APPLICATION OF VALUE STREAM MAPPING WITH MODULAR ARRANGEMENT OF PREDETERMINED TIME STANDARDS TO REDUCE LEAD TIME: A CASE STUDY IN THE METAL SECTOR

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I certify that in my opinion the thesis submitted by Ömer Abdulaziz KORKMAZ titled "APPLICATION OF VALUE STREAM MAPPING WITH MODULAR ARRANGEMENT OF PREDETERMINED TIME STANDARDS TO REDUCE LEAD TIME: A CASE STUDY IN THE METAL INDUSTRY" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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Ömer Abdulaziz KORKMAZ

ABSTRACT

Master Thesis

APPLICATION OF VALUE STREAM MAPPING WITH MODULAR ARRANGEMENT OF PREDETERMINED TIME STANDARDS TO REDUCE LEAD TIME: A CASE STUDY IN THE METAL SECTOR

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Just as producing is necessary for people, production efficiency has become an obligation for companies' sustainability today. Making production better is a never-ending process. Feedback from the system plays a key role. Productivity development is the primary matter preoccupying all factory supervisors. All feedbacks start from improving production area leading to capacity increase, deadline decrease, and profit growth. In the production environment, numerous challenges exist; the primary concern is the ability to discern and recognize these problems. Most production obstacle stations are hidden, so their solutions begin with learning to see them. This thesis works on a real-life case study that deals with unobserved production area problems using Lean Manufacturing techniques. It presents a new model that combines Value Stream Mapping (VSM) and Modular Arrangement of Predetermined Time Standards (MODAPTS), to bring their complementary strengths together.

Much wasted time was noted during the production process. VSM was used to identify the current state by revealing obstacles, and MODAPTS was responsible for time standardization to generate the future state jointly. This study improved lead time by 47% when production time decreased from 36 days to 19 days only. This paper targets proving this combination's value and being a foundation stone on which considerable future research will be built on it.

Key Word **:** Lean Manufacturing, Value Stream Mapping, Predetermined Motion Time System, MODAPTS, Delivery time.

Science Code : 90617

ÖZET

Yüksek Lisans Tezi

TESLİM SÜRESİNİ AZALTMAK İÇİN MODAPTS İLE DEĞER AKIŞI HARİTALAMANIN UYGULANMASI: METAL SEKTÖRÜNDE VAKA ÇALIŞMASI

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Karabük Üniversitesi
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Üretimin insanlar için gerekli oluşu gibi, günümüzde üretim verimliliği de şirketlerin sürdürülebilirliği için zorunlu bir hale gelmiştir. Üretimi iyileştirmek bitmeyen bir süreçtir. Sistemden alınan geri bildirimler önemli bir rol oynamaktadır. Verimliliğin geliştirilmesi, yöneticileri meşgul eden başlıca konudur. Tüm geri bildirimler, kapasitenin arttırılmasına, teslimat süresinin azalmasına ve kârın büyümesine yol açan üretim alanının geliştirilmesiyle başlar. Üretim alanında bulunan birçok zorlukla birlikte temel endişe bu problemleri fark edip tanımaktır. Üretimi engelleyici çoğu nokta gizli olduğu için çözümleri de onları görmeyi öğrenmekle başlar. Bu tezin konusu, Yalın Üretim tekniklerini kullanarak gözlemlenmeyen üretim alanı problemlerini ele alan bir gerçek hayat vaka çalışmasıdır. Değer Akışı Haritalama (VSM) ve Önceden Belirlenmiş Zaman Standartlarının Modüler Düzenlemesi (MODAPTS) yöntemlerinin birleşimi sonucu tamamlayıcı güçlerini ortaya çıkaracak yeni bir model sunulmaktadır. Üretim süreci esnasında çok fazla zaman kaybı gözlemlenmiştir. VSM, engelleri ortaya çıkararak mevcut durumu tanımlamak için kullanılırken MODAPTS, gelecekteki durumu ortaklaşa bir şekilde oluşturma amacıyla zamanın standardize edilmesinden sorumluydu. Çalışma, üretim süresi 36 günden sadece 19 güne düştüğünde teslimat süresini %47 oranında iyileştirmiştir. Bu çalışmanın hedefi bu birleşimin değerini ispatlamak ve gelecekte yapılacak önemli araştırmalar için yapı taşı olmaktır.

Anahtar Sözcükler : Yalın Üretim, Değer Akışı Haritalama, Önceden Belirlenmiş Hareket Zamanı Sistemleri, MODAPTS, Teslimat süresi.

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VSM	: Value Stream Mapping
MODAPTS	: Modular Arrangement of Predetermined Time Standards
MOD	: MODAPTS Measurement Unit
PMTS	: Predetermined Motion Time System
NVAs	: Non-Value-Added Activities
MTM	: Methods Time Measurement
MTM-UAS	: Methods Time Measurement Universal Analysis System
MOST	: Maynard Operation Sequence Technique
FIFO	: First in First out
WIP	: Work in Process
C/T	: Cycle Time
C/O	: Change Over Time
%C&A	: The Percentage of Complete and Accurate
Ele. No.	: Element Number
DESC.	: Description
PER.	: Number of Personnels

CHAPTER 1

INTRODUCTION

Developing productivity is the main aim in the production environment. There are many methodologies to improve production processes. Among them, a portion consists of conventional techniques rooted in classical methodologies, while others encompass novel and contemporary approaches. The classical methods are usually about the general problems that may happen to the workers or/and the machines. On the other hand, some fields, such as Lean Manufacturing, provide many modern techniques, and it builds a new mindset to observe new problems. It makes people learn how to see waste, whether they are materialistic or not, such as wasted time. Using Lean Manufacturing techniques enhances the ability to analyse and solve problems effectively. After observing these micro problems, Lean Manufacturing techniques provide methods to solve them, and sometimes these methods are very simple but with great influence on the entire production system. There are many techniques of Lean Manufacturing, such as Kaizen, 5S, and Value Stream Mapping (VSM), which achieved great success and proved their efficiency. Lean production improves the efficiency of the manufacturing system by applying new activities through its tools to shape new guidance and direction [1]. For facilities that start applying Lean Manufacturing techniques, VSM is highly recommended to start because it is a way to change of seeing the production processes and figure out the real troubles in the system. In this thesis, the VSM technique is applied in the metal sector, specifically in a gas springs factory that currently begins to use Lean Manufacturing methodologies. VSM deals with time; where to see the wasted time, and how to minimise it. According to Patil, Pisal, and Suryavanshi, VSM is an effective tool for decreasing lead time, directly influencing the productivity situation [1]. Therefore, using VSM in this factory benefits for the production processes, explores the hidden reasons for time wasting, and gets rid of them as much as possible.

VSM only shows the current situation regarding the flow in production and indicates at which stations there is a possibility for improvement. After this stage, the question arises of how the progress will be made. Modular Arrangement of Predetermined Time Standards (MODAPTS) assumes a significant role in this context, presenting avenues for seizing improvement opportunities. MODAPTS is a Predetermined Motion Time System (PMTS) tool which applies to standardise the working time of any process. It analyses all the body motions, from the fingers to the entire body movement. It would be an added value for any study or application to determine its working time precisely. Consequently, MODAPTS is used as a supportive method in this study. It is done to determine the actual processing time for each station in the VSM. Thus, the problem addressed in this study becomes a real-world problem. The contribution of the paper is twofold. First, we present a new perspective by combining the unrelated VSM and MODAPST methods. Second, we present step-by-step how to reduce production time by addressing a real problem. In the following sections, the literature review mentions VSM and MODAPTS methods to explain them in detail and provides previous work that has worked on them to prove their competence. Then, the methodology section shows the steps of this application and reveals how VSM and MODAPTS work together in an effective combination. The application is conducted in a gas springs factory and on real data. The results should prove the significance of the Lean manufacturing techniques, especially for VSM methodology as an effective lean tool

CHAPTER 2

METHODS AND LITERATURE REVIEW

The methodology of this study is built on two techniques: VSM and MODAPTS. The main technique is VSM, a Lean Manufacturing tool that supposes to identify wasted time by drawing the whole production process as stations. MODAPTS is analysing the working time of each operator ergonomically to have precise information about the time that all workers spend doing their work individually, so this is the supporting tool for VSM. The following paragraphs will go smoothly deep into each approach to give a full understanding of the final approach and the model of the thesis.

2.1. LEAN MANUFACTURING

Through decades lean manufacturing has proven its efficiency in many studies. It provides solutions to an enormous number of obstacles and improves the performance in the production area and also some of its techniques were able to be applied in office work too. The main idea of lean manufacturing is to reduce waste to the lowest possible percentage. These wastes could be materialistic such as raw materials or nonmaterialistic like time. There are many challenges in the market such as the global competition and the lifecycle of the products that led the firms to rely on lean manufacturing to enhance their productivity [2]. Lean Manufacturing was invented in the factories of Toyota and lean refers to flexibility. It was applied in Toyota Production System, and it seeks to reach the highest efficiency by eliminating the causes of inflexibility in each process [3]. By reducing waste, the costs decrease in parallel leading to revenue increases for the companies. This advantage became essential for the firms to be able to compete in any market. Lean Manufacturing is managing the processes with the lowest cost possible in addition to taking all the customers' demands into consideration [4]. When some companies started to apply the Lean Manufacturing technique after Toyota, the customers' needs increased because the same products were provided with higher quality and with shorter lead times. That forced many firms to start applying those techniques. The companies that applied the modern techniques of lean manufacturing were the companies that could survive in the market due to their flexibility and quick response to the needs of the customers leading to achieving their satisfaction [5]. All in all, lean manufacturing is like a production ideology or mentality that has many important methods and techniques and using them became a must to be able to survive and compete in today's global market circumstances.

2.1.1. Lean Manufacturing Tools and Techniques

There are many lean manufacturing techniques that had been used by many firms. Some of them are popular and common that often of the factories applying lean production use them and there are uncommon techniques too. It is very significant to have studied a group of tools from the same production philosophy to determine the most suitable choice with the highest economic benefit [6]. Thus, passing through the common lean manufacturing techniques briefly would give a better understanding of the case study. According to a Croatian study, the most commonly used lean manufacturing techniques are VSM, Kaizen, 5S, KPIs, and Standardized Work but the companies which are freshly transferring to the lean system usually tend to start with Kaizen or 5S [7]. Most of the lean manufacturing studies mention the importance and impact of Kaizen and 5S. That shows their importance of being added to this study or similar ones in the same scope. Kaizen is the basic tool of lean manufacturing which is used with other tools. Kai means development and Zen means continues so combined they mean continuous development, and it is about predicting the problems and providing clues to observe, identify, and improve the practice or process [8]. When kaizen became a work habit, it could increase the level of productivity more than expected due to the contribution of employees from all levels. 5S (Sort, Set, Shine, Standardize, Sustain) is also a significant tool. Sort is to separate the essential materials and equipment from the nonessential ones. Set is to put the essential stuff in easy places to get and put smoothly. Shine is to clean the workplace always and regularly.

Standardize is to make standard procedures which should be easy to understand and use them. Sustain is making sure of applying these procedures always and improving them [8]. In order to use 5S effectively, it should be applied as a continuous work culture and habit. Another tool that could be beneficial to start within a production area is VSM due to the fact that it already contains Kaizen as one of its improvement processes. It is detecting hidden problems by mapping the whole production process and uses Kaizen to eliminate them. Therefore, VSM was the most suitable lean manufacturing tool to be used in this study because it improves the production processes from an economic point of view, and it contains Kaizen one of the most common lean manufacturing tools.

2.1.2. Value Stream Mapping (VSM)

The real problems in production areas are often hidden and not seen. VSM expands the horizon and reshapes the way of thinking to see all non-value-added activities. VSM was invented firstly by Taiichi Ohno in 1978 as Muda Classification which means Waste Classification to identify the waste happening in companies. then, it was developed by Taiichi Ohno and Shigeo Shingo in 1980 to be known as VSM that's used to develop and improve companies by reducing wastes [9]. It covers the whole process to make it in the most effective shape as much as possible. VSM was invented in Toyota, Japan. It was identified by Taichi Ohno, who found it as observing the timeline to take away the non-value-added wastes from the customer sending the order until receiving money [10]. It became a very popular technique that is used in many studies all over the world due to its efficiency in deducting problems.

As mentioned before, Muda means waste and lean manufacturing deals with waste to reduce or eliminate them. There are different types of waste that Lean Manufacturing is interested in. These mudas or wastes are overproduction, inventory, motion, defects, overprocessing, waiting, and transport. Overproduction is considered the most hazardous waste because overstocked items give manufacturers confidence. This sense of trust covers up the problems in production and destroys the possibility of improvement. Inventory is risky deterioration, breaking, burning, etc. As a result, materials may become unusable. In addition, resources that can be spent for more production are spent on operations such as managing, transporting, protecting and storing stocks. The motions of the workers and machines should be studied, too, because some wrong or unnecessary motions may lead to an increase in production time. Manufacturing defects are one of the common wastes in all production areas. The defects are very costly regarding the repairing cost or the whole cost of the product if the defect is unrepairable and the products will be scraps. Overprocessing is mainly about adding unnecessary features that will not be used or needed in the products. These kinds of activities should be eliminated and focus only on the targeted features requested for the product. Waiting for the part in a production line prevents the flow of production. In addition, while the part is being processed on the machine, it should be ensured that the personnel are busy with another job simultaneously. As a result, part, machine, and personnel waiting times should be reduced to zero. Transport means the movement of materials from one production station to another one. The time and resources used in transporting the materials must be minimized to enhance the workflow on the production line. In this study, VSM and MODAPTS work on inventory, motion, waiting, and transport wastes.

To deal with waste effectively, the meaning and definition of the value should be well understood before any VSM application; the value in Lean Manufacturing is related to all the needed activities to make the requested product. In other words, they are activities that only make changes that the customer wants to the raw material or semi-finished product. So, any activity that interests the customer to consent to pay for leading to producing the final product is a value-adding activity. Rather than that, all the other activities are non-value-added activities (NVAs). However, not all non-value-added activities should be removed or eliminated because some of them are necessary activities. For instance, checking and controlling periodically in the middle of the production processes is not an activity that interests the customers and makes them willing to pay for it; it is a very significant activity to ensure the quality of the final product. The necessary NVAs shouldn’t be treated as pure wastes that don’t add any value or benefit and destroy the efficiency of the workflow of the production line. Dealing with the necessary NVAs has to be done by ensuring minimizing their spent time as much as possible with keeping the activity itself, which is in the ultimate interest of the completeness of the product effectively. In this study, the classification of values and activities is done in this way.

VSM Methodology: Appling VSM is not complicated, but it needs to be accurate to come up with real results. It starts with drawing all the processes beginning with receiving the order and ending with delivering the goods. VSM works by drawing the current state that shows the whole processes of production to identify the largest number of wastes to eliminate them in a future state [11]. Basically, it works on developing the delivery time, which is the time from receiving the order from the customer to the end of the shipment process. After that, the wastes and non-value-added activities (NVAs) should be eliminated by a process called Kaizen. Kaizen is the improvement procedure, and it is an ongoing process to develop productivity and enhance the workplace by decreasing hard work and removing waste [12]. Finally, the final status should be drawn too to produce results.

2.1.3. Applying Value Stream Mapping in the Study

VSM starts with selecting the product family. Usually, the product family is chosen after studying all the products and finding out which family passes from most of the production process in the factory. The product family could be one item or a group of items that share the same production processes. Moreover, the cost and price should be considered while choosing the product family and prioritise the products with high costs or prices. The demand for the product is also helping to decide because it is preferable to work on ongoing demanded products. Ultimately, the product family should be chosen wisely to reflect the need of the application in the field.

There are two main parts to VSM. A current state has to be drawn to understand the production processes. The tool that will be used for drawing is Creately which is a diagramming and designing tool developed by Cinergix. A map will be developed in a future state after detecting and reducing the waste as much as possible. At first, there are special symbols to use for drawing a value stream map. These symbols have been identified and globalized since the born of VSM. Having common signs makes the map readable globally and breaks the barrier of languages. The used symbols for VSM are explained in Figure 2.1 with their shapes in the Creately tool.

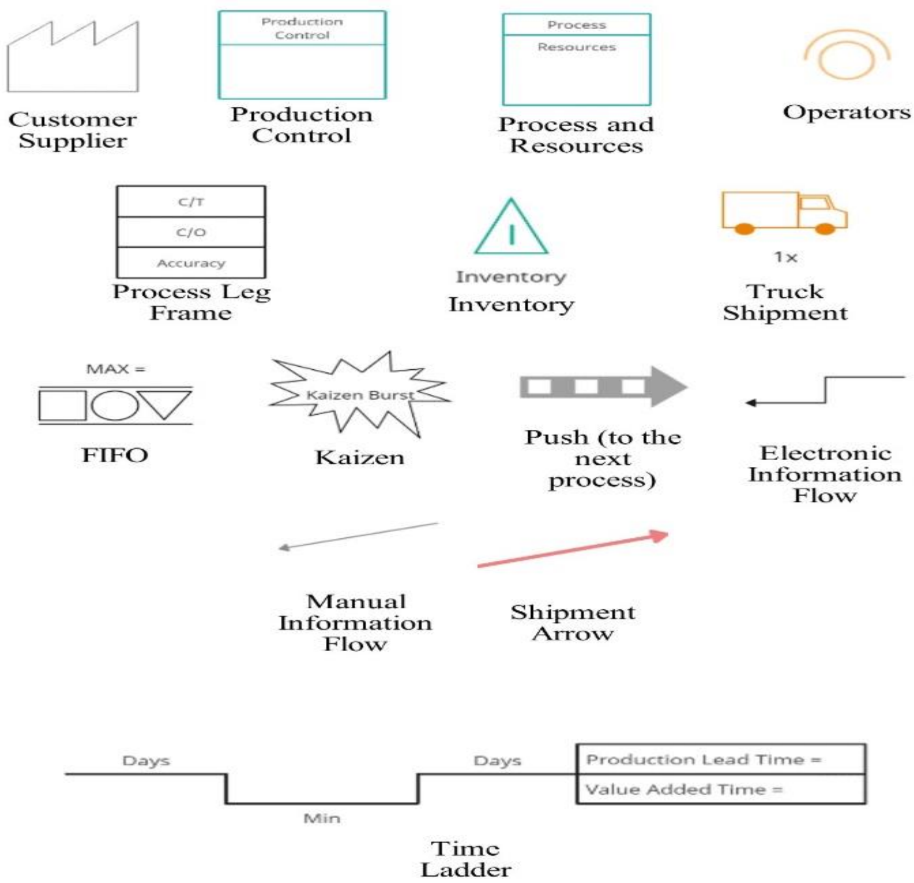


Figure 2.1. VSM symbols

The current map should be drawn in order to know the situation of the production process. The map always starts from the customer in the up-right corner of the page. Then, the production control receives the order information and electronically passes the needed components to the suppliers. The suppliers send the components to the warehouse, which transfers them to the production area and at the same time, the production control gives the orders to the production area manually (sometimes electronically too). After that, the items are pushed from one process to another until complete the finished goods and shipped to the customer. In each process (station) cycle time, change over time, accuracy, and operators' number are identified. Cycle time (C/T) means the time needed to finish one piece in each station, while change over time (C/O) means the time needed to finish a whole order and start another one.

Accuracy is a percentage that shows the efficiency of each machine by calculating the working and stopping time for the machines. The time ladder displays the entire time spent producing the order, including the Work in Process (WIP) inventory. To come up with the production lead time, value-added time, activity ratio, and rolled %C&A (the percentage of complete and accurate). These are the general steps for drawing the current situation map. However, in this study, before drawing the process leg frame and the time ladder, the MODAPTS technique is conducted on each station to calculate working time as a supporting tool for this methodology.

2.2. PREDETERMINED MOTION TIME SYSTEMS (PMTS)

VSM is working on finding the wasted time to improve productivity. Therefore, this study uses predetermined motion time systems (PMTS) as a supporter methodology to produce more accurate results. A study was conducted in Turkey combined VSM with MTM-UAS in the textile sector. MTM-UAS is a PMTS tool that was developed from MTM one of the most famous PMTS tools. After combining VSM and MTM-UAS in the textile factory, improvements occurred in the production lead time and non-value-added activities. The delivery time of the production decreased by 56% and the non-value-added activities by 57% [13]. Time is one of the most important factors in the production system. The production in a shorter time with keeping quality and cost at an accepted level always gives an advantage in the market. It can determine the capability of competition for the companies. So, time plays a serious role in the criteria of customer satisfaction. At the same time, production is a group of very complicated processes, and it is extremely difficult to be able to measure the time of a production process accurately. There are many techniques that have been created to measure the process time such as the stopwatch which is one of the most popular techniques in this field. Nevertheless, the accuracy of the stopwatch and the similar techniques is questionable due to the fact that they measure in seconds and sometimes there is a need for much more smaller measuring unit. From this standpoint, the predetermined motion time systems (PMTS) were created as a more efficient alternative to measure time accurately. The idea of PMTS is to analyse the motions in one or more tasks and there is a specific standard time that was predetermined already for each movement, and the total of these motions in one task will represent the fulfilment time of the task

[14]. Thus, by analysing the motions with small parts of seconds, the accuracy of timing was developed. The high competition in all markets demands a day-by-day evolution, especially in the production areas. It is impossible to improve what you cannot measure so PMTS provides accurate results by the analysis of the motions that can lead to a decrease in the movements so time will be shorter [15]. The detailed motion analysis of PMTS allows the applicators to eliminate the extra motions that add time to fulfil the task without any benefit. Generally, the way of analysing the motions through the PMTS technique is by filming the whole activity via a picture camera that allows seeing the activity in a very slow way to be able to be analysed. While filming, it must be ensured that the atmosphere is natural as the normal situation of the production. To be accurate, the operator who will be filmed while conducting the activity should be experienced and all factors and limitations should be taken into consideration [16]. Being cautious and precise in applying a PMTS analysis is very important because all the results will be built on the outputs of this analysis. In short, PMTS is a way to measure time, which is usually used in production to determine the time of a task or activity more accurately than the classical methods. Eventually, PMTS became more popular because of its many tools and each one of them proved its efficiency in many studies in different fields and all over the world.

2.2.1. PMTS Tools and Techniques

There are many techniques for PMTS and each one of them has its own characteristics. They are all deepened in coding the motions and standardizing the time for each movement. Having many tools and techniques doesn’t mean that one is better than the other. However, each tool could be more suitable according to the case and its conditions. Therefore, before conducting a motion time analysis the applicator should study carefully more than one technique to decide which one is more suitable for the studied case. The most popular tools are MTM (Methods Time Measurement), MOST (Maynard Operation Sequence Technique), and MODAPTS (Modular Arrangement of Predetermined Time Standards); MTM and MOST are the often-used tools because of their similarity while the coding of MODAPTS is different [17]. MTM is known for its complexity and difficulty but still, it is the most preferable technique due to its unquestionable accuracy. Maybe the other tools aren’t as accurate as MTM, but their accuracy level could be enough for some activities and tasks. Also, some processes need more flexibility than accuracy. That's why, it is a must to have a basic knowledge at least about these 3 PMTS tools. To begin with, MTM is the original PMTS method, and it is developing day by day until these days. The impressive results of MTM made analysts turn a blind eye to its complexities so for sure it deserves to be explained in all PMTS studies. As a PMTS tool, the motions are coded, and each code is identified with a standard time. There are 4 main variables for MTM which are limbs, the transfer of motion, the manual control, and the affected weight or obstacle [18]. Each task is analysed in a very detailed sheet which makes MTM more complicated. On the other hand, this complexity led to generate many versions of MTM such as MTM1, MTM2, MTM-MEK, and MTM-UAS. Each one of them could be better according to the usage of the analysis. For instance, if the product has a medium time cycle with many repetitions, it is recommended to use MTM-UAS because it is simpler and could find the weaknesses directly with fewer analysing procedures [19]. The other popular tool is MOST which is always compared with MTM due to their similarities that made some researchers make studies just about comparing between these two techniques. MOST also uses coding but its way of analysing the motions is a bit different. What distinguishes MOST is dividing every single operation into smaller sub-operations that would be analysed separately and then combined at the end to come up with the standardized time of the whole operation [20]. A common point also with MTM, some versions were generated from MOST such as basic MOST, mini MOST, and maxi MOST. This was a brief explanation for two of the most popular PMTS tools, that gives a general idea about each one of them and it is important to give them a credit in this study as we use another popular PMTS tool which is MODAPTS. The coding system of MODAPTS is more interactive and direct so it simplifies the analysing process. Thus, owing to the high number of repetitions in the processes for the case study of this thesis, MODAPTS were preferred more than MTM. Choosing between MOST and MODAPTS was challenging but MODAPTS had an advantage because of 2 reasons. Firstly, taking more ergonomic aspects into consideration. Secondly, the harmony between MODAPTS and VSM because of the way MODAPTS identify the non-value-added motions. The following paragraphs will explain all these points related to MODAPTS in very informative details.

2.2.2. Modular Arrangement of Predetermined Time Standards (MODAPTS)

The method used in this study is the MODAPTS technique. MODAPTS is a PMTS from the third generation. Chris Heyde presented MODAPTS in 1966 to provide an accurate and easily applied system that can express the time that any body part takes in any movement starting from the finger movement, which needs the lowest possible amount of energy [21]. There are many similar techniques, such as MTM and MOST, which represent motions by standard times. The standard times are not always the real times; sometimes, they are more or less according to the circumstances. MODAPTS is a technique that gives the physical performance standard time represented as modules, and each movement is calculated through the multiple of the smallest unit in this system which is MOD [22]. MODAPTS is a developed version of MTM that can be used more quickly and gives more accurate results. Ergonomics and action analysis experiences of Heyde were combined in MODAPTS with analysing 21 actions of human bodies to reduce the timing scale to 0.1 seconds to be more efficient [23]. So, creating MODAPTS wasn't only about time measurement through its basic concept but also via taking the human factor into consideration. MODAPTS tries to consider the aspects that aren't considered by other standard PMTSs and fill some of their gaps, so it takes into count human error and studies human performance not only from the systems' approach but also the individual aspects [24]. It is important to choose which PMTS to be used because, as mentioned before, the standard time can be inaccurate according to the circumstances. In this study, MODAPTS was chosen because human factors play a significant role in this case.

2.2.3. Modular Arrangement of Predetermined Time Standards in the Study

MODAPTS is an MPTS method and according to previous studies, it is accurate to be applied in assembly production lines. It gives each movement a special code to be converted to time starting from the finger movement. The coding of the movements in MODAPTS is simple as shown in the Figures 2.2 and 2.3 that had been prepared by the International MODAPTS Association [25].

MODAPTS pocket guide simplifies the coding process. The codes are M, G, and P where M means the movement and after the latter M, a number will be selected according to which part of the body made the move. If the whole arm moved, number 4 is supposed to be chosen so it becomes M4. Each movement has a purpose starting with getting something and then putting it in a different place. For example, getting a screw from a complex area to be assembled in a specific location can be represented as M4G3M4P2. The unit of MODAPTS is MOD which is able to be converted to minutes by multiplying the number of MODs by 0.00215 and to seconds by multiplying by 0.129 so for the previous example there are 13 MODs that make 0.02795 min and 1.677 sec.

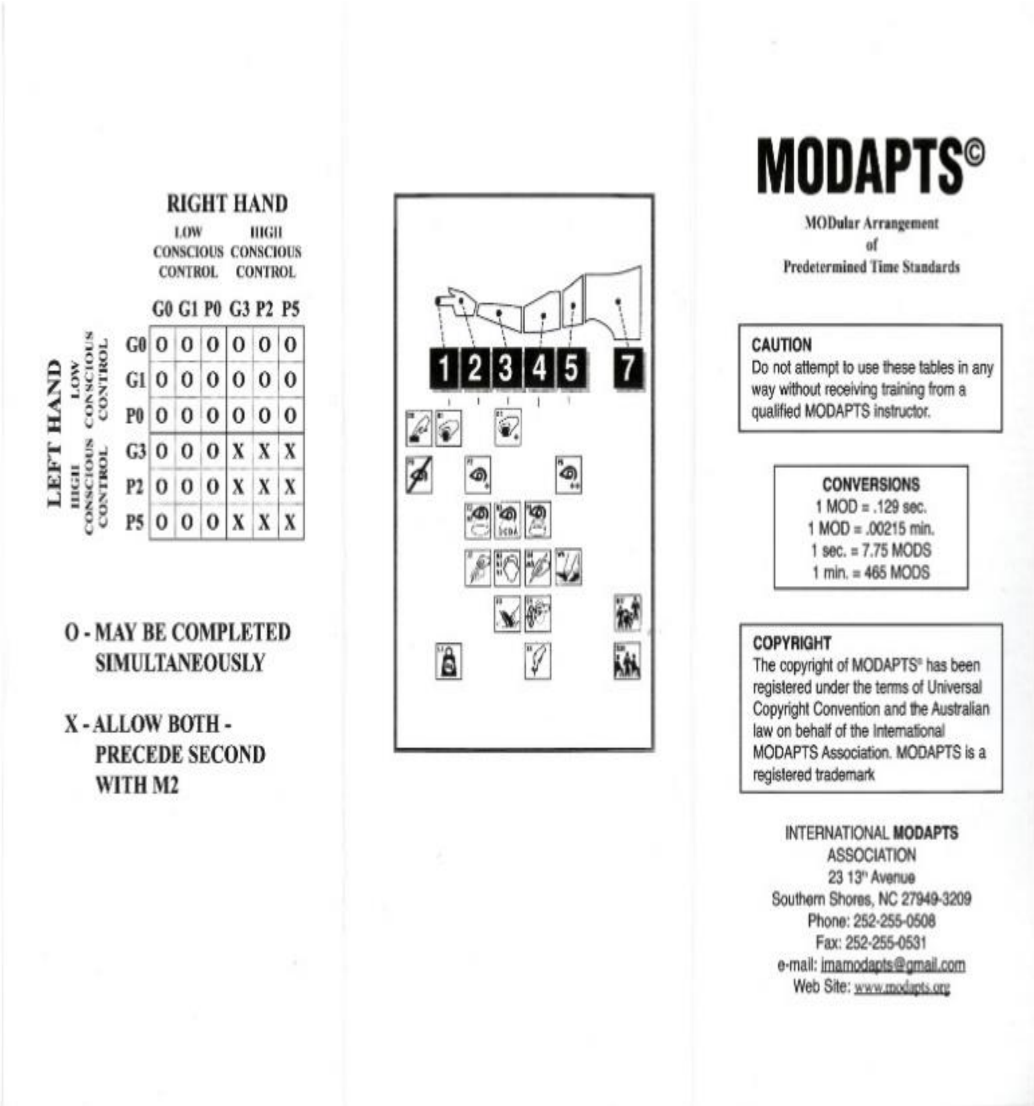
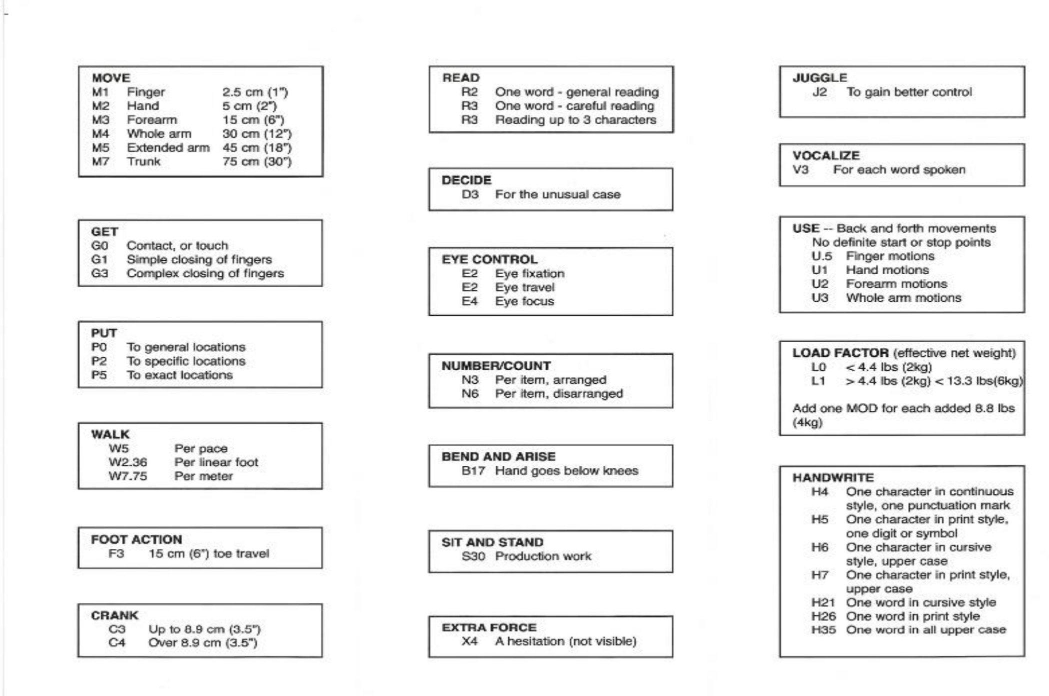


Figure 2.2. MODAPTS pocket guide page 1


MOVE
M1 Finger 2.5 cm (1")
M2 Hand 5 cm (2")
M3 Forearm 15 cm (6")
M4 Whole arm 30 cm (12")
M5 Extended arm 45 cm (18")
M7 Trunk 75 cm (30")

GET
G0 Contact, or touch
G1 Simple closing of fingers
G3 Complex closing of fingers

PUT
P0 To general locations
P2 To specific locations
P5 To exact locations

WALK
W5 Per pace
W2.36 Per linear foot
W7.75 Per meter

FOOT ACTION
F3 15 cm (6") toe travel

CRANK
C3 Up to 8.9 cm (3.5")
C4 Over 8.9 cm (3.5")

READ
R2 One word - general reading
R3 One word - careful reading
R3 Reading up to 3 characters

DECIDE
D3 For the unusual case

EYE CONTROL
E2 Eye fixation
E2 Eye travel
E4 Eye focus

NUMBER/COUNT
N3 Per item, arranged
N6 Per item, disarranged

BEND AND ARISE
B17 Hand goes below knees

SIT AND STAND
S30 Production work

EXTRA FORCE
X4 A hesitation (not visible)

JUGGLE
J2 To gain better control

VOCALIZE
V3 For each word spoken

USE -- Back and forth movements
No definite start or stop points
U.5 Finger motions
U1 Hand motions
U2 Forearm motions
U3 Whole arm motions

LOAD FACTOR (effective net weight)
L0 < 4.4 lbs (2kg)
L1 > 4.4 lbs (2kg) < 13.3 lbs(6kg)
Add one MOD for each added 8.8 lbs (4kg)

HANDWRITE
H4 One character in continuous style, one punctuation mark
H5 One character in print style, one digit or symbol
H6 One character in cursive style, upper case
H7 One character in print style, upper case
H21 One word in cursive style
H26 One word in print style
H35 One word in all upper case

Figure 2.3. MODAPTS pocket guide page 2

2.3. LITERATURE REVIEW

This section provides very informative studies about the usage of VSM and MODAPTS. Thus, this literature review will be significantly rich with information in different fields such as Ergonomics, Time Standardization & Optimization, and of course Lean Production and manufacturing approaches in several sectors. The studies used in this thesis combined supported the building of the new model that this study works on effectively.

2.3.1. Studies Used VSM

Many studies in different fields and sectors rely on VSM. A review of the Scopus database reveals that the use of VSM has increased significantly only in the last five years. This increase is shown in Figure 2.4.

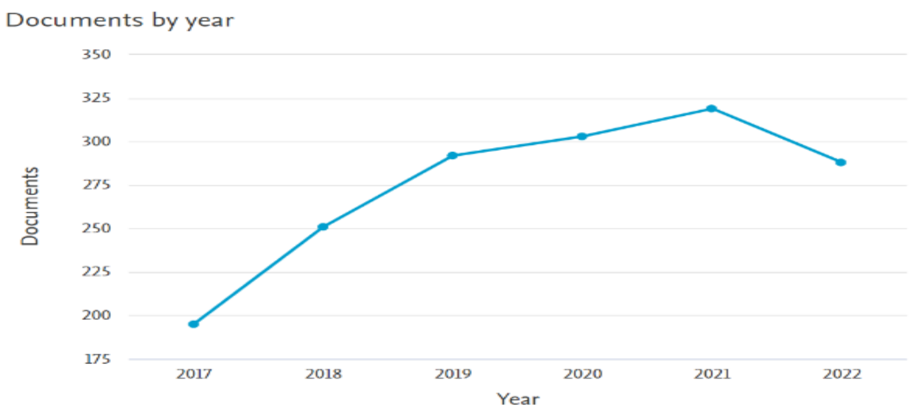


Figure 2.4. Documents by year that used VSM

2.3.1.1. Applying VSM in Different Regions

As mentioned, VSM has become a prevalent Lean Manufacturing technique worldwide. Many countries from different continents are using VSM. It has been applied in many studies that achieved great results. A steel factory in South Africa was suffering from waste and the cost of waste and its removal. After only one year of applying VSM, the waste decreased by 28% and the cost of waste disposal by 45% [26]. These rates are a very high percentage that shows how VSM can benefit any firm. Another study that had also been made in a steel factory in India sought to decrease the deadline for delivering goods. After eliminating NVAs in a steel factory in India, the lead time could be decreased from 33.41h to 14.55h [27]. In Indonesia, a food industry factory is looking for the same and reducing the lead time. The delivery time became 693 min after it was 773 min, and the non-value-added activities decreased from 3.10% to 1.01% [28]. These results have a major impact on the productivity of these factories. An automotive interior parts manufacturer in Bosnia and Herzegovina implemented VSM also to decrease production time. The lead time decreased to 7.4 days from 38.2 days, and the cycle time from 3.48 min to 1.16 min [29]. The improvement in lead time was almost 75%, so an extremely high development was achieved in this study. In short, these studies were from 4 different countries and three different continents, Africa, Asia, and Europe, and they all confirmed the efficiency of VSM.

2.3.1.2. Applying VSM in Different Industries

VSM was used in various industries and on different scales. It can be used with small product industries requiring precise manufacturing processes, such as the lock industry. After applying VSM, the lead time was reduced by 62.74% and the work-in-process inventory by 66.09% [30]. A small-scale heater manufacturer applied VSM too. As a result, the lead time decreased to 11 days from 17.5 days, and the NVAs became 2415 seconds from 3412 seconds [31]. Applying Lean Manufacturing techniques in these small industries are usually complicated. However, the results showed a high level of utility from using VSM. On a bigger scale, a gas stove manufacturer used VSM to reduce the lead time too. It was reduced from 5904.4 seconds to 4805.1 seconds, and the non-value-added from 485.65 seconds to 153.35 seconds [32]. A large-scale beam axle manufacturer applied VSM to increase the productivity of each section. The productivity in units/hr increased from 0.2094 to 0.3459 for section 1, 0.2314 to 0.4714 for section 2, 0.184 to 0.3435 for section 3, 0.115 to 0.3840 for section 4, 0.15 to 0.39 for section 5 [1]. The high increase in productivity rate in each section displays the success of implementing VSM. Even in the food industry, VSM showed a significant effect in finding solutions as a Chinese study presented. Kanban and Supermarket systems were suggested to improve communication in the production area due to the idea of receiving the feedback from the former process directly to keep the flow, and also the FIFO system reduced both the waiting time and the inventories between processes[33]. In brief, VSM proved that it is functional in all scales of production and in different industries, whether for simple products or complicated ones.

2.3.1.3. VSM Impact on Different Fields

This significant evolution in the production processes due to VSM has also had a massive impact on other departments. When there is an improvement in the productivity level, that will lead to a revival in different fields. Capacity improvement is one of the direct impacts of productivity development after applying VSM. A recent study focused on the effectiveness of VSM on capacity. There was a growth in capacity by 86% and a reduction in the workforce by 28% [34]. Minimizing the lead time by

VSM generates a new capacity space for new orders to increase profits or decrease costs. Generally, one of the common challenges that confront VSM is quality control because it is not a production process, but it is essential to complete the process in the right way. However, a developing company implemented VSM on the activity of the quality control department only. The NVAs were figured out as 778 min out of 848 min owing to the movement of the goods from the assembly line to the quality control station and the long time the goods wait until being checked [35]. The future status of this study could decrease the quality control time by 46%, and this percentage proves the capability of VSM to improve quality control too. E-commerce is playing a significant role in all markets nowadays. Between 2019 and 2020, Amazon used VSM on its supply chain process to improve it. A retailer from China who sell to North America was chosen, and after applying VSM to improve the supply chain process, the result was a dramatic sales increase for some goods, such as phone covers at 67% and party decorations at 72%, and without any complaint from customers regarding the delivery process [36]. This study proves the high impact of VSM that goes beyond the production lines and achieves success in different fields. Overall, these applications and their results give credibility for VSM and motivation to conduct it in all fields.

2.3.2. Studies Used MODAPTS

According to the Scopus database, recently, MODAPTS became an interesting topic for researchers in different fields, as shown in Figure 2.5. The larger percentage is for the engineering field. However, the percentage of computer science studies is large, due to the fact that some studies tend to automize this technique, and this proves its efficiency.

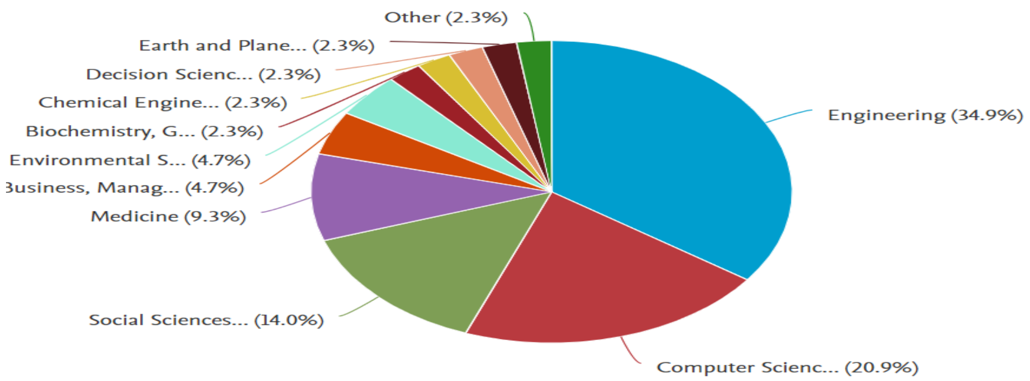


Figure 2.5. Fields that studied MODAPTS in the last 5 years

2.3.2.1. Applying MODAPTS in Different Industries

Many companies started to apply MODAPTS to test their efficiency, and some studies showed excellent results that confirmed the theoretical aspects in a practical way. MODAPTS validated accurate results as an analytical tool in both industrial and commercial companies [37]. An arc welding shop used MODAPTS, and after the application, the satisfaction level was high, and it was suggested for all companies start applying it. MODAPTS standardised the welding time, so the work timing became more rationalized, and welding hours were developed [38]. The production processes can be enhanced a lot by applying MODAPTS. A plastic pipeline manufacturer could achieve an improvement. MODAPTS analysed the motions of working and allowed the firm to identify the bottlenecks and reduce them to reach a productivity improvement of 25.35% [39]. There are other beneficial usages of MODAPTS. A cement packing facility applied it for a different purpose. The time of each operation was standardised with MODAPTS and calculate the working time for each operator was in order to know the workers who are doing a good job and increase productivity accordingly [40]. It is beneficial to have a method to test the performance of the worker because this allows managers and supervisors to be able to reallocate the workers according to their capabilities. An important advantage a warping process shop works on which is the ergonomic part. By using MODAPTS, the workplace had been redesigned to be safer and smoother for working; also, many solutions were found to eliminate the harmful working movements and positions that had been detected by MODAPTS [41]. The safety of the workers and their comfort while working will directly increase their productivity level, and their tasks will be finished faster and with higher quality. Ultimately, these studies showed the advantages of applying MODAPTS in real-life applications, especially in the production area that this study will focus on to present another implementation in the same field.

2.3.2.2. The Combination of MODAPTS with Different Methods

The flexibility of MODAPTS allows it to be developed to be used for different purposes. Such applications increase the value of the methodology. For example, an electrical devices company used MODAPTS and a design factor technique called DFA to estimate costs in the design stage. MODAPTS is accurate enough to analyse the assembling line movements, and the model combined with DFA saves a lot of effort and time for the product design engineers to estimate the costs while designing the process [42]. Another study that supports this idea; proposed another method for time estimation and the design step for an assembly line built on PMTS. In order to choose the most suitable PMTS, tests were applied on MODAPTS, MTM, and AEM. The difference between actual time and MODAPTS results was a maximum of 9.5%, with MTM results between 13% - 18% and AEM results around 15% [43]. These numbers give credibility to prefer MODAPTS, which outperformed MTM and AEM, which is an assembling evaluation method and also proves its flexibility to be combined with other methodologies to achieve different purposes, such as a study in Korea that was focused on helping the elderly and disabled people. The study was built on the Universal Design (UD) method and principles, which aim to make everything usable and accessible for everyone, including people with disabilities. Also, there is a tool called the Product Performance Programme (PPP) which is used with UD to make sure that products are human-centred design so everyone can use them. The study suggested combining MODAPTS with these tools to have better results. MODAPTS coding and scoring for moving, getting, and putting activities is applicable and useful for designing UD products. That will lead the product design engineers to develop and systemize this model [44]. Thus, MODAPTS can play an important role to serve in evaluating special products, so this increases its value and makes it a great material for more studies. In brief, MODAPTS is a flexible and easy method to be merged with other methods to create new systems with more accurate results either in the Lean

Manufacturing field by dealing with wasted time or in the ergonomic area by highlighting harmful movements for the body.

All the solutions start from realizing and seeing the problems, so the main book of VSM is called Learning to See [45] which was a great guide in this study. This book in addition to the studies that this literature review covered makes a solid ground to start building the system that combines VSM and MODAPTS. All the studies used in this thesis demonstrated the leverage of VSM and MODAPTS compared to their competing techniques because they present real-life examples from different regions such as South Africa, Indonesia, and Bosnia in several different industries. Moreover, they displayed how this combination can be created and used successfully, and how both techniques can complete each other.

2.4. THE COMBINED MODEL OF VSM AND MODAPTS

This study is working on a combination between VSM and MODAPTS, which had been chosen as a supporting method to enhance the accuracy of VSM. MODAPTS was selected due to the common points between it and VSM that would make this combination works effectively. MODAPTS is a technique that evaluates time to decide the best moves for the workers in their workstations by considering the visual connection of the workers with the components or the tools they deal with after filming the station to be analysed [46]. Workstation is a common term between VSM and MODAPTS. They both divide the whole production process into stations and work on them separately, one by one. MODAPTS is used to analyse the process, and by combing process time, a standard cycle time can be estimated so efficiency will be able to be evaluated [47]. So, the cycle time in the VSM can be estimated and standardized by MODAPTS, which improves the entire model. The previously mentioned studies proved the efficiency of MODAPTS as a PMTS method in standardizing time for the assembly lines in the production area. Therefore, building the cycle time of VSM on MODAPTS will give it more credibility. Researchers found that MODAPTS is a valuable method to detect and remove non-value-added activities, which will improve performance, increase productivity, and minimize bottlenecks [48]. Eliminating the NVAs is the main purpose of VSM, which makes MODAPTS very appropriate for this combination. The results of MODAPTS can clearly show the non-value-added activities that should be minimized in the value stream map. Both VSM and MODAPTS deal with time. VSM seeks to decrease wasted time, and MODAPTS analyse the processing time, and this leads to productivity improvement. For instance, a machine manufacturer used MODAPTS to analyse the assembly line of a packaging machine. MODAPTS were used to find inactive time in each station to be eliminated, and as a result, the productivity level grew to 41.72% [49]. This real-life example proves that there are many intersectional points between MODAPTS and VSM. They both work on time, workstations, and NVAs to develop productivity. To sum up, the mutual aspects between VSM and MODAPTS make them create an integrated system that this paper proves the success and effectiveness of this system.

For this study, a MODAPTS sheet is used as shown in the tables in the application section. A separate sheet was used for each station and each movement was added as an element in the sheet after recording a video for each working station. The movements were coded according to MODAPTS Pocket Guide, and the MODs were calculated and converted to minutes and seconds. There are two parts in the sheet; the first one is for repeated movements that happen while producing the whole order according to the order quantity. The second part is for the non-cyclic elements that are not repeated during the entire production process, such as machine adjustments and some quality control activities. Finally, the sheet contains the standard time to produce one piece and the time to produce the whole order. The time to produce one item can represent the C/T, and the total time for the whole order plus breaks and wasted time generates the C/O time in VSM.

The table of the MODAPTS sheet analyses the workers' movements, so it is also used to identify the non-value-added activities on it. The elements that do not add value were painted in dark grey. Some of these elements cannot be removed or reduced because of their importance, such as quality control activities that are not adding value to production, but they cannot be eliminated, so they were painted light grey. These data were entered in the Process Leg Frame and the Time Ladder of the value stream map to finalize the current status.

The future status was built on the MODAPTS sheet of each station, and the outlooks were gained after completing the analysis for the production processes. The dark grey areas should be reduced as much as possible to increase efficiency. Moreover, some VSM tools, such as merging two stations, continuous flow, and FIFO was used as well. After that, the future state was drawn, but again before completing the map, a re-MODAPTS step for all stations with their new status was made. VSM was finalized by adding new MODAPTS results to the map as was done in the current status. The final stage was making Time & Quality Value Stream Performance Metric to compare the current status with the future status. The outcomes of this Metric present the efficiency and success of the application. Employing all these tools for both of these techniques should lead to a huge development and prove the success of combining MODAPTS and VSM. The next section of this thesis transforms the methodologies into an applied experience in a gas springs factory.

Table 2.1. Literature review table

No	Author name(s)	Title	Publisher	Usage
1	Patil et al. (2021)	Application of value stream mapping to enhance productivity by reducing manufacturing lead time in a manufacturing company: A case study	Journal Of Applied Research and Technology	VSM's efficiency and usage in Beam Axle Industry
2	Buer et al. (2021)	The complementary effect of lean manufacturing and digitalisation on operational performance	Int J Prod Res	Lean Manufacturing importance
3	Budianto et al. (2021)	The effect of manufacturing agility competencies on lean manufacturing in increasing operational performance	Uncertain Supply Chain Management	The origin of Lean Manufacturing
4	Abidin et al. (2022)	Lean impact on manufacturing productivity: A case study of industrialized building system (IBS) manufacturing factory	J Teknol	The main target of Lean Manufacturing
5	Wassan et al. (2022)	The current status of lean manufacturing in small, medium and large scale manufacturing companies of Karachi, Pakistan	Journal of Applied Engineering Science	The features of Lean Manufacturing

6	Díaz-Reza et al. (2022)	Relationship between lean manufacturing tools and their sustainable economic benefits	International Journal of Advanced Manufacturing Technology	Introducing Lean Manufacturing Tools
7	Leksic et al. (2020)	The impact of using different lean manufacturing tools on waste reduction	Advances in Production Engineering and Management	The most popular Lean Manufacturing Tools
8	Guzel & Asiabi (2022)	Increasing productivity of furniture factory with lean manufacturing techniques (case study)	Tehnicki Glasnik	Brief explanations for Kaizen and 5S
9	Salwin et al. (2021)	Using value stream mapping to eliminate waste: A case study of a steel pipe manufacturer	Energies	VSM's history
10	Romero & Arce (2017)	Applying value stream mapping in manufacturing: A systematic literature review	IFAC Papers OnLine	VSM's history
11	Kale & Parikh (2019)	Lean implementation in a manufacturing industry through value stream mapping	International Journal of Engineering and Advanced Technology	VSM methodology
12	Jasti et al. (2020)	An application of value stream mapping in auto-ancillary industry: A case study	TQM Journal	Kaizen meaning
13	Demirci & Gündüz (2020)	Combined application proposal of value stream mapping (VSM) and methods time measurement universal analysis system (MTM-UAS) methods in textile industry	Endüstri Mühendisliği	A combination of VSM and a PMTS tool in a study from Turkey
14	León-Duarte et al. (2019)	A software tool for the calculation of time standards by means of predetermined motion time systems and motion sensing technology	Advances in Intelligent Systems and Computing	The definition of PMTS

15	Mondal & Jana (2022)	Application of predetermined motion and time system in sewing automat to enhance the productivity and operator utilisation	Research Journal of Textile and Apparel	The main target of PMTS
16	Angel et al. (2022)	Developing an AR based tool for teaching motion analysis on assembly tasks	Institute of Electrical and Electronics Engineers Inc	Conducting PMTS
17	Viharos & Bán (2020)	Comprehensive comparison of MTM and BasicMOST, as the most widely applied PMTS analysis methods	International Measurement Confederation, IMEKO	Introducing PMTS Tools
18	Engineering & Sumarmi (2019)	Measurement of standard time work with the predetermined motion time system method at the production department in PT	The Asian Institute of Research Engineering and Technology Quarterly Reviews	MTM explanation
19	Bellarbi et al. (2019)	Towards method time measurement identification using virtual reality and gesture recognition	IEEE	MTM versions
20	Kumar et al. (2020)	Productivity enhancement of assembly line by using Maynard operation sequence technique after identification of lean wastages	International Journal of Productivity and Quality Management	MOST explanation
21	Genaidy et al. (1990)	Computerized predetermined motion-time systems in manufacturing industries	Computers and Industrial Engineering	History of MODAPTS
22	Wygant et al. (1993)	Combining ergonomics and work measurement for job analysis	Computers And Industrial Engineering	MODAPTS technique explanation
23	Hu (2021)	Research on the application of mod method, the core technology of industrial engineering	IOP Science	MODAPTS technique explanation

24	Chan et al. (2017)	Subjective estimates of times for assembly work	International Journal of Industrial Ergonomics	Advantage of MODAPTS
25	International MODAPTS Association (2018)	MODAPTS pocket guide	Eisbrenner Productivity Group	Explaining the codes of MODAPTS
26	Schoeman et al. (2021)	Value stream mapping as a supporting management tool to identify the flow of industrial waste: A case study	Sustainability, Switzerland	Presenting a study from South Africa
27	Sudhakara et al. (2020)	Management of non-value-added activities to minimize lead time using value stream mapping in the steel industry	Acta Montanistica Slovaca	Presenting a study from India
28	Zahrotun & Taufiq. (2018)	Lean manufacturing: waste reduction using value stream mapping	EDP Sciences	Presenting a study from Indonesia
29	Yüksel & Uzunović (2019)	Application of value stream mapping in a manufacturing firm in Bosnia and Herzegovina	Yönetim Ve Ekonomi: Celal Bayar Üniversitesi İktisadi Ve İdari Bilimler Fakültesi Dergisi	Presenting a study from Bosnia and Herzegovina
30	Parab & Shirodkar (2019)	Value stream mapping: A case study of lock industry	AIP Publishing	Using VSM in Lock Industry
31	Zahraee et al. (2020)	Lean manufacturing analysis of a heater industry based on value stream mapping and computer simulation	Procedia Manufacturing	Using VSM in Heater Industry
32	Hernadewita & Rohimah (2018)	Lean manufacturing implementation using value stream mapping to	International Journal of Mechanical	Using VSM in Gas Stove Industry

		eliminate seven waste in painting process	and Production Engineering Research and Development	
33	Liu et al. (2020)	Applying value stream mapping in an unbalanced production line: A case study of a Chinese food processing enterprise	Quality Engineering	Using VSM in Food Industry
34	Dinesh et al. (2019)	Capacity enhancement through value stream mapping and line balancing technique in compressor assembly line	International Journal of Innovative Technology and Exploring Engineering	VSM impact on capacity growing
35	Ikatrinasari & Kosasih (2018)	Improving quality control process through value stream mapping	International Journal of Engineering and Technology	VSM impact on quality control
36	Qin & Liu (2022)	Application of value stream mapping in e-commerce: A case study on an Amazon Retailer	Sustainability, Switzerland	VSM impact on e-commerce
37	Chen et al. (2020)	A maintenance time estimation method based on virtual simulation and improved modular arrangement of predetermined time standards	International Journal Of Industrial Ergonomics	Th efficiency of MODAPTS
38	Ma et al. (2014)	Arc welding working hours based on MODAPTS	Trans Tech Publications	MODAPTS advantages in the production area
39	Xu et al. (2013)	The discussion on the application of MODAPTS about improving the pipeline of plastic enterprise	Proceedings of 20th Int. Conf. on Industrial Engineering and Engineering Management	MODAPTS advantages in the production area

40	Erliana and Abdullah (2018)	Application of the MODAPTS method with innovative solutions in the cement packing process	Inter. Journal of Engineering and Technology	MODAPTS advantages in the production area
41	Šabarić et al. (2013)	Application of the MODAPTS method with innovative solutions in the warping process	Fibres And Textiles in Eastern Europe	MODAPTS advantages in the production area
42	Cho et al. (2014)	Time estimation method for manual assembly using MODAPTS technique in the product design stage	International Journal of Production Research	MODAPTS combination with other methods
43	Cho & Park (2014)	Motion-based method for estimating time required to attach self-adhesive insulators	CAD Computer Aided Design	MODAPTS combination with other methods & comparison with MTM and AEM
44	Park (2014)	Design evaluation method for universal product development	Trans Tech Publications	MODAPTS combination with other methods
45	Rother & Shook (1999)	Learning to see	Lean Enterprise Institute	Mentioning the main book in VSM
46	Assef et al. (2018)	Confrontation between techniques of time measurement	Journal of Manufacturing Technology Management	Common points between VSM and MODAPTS
47	Stewart & Athinarayanan (2000)	MODAPTS and human data simulation	SAE International	Common points between VSM and MODAPTS
48	RAJ et al. (2021)	Productivity improvement of an automotive assembly line using modular arrangement of predetermined time standards (MODAPTS)	I-Manager's Journal on Future Engineering and Technology	Common points between VSM and MODAPTS

49	Sun et al. (2009)	Study on work improvement in a packaging machine manufacturing company	IEEE	Common points between VSM and MODAPTS

All the studies used in this thesis contributed significantly to complete the model. As Table 2.1 shows each study had a role to explain and clarify a topic either about VSM or MODAPTS. Also, the real-life examples in some studies approved the efficiency of the techniques. Moreover, some studies are used to support the idea of the harmony of both techniques, and they can be combined into one model. The new model of the combination of VSM and MODAPTS is what differentiates this thesis from the other studies used in the methodology or the literature review. This model can be considered as the added value and the new contribution of the study, which gathered the substance of the studies to shape and introduce the combination of VSM and MODAPTS in one model. Hence, this thesis provides a new and different contribution to support either VSM and MODAPTS techniques separately or combined.

CHAPTER 3

APPLICATION IN THE METAL SECTOR

This study is going to be conducted in the metal sector, which means the industries of shaping metal materials to make useful goods. It is a real-life case study that was applied in a gas springs factory by the Production Planning Engineer who is responsible for this field in the workplace and under the supervision of the Planning Manager. The application aims to approve and support the studies in the literature review and add to them through its touchable results. The application will go through some sections. Firstly, a brief about the company. Then, VSM and MODAPTS are applied separately. After that, combining them in one model for both the current status and future status. This model leads to very accurate and realistic results which have a great value for the applied field and the research field.

3.1. COMPANY INFORMATION

The application was made in the Global Gas Springs factory which is a multinational (Turkish – French – German) enterprise in Tekirdag - Turkey. The factory specializes in gas springs and their own end fittings and spare parts with more than 25 years of experience in that field. The company was established in 2003 in Istanbul and in 2019 it moved to Tekirdag for a bigger facility while keeping the branch in Istanbul for selling purposes. The enterprise is interested in all the industries related to the gas springs such as automotive, medical, defence, and more. The main competing area of the factory is France, Germany, England, and the Netherlands with more than 85% of exporting rate all over the world. The staffing of the factory exceeds 100 people with 15 office employees (5 of them are Engineers) and the ability of contact with Turkish, English, French, German, Portuguese, and Arabic. In the gas springs factory, there are many processes for shaping and reshaping metals to be more beneficial components.

Gas springs are products that help to lift heavy items dynamically and hydraulically by the support of the gas and oil inside of them.

3.2. VSM APPLICATION FOR CURRENT STATE

There are many types of gas springs, and they go through different processes. Thus, to apply VSM, there is a need to identify a specific product or a product family that shares the same production processes and goes through the same manufacturing stations. In this study, the gas springs used for Double Decker Bicycle Racks whose orders come as 4000 pcs/order were chosen for a couple of reasons. Firstly, they pass through 81% of all production processes in the factory. Also, they are in second place for the highest orders prices, which means one of the most profitable goods for the firm. Lastly, there is a dramatic increase in demand as the following chart in Figure 3.1 displays.

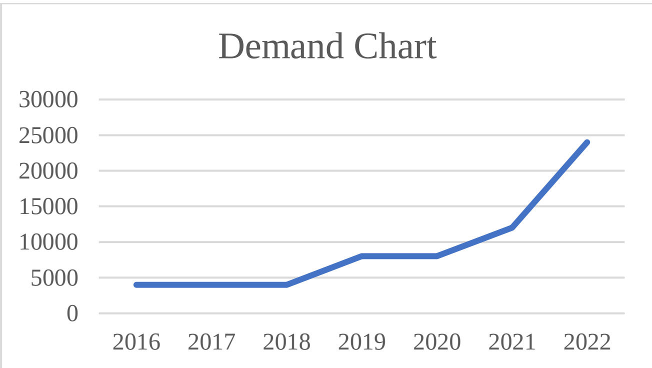


Figure 3.1. The demand increase for the chosen product

The current situation started by getting the order from the customer and verifying the delivery time of receiving the missing components from the suppliers. Then, analyse the workstations that the product goes through. There were 13 stations that were studied, which are rod cutting, rod shaping, tube cutting, tube chamfering, pistons assembling, riveting, end plug assembling, oil filling, rolling & closing, gas filling, painting, end fitting assembling, and packaging. After studying them, they all have been presented in the pre-current status of VSM as shown in Figure 3.2.

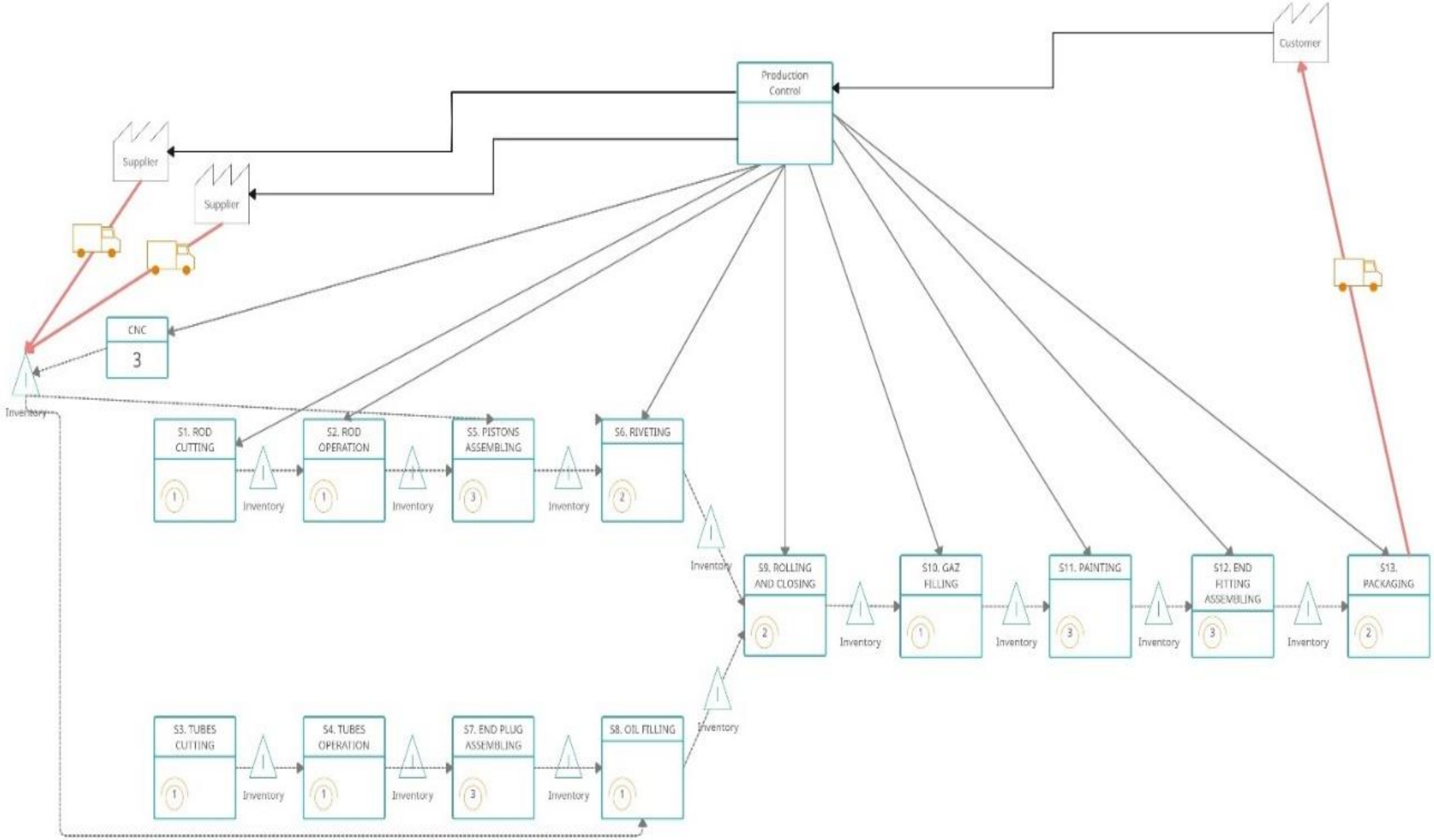


Figure 3.2. The pre-current state of VSM

3.3. MODAPTS APPLICATION

MODAPTS were applied on each station separately, and the non-value-added activities were indicated in the tables. The tables below show the 13 MODAPTS tables for the 13 stations of this study in their current state. Each motion has a unique MODAPTS code representing the distance or the way that any part of the body moves in letters and numbers that can be converted to time. For instance, The MODAPT study performed at Station 1 is presented in Table 4.1. The ninth move in the table is getting the rod, so its code is M5G1, M for movement, five because the body moved with the whole arm, G for getting the rod, and one because the rod is not in a complex place. The total MODs for this motion is six and to get minutes, we multiply five by 0.00215 and for seconds, we multiply by 0.129. The frequency means how many times this motion is repeated in the whole order, and the next column is for the number of persons or operators conducting this activity. Then, to get the total MODs, minutes, and seconds, we multiply them by the frequency and divide them by the number of persons. Table 3.1 is the MODAPTS table for station 1 where an operator is responsible for cutting the rods.

Table 3.1. MODAPTS table for station 1

STATION NAME	STATION NUMBER
RODS CUTTING	1

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the cutter	RH	M4G1S30	35	0.075	4.515	160	1	5600	12.04	722.4
		LH									
2	Put the cutter on the rod's cover	RH	M4P5	9	0.019	1.161	160	1	1440	3.096	185.76
		LH									
3	Cut the cover	RH	W23.25X4	27.25	0.059	3.515	160	1	4360	9.374	562.44
		LH									
4	Get a part of the cover out	RH	M4G1	5	0.011	0.645	160	1	800	1.72	103.2
		LH									
5	Take the part of the cover out	RH	M4P0	4	0.009	0.516	160	1	640	1.376	82.56
		LH									

6	Go back to the machine	RH	W23.25S30	53.25	0.114	6.869	160	1	8520	18.318	1099.08
		LH									
7	Get another part of the cover	RH	M4G1	5	0.011	0.645	160	1	800	1.72	103.2
		LH									
8	Take the part of the cover out	RH	M4P0	4	0.009	0.516	160	1	640	1.376	82.56
		LH									
9	Get the rod	RH	M5G1	6	0.013	0.774	4000	1	24000	51.6	3096
		LH									
10	Put the rod in the machine	RH	M5P5	10	0.022	1.29	4000	1	40000	86	5160
		LH									
11	Foot press	RH	F3	3	0.006	0.387	4000	1	12000	25.8	1548
		LH									
12	Get the cut rod	RH	M3G1	4	0.009	0.516	4000	1	16000	34.4	2064
		LH									
13	Put the cut rods in the box	RH	M5P2	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
14	Check the rods	RH			0.2	12	320	1		64	3840
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the machine	RH			3.58	214.8	1	1		3.58	3.58
		LH									
2	Get the compass	RH	M5G1	5	0.011	0.645	2	1	10	0.022	1.29
		LH									
3	Put the compass on the rod	RH	M5P5E4	14	0.03	1.806	2	1	28	0.06	3.612
		LH									
4	Put the compass back	RH	M5P2	7	0.015	0.903	2	1	14	0.03	1.806
		LH									
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				198.5	4.207	252.407			142852	374.712	22271.488

Table 3.2 shows the MODAPTS analysis for station 2 where an operator is machining both sides of the rods, one for the piston side and the other for the thread.

Table 3.2. MODAPTS table for station 2

STATION NAME			STATION NUMBER								
RODS OPERATION			2								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the rods from the box	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
		LH									
2	Put the rod in the machine for piston side operation	RH	W5M4P5	14	0.03	1.806	4000	1	56000	120.4	7224
		LH									
3	Press the first button	RH	M4G0X4	8	0.017	1.032	4000	1	32000	68.8	4128
		LH									
4	Press the second button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
5	Machining time	RH			0.3	18	4000	1		1200	72000
		LH									
6	Get the rod from the machine	RH	M4G3	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
7	Put the rod in the box	RH	W5M4P2	11	0.024	1.419	4000	1	44000	94.6	5676
		LH									
8	Get the rods from the box	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
		LH									
9	Put the rod in the machine for thread side operation	RH	W5M4P5	14	0.03	1.806	4000	1	56000	120.4	7224
		LH									
10	Press the first button	RH	M4G0X4	8	0.017	1.032	4000	1	32000	68.8	4128
		LH									
11	Press the second button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
12	Machining time	RH			0.51	30.6	4000	1		2040	122400
		LH									
13	Get the rod from the machine	RH	M4G3	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
14	Put the rod in the box	RH	W5M4P2	11	0.024	1.419	4000	1	44000	94.6	5676
		LH									
NON-CYCLIC ELEMENTS											
1	Adjusting the machine	RH			10	600	1	1		10	600
		LH									

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
	for piston side										
2	Get the compass	RH	M5G1	6	0.013	0.774	400	1	2400	5.16	309.6
		LH									
3	Put the compass on the rod	RH	M5P5E4	14	0.03	1.806	400	1	5600	12.04	722.4
		LH									
4	Put the compass back	RH	M5P2	7	0.015	0.903	400	1	2800	6.02	361.2
		LH									
7	Adjusting the machine for thread side	RH			15	900	1	1		15	900
		LH									

	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
TOTAL	131	26.092	1565.5	426800	4182.62	250957.2

Table 3.3 displays the MODAPTS sheet for station 3 where the tubes are cut by one operator.

Table 3.3. MODAPTS table for station 3

STATION NAME	STATION NUMBER										
TUBES CUTTING	3										
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the tubes from the shelves	RH	M7G3	10	0.022	1.29	20	1	200	0.43	25.8
		LH									
2	Pull the tubes	RH	M7W14.16L8	29.16	0.063	3.762	20	1	583.2	1.254	75.233
		LH									
3	Put the tubes on the shoulders	RH	M5P2L8	15	0.032	1.935	20	1	300	0.645	38.7
		LH									
4	Walk to the cutting machine	RH	W47.2L8	55.2	0.119	7.121	20	1	1104	2.374	142.416
		LH									
5	Get the tubes from the shoulders	RH									
		LH	M5G1	6	0.013	0.774	20	1	120	0.258	15.48
6	Put the tubes in the machine	RH	M7P5L8	20	0.043	2.58	20	1	400	0.86	51.6
		LH									
7	Hold the hanger of the machine cover	RH	M4G1	5	0.011	0.645	40	1	200	0.43	25.8
		LH									
8		RH	M5P0	5	0.011	0.645	40	1	200	0.43	25.8

	Pull up the machine cover	LH									
9	Get 2 tubes from the feeder	RH	M7G3	10	0.022	1.29	40	1	400	0.86	51.6
		LH									
10	Feed the machine with the tubes	RH	M7P5L4U3	19	0.041	2.451	40	1	760	1.634	98.04
		LH									
11	Press the button	RH	W5M4G0	9	0.019	1.161	40	1	360	0.774	46.44
		LH									
12	Machining time	RH			0.3	18	2000	1		600	36000
		LH									
13	Get the tubes from the machine	RH	M7G3L2M7	19	0.041	2.451	400	1	7600	16.34	980.4
		LH									
14	Put them on the wheel	RH	W5M5P5L2	17	0.037	2.193	400	1	6800	14.62	877.2
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the machine	RH			15	900	1	1		15	900
		LH									

	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
TOTAL	219.36	15.772	946.297	19027.2	655.908	39354.509

Table 3.4 represents the MODAPTS motion analysis for the operator during the chamfering process.

Table 3.4. MODAPTS table for station 4

<u>STATION NAME</u>		<u>STATION NUMBER</u>									
TUBES OPERATION		4									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the tubes from the wheel	RH	M7G3L2M7	19	0.041	2.451	800	1	15200	32.68	1960.8
		LH									
2	Put them in the chamfering machine	RH	W5M5P5L2	17	0.037	2.193	800	1	13600	29.24	1754.4
		LH									
3	Chamfering time	RH			0.083	5	8000	1		666.667	40000
		LH									
4		RH	B17M4G1L11	33	0.071	4.257	160	1	5280	11.352	681.12

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
	Get the chamfered tubes	LH									
5	Put them on the wheel	RH	W5M5P5L11	26	0.056	3.354	160	1	4160	8.944	536.64
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the machine	RH			30	1800	1	1		30	1800
		LH									
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				95	30.288	1817.255			38240	778.883	46732.96

Table 3.5 shows the MODAPTS table of the assembling of the pistons and their components such as orings and washers together done by 3 operators.

Table 3.5. MODAPTS table for station 5

STATION NAME			STATION NUMBER								
PISTONS ASSEMBLING			5								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the guiding	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 1	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
2	Assemble the guiding with Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
3	Put it on the table	RH	M3P0	3	0.006	0.387	4000	3	4000	8.6	516
		LH									
4	Get the front guiding	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get the seals	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
5	Assemble the front guiding with seals	RH	M3P2X4	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
6	Get glow	RH	M7G0	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
7	Put on output of 5	RH	M7P0	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									

8	Spread the glow	RH	M2P0	2	0.004	0.258	20000	3	13333.3	28.667	1720
		LH									
9	Clean hand	RH	M7G0	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
10	Clean hand	RH	M2	2	0.004	0.258	8000	3	5333.33	11.467	688
		LH									
11	Get output of 3	RH	M7G1	8	0.017	1.032	4000	3	10666.7	22.933	1376
		LH									
12	Put output of 3 on output of 7	RH	P2	2	0.004	0.258	4000	3	2666.67	5.733	344
	Put output of 7 under press machine	LH	M5P0	5	0.011	0.645	4000	3	6666.67	14.333	860
13	centralize the machine and press	RH	M4U2F3	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
14	Pressing time	RH			0.05	3	4000	3		66.667	4000
		LH									
15	Get Oring no 2	RH	M7G3	10	0.021	1.29	4000	3	13333.3	28.667	1720
	Get output 14	LH	M4P0	4	0.009	0.516	4000	3	5333.33	11.467	688
16	Put on output 14	RH	M7P5	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
17	Get the rods	RH	W5M7G1	13	0.028	1.677	4000	3	17333.3	37.267	2236
	Get output 16	LH	BOTH								
18	Assemble them	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
19	Put on the table	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
20	Get the washer no 1 and lift it	RH	M4G3M3	10	0.022	1.29	4000	3	13333.3	28.667	1720
	Get the washer no 1 from the right hand	LH	M3G1	4	0.009	0.516	4000	3	5333.33	11.467	688
21	Put the washer no 1 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
22	Get the piston no 1	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 3	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
23		RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
	Assemble the piston no 1 with Oring no 3	LH									
24	Put output 23 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
25	Get the washer no 2 and lift it	RH	M4G3M3	10	0.022	1.29	4000	3	13333.3	28.667	1720
	Get the washer no 2 from the right hand	LH	M3G1	4	0.009	0.516	4000	3	5333.33	11.467	688
26	Put the washer no 2 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
27	Get the piston no 2	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 4	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
28	Assemble the piston no 2 with Oring no 4	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
29	Put output 28 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
NON-CYCLIC ELEMENTS											
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				152	0.588	35.25			346666.7	812	48720

Table 3.6 is the MODAPTS table for the riveting process in station 6 where 2 operators press the assembled pistons from station 5 on top of the machined rods from station 2.

Table 3.6. MODAPTS table for station 6

STATION NAME		STATION NUMBER									
RIVETING		6									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the rod	RH									
		LH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290

2	Juggling	RH									
		LH	J2	2	0.004	0.258	4000	2	4000	8.6	516
3	Put in the machine	RH	M3P2	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
4	Foot press	RH	F3	3	0.006	0.387	4000	2	6000	12.9	774
		LH									
5	Pressing time	RH			0.25	15	4000	2		1000	60000
		LH									
6	Get the rod back	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
7	Control	RH	M4	4	0.009	0.516	4000	2	8000	17.2	1032
		LH	M2G1X4	7	0.015	0.903	4000	2	14000	30.1	1806
8	Put on table	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH					4000	2			
					NON-CYCLIC ELEMENTS						
1	Adjust the machine	RH	M4G3C4	11	0.024	1.419	3	1	33	0.071	4.257
	Get the mold	LH	M4G3C4	11	0.024	1.419	3	1	33	0.071	4.257
2	Put the mold back	RH	M4P5	9	0.019	1.161	3	1	27	0.058	3.483
		LH									
3	Check the rod position	RH	M4G1E4	9	0.019	1.161	3	1	27	0.058	3.483
		LH	M4G1E4	9	0.019	1.161	3	1	27	0.058	3.483
4	Put the rod back	RH	M4P2	6	0.013	0.774	3	1	18	0.039	2.322
		LH									

			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				92	0.448	26.868			74165	1159.455	69567.285

Table 3.7 represents the MODAPTS table for station 7 where the end plugs and their components such as rings and valves are combined and assembled which is very similar to station 5 but additionally, at the end of the process the end plugs are assembled to the chamfered tubes from station 4.

Table 3.7. MODAPTS table for station 7

STATION NAME			STATION NUMBER								
END PLUG ASSEMBLING			7								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS

1	Get the end plug	RH	M4G3	7	0.015	0.903	4000	3	9333.3	20.067	1204
	Get Oring no 1	LH	M4G3	7	0.015	0.903	4000	3	9333.3	20.067	1204
2	Assemble the guiding with Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
3	Get another Oring no 1	RH									
		LH	M4G3	7	0.015	0.903	4000	3	9333.3 3	20.067	1204
4	Assemble the guiding with the second Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
5	Put the end plug on its place	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
6	Get the Oring no 2	RH	M4G3	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
7	Put the Oring no 2	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
8	Get a squeezer	RH	M4G1	5	0.011	0.645	1	3	1.667	0.004	0.215
		LH									
9	Press the parts	RH	M4P2J2X4	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
10	Put the pen back	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
11	Get the bobbin	RH	M4G3	7	0.015	0.903	4000	3	9333.3	20.067	1204
		LH									
12	Put the bobbin	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
13	Get the valve	RH	M4G3	7	0.015	0.903	4000	3	9333.3	20.067	1204
		LH									
14	Put the valve	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
15	Get the holder	RH	M4G1	5	0.011	0.645	1	3	1.667	0.004	0.215
		LH									
16	Get the metal ring	RH	M4G3	7	0.015	0.903	4000	3	9333.3	20.067	1204
		LH									
17	Put in the holder	RH	M3P2	5	0.011	0.645	4000	3	6666.7	14.333	860
		LH									
18	Put the metal ring	RH	M4P5X4	13	0.028	1.677	4000	3	17333. 3	37.267	2236
		LH									

19	Get a squeezer	RH	M4G1	1	0.002	0.129	4000	3	1333.3	2.867	172
		LH									
20	Press the parts	RH	M4P2J2X4	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
21	Transfer to closing machine	RH	W5L2	7	0.015	0.903	75	1	525	1.129	67.725
		LH									
22	Get the tube	RH	M4G1	5	0.011	0.645	4000	3	6666.7	14.333	860
	Get the end plug	LH	M4G1	5	0.011	0.645	4000	3	6666.7	14.333	860
23	Put the end plug in the tube	RH	M3P2X4	9	0.019	1.161	1	1	9	0.019	1.161
	(The other assembling with machining time)	LH									
24	Put in the machine	RH	M7P5U2	14	0.03	1.806	4000	2	28000	60.2	3612
		LH									
25	Foot press	RH	F5	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
26	Pressing time	RH			0.133	8	4000	2		266.66	16000
		LH									
27	Get out the tube	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
28	Check	RH	M4E4	8	0.017	1.032	4000	2	16000	34.4	2064
		LH									
29	Put the tube	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH									
NON-CYCLIC ELEMENTS											
1	Reach the bags	RH	M4G3	7	0.015	0.903	5	1	35	0.075	4.515
		LH									
2	Open the bags	RH	M2P2X4	8	0.017	1.032	5	1	40	0.086	5.16
		LH									
3	Put the bags down	RH	M2P2	4	0.009	0.516	5	1	20	0.043	2.58
		LH									
4	Recheck with holder (10%)	RH	M4G1	5	0.011	0.645	400	3	666.67	1.433	86
		LH	M4P5	9	0.01935	1.161	400	3	1200	2.58	154.8
5	In the closing machine	RH	M4G1	4	0.009	0.516	1	1	4	0.009	0.516
	Check the plug dimension by compass	LH									
6	Using the compass	RH	M4P2E4	10	0.022	1.29	1	1	10	0.022	1.29
		LH									
7	Get the tube	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
	Put the plug inside	LH	M3P2X4	9	0.019	1.161	1	1	9	0.019	1.161

8	Check with compass	RH	M7P5E4	16	0.034	2.064	1	1	16	0.034	2.064
		LH									
9	Leave compass	RH	M4P2	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
10	Get pen	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
11	Sign the right place	RH	M4P2H4	10	0.022	1.29	1	1	10	0.022	1.29
		LH									
12	Leave the pen	RH	M4P2	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
13	Get the tube	RH	M2G0	2	0.004	0.258	1	1	2	0.004	0.258
		LH									
14	Put in the machine	RH	M4P5	9	0.019	1.161	1	1	9	0.019	1.161
		LH									
15	Adjusting	RH			1.417	85	1	1		1.417	85
		LH									

	TOTAL	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
		334	2.268	136.086	285247.67	881.359	52881.949

Table 3.8 is the MODAPTS sheet for station 8 where one operator is responsible for filling the oil in the tubes after assembling the end plugs in station 7.

Table 3.8. MODAPTS table for station 8

STATION NAME			STATION NUMBER								
OIL FILLING			8								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the tube	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
		LH									
2	Put in the filling machine	RH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096
		LH									
3	Press button	RH	M3U0.5	3.5	0.008	0.452	4000	1	14000	30.1	1806
		LH									
4	Filling time	RH			0.033	2	4000	1		133.32	8000
		LH									
5	Put the tube back	RH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096
		LH									
NON-CYCLIC ELEMENTS											

1	Adjust the filling machine	RH			0.167	10	1	1		0.167	10
		LH									
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				20.5	0.244	14.645			82000	309.787	18588

Table 3.9 shows the MODAPTS motion analysis for combining the output of stations 6 and 8 in station 9 where the rods and tubes are assembled in the rolling and closing machines by 2 operators.

Table 3.9. MODAPTS table for station 9

STATION NAME		STATION NUMBER									
ROLLING AND CLOSING		9									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the installation tool	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
2	Put the tool in its place	RH	M4P0	4	0.009	0.516	4000	2	8000	17.2	1032
		LH									
3	Get the tube	RH									
		LH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
4	Put the tube in installation place	RH									
		LH	M4P0	4	0.009	0.516	4000	2	8000	17.2	1032
5	Install on the tube	RH	M3P2	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
6	Get the rod	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
7	Put the rod in the tube	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH									
8	Move to the pressing machine	RH	M2G0	2	0.004	0.258	4000	2	4000	8.6	516
		LH									
9	Foot press	RH	F3	3	0.006	0.387	4000	2	6000	12.9	774
		LH									
10	Pressing time	RH			0.033	2	4000	2		66.6	4000
		LH									
11	Put the assembled part back	RH									
		LH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548

12	Transfer to rolling and closing machine	RH	W23.5L2	25.5	0.055	3.29	200	2	2550	5.483	328.95
		LH									
13	Get the gas spring	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
		LH									
14	Put the gas spring in the machine	RH	M4P2U2	8	0.017	1.032	8000	2	32000	68.8	4128
		LH									
15	Foot press	RH	F3	3	0.006	0.387	8000	2	12000	25.8	1548
		LH									
16	Machining time (get the next one while machining)	RH			0.133	8	8000	2		533.32	32000
		LH									
17	Get the gas spring from the machine	RH	M4G1	5	0.011	0.645	8000	2	20000	43	2580
		LH									
18	Put the gas spring back	RH	M4P2	6	0.013	0.774	8000	2	24000	51.6	3096
		LH									
19	Get the gas spring for second rolling	RH	M4G1	5	0.011	0.645	8000	2	20000	43	2580
		LH									
20	Put in the machine	RH	M4P2U2	8	0.017	1.032	8000	2	32000	68.8	4128
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjust the assembling machine	RH			3.7	222	2	2		3.7	222
		LH									
2	In the closing machine	RH	M4G1	4	0.009	0.516	2	2	4	0.009	0.516
	Check the plug dimension by compass	LH									
3	Using the compass	RH	M4P2E4	10	0.022	1.29	2	2	10	0.022	1.29
		LH									
4	Get the tube	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
	Put the plug inside	LH	M3P2X4	9	0.019	1.161	2	2	9	0.019	1.161
5	Check with compass	RH	M7P5E4	16	0.034	2.064	2	2	16	0.034	2.064
		LH									
6	Leave compass	RH	M4P2	6	0.013	0.774	2	2	6	0.013	0.774
		LH									
7	Get pen	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
		LH									
8	Sign the right place	RH	M4P2H4	10	0.022	1.29	2	2	10	0.022	1.29
		LH									
9	Leave the pen	RH	M4P2	6	0.013	0.774	2	2	6	0.013	0.774
		LH									
10	Get the tube	RH	M2G0	2	0.004	0.258	2	2	2	0.004	0.258

		LH									
11	Put in the machine	RH	M4P5	9	0.019	1.161	2	2	9	0.019	1.161
		LH									
12	Adjusting	RH			2.833	170	2	2		2.833	170
		LH									

	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
TOTAL	192.5	7.114	426.833	232637	1106.623	66402.173

Table 3.10 is the MODAPTS table for the gas charging process in station 10 which is done by one operator.

Table 3.10. MODAPTS table for station 10

STATION NAME			STATION NUMBER								
GAS FILLING			10								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the first gas spring	RH	M7G1	8	0.017	1.032	1	1	8	0.017	1.032
		LH									
2	Put in the machine	RH	M7P2J2	11	0.024	1.419	1	1	11	0.024	1.419
		LH									
3	Press the button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
4	Filling time (get the next one while filling)	RH			0.167	10	4000	1		666.68	40000.8
		LH									
5	Take the filled gas spring	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
	Put the next one	LH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096
6	Put the filled gas spring	RH	M7P2	9	0.019	1.161	4000	1	36000	77.4	4644
		LH									
					NON-CYCLIC ELEMENTS						
1	Get the mold of the machine	RH	M4G1C4	9	0.019	1.161	1	1	9	0.019	1.161
		LH	M4G1C4	9	0.019	1.161	1	1	9	0.019	1.161
2	Pull the mold	RH	M4G0	4	0.009	0.516	1	1	4	0.009	0.516
		LH	M4G0	4	0.009	0.516	1	1	4	0.009	0.516
3	Put on the table	RH	M7P2	9	0.019	1.161	1	1	9	0.019	1.161
		LH	M7P2	9	0.019	1.161	1	1	9	0.019	1.161

4	Get the upper part	RH	M3G1	4	0.009	0.516	1	1	4	0.009	0.516
	Get the new mold	LH	M3G1	4	0.009	0.516	1	1	4	0.009	0.516
5	Put the upper part	RH	M7P5	12	0.026	1.548	1	1	12	0.026	1.548
	Put the new mold	LH	M7P5C4	16	0.034	2.064	1	1	16	0.034	2.064
6	Adjust the mold in the machine	RH			3.167	190	1	1		3.167	190
		LH									

	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
TOTAL	126	3.604	216.254	108099	902.26	54135.571

Table 3.11 is the MODAPTS analysis for the motions of the operators in station 11 to feed the painting robot in the painting room.

Table 3.11. MODAPTS table for station 11

STATION NAME	STATION NUMBER
PAINTING	11

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the gas springs	RH	M4G3	7	0.015	0.903	800	1	5600	12.04	722.4
		LH									
2	Go to the pool	RH	W2.36	2.36	0.005	0.304	800	1	1888	4.059	243.552
		LH									
3	Put the gas springs in the water	RH	M7P2	9	0.019	1.161	800	1	7200	15.48	928.8
		LH									
4	Washing time	RH			0.167	10	800	1		133.336	8000.16
		LH									
5	Pull the gas spring	RH	M7G1U6	14	0.03	1.806	800	1	11200	24.08	1444.8
		LH									
6	Put the gas spring in the next pool	RH	W2.36M7P2	11.36	0.024	1.465	800	1	9088	19.539	1172.352
		LH									
7	Washing time	RH			0.167	10	800	1		133.336	8000.16
		LH									
8	Pull the gas spring	RH	M7G1U6	14	0.03	1.806	800	1	11200	24.08	1444.8
		LH									
9	Put them back	RH	W2.36M5P2	9.36	0.02	1.207	800	1	7488	16.099	965.952
		LH									

10	Get the gas springs	RH	M7G1	8	0.017	1.032	4000	3	10666.67	22.933	1376
		LH									
11	Hang the gas springs	RH	M7P2J2C4	15	0.032	1.935	4000	3	20000	43	2580
		LH									
12	Get the rod protection cover	RH	M7G3	10	0.022	1.29	4000	3	13333.33	28.667	1720
		LH									
13	Put the covers on rods	RH	M7P5J2	14	0.03	1.806	4000	3	18666.67	40.133	2408
		LH									
14	Get a rag	RH	W2.36M7G1	10.36	0.022	1.336	3	3	10.36	0.022	1.336
		LH									
15	Wipe the tubes	RH	M4P2J2U3	11	0.024	1.419	4000	3	14666.67	31.533	1892
		LH									
16	Get the rod covers after painting	RH	W2.36M4G1	7.36	0.016	0.949	4000	3	9813.333	21.099	1265.92
		LH									
17	Take the cover off and put them away	RH	M5P2	7	0.015	0.903	4000	3	9333.333	20.067	1204
		LH									
18	Get the gas springs	RH	M7G1J2C4	14	0.03	1.806	4000	3	18666.67	40.133	2408
		LH									
19	Take the gas spring off	RH	M7P2	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
NON-CYCLIC ELEMENTS											
1	Hold the water pool	RH	M5G1	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
2	Open the water pool	RH	M7P0	7	0.015	0.903	1	1	7	0.015	0.903
		LH									
3	Get the gloves	RH	W2.36M7G1	10.36	0.022	1.336	1	1	10.36	0.022	1.336
	Get the gloves	LH	W2.36M7G1	10.36	0.022	1.336	1	1	10.36	0.022	1.336
4	Wear the gloves	RH	M2P5	7	0.015	0.903	1	1	7	0.015	0.903
	Wear the gloves	LH	M2P5	7	0.015	0.903	1	1	7	0.015	0.903
5	Go to the gas springs	RH	W2.36	2.36	0.005	0.304	1	1	2.36	0.005	0.304
		LH									
6	Get the air gun	RH	M4G3	7	0.015	0.903	1	1	7	0.015	0.903
	Press the button	LH	M4G0X4	8	0.017	1.032	1	1	8	0.017	1.032
7	Drying time	RH			10	600	1	1		10	600
		LH									
8	Transfer to the painting room	RH	W38.75	38.75	0.083	4.999	1	1	38.75	0.083	4.999
		LH									
9		RH			120	7200	1	1		120	7200

	Painting time	LH

	TOTAL	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
		276.63	130.928	7855.686	180924.857	785.66	47139.62

Table 3.12 displays the MODAPTS table of station 12 where 3 operators assemble the end fittings on the two sides of the gas springs.

Table 3.12. MODAPTS table for station 12

STATION NAME			STATION NUMBER								
END FITTING ASSEMBLING			12								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the gas springs from the trolley	RH	M7G1	8	0.017	1.032	800	3	2133.333	4.587	275.2
		LH									
2	Put the gas spring on the table	RH	M7P2	9	0.019	1.161	800	3	2400	5.16	309.6
		LH									
3	Get the gas spring	RH	M4G1	5	0.011	0.645	4000	3	6666.667	14.333	860
	Get the fork	LH	M4G3	7	0.015	0.903	4000	3	9333.333	20.067	1204
4	Assemble the fork	RH	M4P2C4	10	0.022	1.29	4000	3	13333.33	28.667	1720
		LH									
5	Switch the gas spring	RH	M2	2	0.004	0.258	4000	3	2666.667	5.733	344
	Get the joint	LH	M4G3	7	0.015	0.903	4000	3	9333.333	20.067	1204
6	Assemble the joint	RH	M4P2C4	10	0.022	1.29	4000	3	13333.33	28.667	1720
		LH									
7	Put the gas spring back	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
8	Get the gas spring again	RH		5	0.011	0.645	4000	2	10000	21.5	1290
		LH	M4G1								
9	Put the fork in the director tool	RH		9	0.019	1.161	4000	2	18000	38.7	2322
		LH	M4P5								
10	Get a holder	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
11	Put the holder on the joint	RH	M7P2J2C4	15	0.032	1.935	4000	2	30000	64.5	3870
		LH									

12	Get the gas spring	RH										
		LH	M1G0	1	0.002	0.129	4000	2	2000	4.3	258
13	Put on the table	RH										
		LH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
NON-CYCLIC ELEMENTS											
	TOTAL		MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
			105	0.226	13.545			139205	299.291	17957.445

Table 3.13 shows the MODAPTS table of the last station number 13 where 3 workers pack the gas springs in their boxes and put them in the shipment parcels.

Table 3.13. MODAPTS table for station 13

STATION NAME		STATION NUMBER									
PACKAGING		13									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the gas spring	RH	M4G1	5	0.011	0.645	4000	3	6666.667	14.333	860
	Get the plastic bag	LH	M4G3	7	0.015	0.903	4000	3	9333.333	20.067	1204
2	Put the gas spring in the bag	RH	M4P5J2	11	0.024	1.419	4000	3	14666.67	31.533	1892
		LH									
3	Put the gas spring on the table	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
4	Open a box	RH			0.3	18	160	2		24	1440
		LH									
5	Get the gas springs (5 pcs)	RH	M4G3	7	0.015	0.903	800	2	2800	6.02	361.2
		LH									
6	Put in the box	RH	M7P5	12	0.026	1.548	800	2	4800	10.32	619.2
		LH									
7	Close the box	RH			0.183	11	160	2		14.666	880
		LH									
8	Get the box	RH	M4G3L3	10	0.022	1.29	160	2	800	1.72	103.2

		LH									
9	Put in the parcel	RH	W15.5M7P5 L3	30.5	0.066	3.935	160	2	2440	5.246	314.76
		LH									
10	Close the parcel	RH			2.5	150	2	1		2.5	150
		LH									
NON-CYCLIC ELEMENTS											
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				88.5	3.174	190.417			49506.67	147.606	8856.36

These tables show a very solid database for this study. The standardized time that was the output of the MODAPTS tables will be used in the value stream map to complete the model as the following section explains the methodology.

3.4. COMBINING VSM AND MODAPTS

The light grey painted cells are the non-value-added activities that are necessary (necessary NVAs) and difficult to be eliminated. The dark grey cells are the NVAs that should be removed or reduced at least (pure waste). At the same time, the value-adding activities remained white and not painted. The ‘TOTAL’ cells at the bottom of the table are the results that were used in VSM. For example, the cell “Minutes” is the total minutes to produce one piece, so it represents the cycle time C/T and Total Minutes is the time to produce the whole order (4000 pcs). So, after adding the break periods and wasted time, the result would represent the change over time C/O. These are the steps of combining MODAPTS and VSM that would generate the current state of VSM. This is the analysis part of the study where the problems are identified. The next part is developing the current status and after that generating the future status. After combining VSM with MODAPTS, the result is as Figure 3.3 shows. It displays the current status of the Value Stream Mapping. The data shown in this map is very accurate owing to the MODAPTS study that enhanced the accuracy and the creditability of the whole study.

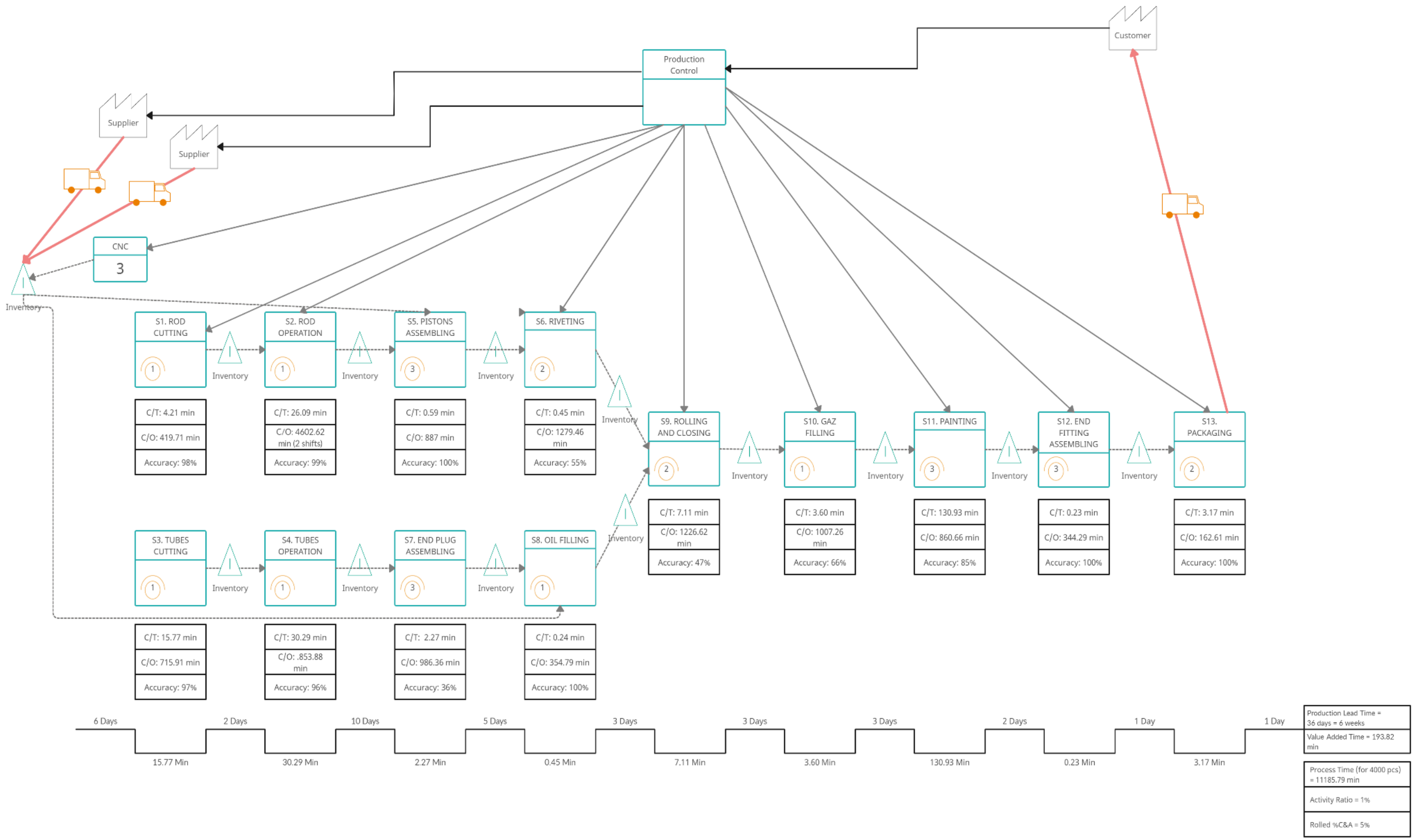


Figure 3.3. The current state of VSM

3.4.1. VSM Development Tools

After eliminating unnecessary activities, the first technique applied in this case is merging the stations to decrease stocking items in the production area. There are some factors to conduct a successful merging. To begin with, the cycle time C/T should be checked for each station, and there must be a kind of harmony between the stations planned to be merged. Table 3.14 shows the cycle time of each station.

Table 3.14. C/T for the stations

Station No	C/T (min)
1	4.207
2	26.092
3	15.772
4	30.288
5	0.588
6	0.448
7	2.268
8	0.244
9	7.114
10	3.604
11	130.928
12	0.226
13	3.174

Another factor is the physical place of each station. The stations that would be merged should be close to each other or movable to be connected, shaping a new merged station. Lastly, the purpose of the merge is to serve the workflow, so after checking the suitability of C/T and station location or its mobility, the sequence of the stations should be taken into consideration to ensure that the flow of the processes would be improved with the applied merging of stations. The stations that had been merged are 3&4 (tube cutting & tube chamfering), 5&6 (pistons assembling & riveting), 7&8 (end plug assembling & oil filling), and 12&13 (end fitting assembling & packaging). All of those stations were working as isolated islands; then they became working as a continuous flow by connecting the machines, such as the merging of stations 3&4 or by linking the assembling tables as done with the other merging situations. The number of stations had decreased from 13 stations to only nine stations. In addition, to apply the merge effectively, the working table of the first five stations had been rearranged to make a continuous flow to achieve the goal of the merge. Moreover, instead of WIP inventory between stations, the FIFO technique was applied in three different areas to reduce the production lead time and to be dynamic as Figure 3.4 displays.

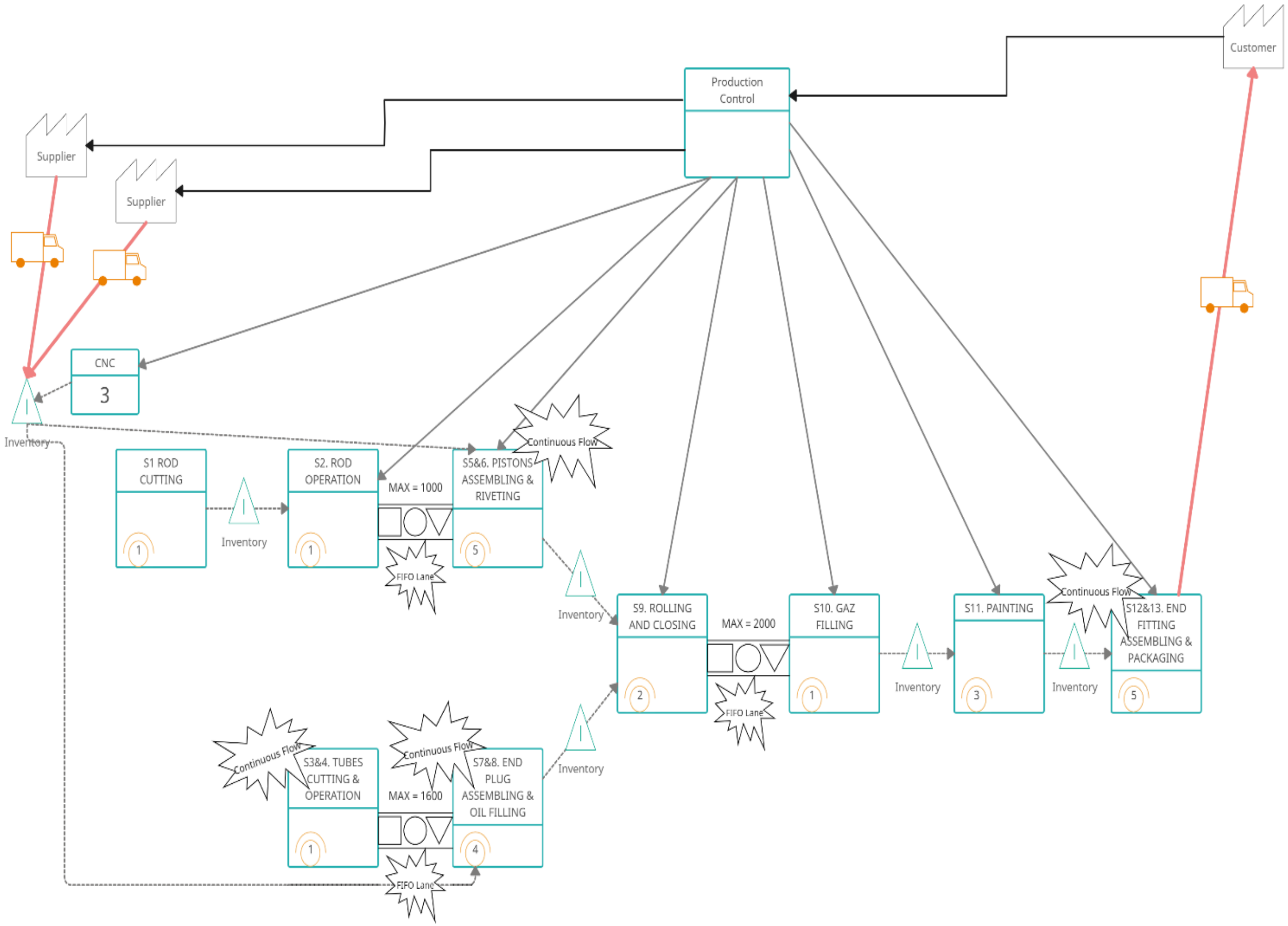


Figure 3.4. The pre-future state of VSM

3.4.2. Re-MODAPTS

As happened with the current status, a re-MODAPTS analysis was obtained for the stations with their new formation to come up with the future state of this study. The following tables shows the MODAPTS tables of the re-MODAPTS process.

Table 3.15 shows the Re-MODAPTS table for station 1 after eliminating 3 of the non-value-added activities.

Table 3.15. Re-MODAPTS table for station 1

STATION NAME		STATION NUMBER										
RODS CUTTING		1										
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the cutter (cut 10 by 10 pcs)	RH	M4G1S30	35	0.075	4.515	16	1	560	1.204	72.24
		LH									
2	Put the cutter on the rod's cover	RH	M4P5	9	0.019	1.161	160	1	1440	3.096	185.76
		LH									
3	Cut the cover	RH	W23.25X4	27.25	0.059	3.515	160	1	4360	9.374	562.44
		LH									
4	Get a part of the cover out	RH	M4G1	5	0.011	0.645	160	1	800	1.72	103.2
		LH									
5	Take the part of the cover out	RH	M4P0	4	0.009	0.516	160	1	640	1.376	82.56
		LH									
6	Go back to the machine	RH	W23.25S30	53.25	0.114	6.869	16	1	852	1.832	109.908
		LH									
7	Get another part of the cover	RH	M4G1	5	0.011	0.645	160	1	800	1.72	103.2
		LH									
8	Take the part of the cover out	RH	M4P0	4	0.009	0.516	160	1	640	1.376	82.56
		LH									
9	Get the rod	RH	M5G1	6	0.013	0.774	4000	1	24000	51.6	3096
		LH									
10	Put the rod in the machine	RH	M5P5	10	0.022	1.29	4000	1	40000	86	5160
		LH									
11	Foot press	RH	F3	3	0.006	0.387	4000	1	12000	25.8	1548
		LH									
12	Get the cut rod	RH	M3G1	4	0.009	0.516	4000	1	16000	34.4	2064

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
		LH									
13	Put the cut rods in the box (put 5 by 5)	RH	M5P2	7	0.015	0.903	800	1	5600	12.04	722.4
		LH									
14	Check the rods	RH			0.2	12	320	1		64	3840
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the machine	RH			3.58	214.8	1	1		3.58	3.58
		LH									
2	Get the compass	RH	M5G1	5	0.011	0.645	2	1	10	0.022	1.29
		LH									
3	Put the compass on the rod	RH	M5P5E4	14	0.03	1.806	2	1	28	0.06	3.612
		LH									
4	Put the compass back	RH	M5P2	7	0.015	0.903	2	1	14	0.03	1.806
		LH									

TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
	198.5	4.207	252.407			107744	299.23	17742.556

Table 3.16 is the Re-MODAPTS table for station 2 where 2 non-value-added activities were deducted.

Table 3.16. Re-MODAPTS table for station 2

STATION NAME		STATION NUMBER									
RODS OPERATION		2									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the rods from the box	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
2	Put the rod in the machine for piston side operation	RH	W5M4P5	14	0.03	1.806	4000	1	56000	120.4	7224
		LH									
3	Press the first button	RH	M4G0X4	8	0.017	1.032	4000	1	32000	68.8	4128
		LH									
4	Press the second button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
5	Machining time (get the next one	RH			0.3	18	4000	1		1200	72000
		LH									

	while machining)										
6	Get the rod from the machine	RH	M4G3	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
7	Put the rod in the box	RH	W5M4P2	11	0.024	1.419	4000	1	44000	94.6	5676
		LH									
8	Get the rods from the box	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
9	Put the rod in the machine for thread side operation	RH	W5M4P5	14	0.03	1.806	4000	1	56000	120.4	7224
		LH									
10	Press the first button	RH	M4G0X4	8	0.017	1.032	4000	1	32000	68.8	4128
		LH									
11	Press the second button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
12	Machining time (get the next one while machining)	RH			0.51	30.6	4000	1		2040	122400
		LH									
13	Get the rod from the machine	RH	M4G3	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
14	Put the rod in the box	RH	W5M4P2	11	0.024	1.419	4000	1	44000	94.6	5676
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the machine for piston side	RH			10	600	1	1		10	600
		LH									
2	Get the compass	RH	M5G1	6	0.013	0.774	400	1	2400	5.16	309.6
		LH									
3	Put the compass on the rod	RH	M5P5E4	14	0.03	1.806	400	1	5600	12.04	722.4
		LH									
4	Put the compass back	RH	M5P2	7	0.015	0.903	400	1	2800	6.02	361.2
		LH									
7	Adjusting the machine for thread side	RH			15	900	1	1		15	900
		LH									

	TOTAL	MODS	MINUTES	SECONDS		Total MODS	Total MINUTES	Total SECONDS
		131	26.092	1565.5		386810	4096.642	245798.49

Table 3.17 represents the Re-MODAPTS table of the merge of stations 3 and 4 with the elimination of 5 non-value-added activities.

Table 3.17. Re-MODAPTS table for station 3&4

STATION NAME			STATION NUMBER								
TUBES CUTTING & OPERATION			3&4								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the tubes from the shelves	RH	M7G3	10	0.022	1.29	20	1	200	0.43	25.8
		LH									
2	Pull the tubes	RH	M7W14.16L8	29.16	0.063	3.762	20	1	583.2	1.254	75.233
		LH									
3	Put the tubes on the shoulders	RH	M5P2L8	15	0.03225	1.935	20	1	300	0.645	38.7
		LH									
4	Walk to the cutting machine	RH	W23.6L8	31.6	0.068	4.076	20	1	632	1.359	81.528
		LH									
5	Get the tubes from the shoulders	RH									
		LH	M5G1	6	0.013	0.774	20	1	120	0.258	15.48
6	Put the tubes in the machine	RH	M7P5L8	20	0.043	2.58	20	1	400	0.86	51.6
		LH									
7	Hold the hanger of the machine cover	RH	M4G1	5	0.011	0.645	40	1	200	0.43	25.8
		LH									
8	Pull up the machine cover	RH	M5P0	5	0.011	0.645	40	1	200	0.43	25.8
		LH									
9	Get 2 tubes from the feeder	RH	M7G3	10	0.022	1.29	1	1	10	0.022	1.29
		LH									
10	Feed the machine with the tubes	RH	M7P5L4U3	19	0.041	2.451	1	1	19	0.041	2.451
		LH									
11	Press the button	RH	W5M4G0	9	0.019	1.161	40	1	360	0.774	46.44
		LH									
12	Machining time (get the next 2 while machining)	RH			0.3	18	2000	1		600	36000
		LH									
13	Get the tubes from the machine	RH	M7G3L2M7	19	0.041	2.451	400	1	7600	16.34	980.4
		LH									
14	Put them in the chamfering machine	RH	W5M5P5L2	17	0.037	2.193	800	1	13600	29.24	1754.4
		LH									

15	Chamfering time	RH			0.083	5	8000	1		666.667	40000
		LH									
16	Get the chamfered tubes	RH	B17M4G1L11	33	0.071	4.257	160	1	5280	11.352	681.12
		LH									
17	Put them on the wheel	RH	W5M5P5L11	26	0.056	3.354	160	1	4160	8.944	536.64
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjusting the cutting machine	RH			15	900	1	1		15	900
		LH									
2	Adjusting the chamfering machine	RH			30	1800	1	1		30	1800
		LH									

	TOTAL	MODS	MINUTES	SECONDS		Total MODS	Total MINUTES	Total SECONDS
		254.76	45.931	2755.864		33664.2	1384.045	83042.682

Table 3.18 is the Re-MODAPTS table of the combination of stations 5 and 6 in addition to decrease the non-value-added activities to 5 out of 7.

Table 3.18. Re-MODAPTS table for station 5&6

STATION NAME	STATION NUMBER
PISTONS ASSEMBLING & RIVETING	5&6

Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the guiding	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 1	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
2	Assemble the guiding with Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
3	Put it on the table	RH	M3P0	3	0.006	0.387	4000	3	4000	8.6	516
		LH									
4	Get the front guiding	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get the seals	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
5	Assemble the front guiding with seals	RH	M3P2X4	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
6	Get glow	RH	M7G0	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
7		RH	M7P0	7	0.015	0.903	4000	3	9333.33	20.067	1204

	Put on output of 5	LH									
8	Spread the glow	RH	M2P0	2	0.004	0.258	20000	3	13333.3	28.667	1720
		LH									
9	Clean hand	RH	M7G0	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
10	Clean hand	RH	M2	2	0.004	0.258	8000	3	5333.33	11.467	688
		LH									
11	Get output of 3	RH	M7G1	8	0.017	1.032	4000	3	10666.7	22.933	1376
		LH									
12	Put output of 3 on output of 7	RH	P2	2	0.004	0.258	4000	3	2666.67	5.733	344
	Put output of 7 under press machine	LH	M5P0	5	0.011	0.645	4000	3	6666.67	14.333	860
13	Centralize the machine and press	RH	M4U2F3	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
14	Pressing time	RH			0.05	3	4000	3		66.667	4000
		LH									
15	Get Oring no 2	RH	M7G3	10	0.022	1.29	4000	3	13333.3	28.667	1720
	Get output 14	LH	M4P0	4	0.009	0.516	4000	3	5333.33	11.467	688
16	Put on output 14	RH	M7P5	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
17	Get the rods	RH	M7G1	8	0.017	1.032	4000	3	10666.7	22.933	1376
	Get output 16	LH	BOTH								
18	Assemble them	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
19	Put on the table	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
20	Get the washer no 1 and lift it	RH	M4G3M3	10	0.022	1.29	4000	3	13333.3	28.667	1720
	Get the washer no 1 from the right hand	LH	M3G1	4	0.009	0.516	4000	3	5333.33	11.467	688
21	Put the washer no 1 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
22	Get the piston no 1	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 3	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
23	Assemble the piston no 1 with Oring no 3	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
24	Put output 23 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032

25	Get the washer no 2 and lift it	RH	M4G3M3	10	0.022	1.29	4000	3	13333.3	28.667	1720
	Get the washer no 2 from the right hand	LH	M3G1	4	0.009	0.516	4000	3	5333.33	11.467	688
26	Put the washer no 2 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
27	Get the piston no 2	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 4	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
28	Assemble the piston no 2 with Oring no 4	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
29	Put output 28 on the rod	RH									
		LH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
30	Get the rod	RH									
		LH	M4G1	5	0.011	0.645	1	2	2.5	0.005	0.323
31	Juggling	RH									
		LH	J2	2	0.004	0.258	4000	2	4000	8.6	516
32	Put in the machine	RH	M3P2	5	0.011	0.645	4000	2	10000	21.5	1290
		LH					4000	2			
33	Foot press	RH	F3	3	0.006	0.387	4000	2	6000	12.9	774
		LH					4000	2			
34	Pressing time (get the next one while machining)	RH			0.25	15	4000	2		1000	60000
		LH					4000	2			
35	Get the rod back	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH					4000	2			
36	Control	RH	M4	4	0.009	0.516	4000	2	8000	17.2	1032
		LH	M2G1X4	7	0.015	0.903	4000	2	14000	30.1	1806
37	Put on table	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH					4000	2			
NON-CYCLIC ELEMENTS											
1	Adjust the machine	RH	M4G3C4	11	0.024	1.419	3	1	33	0.071	4.257
	Get the mold	LH	M4G3C4	11	0.024	1.419	3	1	33	0.071	4.257
2	Put the mold back	RH	M4P5	9	0.019	1.161	3	1	27	0.058	3.483
		LH									
3	Check the rod position	RH	M4G1E4	9	0.019	1.161	3	1	27	0.058	3.483
		LH	M4G1E4	9	0.019	1.161	3	1	27	0.058	3.483
4	Put the rod back	RH	M4P2	6	0.013	0.774	3	1	18	0.039	2.322
		LH									

		MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
	TOTAL	337	1.025	61.473	404167.5	1935.627	116137.608

Table 3.19 shows merged station that gathered stations 7 and 8 into one.

Table 3.19. Re-MODAPTS table for station 7&8

STATION NAME				STATION NUMBER							
S7&8 END PLUG ASSEMBLING & OIL FILLING				7&8							
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the end plug	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
	Get Oring no 1	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
2	Assemble the guiding with Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
3	Get another Oring no 1	RH									
		LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
4	Assemble the guiding with the second Oring no 1	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
5	Put the end plug on its place	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
6	Get the Oring no 2	RH	M4G3	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
7	Put the Oring no 2	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
8	Get a squeezer	RH	M4G1	5	0.011	0.645	1	3	1.667	0.004	0.215
		LH									
9	Press the parts	RH	M4P2J2X4	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
10	Put the pen back	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
11		RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204

	Get the bobbin	LH									
12	Put the bobbin	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
13	Get the valve	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
14	Put the valve	RH	M4P5	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
15	Get the holder	RH	M4G1	5	0.011	0.645	1	3	1.667	0.004	0.215
		LH									
16	Get the metal ring	RH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
17	Put in the holder	RH	M3P2	5	0.011	0.645	4000	3	6666.67	14.333	860
		LH									
18	Put the metal ring	RH	M4P5X4	13	0.028	1.677	4000	3	17333.3	37.267	2236
		LH									
19	Get a squeezer	RH	M4G1	1	0.002	0.129	4000	3	1333.33	2.867	172
		LH									
20	Press the parts	RH	M4P2J2X4	12	0.026	1.548	4000	3	16000	34.4	2064
		LH									
21	Transfer to closing machine	RH	W5L2	7	0.015	0.903	75	1	525	1.129	67.725
		LH									
22	Get the tube	RH	M4G1	5	0.011	0.645	4000	3	6666.67	14.333	860
	Get the end plug	LH	M4G1	5	0.011	0.645	4000	3	6666.67	14.333	860
23	Put the end plug in the tube	RH	M3P2X4	9	0.019	1.161	1	1	9	0.019	1.161
	(The other assemblin g with machinin g time)	LH									
24	Put in the machine	RH	M7P5U2	14	0.03	1.806	4000	2	28000	60.2	3612
		LH									
25	Foot press	RH	F5	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
26	Pressing time	RH			0.133	8	4000	2		266.66	16000
		LH									
27	Get out the tube	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
28	Check	RH	M4E4	8	0.017	1.032	4000	2	16000	34.4	2064
		LH									
29	Put the tube	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH									
30	Get the tube	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
		LH									
31		RH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096

	Put in the filling machine	LH									
32	Press button	RH	M3U0.5	3.5	0.008	0.452	4000	1	14000	30.1	1806
		LH									
33	Filling time	RH			0.033	2	4000	1		133.32	8000
		LH									
34	Put the tube back	RH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096
		LH									
					NON-CYCLIC ELEMENTS						
1	Reach the bags	RH	M4G3	7	0.015	0.903	5	1	35	0.075	4.515
		LH									
2	Open the bags	RH	M2P2X4	8	0.017	1.032	5	1	40	0.086	5.16
		LH									
3	Put the bags down	RH	M2P2	4	0.009	0.516	5	1	20	0.043	2.58
		LH									
4	Recheck with holder (10%)	RH	M4G1	5	0.011	0.645	400	3	666.667	1.433	86
		LH	M4P5	9	0.019	1.161	400	3	1200	2.58	154.8
5	In the closing machine	RH	M4G1	4	0.009	0.516	1	1	4	0.009	0.516
	Check the plug dimension by compass	LH									
6	Using the compass	RH	M4P2E4	10	0.022	1.29	1	1	10	0.022	1.29
		LH									
7	Get the tube	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
	Put the plug inside	LH	M3P2X4	9	0.019	1.161	1	1	9	0.019	1.161
8	Check with compass	RH	M7P5E4	16	0.034	2.064	1	1	16	0.034	2.064
		LH									
9	Leave compass	RH	M4P2	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
10	Get pen	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
11	Sign the right place	RH	M4P2H4	10	0.022	1.29	1	1	10	0.022	1.29
		LH									
12	Leave the pen	RH	M4P2	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
13	Get the tube	RH	M2G0	2	0.004	0.258	1	1	2	0.004	0.258
		LH									
14	Put in the machine	RH	M4P5	9	0.019	1.161	1	1	9	0.019	1.161
		LH									
15	Adjust the assembling machine	RH			1.417	85	1	1		1.417	85
		LH									

16	Adjust the filling machine	RH			0.167	10	1	1		0.167	10
		LH									
TOTAL				MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				354.5	2.512	150.731			367247.667	1191.146	71469.949

Table 3.20 is the Re-MODAPTS sheet for station 9 where no change occurred due to the importance of the existence of the non-value-added activities of this process.

Table 3.20. Re-MODAPTS table for station 9

STATION NAME			STATION NUMBER								
ROLLING AND CLOSING			9								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the installation tool	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
2	Put the tool in its place	RH	M4P0	4	0.009	0.516	4000	2	8000	17.2	1032
		LH									
3	Get the tube	RH									
		LH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
4	Put the tube in installation place	RH									
		LH	M4P0	4	0.009	0.516	4000	2	8000	17.2	1032
5	Install on the tube	RH	M3P2	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
6	Get the rod	RH	M4G1	5	0.011	0.645	4000	2	10000	21.5	1290
		LH									
7	Put the rod in the tube	RH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
		LH									
8	Move to the pressing machine	RH	M2G0	2	0.004	0.258	4000	2	4000	8.6	516
		LH									
9	Foot press	RH	F3	3	0.006	0.387	4000	2	6000	12.9	774
		LH									
10	Pressing time	RH			0.0333	2	4000	2		66.6	4000
		LH									
11	Put the assembled part back	RH									
		LH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
12	Transfer to rolling and	RH	W23.5L2	25.5	0.055	3.29	200	2	2550	5.483	328.95
		LH									

	closing machine										
13	Get the gas spring	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
		LH									
14	Put the gas spring in the machine	RH	M4P2U2	8	0.017	1.032	8000	2	32000	68.8	4128
		LH									
15	Foot press	RH	F3	3	0.006	0.387	8000	2	12000	25.8	1548
		LH									
16	Machining time (get the next one while machining)	RH			0.133	8	8000	2		533.32	32000
		LH									
17	Get the gas spring from the machine	RH	M4G1	5	0.011	0.645	8000	2	20000	43	2580
		LH									
18	Put the gas spring back	RH	M4P2	6	0.013	0.774	8000	2	24000	51.6	3096
		LH									
19	Get the gas spring for second rolling	RH	M4G1	5	0.011	0.645	8000	2	20000	43	2580
		LH									
20	Put in the machine	RH	M4P2U2	8	0.017	1.032	8000	2	32000	68.8	4128
		LH									
					NON-CYCLIC ELEMENTS						
1	Adjust the assembling machine	RH			3.7	222	2	2		3.7	222
		LH									
2	In the closing machine	RH	M4G1	4	0.009	0.516	2	2	4	0.009	0.516
	Check the plug dimension by compass	LH									
3	Using the compass	RH	M4P2E4	10	0.022	1.29	2	2	10	0.022	1.29
		LH									
4	Get the tube	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
	Put the plug inside	LH	M3P2X4	9	0.019	1.161	2	2	9	0.019	1.161
5	Check with compass	RH	M7P5E4	16	0.034	2.064	2	2	16	0.034	2.064
		LH									
6	Leave compass	RH	M4P2	6	0.013	0.774	2	2	6	0.013	0.774
		LH									
7	Get pen	RH	M4G1	5	0.011	0.645	2	2	5	0.011	0.645
		LH									
8	Sign the right place	RH	M4P2H4	10	0.022	1.29	2	2	10	0.022	1.29
		LH									
9	Leave the pen	RH	M4P2	6	0.013	0.774	2	2	6	0.013	0.774
		LH									
10	Get the tube	RH	M2G0	2	0.004	0.258	2	2	2	0.004	0.258

		LH										
11	Put in the machine	RH	M4P5	9	0.019	1.161	2	2	9	0.019	1.161
		LH									
12	Adjusting	RH			2.833	170	2	2		2.833	170
		LH									
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				192.5	7.114	426.833			232637	1106.623	66402.173

Table 3.21 represents the RE-MODAPTS table of station 10 which also remained the same because it already had only one non-value-added activity that is important for the process.

Table 3.21. Re-MODAPTS table for station 10

STATION NAME			STATION NUMBER								
GAS FILLING			10								
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the first gas spring	RH	M7G1	8	0.017	1.032	1	1	8	0.017	1.032
		LH									
2	Put in the machine	RH	M7P2J2	11	0.024	1.419	1	1	11	0.024	1.419
		LH									
3	Press the button	RH	M3G0X4	7	0.015	0.903	4000	1	28000	60.2	3612
		LH									
4	Filling time (get the next one while filling)	RH			0.167	10	4000	1		666.68	40000.8
		LH									
5	Take the filled gas spring	RH	M4G1	5	0.011	0.645	4000	1	20000	43	2580
	Put the next one	LH	M4P2	6	0.013	0.774	4000	1	24000	51.6	3096
6	Put the filled gas spring	RH	M7P2	9	0.019	1.161	4000	1	36000	77.4	4644
		LH									
NON-CYCLIC ELEMENTS											
1	Get the mold of the machine	RH	M4G1C4	9	0.019	1.161	1	1	9	0.019	1.161
		LH	M4G1C4	9	0.019	1.161	1	1	9	0.019	1.161
2	Pull the mold	RH	M4G0	4	0.009	0.516	1	1	4	0.009	0.516
		LH	M4G0	4	0.009	0.516	1	1	4	0.009	0.516
3	Put on the table	RH	M7P2	9	0.019	1.161	1	1	9	0.019	1.161
		LH	M7P2	9	0.019	1.161	1	1	9	0.019	1.161

4	Get the upper part	RH	M3G1	4	0.009	0.516	1	1	4	0.009	0.516
	Get the new mold	LH	M3G1	4	0.009	0.516	1	1	4	0.009	0.516
5	Put the upper part	RH	M7P5	12	0.026	1.548	1	1	12	0.026	1.548
	Put the new mold	LH	M7P5C4	16	0.034	2.064	1	1	16	0.034	2.064
6	Adjust the mold in the machine	RH			3.167	190	1	1		3.167	190
		LH									

	TOTAL	MODS	MINUTES	SECONDS		Total MODS	Total MINUTES	Total SECONDS
		126	3.604	216.254		108099	902.26	54135.571

Table 3.22 displays the Re-MODAPTS table of station 11 and similarly to stations 9 and 10, it had no modification owing to its reliance on a semi-automated system.

Table 3.22. Re-MODAPTS table for station 11

STATION NAME		STATION NUMBER									
PAINTING		11									
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the gas springs	RH	M4G3	7	0.015	0.903	800	1	5600	12.04	722.4
		LH									
2	Go to the pool	RH	W2.36	2.36	0.005	0.304	800	1	1888	4.059	243.552
		LH									
3	Put the gas springs in the water	RH	M7P2	9	0.019	1.161	800	1	7200	15.48	928.8
		LH									
4	Washing time	RH			0.167	10	800	1		133.336	8000.16
		LH									
5	Pull the gas spring	RH	M7G1U6	14	0.03	1.806	800	1	11200	24.08	1444.8
		LH									
6	Put the gas spring in the next pool	RH	W2.36M7P2	11.36	0.024	1.465	800	1	9088	19.539	1172.352
		LH									
7	Washing time	RH			0.167	10	800	1		133.336	8000.16
		LH									
8	Pull the gas springs	RH	M7G1U6	14	0.03	1.806	800	1	11200	24.08	1444.8
		LH									
9	Put them back	RH	W2.36M5P2	9.36	0.02	1.207	800	1	7488	16.099	965.952
		LH									

10	Get the gas springs	RH	M7G1	8	0.0172	1.032	4000	3	10666.7	22.933	1376
		LH									
11	Hang the gas springs	RH	M7P2J2C4	15	0.032	1.935	4000	3	20000	43	2580
		LH									
12	Get the rod protection cover	RH	M7G3	10	0.022	1.29	4000	3	13333.3	28.667	1720
		LH									
13	Put the covers on rods	RH	M7P5J2	14	0.03	1.806	4000	3	18666.7	40.133	2408
		LH									
14	Get a rag	RH	W2.36M7G1	10.36	0.022	1.336	3	3	10.36	0.022	1.336
		LH									
15	Wipe the tubes	RH	M4P2J2U3	11	0.0237	1.419	4000	3	14666.7	31.533	1892
		LH									
16	Get the rod covers after painting	RH	W2.36M4G1	7.36	0.016	0.949	4000	3	9813.33	21.099	1265.92
		LH									
17	Take the cover off and put them away	RH	M5P2	7	0.015	0.903	4000	3	9333.33	20.067	1204
		LH									
18	Get the gas springs	RH	M7G1J2C4	14	0.03	1.806	4000	3	18666.7	40.1333	2408
		LH									
19	Take the gas spring off	RH	M7P2	9	0.019	1.161	4000	3	12000	25.8	1548
		LH									
NON-CYCLIC ELEMENTS											
1	Hold the water pool	RH	M5G1	6	0.013	0.774	1	1	6	0.013	0.774
		LH									
2	Open the water pool	RH	M7P0	7	0.015	0.903	1	1	7	0.015	0.903
		LH									
3	Get the gloves	RH	W2.36M7G1	10.36	0.022	1.336	1	1	10.36	0.022	1.336
	Get the gloves	LH	W2.36M7G1	10.36	0.022	1.336	1	1	10.36	0.022	1.336
4	Wear the gloves	RH	M2P5	7	0.015	0.903	1	1	7	0.015	0.903
	Wear the gloves	LH	M2P5	7	0.015	0.903	1	1	7	0.015	0.903
5	Go to the gas springs	RH	W2.36	2.36	0.005	0.304	1	1	2.36	0.005	0.304
		LH									
6	Get the air gun	RH	M4G3	7	0.015	0.903	1	1	7	0.015	0.903
	Press the button	LH	M4G0X4	8	0.017	1.032	1	1	8	0.017	1.032
7	Drying time	RH			10	600	1	1		10	600
		LH									
8		RH	W38.75	38.75	0.083	4.999	1	1	38.75	0.083	4.999

	Transfer to the painting room	LH									
9	Painting time	RH			120	7200	1	1		120	7200
		LH									

TOTAL	MODS	MINUTES	SECONDS	Total MODS	Total MINUTES	Total SECONDS
	276.63	130.928	7855.686	180924.857	785.66	47139.627

Table 3.23 shows the Re-MODAPTS table that analyses the motions of the operators after combining stations 12 and 13 in one final station.

Table 3.23. Re-MODAPTS table for station 12&13

STATION NAME				STATION NUMBER							
END FITTING ASSEMBLING & PACKAGING				12&13							
Ele. No.	DESC.	Hand	MODAPTS CODES	MODS	MINUTES	SECONDS	FREQ.	PER.	Total MODS	Total MINUTES	Total SECONDS
1	Get the gas springs from the trolley	RH	M7G1	8	0.017	1.032	800	3	2133.33	4.587	275.2
		LH									
2	Put the gas spring on the table	RH	M7P2	9	0.019	1.161	800	3	2400	5.16	309.6
		LH									
3	Get the gas spring	RH	M4G1	5	0.011	0.645	4000	3	6666.67	14.333	860
	Get the fork	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
4	Assemble the fork	RH	M4P2C4	10	0.022	1.29	4000	3	13333.3	28.667	1720
		LH									
5	Switch the gas spring	RH	M2	2	0.004	0.258	4000	3	2666.67	5.733	344
	Get the joint	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
6	Assemble the joint	RH	M4P2C4	10	0.022	1.29	4000	3	13333.3	28.667	1720
		LH									
7	Put the gas spring back	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
8	Get the gas spring again	RH		5	0.011	0.645	4000	2	10000	21.5	1290
		LH	M4G1								
9	Put the fork in the director tool	RH		9	0.019	1.161	4000	2	18000	38.7	2322
		LH	M4P5								

10	Get a holder	RH	M4G1	5	0.011	0.645	1	1	5	0.011	0.645
		LH									
11	Put the holder on the joint	RH	M7P2J2C4	15	0.032	1.935	4000	2	30000	64.5	3870
		LH									
12	Get the gas spring	RH									
		LH	M1G0	1	0.002	0.129	4000	2	2000	4.3	258
13	Put on the table	RH									
		LH	M4P2	6	0.013	0.774	4000	2	12000	25.8	1548
14	Get the gas spring	RH	M4G1	5	0.011	0.645	4000	3	6666.67	14.333	860
	Get the plastic bag	LH	M4G3	7	0.015	0.903	4000	3	9333.33	20.067	1204
15	Put the gas spring in the bag	RH	M4P5J2	11	0.024	1.419	4000	3	14666.7	31.533	1892
		LH									
16	Put the gas spring on the table	RH	M4P2	6	0.013	0.774	4000	3	8000	17.2	1032
		LH									
17	Open a box	RH			0.3	18	160	2		24	1440
		LH									
18	Get the gas springs (5 pcs)	RH	M4G3	7	0.015	0.903	800	2	2800	6.02	361.2
		LH									
19	Put in the box	RH	M7P5	12	0.026	1.548	800	2	4800	10.32	619.2
		LH									
20	Close the box	RH			0.183	11	160	2		14.666	880
		LH									
21	Get the box	RH	M4G3L3	10	0.022	1.29	160	2	800	1.72	103.2
		LH									
22	Put in the parcel	RH	W15.5M7P5L3	30.5	0.066	3.935	160	2	2440	5.246	314.76
		LH									
23	Close the parcel	RH			2.5	150	2	1		2.5	150
		LH									
					NON-CYCLIC ELEMENTS						
			TOTAL	MODS	MINUTES	SECONDS			Total MODS	Total MINUTES	Total SECONDS
				193.5	3.399	203.962			188711.667	446.897	26813.805

These MODAPTS tables provide the data of the standardize time of each station and process after using VSM tools to improve the production area and build a new and better status. The new data was used in the future status of VSM to complete it.

3.4.3. The Final Status

This study used some VSM techniques combined with MODAPTS methodology in order to improve a production line, as shown in Figure 3.5 which displays the future status of the value stream mapping. A new real-life example to prove the adding value of Lean Manufacturing tools and their great impact on production facilities. The next section will discuss the results and the limitations of the study proving its success and prefacing new studies to build on this case.

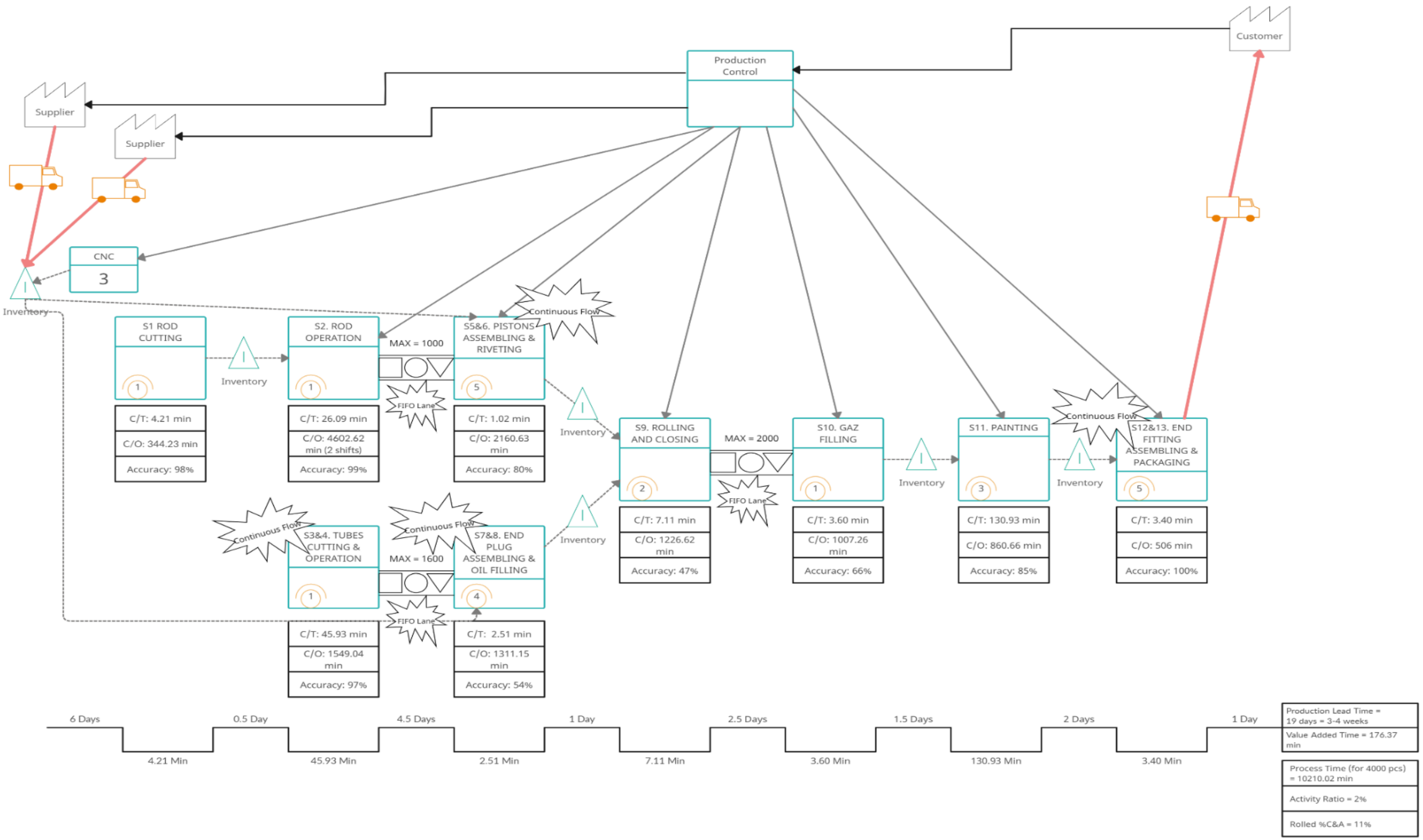


Figure 3.5. The future state of VSM

CHAPTER 4

DISCUSSION AND CONCLUSION

The application outputs in this study display the efficiency of the VSM and MODAPTS combined model. By analysing the output data, the model's capability will be proved to apply, and the obstacles will be observed to improve.

4.1. DISCUSSION

The figures of the current state and future state display an improvement that happened from the application. To be able to evaluate the results objectively, Time & Quality Value Stream Performance Metrics provide a numerical comparison between the current state and the future state of VSM. The matric of this case study is going to be as Table 4.1 shows.

Table 4.1. Time & quality value stream performance metric

Metric	Current	Future	Improvement
Production Lead Time	36 days	19 days	47%
Value Added Time	193.82 min	176.37 min	9%
Process Time for 4000 pcs	11185.79 min	10210.02 min	9%
Activity Ration	1%	2%	100%
Rolled %C&A	5%	11%	120%

The improvement percentages evidence touchable progress in different ranges. Improving the lead time by 47% increases the satisfaction level of the customer due to the fact that the delivery time became shorter by more than two weeks. Also, saving two weeks in the gas spring industry is an advantage that puts the factory at competitive level with the competitors in the market. The development in activity ratio and rolled percent complete and accurate (%C&A) prove the success of the study as well, especially the percentage of rolled %C&A, which is 11%, and this percentage is close to the general target of VSM, which should be around 15%. These results illustrate and summarize the study and exhibit its success and efficiency. To observe the results in more detail Table 4.2 shows the cycle time and change over time as MODAPTS calculated them for each station.

Table 4.2. MODAPTS output summary

Current			Future		
Station	C/T	C/O	Station	C/T	C/O
1	4.207	374.712	1	4.207	**299.23**
2	26.092	4182.62	2	26.092	**4096.642**
3	15.772	655.908	3&4	**45.931**	**1384.045**
4	30.288	778.883			
5	0.588	812	5&6	**1.025**	**1935.627**
6	0.448	1159.455			
7	2.268	881.359	7&8	2.512	1191.146
8	0.244	309.787			
9	7.114	1106.623	9	7.114	1106.623
10	3.604	902.26	10	3.604	902.26
11	130.928	785.66	11	130.928	785.66
12	0.226	299.291	12&13	3.399	446.896
13	3.174	147.606			

The table compares the consumed time for each station, and it is obvious that most of the development happened in the first six stations whether for the C/T or the C/O. This output shows the influence of MODAPTS on VSM and its effectiveness. In summary, the model's competence that combines VSM and MODAPTS has been proved with numbers in a real-life experience.

Nevertheless, there were some limitations too. The obstacle confronting the study is the wasted time adjusting the machines. The workers spend too much time adjusting the machines because the adjustment is set manually, and they set the machine calibration, try, check, reset, try, check...etc. These useless repeated activities should be reduced as much as possible, but this model couldn't interfere with solving this issue because it needs machinery modification. After the machinery modification or even with it, using SMED as a lean manufacturing tool would also be very effective. The development in this area would directly affect all the parameters in the value stream metric. It is believed that value-added time would be influenced and get better by solving this issue. This was the dilemma recognized while conducting this study.

Mainly, there are four processes that urgently need to be interfered mechanically to eliminate the adjusting time of the machines. These operations are riveting, end plug assembling, rolling & closing, and gas filling. In this section, approximate data will be provided assuming that all these machines were adjusted and ready to be used directly to eliminate the adjusting time and get a theoretical overview about the change that could happen by developing the time of adjustment. For riveting, checking the length of the rod and adjusting it with the mold of the machine is taking too much time and the workers are checking it at least 3 times. With improving the adjusting time, the cycle time would be improved by 11.54% and increasing the accuracy of the process to 89%. Assembling the end plug and rolling & closing processes are very similar. They both go through machines that they dig lines in particular places on the tubes of the gas springs. In this process, there are 2 challenges which are determining the distance between the line and the beginning of the tube and the depth of the line. The complexity of assembling the end plug is less than the rolling & closing process due to the fact that the assembling needs only digging one line, but it needs 2 for rolling & closing so it makes the determination of distance and depth much harder. This does not negate the increase in efficiency that would happen after eliminating the adjusting time for assembling the end plug. The cycle time would decrease by 56.39% and the accuracy might increase from 54% to 84%. Similarly, the accuracy of the rolling & closing process might increase from 47% to 90% while the cycle time could reach an enormous improvement with 91.84%. The situation is the same in the operation of gas filling. There is a big mold that needs both physical power and flexibility to be assembled and adjusted. Also, after adjusting, it needs to be tested by charging the first gas spring smoothly and carefully and then checking the gas because any mistake in this process may lead the gas spring to explode causing a real disaster in the workplace. This checking process is a must because the adjustment is done manually but if there is an automated adjusted machine to be ready directly to be fed, the cycle time would have increased by 87.86% and the accuracy could be almost 100%. Using this data in the performance metric will change the rolled %C&A of the future status to 50% showing a 1000% development rate. Of course, these numbers and output are purely theoretical and not practical at all, but they give the motivation to apply a new real-life case study to develop this one and come up with real and practical data. Additionally, the time spent on the rod operation and painting is too much, but this study couldn't detect the possible reasons and suggested solutions, it shows that there are potential hidden obstacles in these working stations, so it might be needed to change the mechanism of the whole operation so studying these processes could be also a future project.

All in all, the study showed enormous progress in the production line and achieved the target of the application. There was a limitation to which could make bigger improvement. It is healthy for any study to recognize these obstacles in order to solve them and this study highlighted them with some details and suggested future projects that can be done to solve these problems and develop this study more and more. That's the core of lean manufacturing technique in general and VSM particularly, it is an ongoing process that needs to be conducted and developed day by day. Lastly, it is possible to claim that by using MODAPTS to support VSM, most of the production problems and wastes, especially the hidden ones, can be found and solved from a Lean Manufacturing perspective.

4.2. CONCLUSION

In conclusion, this thesis worked on an interesting model that could be helpful and useful for factory supervisors. VSM alone is a perfect method to use to be able to identify the troubles in the workplace. With the support of a PMTS methodology that takes the ergonomic aspects into consideration, the influence of VSM aggrandizes. Most of the problems executives seek to solve are classical and obvious disorders.

However, this model would enhance their way of seeing to start recognizing the hidden deficiencies in all processes. Applying this model is just like using a microscope to see the unseen. The main purpose of these improvements is to decrease the delivery time of the orders. This study could reduce the delivery time from 36 days to 19 days which means two weeks earlier and almost doubling the production capacity. VSM provides different tools to be used in order to eliminate non-value-added activities, such as merging stations and FIFO, which were used to improve the production line in this case study. An advancement could happen simply by reordering the assembling tables in the workstations. This is the advantage of Lean Manufacturing tools, reaching developments doesn’t need complicated or costly solutions always, sometimes these issues can be solved with a very simple move like these kinds of studies focus on. Although VSM was the main methodology and MODAPTS was a supporter method, MODAPTS added great value to the study, which makes it no less important than VSM. MODAPTS was conducted on 13 stations in the current state and nine stations in the future state of the VSM, providing very accurate standardization for the spent time in each workstation. On the other hand, there was a limitation too: the machines' adjustment time. That was a non-value-added activity that the application couldn’t eliminate. Nonetheless, the study showed very valuable results. Therefore, I suggest building on this study by finding solutions for the wasted time in adjusting and preparing machines for work such as direct mechanical interference or with a lean manufacturing tool like SMED. Also, it is recommended to convert this model to an automatic program or application that can be used on computers or similar devices to make this model easier and more effective. Finally, this study displayed the harmony between VSM and MODAPTS in an active combination. It confirmed the prosperity that this model can achieve and expanded the horizon for more studies in the future.

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RESUME

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