estimate times for new operations accurately. Finally, the PII owners generate a comprehensive list of operations and estimated times for assembling the components, ensuring a smooth and efficient product emergence phase.

Time estimations play a significant role in planning activities during the early stages of new product emergence. The necessary information is forwarded to an expert to generate a list of operations with time estimations. Then, the assigned expert analyzes the time using the Volvo-SAM system. Certified experts in Volvo-SAM break down the operations into individual tasks and steps, using drawings and pictures to identify the dimensions and distances required for assembly. If necessary, additional information is discussed with the process owner. The tasks are allotted respective codes based on the type of task and movement, and the frequency of tasks is allotted individually. The software then calculates the time required for each operation using SAM codes and task frequency. The time bases generated through Volvo-SAM have various applications across the organization, including station-level line balancing and cost estimation.

However, the process of determining time bases using SAM requires a significant amount of effort and time to analyze every operation for every PII. With the multiple types of cars being manufactured and assembled across different continents, the effort required to determine time bases using SAM increases exponentially. Furthermore, the electrification strategy of Volvo will demand multiple changes in the existing assembly stations and products, increasing pressure on the manufacturing department to determine time bases quickly. Although the current process is efficient, the upcoming phase will demand more resources, effort, and time.

4.2 Volvo-SAM

At VCC, they have a specific time system that they rely on to determine time bases. This system, known as Volvo-SAM, is tailored to meet the company's unique needs. All time data is measured in TMU (Time Measuring Unit), meaning that times determined using Volvo-SAM are also in TMU. To ensure accurate analysis, time experts follow established guidelines or regulations. These regulations consist of a common set of rules that the organisation has agreed upon. Although the procedures for breaking down operations into SAM tasks or steps may vary slightly between MTM-SAM and Volvo-SAM, these differences can significantly impact the final time value.

5

Results

Within this chapter, the outcomes of the thesis project shall be disclosed and expounded upon by employing the methodology previously delineated.

5.1 Organization of work

The primary purpose of this initial step was to understand the organization's current structure and existing standards. This was the planning stage of the project, through which the scope and timeline of the thesis project were determined.

The process of PII creation and information related to assembly operations being added into the PII with the time bases were of focus. Initially, the documents available were referred to understand the organization's structure, working procedures, and field of concerned departments. The top-down approach was used to identify the organisations' applications and stakeholders of the time bases or time data. Discussions with process owners and time experts were carried out. The map was generated based on the findings to understand the steps in determining time bases. This has been done for each process and operation involved within the processes. The observations were made on how time data are determined by time experts, methods used and regulations involved within the organization. The following figure 5.1 will explain the finding and understanding of the working structure within the organization related to time data management.

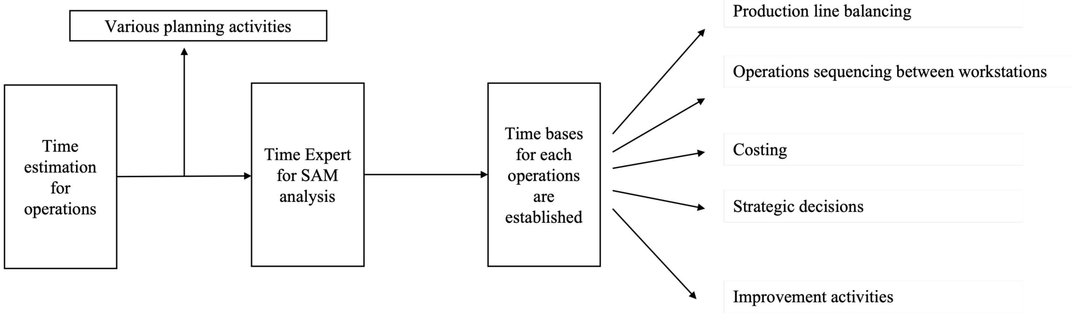


Figure 5.1: Process flow of Time Determination - generalised

Parallelly, visits were made to the final assembly area at VCT to observe the assembly operations involved in completing individual vehicles. It was found that

VCT has a multi-model moving assembly line across the assembly area, and operations are equally divided between workstations. Further, it was identified that every workstation performs similar assembly operations regardless of the vehicle model and variants involved within the models of the vehicle, with few changes or variables between vehicle models. The tools used at individual stations are similar, which confirms that similar operations are performed at the workstation level. The cycle time of these workstations was balanced to be around the same across the assembly line. Further, it was found that assembly operations are differentiated as value-adding and non-value-adding operations. The manufacturing engineering department at VCC deal with only value-adding operations where the thesis project was performed. Hence, the initial scope for the thesis project was set for only value-adding operations, which was the working area of the department where the thesis project was conducted.

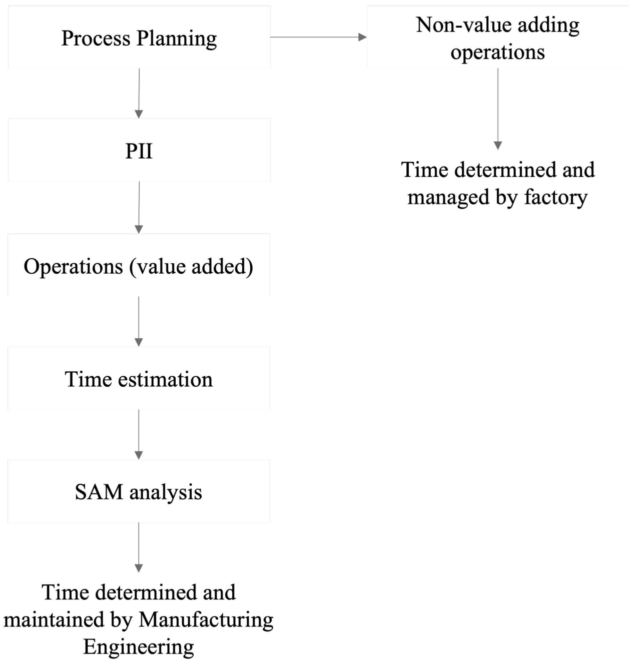


Figure 5.2: Value-added and non-value-added operation - generalised

5.2 Activity analysis

The primary purpose of this step was to establish the level at which the time blocks should be built. Further, the time blocks would be built within the particular assembly area for the thesis project.

The time blocks can be built at any desired level based on the organization's accuracy requirements and applications of the time bases. The time blocks can be built at a very high level or at the workstation level to determine the cycle time for the completion of the assembly of the entire level. However, when the application of the time bases at the early level was analyzed, it was mentioned that various applications were found to demand it at a much lower level, like the operation level or PII level. The time bases will provide inputs to various strategic levels to make decisions and plan production, which demands time bases accurately at operations and PII levels. Hence, time blocks at the operation level were preferred.

Further, the tunnel assembly area operations were selected for the thesis project. This assembly line involves multiple stations performing various operations, including kitting, manual assembly, handling of materials and quality inspection. Various components were involved, including components with different materials in this assembly area. Also, this was a multi-model moving assembly line, representing the overall assembly set-up of the entire VCT. Hence, this tunnel assembly line represented a multi-model complex assembly environment involving various operations divided between multiple stations. This would provide an overall picture of the assembly set-up at VCT, where feasibility can be studied, which can depict the VCT production system. The figure 5.3 below represents the assembly area of the tunnel, which was the scope of the thesis project. This is only the representation of tunnel assembly and does not match with the reality.

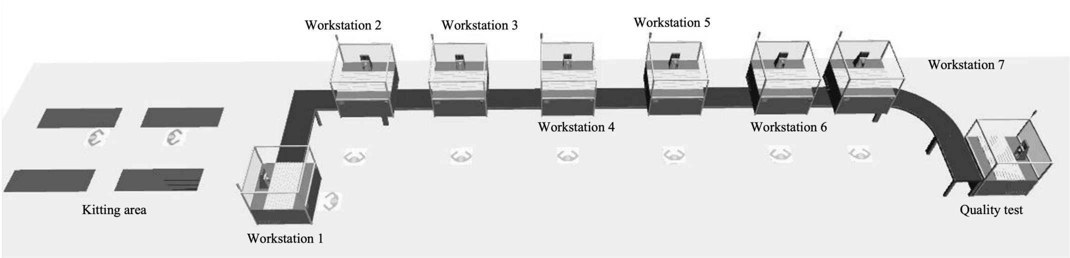


Figure 5.3: Schematic representation of tunnel assembly

In addition, for better understanding the picture of Tunnel of a car is given below as example.

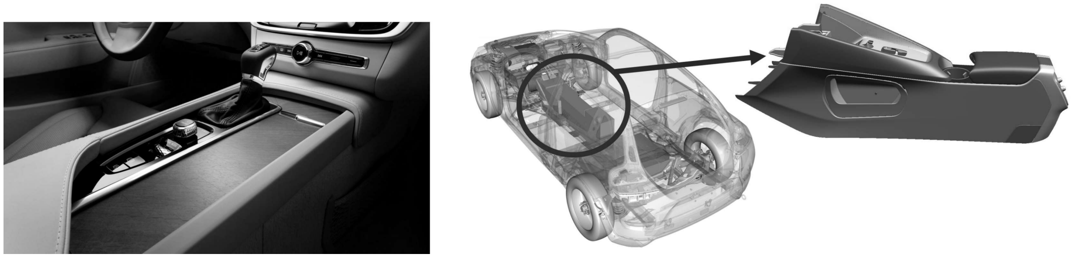


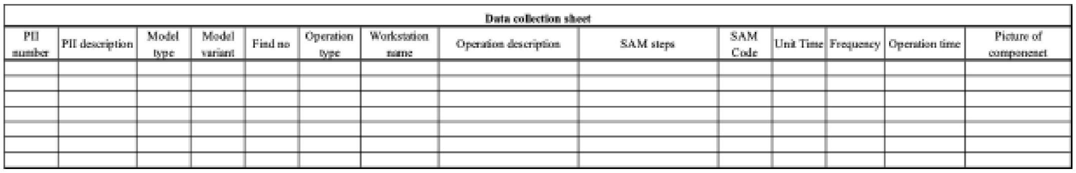
Figure 5.4: Example illustration of Tunnel unit in a car

5.3 Application analysis

The primary purpose of this step was to identify the data requirements to build the time blocks for the selected assembly area. Also, to roughly structure how time blocks would look and identify the possible benefits of using time blocks in place of traditional SAM.

Observations and discussions with stakeholders and time experts were held to understand the processes involved in determining the time data for individual operations. It was found that many operations for different models and variants of the vehicle would remain the same with few changes like the number of screws, clips and so on. There can be instances where similar components and parts are assembled similarly. As found previously, similar operations are performed in the same workstation regardless of the model of the vehicle. The process can be repetitive when these operations need to be analyzed for time determination using SAM. For example, component X must be assembled on Y with four screws for model A1. The same component, X, might need six screws to be assembled for model A2. When these operations are analyzed for time determination using SAM, existing in completely different PII, and are introduced at different time frames, the time expert would spend considerable time and resources analyzing these similar operations multiple times. These complications could be handled by having a standard time block with a constant time to assemble one screw and a variable of the number of screws need to tighten. They can be used multiple times to determine the time without performing SAM analysis whenever component X needs to be assembled by screwing. The major benefit would be the effort and resources spent analyzing these similar operations. This can also speed up other activities dependent on time data like planning and other production commissioning activities before the full fledge production. These benefits of using time blocks concerning the current processes and stages in time determination were identified, which are organization and working procedure specific.

Further, the spreadsheet - illustrated in the below figure 5.4 shows the empty data collection table created to collect the existing time data on time bases and SAM analysis steps to understand and analyze the similar tasks and steps involved in performing the operations. As the project scope was limited to building time blocks, the data was not collected from observing the assembly operations being performed. Still, the existing individual time data for all the operations performed in the tunnel assembly area, which already existed individually in different PII were collected into a single spreadsheet in a tabular form. The data has been collected from the PLM software data storage and the operation sequence from the balancing software tool used in the plant, VCT. As shown in the table below, the empty table with all the required data was created at this step which would be necessary to analyze and identify the similarities between the operations performed.



Data collection sheet

PII number	PII description	Model type	Model variant	Find no	Operation type	Workstation name	Operation description	SAM steps	SAM Code	Unit Time	Frequency	Operation time	Picture of componenet

Figure 5.5: Data collection format

5.4 Standard data analysis

The primary purpose of this step was to retrieve all the available data into the created spreadsheet and analyze the similarities with the operations. Further, to identify the variables between these operations through time, blocks can be built with a combination of constants and variables, which can readily determine the time to perform these operations.

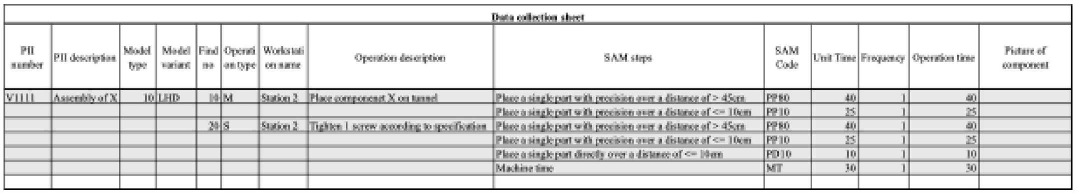
Initially, all the data related to the process and assembly operations were found in the PLM software. The time was spent on getting familiarised with the software environment where the required data are available. It was identified that data like operations and SAM steps for these operations of particular PII are in different formats, and data like drawings and pictures of the components involved in the assembly are in different formats, which are necessary to analyze and identify how these components are assembled by comparing them with SAM steps.

The bottom-up approach was used to collect data at the operation level into the spreadsheet individually. First, the initial filter of a particular factory VCT was applied, and further, the selected tunnel assembly line was applied to collect the data. It was found that around 200 PIIs were involved in this particular selected assembly area. Every PII included multiple operations ranging from 1 to 5 based on the component that is being assembled and the operations required to perform and complete these assemblies. These operations were grouped into assembly, material handing, inspection, and screwing operation types. All the PIIs covering the operations performed in the selected assembly station were selected, and the required data, as in the spreadsheet, was retrieved and filled in the data collection table. The drawings and pictures of the components were also retrieved to analyze further and identify the similarities between operations. The operations included all the models and respective variants of each model, which are manufactured at VCT.

The PIIs and operations within them are not sequenced in the order of the assembly performed at the assembly area, which was one of the required data. Therefore, it was necessary to identify the sequence of the assembly operations through which the workstation where the respective operation is performed can be identified. Furthermore, as identified earlier, every workstation is designed to perform similar operations regardless of the model and variant; it was necessary to identify the workstation to group similar operations.

It was found that the sequence of the operations based on the workstation can be found in the balancing software at the VCT. Time was spent on getting familiar with balancing the software environment. The workstations involved with this assembly line were identified, all the operations performed at these workstations were compared with the existing data, and the sequence of all operations was determined. These operations were colour coded in the respective sequence for further analysis.

Finally, the spreadsheet with all the operations involved in the tunnel assembly with workstations and the sequence involving time data, drawings and pictures and SAM analysis with steps was finalized. The below figure shows the representation of the spreadsheet.



Data collection sheet

PII number	PII description	Model type	Model variant	Find no	Operation type	Workstation name	Operation description	SAM steps	SAM Code	Unit Time	Frequency	Operation time	Picture of component
V1111	Assembly of X	10	LHD	10	M	Station 2	Place component X on tunnel	Place a single part with precision over a distance of > 45cm	PP80	40	1	40	
								Place a single part with precision over a distance of <= 10cm	PP10	25	1	25	
				20	S	Station 2	Tighten 1 screw according to specification	Place a single part with precision over a distance of > 45cm	PP80	40	1	40	
								Place a single part with precision over a distance of <= 10cm	PP10	25	1	25	
								Place a single part directly over a distance of <= 10cm	PD10	10	1	10	
								Machine time	MT	30	1	30	

Figure 5.6: Spreadsheet sample for data collection

Once all the required data were collected in the spreadsheet, the operations performed at single workstations were grouped and separated from other operations. Since similar operations are performed in workstations, these operations were compared with each other to identify the commonalities in the total time taken to perform any tasks or steps involved in performing the operations, which were available from SAM analysis. Finally, these similarities and minor differences were analyzed and divided as constants and variables.

5.5 Standard data development

The primary purpose of this step was to build the time blocks with a combination of constants and variables, which can determine the time of operations by providing an input of variables. Also, to structure these time blocks in the form of a library where all time blocks can be stored and used further at any time when the time of any operation needs to be determined.

Initially, the data of individual workstations were considered separately, and similar operations were identified. It was identified that operations with higher cycle time had more complex steps to complete and vice versa.

5.5.1 Operations with one variable

The operations with less than three steps analyzed in SAM were separated, and all similar operations were grouped. These grouped operations were analyzed by comparing the SAM steps with the available assembly instructions. Similar components with the exact dimensions and steps were combined with a single time block which would avoid determining time individually for these operations. Further, these operations were readily combined into a single time block with only one variable.

Example: An operation where component M must be placed on the framework with precision and another operation where component N must be placed on the same framework with precision. Regardless of the component M or N, the tasks performed to place the component on the framework remain the same. Because only value-added time is analyzed at VCC Manufacturing Engineering department. The task of getting the component from the kit is considered non-value adding. However, these operations would take some time to complete regardless of the vehicle's component, model or variant. So instead of determining this time by analyzing the operations individually with SAM analysis, a single time block with time to place the component as constant A and the number of component B to be variable can readily determine the time for these operations. The time block for these operations is shown below.

Place the component M/N on the framework with precision = A*B
Where,
A = time required to place any component on framework with precision (constant)
B = number of components to be placed (variable)

In this example, the constant A is predetermined before building time blocks using SAM, where values are programmed into the spreadsheet and variable B is left to be entered manually. Using basic programming in a spreadsheet, the value of B can be taken as input from the user, and the time for the operation can be calculated in no time.

5.5.2 Operations with multiple variables

The operations with more than three steps in SAM were considered complex and further separated to identify similarities. A few of these operations were model or variant-specific, which cannot be combined with any other operations because of the unique steps involved in completing them. These unique operations were converted into time blocks readily without combining them with other operations. However, only some operations were found to be completely different, which is not comparable with any other operations performed across the selected assembly area.

The remaining operations were individually selected to identify the similarities and connections between other operations. These operations had close similarities, but the number of variables between operation to operation differed based on the cycle time, dimensions of the components, number of hands used to operate, machine time for operation performed using a power tool, amount of force required and many more. So, the commonalities were identified, which form the constants for the time block and multiple variables in the process were identified as variables for the time blocks. Since these time blocks had multiple variables, the user can input values for these multiple variables and retrieve the operation time for these complex operations. The resulting time is achieved through programming considering the dependence between variables and constants. Time equations have been created for this

Example: The most general example of these operations can be the multiple-screwing operation. The SAM steps in one screwing operation using a power tool remain the same for standard screws. The variables are the number of screws, the distance between screws and machine time. The machine times depend on the tool used, screw type, and torque regulation for the power tool model. The VCC follows a different method and system to determine the machine time for these operations, which can be provided as an input for the variable in time blocks to determine the time. The other variables, like the number of screws and the distance between screws, can be identified and determined by the reference pictorial assembly instruction of the components. For example, the time equation for the screwing operation looks like this below

Time require for screwing operation = A*x + B*y + C*z + D
Where,
Constants:
A = Required time for screw tightening
B = Required additional time for putting the screw from 10-45CM distance
C = Required additional time for putting the screw over 45CM distance

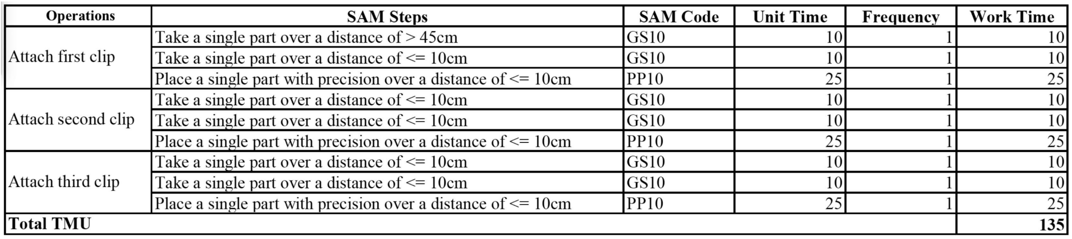
Variables:
x = Number of screws needed to assemble
y = Number of screws from 10-45CM distance
z = Number of screws over 45CM distance
D = Machine time for the specific model of the screw and tightening tool

The exact process was carried out for all the workstations across the selected assembly area to identify the similarities between operations, and these were combined to form time blocks with a combination of constants and variables. These individual time blocks on a single spreadsheet structured together formed a library of time blocks which can be reused multiple times.

5.5.3 Comparison of SAM and Time Blocks

The principle behind determining the time bases for operations using both MTM-SAM and the time blocks is explained and compared below. Firstly, to determine time bases by using SAM, the operations for which the time has to be determined will be analyzed, and the operation steps required to perform the operations need to be identified. These steps should be broken down based on the motions involved to complete the actions like get, put or other activities. Based on the motions involved, these SAM steps must be allotted with the appropriate SAM code based on the distance. The frequency of individual SAM steps would be based on the number of times that particular SAM steps are required to be performed. Finally, the time for each SAM step is added together to determine the time bases of the operation through SAM.

The operation of attaching three clips, as an example, is shown below. The entire operation is analyzed, and appropriate SAM steps (9 SAM steps) based on the motions involved are listed. Further, work time for each SAM step based on the frequency is added together to determine the time as 135 TMU.

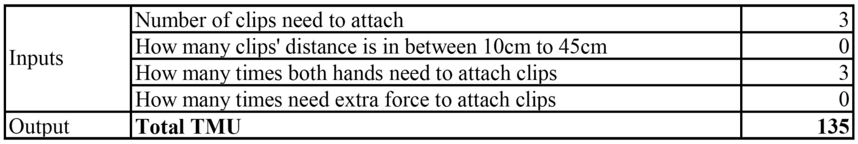


Operations	SAM Steps	SAM Code	Unit Time	Frequency	Work Time
Attach first clip	Take a single part over a distance of > 45cm	GS10	10	1	10
	Take a single part over a distance of <= 10cm	GS10	10	1	10
	Place a single part with precision over a distance of <= 10cm	PP10	25	1	25
Attach second clip	Take a single part over a distance of <= 10cm	GS10	10	1	10
	Take a single part over a distance of <= 10cm	GS10	10	1	10
	Place a single part with precision over a distance of <= 10cm	PP10	25	1	25
Attach third clip	Take a single part over a distance of <= 10cm	GS10	10	1	10
	Take a single part over a distance of <= 10cm	GS10	10	1	10
	Place a single part with precision over a distance of <= 10cm	PP10	25	1	25
Total TMU					**135**

Figure 5.7: Time calculation of attaching three clips with SAM steps

Similarly, when the time base for an operation needs to be determined using time blocks, it will be much simpler. Initially, the operation to be performed needs to be analyzed, and a suitable time block should be identified from the library of time blocks. The type of operations or appropriate filters can be used to identify the suitable time blocks within the library easily. The time block would have variables which need to be determined. The variables can be determined by providing inputs manually by entering numbers or by answering yes or no questions. Once all the variables are determined and linked with the time block, the time base will be calculated based on the equation underlying the time block.

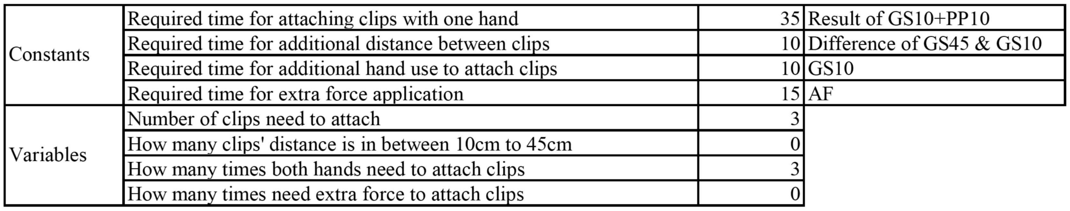
The same operation of attaching three clips as an example using a time block is shown below. The four variables linked with the time block are determined by entering the values, and the time for the operations is directly determined as 135 TMU.



Inputs	Number of clips need to attach	3
	How many clips' distance is in between 10cm to 45cm	0
	How many times both hands need to attach clips	3
	How many times need extra force to attach clips	0
Output	**Total TMU**	**135**

Figure 5.8: Time calculation of attaching three clips with Time Blocks

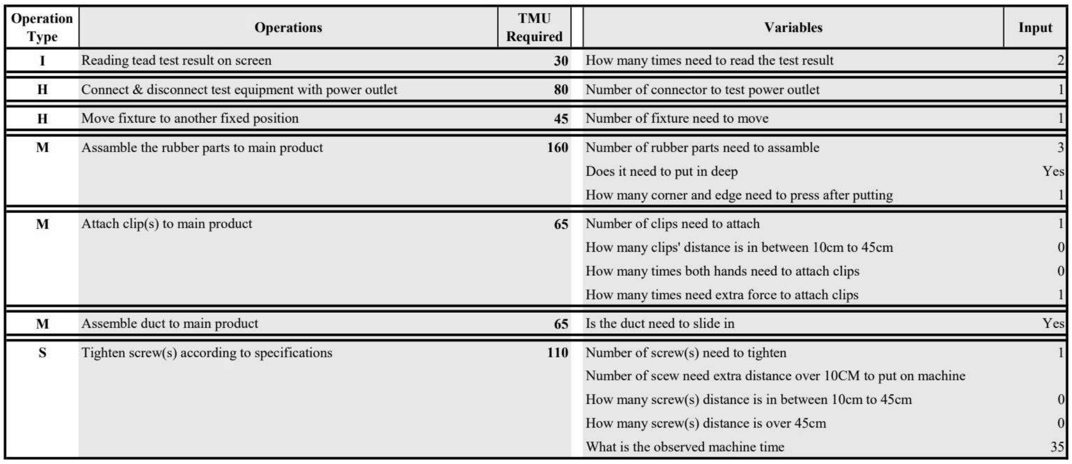
The logic behind the same example time block is that the SAM steps involved with all similar operations involving clips are analyzed to identify the constants and variables. The combination of these constants and variables will add together to determine the time for the operation. In the example operation of attaching clips, when the variables are defined as 3,0,3 and 0, these variables will multiply with constants 35,10,10 and 15. So, (35 X 3) + (10 X 0) + (10 X 3) + (15 X 0) will be the final values for the equation once the variables are determined. Basic programming can solve these equations within the library to answer 135 TMU using time blocks.



Constants	Required time for attaching clips with one hand	35	Result of GS10+PP10
	Required time for additional distance between clips	10	Difference of GS45 & GS10
	Required time for additional hand use to attach clips	10	GS10
	Required time for extra force application	15	AF
Variables	Number of clips need to attach	3	
	How many clips' distance is in between 10cm to 45cm	0	
	How many times both hands need to attach clips	3	
	How many times need extra force to attach clips	0	

Figure 5.9: Background constants and variables for preparing the Time Block

Once all operations involved within the tunnel assembly were analyzed and suitable time blocks were built, a library to structured to store all these time blocks for easy usage. Initially, the time blocks were structured according to the operation types (Assembly-M, Handling-H, Inspection-I, and Screwing-S). However, the library can be structured based on the need and easy-to-use of the specific organization's TDM. The below figure shows the representation of the library we prepared. The right side - blue colour shaded - is for input, and the left side, with green colour shaded area, is the calculated output area.



Operation Type	Operations	TMU Required	Variables	Input
I	Reading tead test result on screen	30	How many times need to read the test result	2
H	Connect & disconnect test equipment with power outlet	80	Number of connector to test power outlet	1
H	Move fixture to another fixed position	45	Number of fixture need to move	1
M	Assamble the rubber parts to main product	160	Number of rubber parts need to assamble	3
			Does it need to put in deep	Yes
			How many corner and edge need to press after putting	1
M	Attach clip(s) to main product	65	Number of clips need to attach	1
			How many clips' distance is in between 10cm to 45cm	0
			How many times both hands need to attach clips	0
			How many times need extra force to attach clips	1
M	Assemble duct to main product	65	Is the duct need to slide in	Yes
S	Tighten screw(s) according to specifications	110	Number of screw(s) need to tighten	1
			Number of scew need extra distance over 10CM to put on machine	
			How many screw(s) distance is in between 10cm to 45cm	0
			How many screw(s) distance is over 45cm	0
			What is the observed machine time	35

Figure 5.10: Example of library formation with Time Blocks

5.6 Validation

The primary purpose of this step was to validate the Time Blocks' performance with the existing SAM method to establish feasibility. The validation was carried out to check the performance of the time blocks based on three aspects. The aspects are coverage, accuracy and effectiveness of the time blocks compared with the existing SAM method to determine and maintain the time bases of the assembly operations.

5.6.1 Coverage

After completing the library of time blocks, the library consisted of around 33 Time Blocks. These blocks were built upon analyzing all the value-adding operations involved in the tunnel assembly area at VCT. This selected assembly area involved around 650 operations distributed across multiple workstations involving all the models of vehicles covering all types of operations performed. So, the time blocks are expected to determine the time bases for all the operations currently performed in this particular assembly area. This was validated by manually determining the time bases for all 650 operations using the time blocks library. All the operations were selected in a separate spreadsheet, and individual operations were selected to identify the suitable time block from the library. When the suitable block was identified with the help of identifying the operation type, the values of variables related to the specific time block were input manually. Once the values were input, the time bases for the operation were calculated in the background and displayed as output. It was found that all the operations could be determined using time blocks, proving the coverage aspect of the validation.

5.6.2 Accuracy

The accuracy of the time blocks was checked by comparing the time bases determined by time blocks with the previously existing time bases from the SAM method. This was performed for all 650 operations involved in the selected assembly area. Then, the time output from the time blocks was entered into the validation spreadsheet, where existing time bases from SAM were present. Then the total time from time blocks and SAM compared. The below figure shows the results.

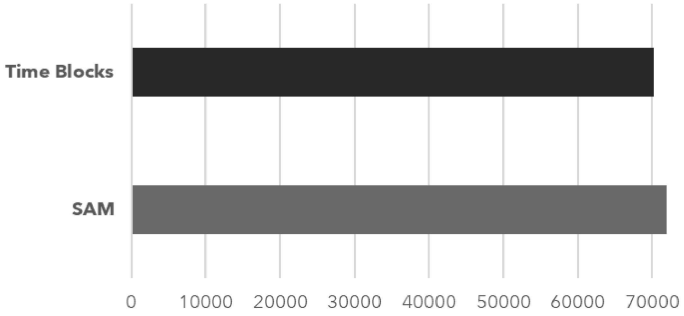


Figure 5.11: Comparison of SAM and Time Blocks in TMU (current operations)

When the time bases for all the operations performed were determined using the time blocks library, it was found to be around 70,000 TMU. The time bases for these operations were previously determined by analyzing the steps involved through SAM. The time from this SAM method was found to be around 72,000. By comparing these two values, the accuracy of time blocks against SAM was around 97 percent. The accuracy level 97 was highly acceptable for the time determination process using predetermined time systems. However, a further bottom-up approach was used to analyze these results further.

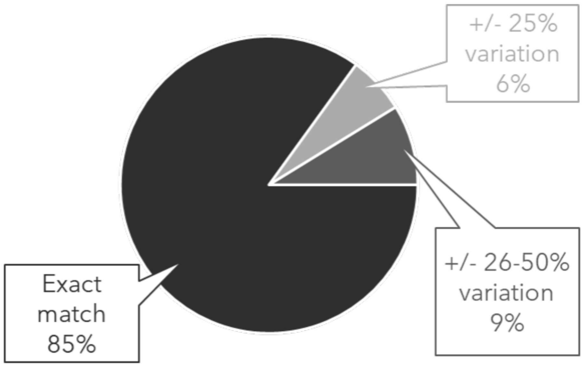


Figure 5.12: Accuracy of time blocks (current operations)

The accuracy of individual operations was analyzed to identify the differences and deviations. It was found that about 85 percent of all the operations involved in the selected assembly area were exactly matched. So, time blocks time has 100 percent accuracy for around 85 percent of operations when comparing the time bases with SAM. Further, the 6 percent varied between + 25 percent, meaning that 6 percent of time determined from time blocks was between 25 percent away and the remaining 9 percent between 26 to 50 percent. The one reason for these deviations between time blocks time and SAM analyzed time for operations might be that different individual performs the SAM analysis for these operations at different time frames. The analysis style and breaking down the operation into different steps in SAM might vary between individuals, which can be one reason for these variations.

Though 15 percent of variation occurred at the operation level while using time blocks, the final accuracy was around 97 percent. This is the outcome of variations getting cancelled between each other as the variations range from +25 percent to -25 percent. This implies that at the higher level, the time determined using time blocks will be almost equal to times determined using SAM. Hence, time blocks can efficiently determine time bases for almost all applications during the product evaluation.

The credibility of using time blocks for time determination was further evaluated by using these time blocks to determine the times for operations involved in upcoming vehicle models. The upcoming model was designed in a completely different architecture with different dimensions, geometry and components, which were new to the organization. The operations related to the tunnel assembly from these new models were gathered, and the existing time blocks library was used to determine the times for these operations. Around 53 operations were gathered randomly from the new model related to tunnel assembly. The existing time blocks library was used to identify the suitable blocks which can be used. The time for these operations was determined using the existing time blocks library. The following observations were found.

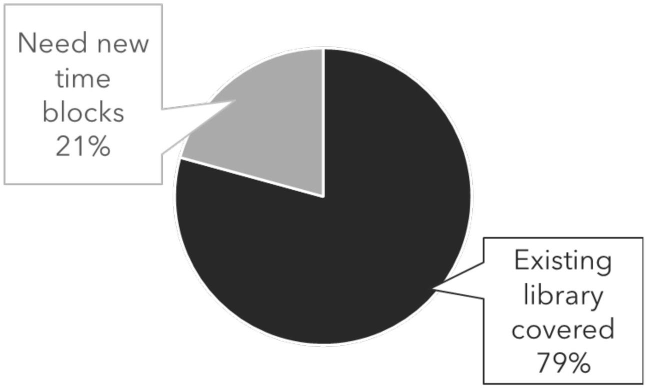


Figure 5.13: Accuracy of time blocks (new PIIs)

About 80 percent of operations from the new model could determine time using the existing time blocks. The remaining 20 percent were new operations which could not be compared with the existing operations. These 20 percent involved handling and assembling new components with different geometry and dimensions. This can conclude that new time blocks might be required to be added to the library when different models from different architectures that are entirely new to the existing systems are introduced. However, the majority of the operations, around 80 percent can still be determined using the previous time blocks, eliminating the effort and resources required to analyze all the operations with SAM.

Finally, the accuracy of these 80 percent operations, which were able to be determined using time blocks, was evaluated. The SAM for these operations were analyzed by time experts and compared with the times determined using time blocks. It was found that the accuracy was around 98 percent. This proves that the operations that can be determined using time blocks will give almost accurate values regardless of the model, variant and design.

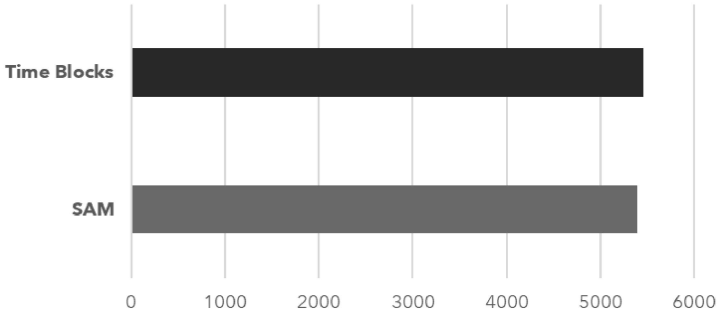


Figure 5.14: Comparison of SAM and Time Blocks in TMU (new PIIs)

5.6.3 Effectiveness

The effectiveness of the time blocks was also evaluated by analyzing the effort required to determine time bases for operations using time blocks as compared with

SAM. The operations from the new model were considered and arranged in a spreadsheet. The required drawing and pictures to analyze the operations were also collected. The time expert was provided with a time blocks library with all the necessary information to determine the time for these operations. The time, expert took to determine the time for these new operations using time blocks was measured using a stopwatch. Further, the same operations were analyzed using SAM by the same time expert to determine the time for the same operations. The time taken to perform SAM analysis to determine the time for these operations was also measured using the exact stopwatch. It was found that using time blocks to determine time took almost one-fourth of the time required by SAM. So, by using time blocks, the time and effort required to determine time can be reduced by four times, as found by this stopwatch study. However, the effort can be further reduced when the time experts familiarize themselves with using time blocks and if they are integrated into the interface. It was observed that a considerable amount of time was consumed to shift between spreadsheets like time blocks library, operation description and pictures of these components involved in operations. These times spent on shifting between tabs and spreadsheets would be reduced once the time blocks method is implemented. Hence, it was concluded that time blocks are highly effective in reducing the time, resources and effort required to determine time bases for operations compared to traditional SAM.

5.7 Application and maintenance

Based on the findings of the thesis project, the following suggestions were developed for creating and using time blocks in the future.

The initial stage for building time blocks has to start by understanding the existing structure of the time bases and methods used to determine and maintain these time bases. The current PTS methods and application areas of these time bases can help understand the requirements of these time bases with TDM. It is preferred to have time bases which can depict the actual operation times on the shop floor through which application of time bases determined using PTS can be generalized from top to bottom levels of the organization.

When the structure of time bases is understood, existing data for building time blocks can be identified. These available data can be collected in a convenient format, which can facilitate the analysis of the operations performed which are involved in the assembly. The existing data from the PTS, like MTM-SAM, can be used to analyze the operations or the operations can be visually analyzed to perform the SAM analysis to generate required data more accurately and consistently. However, when the existing SAM data is used, the quality of the data must be considered. The anomalies in the data and the accuracy of the data to depict the actual operations performed on the shop floor can reduce the efficiency of the time blocks and acceptance of time bases at the bottom levels of the organization. The existing practice to update or maintain the existing time bases should also be considered. It should be preferred to have the highest quality data depicting the actual operations performed.

The data has to be analyzed to identify the similarities between the operations, which would form constants and variables for the time blocks. These similarities can be between products that apply to multiple operations or between processes or operations that apply to all products. Once these similarities are identified, the operation steps which are precisely the same can be considered constants. The slight differences can be covered with variables which will further form the time block.

Combining these constants and variables will form a simple mathematical equation as a time block of that particular operation. When the similarities are identified between products, the formed block would be at the product level, and when the similarities are identified between operations, the formed time block would be at the process level. Though both product-level and process-level time blocks are built on the same principle of using constants and variables in combination, the processing time blocks can be preferred as these time blocks can be generalized across. These time blocks can determine the time for intended operations by defining the value for the variables and solving the underlying equation.

The number of time blocks will depend on the number of operations involved to complete the assembly. These multiple time blocks cover the entire set of operations involved and can be structured to form a library of time blocks. When the time bases for a particular operation need to be determined, the variables for the respective time block can be defined, and the underlying equation can be programmed to solve in the background to get the time base readily from the library. The number of time blocks within the library would depend on the number of different operations performed in the assembly. The structure of the library would be an essential aspect. When there are more and more time blocks in the library, the effort required to select the appropriate block and the chances of human error might also increase. The library can be structured based on operation types at the basic level. For example, manual assembly, handling and inspection operations. Further, this library can be structured based on the organization's needs. The nomenclature for naming the time blocks should be standardized, through which the work content or work instruction for the particular operations can be easily derived from the time blocks library.

The other important aspect of TDM is the maintenance of time bases. When the time bases are not updated on time, it can cause deviation in the data. Also, when the process improvement activities are carried out continuously, the operation steps can change, which has to be updated in the TDM. Therefore, the time blocks can be very advantageous when the time block related to the changed operation can be updated and readily used to update all the time bases affected by the change. Moreover, these time blocks can be reviewed timely to avoid deviation from the time bases.

6

Discussion

In this chapter, we will go over the results and findings of the thesis project and the techniques employed.

6.1 Methods

To complete the thesis project, a general research method and the methodology for standard data development as outlined in Maynard's industrial engineering handbook (Maynard et al., 2001b) were used. The first step was to conduct a literature review, which revealed limited previous research on TDM. Despite the existence of the concept of time blocks, there are few published resources available. Therefore, the literature review focused on identifying existing problems, causes, and implications that manufacturing industries face due to time bases and TDM. The application and implications of PTS in industries were also explored in greater detail.

The methodology for standard data development involved several steps to create and establish a standard in organizations. The purpose of this thesis project was not to create a new standard for the company, but to study the feasibility of using time blocks. Time blocks were chosen because they are an extension of existing PTS and can be implemented as a part of the existing time determination processes for manual operations in any organization. Due to the project's time frame and scope, some adaptations were made to the standard data development method (Maynard et al., 2001b). The method included practical implementation guidelines, but practical implementation was not within this project's scope. The primary outcome of the method is to establish a standard, but for this thesis, the outcome was a concept and framework on how and why time blocks can work effectively in the existing system and what benefits and advantages can be derived from them. Therefore, the method was adopted to fit the scope of the thesis project and derive the necessary outcomes.

6.2 Data quality

The main purpose of TDM is to efficiently determine, maintain and use the time bases of operations performed across manufacturing in industries (Kuhlang et al., 2014). These time bases have various organizational applications for many central activities (Kuhlang et al., 2014). The TDM systems are often neglected and preserved as the time data within TDM are correct (Kuhlang et al., 2014). This can create a gap between operation times in reality and TDM (Almström & Winroth, 2010). The gap can be covered effectively by having an efficient TDM system, avoiding errors in the initial time determination stage and by updating the time bases regularly (Hedman & Almström, 2017)(Almström & Winroth, 2010). The effort and resource requirement for these processes is considerably high. These can be handled efficiently using time blocks, reducing the efforts required to determine and maintain the time bases. In addition, the quality of the data within TDM systems can be increased, which can reduce the existing gap.

When creating time blocks as an extension of the existing PTS (MTM-SAM), it is important to consider the data quality used. The accuracy and effectiveness of the time blocks rely heavily on the quality of the input data. Therefore, the input PTS data's quality directly impacts the time blocks' accuracy.

The VCC uses a PTS system called Volvo-SAM, and the time blocks were created based on existing data. However, the current time data quality was not verified during this thesis project. The data collection process involved retrieving existing data from the PLM software of VCC, which was deemed accurate for the purpose of this thesis. However, it's important to note that variations may occur when different individuals determine times at different time frames and break down operations into SAM steps for analysis. These variations may affect the accuracy of time blocks compared to SAM. Therefore, to ensure maximum accuracy, it's recommended that practitioners evaluate the quality of existing PTS data before building time blocks.

6.3 Design of Time Blocks

Organizations have various applications of time bases ranging from balancing and workplace design to lead time and delivery planning (Hedman & Almström, 2017). The accuracy requirements and level of detail vary between applications. For example, the activities like rough balancing and delivery planning would demand time bases at the production line or workstation level, whereas activities like process improvement, station level balancing and operation sequencing would demand time bases at the individual operation level. Organizations usually maintain time bases and accuracy at the required level based on the applications of these data. The time blocks can also be structured at various levels based on the requirement. These blocks can be arranged sequentially to form an equation that can determine the product's cycle time.

The time blocks can be designed and structured at various levels based on process or product. The constants and variables involved within the blocks can be structured based on the requirement and organization type. When the operations are analyzed to identify constants for the time blocks, the processes between different models or the components (parts involved in assembly) that remain constant across the process can be considered constants. Similarly, the variables can be between processes or the products themselves, like the geometric dimensions of the components. Further, these constants and variables together form time blocks, which can be based on process or product. However, time blocks built in both ways would work similarly; it is preferred to structure the time blocks based on the manufacturing set-up of respective organizations.

The operations and products assembled at the selected tunnel assembly were analyzed, and the similarities and differences between operations mainly exist at the process level. The final product tunnel being assembled mostly remained the same regarding geometry and dimensions at a product level. So, the time blocks built during the thesis project mostly involved constants and variables within the process or operation. Further, time blocks were structured at the operations level as the requirement of time bases at VCC demands time bases at the PII level, a combination of a few operations. However, these time blocks can be arranged sequentially to form a time equation at the workstation level or even for the entire tunnel assembly line.

6.4 Feasibility study

The goal of the thesis project was to assess the feasibility of time blocks from three different angles: coverage, accuracy, and effectiveness. In addition to the results previously mentioned, we discovered that there are additional aspects to examine regarding performance.

Time blocks offer several strengths, such as ease of use, customizable features, and flexibility. These benefits make them an attractive option for industries. For instance, a library has been developed for the tunnel assembly of VCC, which allows PII creators to estimate predetermined times without the need for SAM specialists. The resulting library has been prepared in a spreadsheet but can be implemented in any other software as well. Technical training is optional when using the library, and it can be customized to fit the accuracy level or final objective of a complex assembly plant. Our research found that different specialists estimated different times for the same operations, highlighting the importance of accurate time data updates. The constant base time data and defined variables in the library make updates quick and easy, reducing the challenges presented in papers regarding the gap between planning and actual operational time(Almström & Winroth, 2010). This level of automation and dynamic nature can help industries overcome these challenges.

We have discovered that the time blocks are constructed based on the VCC's historical time data, which means that the output quality is equivalent to the input historical data quality. This reliance on historical data may be seen as a weakness of the concept. Furthermore, creating appropriate and accurate time blocks for a specific organization requires knowledgeable resources and intensive research, leaving no room for error. During our thesis project, we encountered questions regarding the number of time equations or blocks needed for the assembly operations of the entire plant. Only with extensive study, it is feasible to estimate that. All of these considerations align with the theory of time data management, which suggests that systematic time data management is time-, resource-, and cost-intensive(Kuhlang et al., 2014). In fact, time blocks require more resources than MTM or SAM.

Although it may have some inconsistencies, the product performs accurately when time blocks are established. Its versatility is evident within the specific organization and has the potential to provide higher returns on investments. Through our study, we discovered that creating time equations based on operation steps in the assembly area is effective. Additionally, it's possible to use the product dimension as a variable and the required time for the unit dimension as constant for other car parts. For instance, when attaching rubber sealings to a car body, bases can be prepared based on the length of the sealing time.

Finally, there may be significant resource requirements during the initial stages of creating time equations and establishing time blocks, this process has the potential to simplify and standardize the task of determining, maintaining, and updating time data for business purposes.

6.5 Sustainability Aspect

The time blocks for efficient TDM can have few impacts on various aspects of sustainability. First, the established PTS like MTM-SAM with time blocks can facilitate organizations to use PTS for TDM. This will contribute to the social aspect of sustainability. Using PTS like MTM-SAM will enable organizations to establish time bases in a standardized manner with human factors involved. This can improve the consideration for the ergonomics involved within the assembly operations. The accurate time bases with human factors involved enable fair pay for the operators, which has a positive impact on the social aspect of sustainability. One of the major benefits of using time blocks with the PTS is to reduce the time, effort and resources required to determine and maintain the time bases within the TDM. This reduced demand on time, effort and resources within the organizations will have a positive effect on the economic aspects of sustainability.

6.6 Future scope

After thoroughly analyzing our thesis project, we have identified several areas where we can further develop our research. Although we initially focused on time blocks for complex multi-model assembly systems, we believe that there is still a lot of potentials to explore the benefits that this approach may provide to businesses more broadly. To this end, we strongly recommend conducting a comprehensive study to establish guidelines for non-value-added time in the tunnel assembly area and other complex assembly areas.

One area which can be explored is the integration of time blocks into the analysis software. Incorporating time blocks is crucial for effective analysis software. This feature will make determining operation times effortless and can be integrated into TDM. While SAM analysis steps may still be required for certain tasks like creating work instructions, the software can generate them in the background by leveraging the time blocks. This approach makes the steps readily available for immediate use.

In addition, we suggest examining various scenarios involving different types of variables. For instance, data science can predict predetermined time for Industry 4.0, which could lead to significant cost savings and improved efficiency. Furthermore, we believe there is still a lot of potential for discovering new applications for time blocks. By exploring this topic in greater detail, we can unlock new ways to optimize assembly processes and increase productivity. Overall, we are confident that further research will yield valuable insights for businesses looking to improve their operations.

7

Conclusion

We with VCC and Chalmers University of Technology, have completed the project to investigate the feasibility of using time blocks for Time Data Management in the context of the complex manual assembly process. The project found that time blocks can be useful for managing time data, based on their ability to provide accurate and effective coverage for operations.

Analyzing each operation individually using existing PTS data is necessary to formulate time blocks. This involves identifying the similarities and differences between operations and listing them as constants and variables within the process or product respectively. Once these constants and variables are identified, they can be used to formulate time blocks that can be structured together to create a library of time blocks for future use.

The current PTS methods used to determine time bases for operations are accurate but require significant effort, time, and resources. Using time blocks instead, the time, effort and resources required to determine and maintain the time bases with TDM can be considerably reduced. This can facilitate various activities during the product emergence phase that rely on time bases. Additionally, individuals with minimal knowledge of corresponding PTS can determine time bases using time blocks, providing added benefits. However, the formulation of time blocks would still require expertise in corresponding PTS.

Overall, the project's success in establishing the feasibility of using time blocks for Time Data Management in the complex manual assembly process at Volvo Cars highlights the potential benefits of this approach in reducing the time, effort, and resources required to manage time data accurately and effectively.

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