Analysis and improvement of a processing station for bicycle frames

Carolina Ferreira da Costa

Master's Dissertation

Supervisor: Prof. Manuel Romano Barbosa

Co-Supervisor: Prof. António Mendes Lopes

Company Supervisor: Engº. Alexandre Araújo

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Master's Degree in Mechanical Engineering

Specialization in Automation

June 2023

Dedico aos meus pais.

Abstract

This dissertation was developed with the Kaizen Institute in Company X and the objective was to analyze and improve a machining cell for bicycle frames.

The context of the project and respective motivation will be analyzed, both companies will be introduced, the main objectives of this work will be presented, the method to be followed, and the structure of the presented thesis.

Important terms and concepts are presented, and an introduction is made to contextualize the industry under analysis in the world, in Europe and in Portugal. The main advantages and disadvantages of using CNC machines in the manufacture of frames and bicycles, the type of machines used for that purpose, the most common materials for that application, as well as the remaining processes are presented.

The factory layout, the material flow, the machining section, and the information flow are described. The manual and machine operations performed in the machining cell are detailed. After this description, the current situation is analyzed, and improvement opportunities are identified. Among these improvement opportunities, 3 are selected to be performed: threading and top opening performed in a CNC machine and work instructions for the operation period, set-up, and quality control are made, as well as a set-up sheet that specifies tools and parameters per operation in the CNC, for the programmers.

Next, the reasons and objectives for implementing these measures are stated. In short they are: The increase of productivity by decreasing the number of operators in a machining cell; to improve part quality, by allowing inner welding operations, through easier access to the inside of the frame on the manual welding process; Lastly, the execution of the set-up by the operators (instead of by the programmers) and the clarification and instruction of tasks allocated to the operators and programmers. An implementation plan is executed for each measure and its implementation is described. Finally, the performance indicators that will be updated for the selected measures are described and the results of their implementation are presented.

Finally, the main conclusions of this work are drawn. Productivity doubled, there was an improvement in the access of the welder to the area to be welded, there was greater clarity in the tasks to be performed by operators and programmers, and the set-up time was eliminated for the programmers who previously performed it.

Resumo

A presente dissertação foi desenvolvida com o Insituto Kaizen na Empresa X e teve como objeto analisar e melhorar uma célula de maquinagem de quadros de bicicleta.

Será analisado o contexto do projeto e respetiva motivação, serão introduzidas ambas as empresas, apresentados os principais objetivos deste trabalho, o método a seguir durante a sua realização e a estrutura da dissertação apresentada.

Termos e conceitos importantes são apresentados e é realizada uma introdução ao contexto da indústria no mundo, na Europa e em Portugal. São apresentadas as principais vantagens e desvantagens do uso de máquinas CNC no fabrico de quadros e de bicicletas, o tipo de máquinas utilizadas para tal efeito, os materiais mais comuns para essa aplicação, assim como os restantes processos mais utilizados para o mesmo contexto.

É descrito o layout da fábrica, o fluxo de material, a secção de maquinagem e o fluxo de informação. São enumeradas as operações manuais e de máquina executadas na célula de maquinagem. Após esta descrição, é ainda analisada a situação atual e são identificadas oportunidades de melhoria. De entre essas oportunidades de melhoria são selecionadas 3 para serem efetuadas: roscagem e abertura superior realizadas numa máquina CNC e instruções de trabalho para o período de operação, de *set-up*, e controlo de qualidade, assim como uma *set-up sheet* que explicita ferramentas e parâmetros por operação na CNC, para os programadores.

De seguida, são apresentados as razões e os objetivos para a implementação destas medidas. Estes consistem resumidamente em: aumentar a produtividade através da diminuição do número de operadores numa célula de maquinagem; Na melhoria da qualidade das peças, ao permitir operações de soldadura interior, através de um acesso mais fácil ao interior do quadro no processo de soldadura manual; Por último, a execução do set-up pelos operadores (em vez de pelos programadores) e a clarificação e instrução das tarefas atribuídas aos operadores e programadores. Para cada medida é executado um plano de implementação e é descrita a sua execução. Finalmente, são descritos os indicadores de desempenho que serão atualizados para as medidas selecionadas e são apresentados os resultados da sua implementação.

Finalmente, são retiradas as principais conclusões do presente trabalho. A produtividade duplicou, houve uma melhoria no acesso do soldador à zona a soldar, houve maior claridade nas tarefas a executar por parte dos operadores e programadores e foi poupado o tempo de *set-up* aos programadores que o executavam anteriormente.

Acknowledgements

I would like to express my gratitude, first, to my supervisor and co-supervisor in FEUP. They have provided constant help and oversight during this thesis.

I would also like to thank my supervisor and my tutor from Kaizen for their orientation and knowledge.

A special thank you to the CNC programmer from Company X who was always willing to invest his time in this work and who shared just as much enthusiasm for the project as myself.

The head of the CNC machine section, also deserving of my upmost gratitude, for his guidance.

Also, a thank you dedicated to my co-workers in Kaizen and Company X who shared with me their company and ideas.

Finally, I would like to thank my family, who through my whole life have supported me and my work. I could not have done this without them pushing me, bettering me, and comforting me, every step of the way. I hope to have made you proud.

Contents

List of Abbreviations

AM2R - Agenda Mobilizadora para a inovação empresarial do setor das Duas Rodas

Bikinnov - Bike Value Innovation Center

BOL - Border of Line

CAD - Computer-Aided Design

CAGR - Compound Annual Growth Rate

CNC - Computerized Numerical Control

CONEBI - Confederation of the European Bicycle Industry

CS - Chain Stay

CS LH - Left Chain Stay

CS RH - Right Chain Stay

Dropout LH - Left Dropout

Dropout RH - Right Dropout

DT - Down Tube

ERP - Enterprise Resources Planning

HMCs - Horizontal Machining Centers

HT - Head Tube

INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial

KPI - Key Performance Indicator

MB - Motor Bracket

MAG - Metal Active Gas

MIG - Metal Inert Gas

MTM - Multitasking Machine

NC - Numerical Control

OEE - Overall Equipment Efficiency

PIEP - Pólo de Inovação em Engenharia de Polímeros

P1 - Post 1

P2 - Post 2

Rpm - Rotations Per Minute

R&D - Research and Development

SMEs - Small and Medium-sized Enterprises

SS - Seat Stay

SS LH - Left Seat Stay

SS RH - Right Seat Stay

ST - Seat Tube

STEP - Standard for the Exchange of Product

TIG - Tungsten Inert Gas

TT - Top Tube

VAT - Value Added Tax

VMCs - Vertical Machining Centers

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1 Introduction

The first chapter of this dissertation corresponds to the introduction of the present work. It presents the contextualization and motivation of the project, the companies involved, the main objectives of the work, the methodology used during the project, as well as the structure of the thesis.

1.1 Project contextualization and motivation

The subject of the present thesis is the analysis and improvement of a processing station for bicycle frames.

The company in which this project was brought will be called Company X (located in Águeda, Portugal), and it manufactures bicycle frames. This company is a client of the Kaizen Institute in Portugal. Kaizen took on the project to improve the factory floor operations with a goal of achieving better productivity and bettering other production KPIs (Key Performance Indicators) for Company X. This project is centered around the company's machining department, which is responsible for the CNC (Computerized Numerical Control) machines in the production line in the workshop.

This Thesis was written during an internship at Kaizen, which suggested this project as the focus of this dissertation. Kaizen is a consulting firm hired by Company X to improve productivity rates. Thus, Kaizen had conducted a prior phase of problem diagnosis and sold the project responsible for implementing the solutions presented to Company X. This work is embedded in that period of improvement implementation.

Company X was founded in 2015 and has developed a covered retail space of 20,000 m^2. Company X made 3 applications for productive innovation, internationalization, and qualification of SMEs (Small and Medium-Sized Enterprises), all of them eligible. The investment amount was 14 million euros with an incentive of 8 million euros. The project started on 2015-06-01 and ended on 2017-05-31.

The bicycle industry is getting bigger. The ENMAC (Estratégia Nacional para a Mobilidade Ativa Ciclável) sets a target for 2050 of a 7.5% share of cycling on national territory and 10% in cities. A doubling of users in the European Union could lead to the creation of 400,000 new jobs, with more than 650,000 already linked to cycling. According to data on the bicycle industry in the European Union in 2016, the production of bicycle parts and accessories was worth around 1.7 billion euros. With almost 2.7 million bicycles produced and exports worth 402 million euros in 2019, Portugal is the continent's largest bicycle producer [1, 2, 3].

Many of the frames produced in Company X are for electric bicycles. This is particularly noteworthy as this industry is known for its move towards sustainability and zero emissions. Year after year, these vehicles seem to be used more and more and are known all over the world. Companies like Mobismart or LightMobie, which allow sharing electric bikes, also exist in

Portugal, tempting users who need to travel small distances with a cheaper, more sustainable alternative to the car or other means of transport.

Company X was an exciting project because it has innovative technology focused on processing aluminium, such as robotic welding and robotic brazing. The manufacturing process for frames is very extensive and complicated to understand, in terms of mechanical operations. Many parts of the factory were already automated. It was also fascinating to study the product and information flow leading to the machining department. Finally, the product was also a motivation: sustainability and carbon emissions in urban centers go hand in hand with the use of electric bicycles (the main product sold by Company X).

The chance to work with Kaizen was also a great opportunity because they work in a field that is a little different from automation. There was an opportunity to grow and learn in a different direction. As a consultant, the opportunity to understand the philosophy and methodology of Kaizen and improve in areas such as management, business, and industrial improvement arose. The chance to learn something new was taken as a challenge and an opportunity to deepen the education received in the master's program to become a better, more comprehensive, and complete professional in the industrial field.

The Kaizen Institute is based on the ideology of striving for continuous improvement. It was founded in 1985 by Masaaki Imai in Baar, Switzerland. In 1999, Kaizen Institute Portugal was founded and registered in Porto, Portugal. The Kaizen Institute has carried out projects in 6 continents, in over 60 countries, in over 45 industries and in over 30 languages. It operates mainly in 6 sectors: process industries, manufacturing and assembly, logistics, retail, healthcare, shared services, and public sector. It helps companies move from unstructured approaches such as "firefighting" to organized continuous improvement efforts. This requires a behavioral change that begins with visualizing all current problems using data, followed by applying structured targeted problem-solving techniques [4, 5].

For this current work, knowledge of line sizing and balancing using yamazumi diagrams was essential. These charts show the time spent on tasks, while also representing the takt time line, so that balancing is more visual and visual confirmation is given as to whether or not the takt time (time for a part to leave the factory/station) is being met.

1.2 Project's objectives

The present work should focus on the CNC machining processes of bicycle frames with the main aim improving productivity, by reducing the number of operators in a machining cell. Improving part quality was also a goal for this work, mainly for the welding section by allowing access (by machining operations) for the welder to reach the inside of the frame and weld its inside.

This includes the characterization of the parts to be machined and the current machining operations associated with them, the analysis of the current manual tasks, the characterization of the machines used in the machining processes, as well as the implementation of selected improvement suggestions.

1.3 Method followed during the project

The method followed in this project was to discuss and analyze with the company the current problems and ways to fix them, to analyze in full depth the current situation, to propose improvement solutions and attempt to implement some of them. Finally, to do a full review of the progress shown by implementing said measures.

1.4 Thesis structure

The first chapter focuses on the introduction and contextualization of the work, both companies, the material produced and the motivation for the proposed topic. The second chapter deals with the current state of the art to produce bicycles, and current industry. The third chapter is dedicated to the detailed analysis of the machining process and manual operations in its current state, in this machining cell. It also describes other current situations related to the machining process, such as the method followed for part fixtures/orientation and other relevant information. In this chapter, improvement measures are identified for the machining cell, and some chosen to be acted upon. The fourth chapter describes the changes that have been made, i.e., changes to programs, tools, machining processes or operations. This is divided by the plan of implementation, the actual implementation, the performance indicators for said measures and the results of their implementation. In the fifth chapter, the results of the previous chapter are debated, as well as their effects in production or part quality, which were the main motivation for this work. The conclusion of the thesis highlights the main results as well as the subsequent considerations. Finally, future work suggestions are given in this chapter, for the machining cell to be further improved.

2 State of the art for bicycles/frames

In this chapter, the state of the art in the manufacture of bicycles and bicycle frames is presented. For this purpose, some important concepts needed for this work are presented and explained.

In another section, a brief analysis of the world market and the European market is made, as well as a contextualization of the Portuguese market.

Finally, the use of CNC machines in this industry is analyzed, as well as CNC machine options. The most common manufacturing processes and their typical materials are also presented.

2.1 Relevant terms and concepts

Muda is often referred to, later in this work. This concept is connected to the three M’s that are made up by the Japanese terms of muda, mura, and muri. Mura is a word symbolizing a lack of stability and dependability, in other words, there are too many sudden changes in time when there is a lot of mura). Muri, meaning "too difficult" and represents the idea of wasting time and effort. Muda has the meaning of "Waste" and symbolizes an activity that has no value added [6,7].

A product is made in numerous stages, starting with raw materials, and ending with the finished item. At each stage, value is added to the product. Each process has human and/or mechanical resources that either add, or not, value to the final item. Therefore, any activity that does not add value is classified as muda [6,7].

There are seven main categories of muda, the elimination of which can help manufacturers become more competitive: waste due to overproduction; waste due to inventory (stock or materials on hold); waste due to defects; waste due to motion (movement of people); waste due to overprocessing; waste due to waiting (people); waste due to transportation (movement of materials) [6,7].

Cycle time is the actual time it takes each operator to complete a task. Takt time, on the other hand, is the total manufacturing time divided by the number of units required by the customer. The word "Takt" is derived from the German word for the conductor's baton. In the same way, takt time serves as the "pulse" to which production must adhere, to deliver the quantity required by the customer. The most crucial design factor for one-piece flow lines is known to be the takt time. It also indicates the time each process takes to complete a product. A shortage of finished products occurs when each process takes longer than the allotted time (takt) and an excess will happen if each process is faster [6,7].

Another term referred to in this paper is yamazumi. Process diagrams, or yamazumis, are often used to balance lines and consist on grouping processes into cycle-time sized parts. It is a visual balance chart that shows all the operation times, as well as the takt time, and allows the balance of these operations (machine tasks and operator tasks) to be verified [6,7].

2.2 Bicycle world market

The sales in the cycling industry are estimated to reach around 86 billion euros by 2028. Every day, around 364,000 bicycles are manufactured [8, 9].

It is estimated that the global market for electric bicycles was valued at over 16 billion euros in 2021 and is expected to reach more than 38 billion euros by 2030. Their sales increased 240% between 2020 and 2021, as they are one of the fastest growing segments of the bicycle industry, expected to become the dominant product [8, 9, 10].

The bicycle industry is highly connected worldwide, as companies from Asia and Europe have divided up and shared out the process of making a conventional bicycle. As such, this industry grew into a highly integrated achievement of global cooperation [11].

Table 1 - Top 3 bicycle-owning countries in the World [9]

Country	Bicycles (millions)
China	450
United States	100
Japan	72

Analyzing global trends, the country that owns the most bicycles in the world is China with about 450 million, followed by the United States (US) and by Japan, as can be seen in Table 1. These numbers could be due to the number of people living in these countries and their overall habits when it comes to China and the US. For Japan, these results are potentially due to urbanization (short distances between places) and the streets being levelled and not difficult to travel by bicycles [9].

This industry has been impacted by technological advancements that have lowered entrance barriers. Many factors have influenced the rise in bicycle usage around the world. Global population growth, rising gasoline prices, consumer awareness of green living/carbon footprints, urbanization, and the overall search to cut costs all contribute to the use of bicycles as a means of transportation. Their affordable prices also encourage more people to use them for pleasure/sport. This way, the number of bicycles owned worldwide is estimated at 1 billion [8, 9].

Covid-19 also seems to have contributed to this means of transportation's popularity. As can be seen in Figure 1, 27% of people who answered the survey below have said to have been cycling more since Covid-19. Overall, there was a shift to healthier and greener means of transportation (cycling, walking and use of public transportation) and a decrease of less carbon-neutral means (travelling by car, plane or for pleasure) [8, 9].

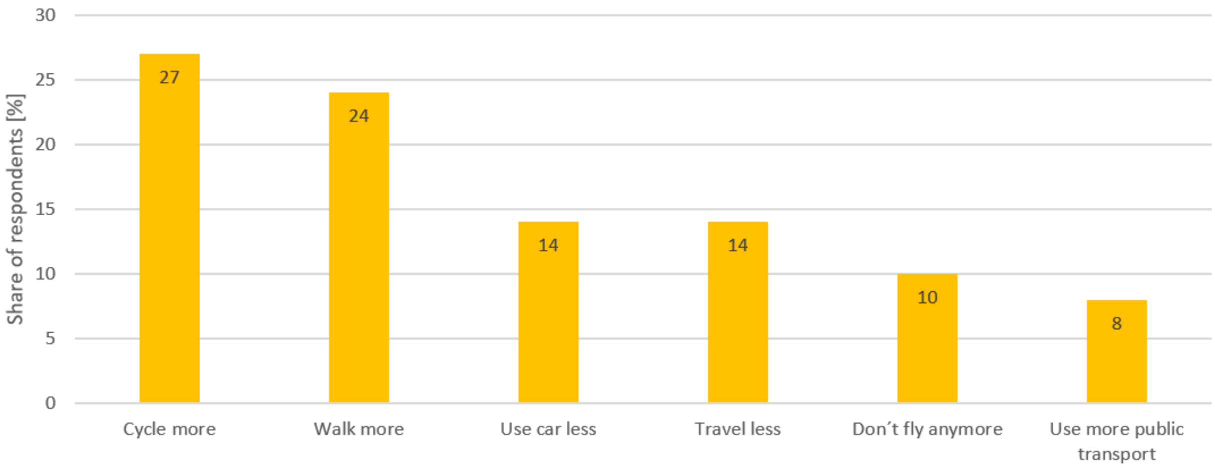


Figure 1 - Changes in mobility due to Covid-19 [8].

2.3 Bicycle manufacturing in Europe and in Portugal

Over the last years, the European Union has taken many measures to stimulate the use of bicycles as a means of transportation. The European Parliament initially adopted a resolution aimed at doubling bicycle usage in Europe by 2030 during the plenary session on February 16th, 2023. It was acknowledged that it is urgent and necessary to provide more support to the bicycle industry, especially due to the current climatic crisis, as a path to seek carbon neutrality [8, 9].

This support can take the form of funding for Research and Development (R&D) initiatives, VAT (Value Added Tax) reductions on bicycles, and the creation of appropriate infrastructure for their users to enjoy, such as cycle paths, specified parks, and electric vehicle charging stations (for electric bicycles). Additionally, the European Union is looking to expand its financial assistance for bicycle purchases [8, 9].

As can be seen in Figure 2, the European market prediction for electric bicycles and conventional bicycles seems to be ever rising. Electrical bicycles will tend to have more sales in Europe than conventional bicycles, and together they will value this market in about 30 million dollars (roughly 28 million euros) [12].

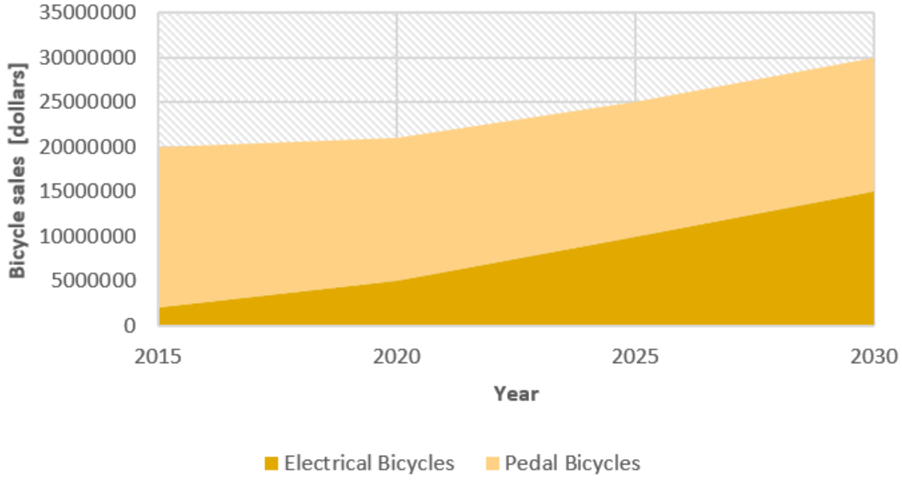


Figure 2 – Forecast for the European market for bicycles (in dollars) [12].

When it comes to the bicycle's popularity, there are three European countries that stand out: the Netherlands, Denmark, and Germany. The percentage of the population that owns a bicycle can be seen in Table 2, for these three countries [9].

Table 2 -Top three bicycle-owning countries in Europe [9]

Country	Bicycles owned (% of the population)
Netherlands	99%
Denmark	80%
Germany	76%

The European market, its policies and legislation will have an impact on the Portuguese bicycle industry. The Portuguese metal and mechanical engineering industry, especially those that produce welded structures (such as tubes, profiles, or sheets), will benefit from the growing trend of the electric bicycle segment, as they have a close relationship with the industry [10].

These products entering the market will also have to comply with the new electrical safety regulations. Portuguese companies, such as Abimota, offer services to verify this through electrical and electromagnetic compatibility tests [10].

By the end of 2021, the mobilization agenda for business innovation in the two-wheeler sector (AM2R) of the Portuguese Economic Recovery and Resilience Plan had been approved by 34 companies belonging to this industry, four of which were academic institutions (the Universities of Aveiro, Coimbra, INEGI, which means Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial, and PIEP which means Pólo de Inovação em Engenharia de Polímeros) and an association (Abimota). With a budget of 210 million euros, 64 projects are under consideration by AM2R with a goal of diversifying the sector's production structure. This is expected to revitalize the industry and stimulate new bicycle models, innovative materials, state-of-the-art parts, new (greener) manufacturing processes, improved logistical efficiency (with the aid of digital and automated technologies), skilled job growth, higher export values for the industry and reduced dependence on external suppliers. The Technological Interface Center, run by the Bike Value Innovation Center (Bikinnov) association, aims to foster innovation with the latest technology in processes for that industry and support the aforementioned objectives [10].

Portugal is currently the largest manufacturer and exporter of bicycles in Europe. The country has the first factory in the world to robotize the production of aluminium bicycle frames (Triangle's), the largest European wheel manufacturer (Rodi), the largest European bicycle chain manufacturer (Sramport), one of the considered most innovative companies in Europe (Miranda), the world leader in children's transport chairs (Polisport), the largest European bicycle assembly company (RTE) and the first company to produce frames in carbon fiber (Carbon Team) [10, 13].

2.4 Manufacturing processes for bicycles and bicycle frames

As for manufacturing processes, the most discussed in this work will be CNC machining. It stands out from casting and forging mainly by its accuracy, versatility, and the quality of the part finish. Forging and casting usually require surface finishes such as polishing, and as such are very rarely an alternative to CNC machining, but often help to reduce machining times when combined with the latter. Also, through their connection to CAD (Computer-Aided Design), enabled the production of personalized bicycles.

For a part to be produced on CNC machines, a CAD file is normally used in the process of generating the numerical control code i.e., G-code, that can be executed by the machine. Once the G-code is transferred, the part can be machined. This process can be repeated many times without sacrificing the precision and quality of the part. Almost any part that makes up a bicycle can be made and customized by CNC machining [14, 15].

CNC machines are very expensive, but in this case, can be very easily paid off by reducing production costs, as they do not require individual operator attendance at all times, and process parts uniformly with great accuracy. The price of manufacturing bicycle parts depends heavily on the type of tooling and materials used in the process, as well as the parts themselves being manufactured. Features such as thin walls and tight tolerances increase production costs. This is due to the need for specialized equipment, constant and precise quality control, and a longer production time [14].

However, there are some limitations to the use of CNC machines in this industry. For example, it is difficult to make accurate inside corners because rotating tools always leave a radius in the cut. In addition, forging and casting can produce irregular shapes faster. However, these alternatives often need to be machined to produce all size-critical features [15].

There are many types of CNCs that can be used. There are two-axis CNC lathes, the simplest of CNCs, three-axis Vertical Machining Centers (VMCs), four-axis VMCs (with an additional fourth axis of rotation), four-axis Horizontal Machining Centers (HMCs), five-axis machines (either VMCs or HMCs with an additional axis of rotation on the cutting tool head or pallet of the workpiece) and turn-mill machines (usually five to six axes). Most of the machines described previously can change tools and automatically clear the workspace of chips. To improve production, some of them have two or more workpiece pallets that can be changed automatically. An industrial-grade two-axis CNC lathe can cost between 37,000 euros and 93,000 euros, and after that, the cost of CNC equipment increases exponentially. The most modern machines used for this manufacturing are called MTMs (Multitasking Machines) and have seven to nine axes (mill/turn machines). They are characterized by combining the advantages of a five-axis machine with full turning capability. The goal of these machines is to mill, turn and finish parts in a single operation set-up. The most popular CNC machines for producing bicycle parts are those that have milling and turning functions [14, 15].

Typical materials for this application are aluminium and steel, both of which can be machined with CNC machines. Manufacturers have been looking for lighter frames compared to traditional steel, especially for electric bicycles, to offset the weight of the battery. Less traditional materials for this industry are carbon fiber and titanium. However, welding in these materials can be a difficult process that requires the right cutting and welding tools. As such, precise laser technology can be a useful substitute in both cases [9].

Some examples of other processes now used in Portuguese companies to manufacture bicycle frames include robotic welding and 3D printing of products with complex geometries. Laser cutting of tubes and sheets is also becoming increasingly popular. The bending of profiles or the production of tubes is also more effective today, thanks to specialized machines. The technology chosen, for example, MIG (Metal Inert Gas) /MAG (Metal Active Gas) welding, TIG (Tungsten Inert Gas) welding, brazing, plasma, or laser depends on the technical requirements of the project, the production quantities, and the material. After welding, the frames are usually also subjected to surface treatment (and possibly heat treatment), painting and quality control to ensure compliance with the final geometry [9].

It is concluded that the use of CNCs in the manufacture of bicycles is widespread. Although they have many positive aspects, there are some challenges that they bring to this and other industries. In this dissertation, a machining cell is analyzed with the aim of improving it and enhancing its performance. Thus, the challenge is to overcome the current obstacles in the process, in order to present possible solutions to these limitations and apply some of them. Afterwards, a conclusion must be drawn as to whether the original obstacle has actually been overcome or whether the implemented measures have not achieved their goal.

3 Analysis of the current state of the CNC station

This chapter describes the current situation of machining processes and operations, as well as the equipment used, such as CNC machines, supporting and additional systems or equipment, tools used and others. The flow of materials and information is also described. In addition, a critical analysis of the current situation is made, and opportunities for improvement are identified, including the possibility for automation solutions.

Company X's factory currently has 5 main pavilions but will soon expand to 7 or 8 pavilions. The factory layout is shown in Figure 3, roughly divided into sections. As can be seen from the diagram mentioned earlier, the machining department is divided into 3 main sections which are machining section 1, 2 and 3. The area that this paper will focus on (discussed in more detail later) is the area in deep red (Machining section 3). It is surrounded by the processes of machining 1 and 2, brazing and washing.

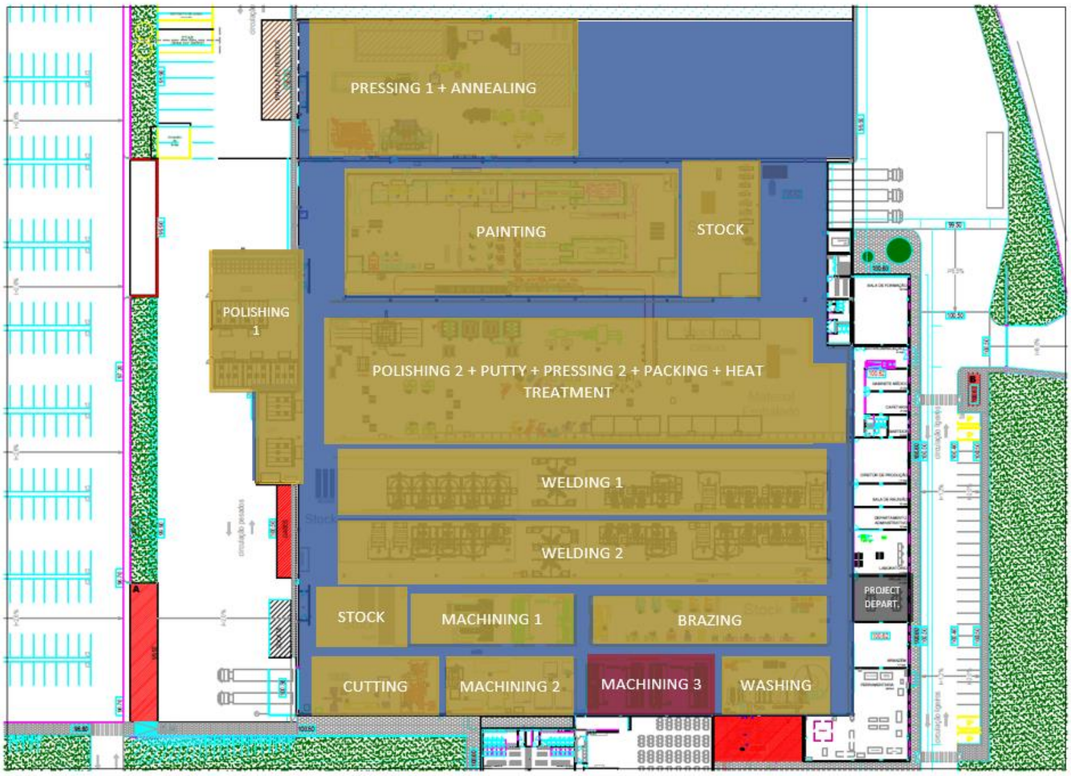


Figure 3 - Rough draft of the factory's sections.

3.1 Material flow for the two frame models

Currently each CNC machine is dedicated to machine parts of a specific model (varying only the size according to the manufacturing order requested). For example, frame Model #1 is machined in Ralc 6 and frame Model #2 in Ralc 7.

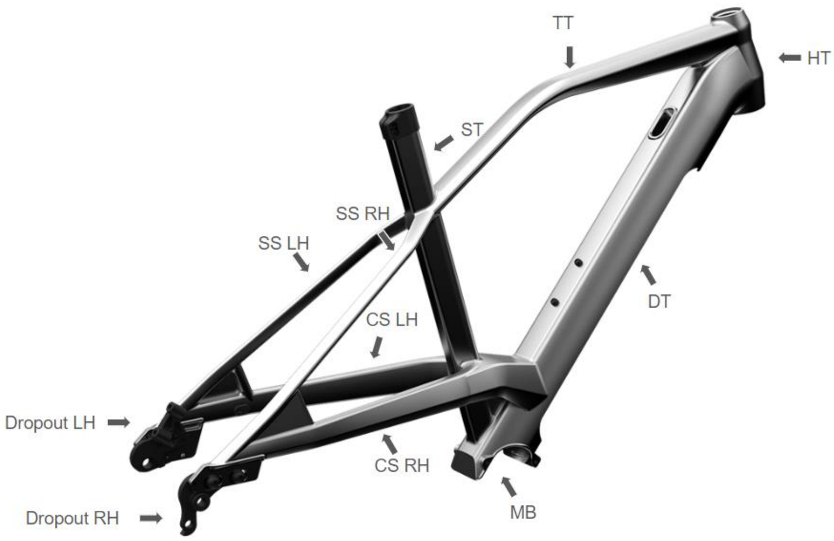


Figure 4 - Scheme of frame parts [16].

Figure 4, above, shows the typical components in a bicycle frame. The abbreviations present in Figure 4 correspond to the designation of each part used by Company X, and generally used by the industry. Thus, the letters LH and RH correspond to the left and right sides, respectively (for cases where two components of a frame are symmetrically attached to it). SS stands for Seat Stay, CS for chain stay, MB for motor bracket, DT for down tube, TT for top tube, HT for head tube, ST for seat tube.

Each model has two CS (one right and one left), two SS (one right and one left), one MB, one DT, one HT, one SS and two Dropouts (one right and one left) and in this case, neither of the selected models has a TT. What will later be referred to as frame is a set made up of a MB, DT and HT welded together. Left and right SS, CS and Dropouts have slightly different geometries. All are made from the same type of aluminium. The parts where geometric accuracy is most important are the DT, SS, CS and MB. Ralc 6 only machines 4 SS and 2 frames and Ralc 7 machines 4 CS, 4 SS and 2 DT.

The material flow diagram is shown for frame Model #1 in Figure 5. Figure 6 shows the flow for frame Model #2. Model #1 has 6 sizes available (6 different references for each part) Model #2 has 4 sizes available (4 different references for each part). All parts start in the warehouse, except the frames, as these are a set of other parts, welded together.

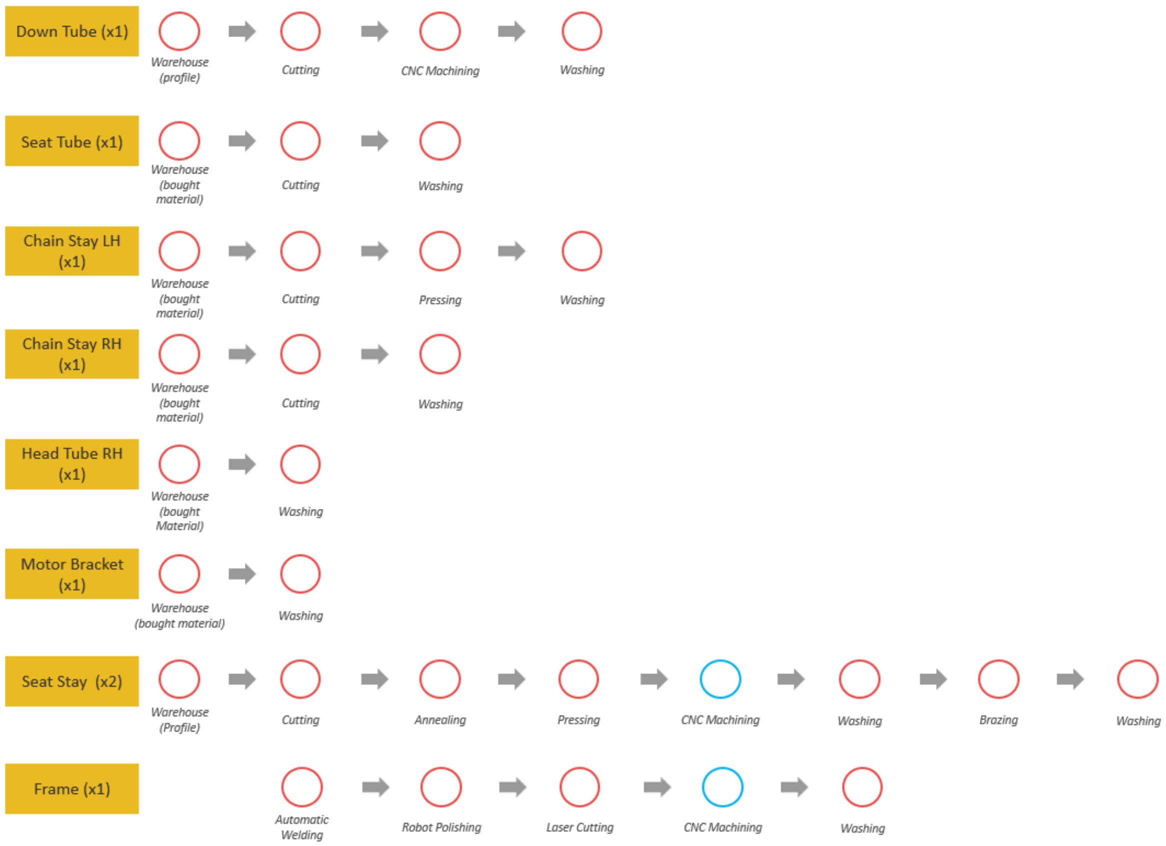


Figure 5 - Material flow for the Model #1.

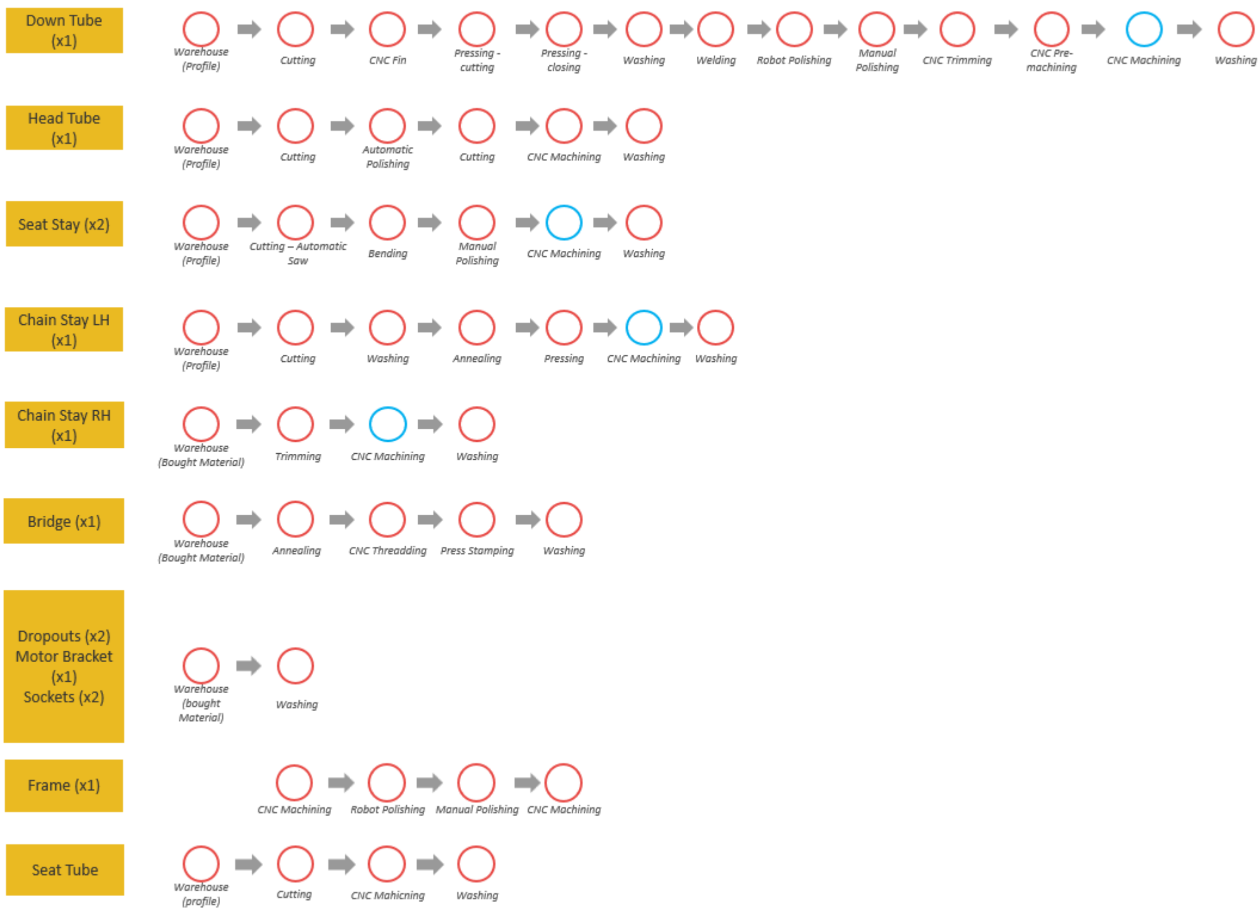


Figure 6 - Material flow for the Model #2.

In Figure 5 and 6, each circle represents a stage and an arrow symbolizes material transfer. Each line corresponds to a specific part that will form the final frame (for Model #1 and #2 respectively). Material transfer takes place about 4-5 times a day in containers or frame cars (manually moved) of different sizes, depending on the production order and the size of the parts. Marked in blue are the operations done in the machining cell under study.

3.2 CNC machining area

The CNC machining station contains four Ralc CNC machining centers and this work will concentrate on two (numbers 6 and 7).

The Ralc Machining Center (Figure 7) is suitable for machining operations such as drilling, milling, and cutting. It is intended for machinery of light alloys, aluminium, plastic, steel (that includes stainless steel) and other metals. The gantry can work in one gabarit and then move to the next as it can move from side to side through two precise guides. It has a bi-directional machining head and is driven by a geared servomotor with an encoder. It has a guard that provides safety while limiting noise, metal chips and odors from lubricants. The spindle is water-cooled and has a maximum speed of 24,000 rpm (rotations per minute). It has a lubrication system that can be programmed via NC (numerical control).

All three axes are equipped with servomotors with absolute encoder, eliminating the need for resetting after start-up or an emergency stop. This is due to both position feedback and reduced backlash in brushless geared motors that allows the CNC machine to maintain accurate axis positions and seamlessly resume operation. By combining a geared servomotor with an absolute encoder, the CNC machine benefits from both high torque capacity and precise position feedback. Ball screws move vertically through the Z-axis and a precision rack moves the X- and Y-axes. The control panel is on a mobile stand and has a pushbutton panel, in addition to a user interface with a 15-inch color display and USB for remote control PC and NC connection. For automatic tool change and tool management, there is a 20-position automatic tool carousel magazine controlled by NC. The CNC machining cell that this paper will focus on consists of two Ralc CNC machining centers. The CNC machining center’s structure is present in Figure 7 and all 5 axes can be seen in Figure 8. Also present in Table 3 are this CNC’s speed characteristics and ranges per axis.

Table 3 - Ralc’s speed characteristics per axis [18]

Axis	Maximum feeding speed	Angular speed	Linear/angular travel
X-axis	80 m/min	-	6700 (± 50) mm
Y-axis	60 m/min	-	1100 (± 50) mm
Z-axis	40 m/min	-	700 mm
A-axis	-	50°/sec	120°
C-axis	-	50°/sec	213°

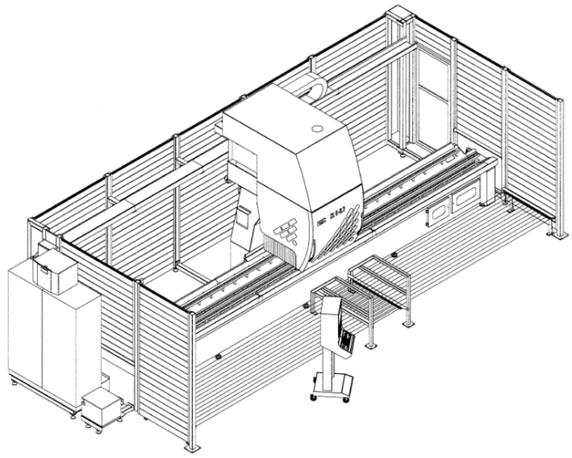


Figure 7 - Scheme of Ralc machining center [17].

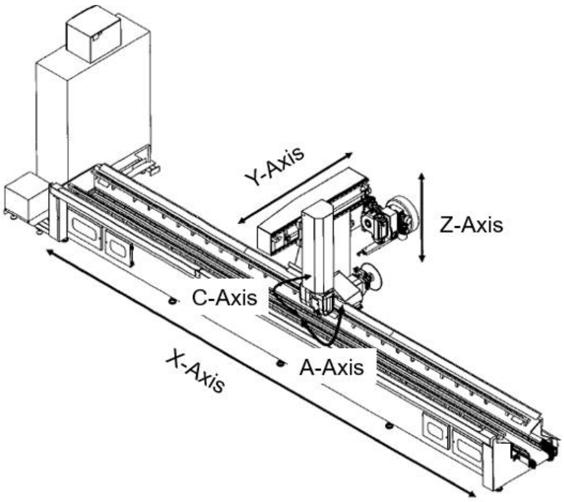


Figure 8 - Scheme of the 5 axes on the Ralc machining center [18].

3.3 Machining cell

The section this work will be focused on is the machining section. Figure 9 shows the processing section (Machining Section 3) where the machining centers are located and marked in red. This section consists of two smaller cells, each with a pair of machining centers facing each other. There is a subsection with Ralcs 4 and 5, and a subsection with Ralcs 6 and 7. The cell in red, present in Figure 9, is the one containing Ralcs 6 and 7, which corresponds to Figure 10, and will be the main focus of this dissertation. The storage, marked in Figure 9 is used for the set-up material and the P1 (Post 1) and P2 (Post 2) are where the machines are programmed by the programmers of the production department, using Mastercam.

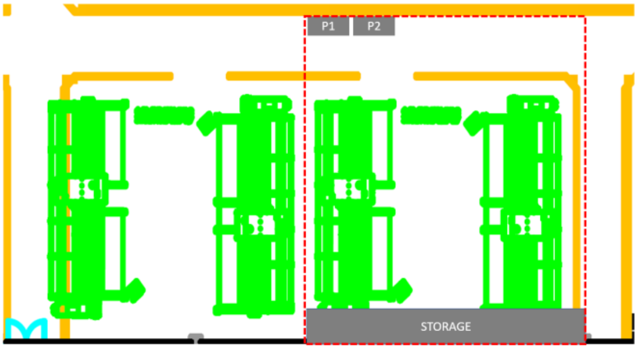


Figure 9 - Machining section containing the Ralcs.

Zooming in on Ralcs 6 and 7, the work zone is also described in detail. The illustration below (Figure 10) shows this sub-area. The BOL (Border of Line) corresponds to the entrance/exit (input/output) location for materials, of each CNC machine. C6 and C7 are the controllers for each CNC machine and the control posts are where quality tests are done. Marked in purple are the gabarits for Model #2 and in orange the ones for Model #1. P7 and P6 are two workstations for manual tasks (such as deburring).

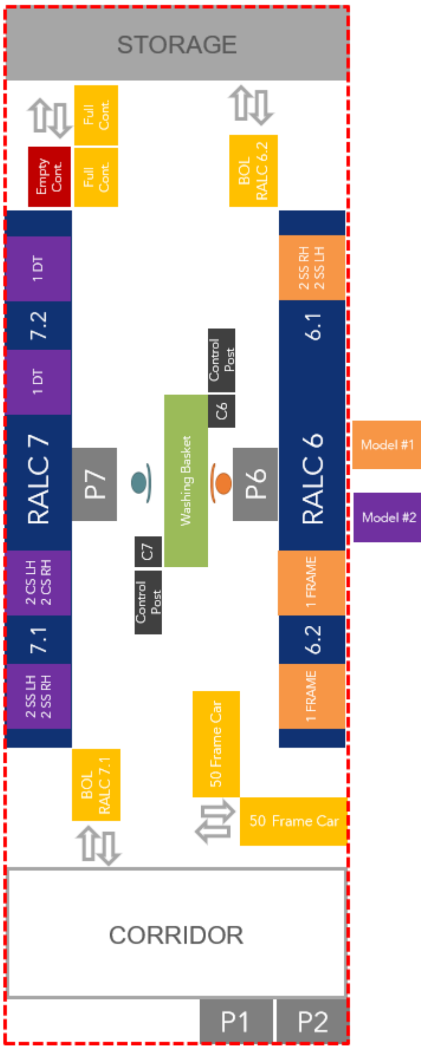


Figure 10 - Scheme of the Ralc 6 and Ralc 7 machining cell.

Each orange or purple square in the previous image represents a gabarit. Each of these squares is shown in one of the following images with the respective parts/work items. In Figure 11, a scheme is presented of the gabarit on the right side of section 7.1 of the machining cell and in Figure 12 the scheme for the left gabarit. In Figure 13 there is a scheme of the two gabarits from section 7.2, in Figure 14 the gabarit from section 6.1 and in Figure 15 the gabarits from section 6.2.

Figure 11 – Two gabarit schemes with 2xCS LH and 2xCS RH from Mode l#2 upwards and 2xCS LH and 2xCS RH from Model #2 sideways (section 7.1).

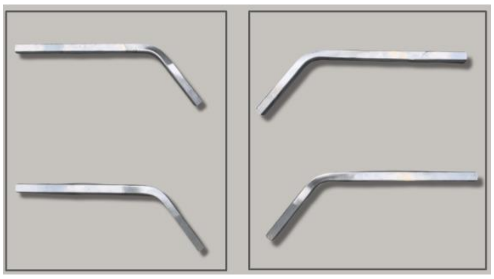


Figure 12 – Two gabarit schemes with work items 2xSS LH and 2xSS RH from Mode l#2 (section 7.1).

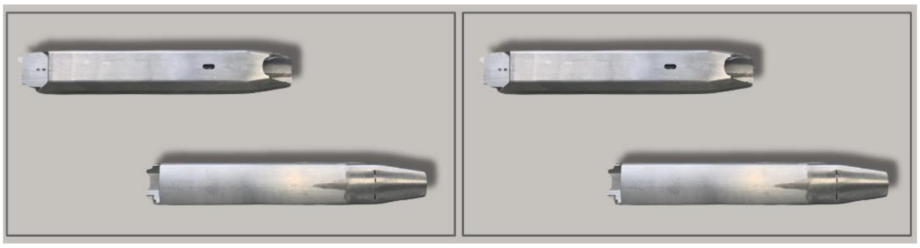


Figure 13 - Two gabarit schemes with work items 2xDT (each) from Model #2 (section 7.2).

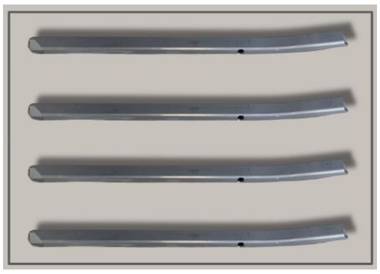


Figure 14 - Gabarit scheme with work items 4xSS from Model #1 (section 6.1).

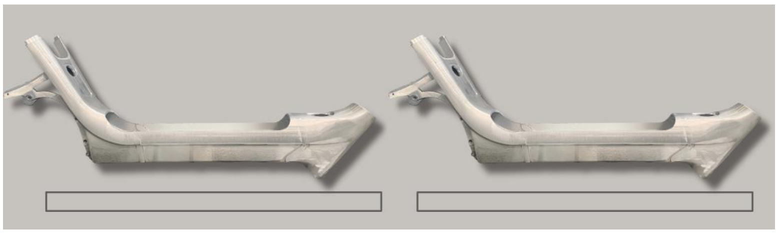


Figure 15 – Two gabarit schemes with work items 2xframes from Model #1 (section 6.2).

The reason why there are 8 CS in Figure 11, even though there are only 4 marked in the scheme present in Figure 10, is because in reality, per cycle only 4 CS are completely machined. This is because each part needs machining on two different surfaces requiring two different orientations. As such, the CS on the right side of the gabarit moves to the left side of the gabarit after being machined the first time. The same happens with the DT: there are two per gabarit on Figure 13, but only one of them leaves the machine finished.

3.4 Information flow

A macro view of factory planning and information flow is briefly presented here. Orders are received by the logistic department, there is an analysis of the quantity by model and date requested, and it is either accepted or a new delivery date is suggested. Once this plan is approved by both parties, a manufacturing order is sent to production. This order is printed and provided to the cutting section of the factory and the washing section of the factory present on the layout in Figure 3, page 9 (because this is where the materials are shipped from first). After these sections, the material is transported directly from section to section in batches (the batch size depends on the product) and with a corresponding QR code label (that corresponds to a manufacturing order). This label allows information to be read if required, such as the contents of the batch, the size of the batch, the corresponding manufacturing order number, where the batch came from (section) and where it is going to, who filled the batch (name of operator) and when. When the batch is complete, a label is printed, and the batch moves to the next section (an operator moves it). Every next section the operator simply reads the QR code and performs the next operation on the batch that has arrived (according to the order in which the batch arrived). Once the operations are completed, the batch receives a new label (printed locally) and is moved to the next station. At this moment there is no ERP (Enterprise Resources Planning) platform being used by Company X, however there is inventory management software. The macro information flow is described in the scheme present in Figure 16.

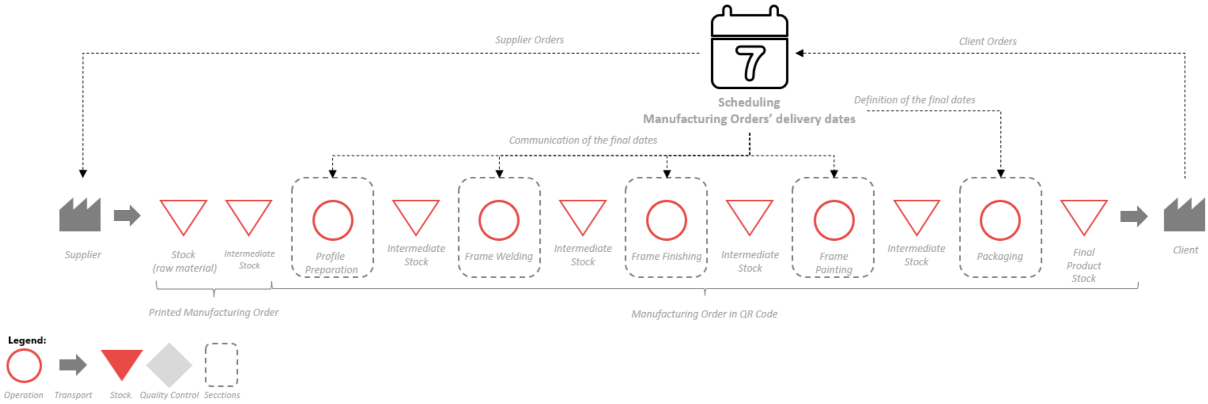


Figure 16 - Macro Information Flow.

3.5 Manual operations in the CNC machining cell

As mentioned earlier, the production order arrives in this department in the form of a QR label that is in the batch of material coming from the previous department (usually the cutting department). There are QR label readers, and the operator reads the label of the batch to find out how many items are in the batch to be produced and what size and model they are. Once this information is found out, the gabarits must be verified and set-up (if required). The stoppers of the gabarits (where the part leans against, when correctly placed) are set/changed (this is a set-up that takes about 10 minutes). Once this is done, the programmer selects the correct NC part program for the model and size in the CNC machine controller (there are many folders arranged by model and then by size). These programs are transferred to the machine, using a memory device. Once the program is selected, the operator starts their standard work, depending on what they are producing. When the previous batch has been processed, a new label is printed in that department and the operator transfers it to the next station. Two computers with Mastercam are available on workstations P1 and P2 (posts 1 and 2) for CNC part programming. The program is developed and created previously in the production department in posts P1 and P2 (present in Figure 10, page 14) and the gabarits are created by the project department (marked in black in Figure 3, page 9). Both departments are in contact and communicate as needed (by phone or e-mail).

Finally, there is one operator for each CNC machining center. The manual operations (operations done in the machining cell by the operator with no use of the CNC machines) are shown in a diagram in Figure 17, each operation is associated with the work parts previously identified in Figure 4 (page 10) and the respective stations and gabarits in each machine (Figure 10, page 14). The arrows indicate where the materials come from and go to. The presence of the operators is also indicated next to each set of operations. Each set of operations is defined as a different colored outline, belonging to one operator, each.

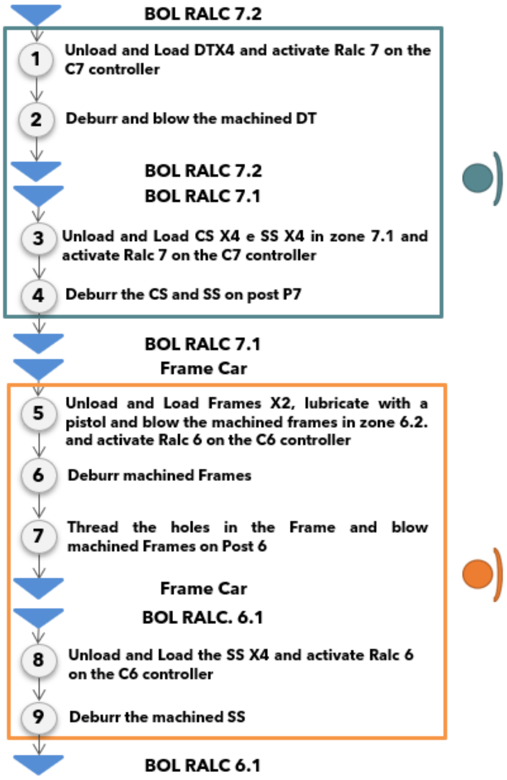


Figure 17 - Manual operations for Ralc 6 and 7.

A special support and tool (for threading) are required for operation 7 to fix the frame while operations are done to it, as can be seen in Figure 18.

Figure 18 – Manual threading of the holes on the frame part (operation 7).

That same support is used in operation 6, for the deburring of the frame (Figure 19), as well.

Figure 19 – Manual deburring of the frame part (operation 6).

Quality control is done every 20 pieces (this frequency follows no statistic rule). This involves measuring and verifying the geometry (through quality control gabarits). The quality control gabarit for the DT of Model #2, machined in section 7.2 of Ralc 7, is present in Figure 20.

Figure 20 - Quality control gabarit for DT of Model #2.

The quality control gabarit for the SS of Model #2, machined in section 7.1 of Ralc 7, is present in Figure 21.

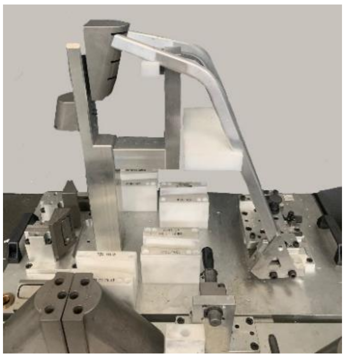


Figure 21 - Quality control gabarit for SS of Model #2.

The quality control gabarit for the CS of Model #2, machined in section 7.1 of Ralc 7, is present in Figure 22.

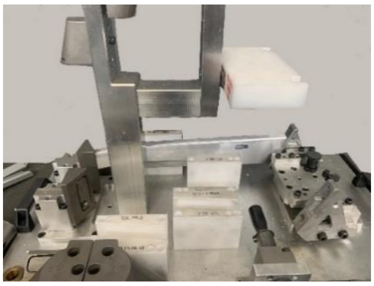


Figure 22 - Quality control gabarit for CS of Model #2.

Both Figures 21 and 22 represent the same gabarit, testing different parts.

The quality control gabarit for the SS of Model #1, machined in section 6.1 of Ralc 6, is present in Figure 23.

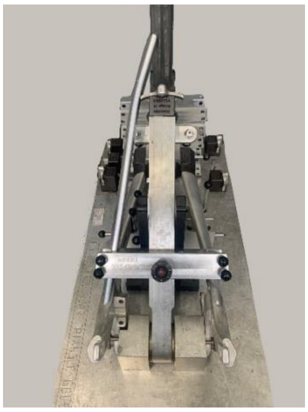


Figure 23 - Quality control gabarit for SS of Model #1.

The quality control gabarit for the frames of Model #1, machined in section 6.2 of Ralc 6, is present in Figure 24.

Figure 24 - Quality control gabarit for the frames of Model #1.

The machine is also attended to when the shift is ending (there are two shifts per day). The machine is cleaned, and oil is replaced.

In Figure 25 is a diagram showing the times of the previously listed manual operations. The most time-consuming operation is the threading of the frames (operation 7).

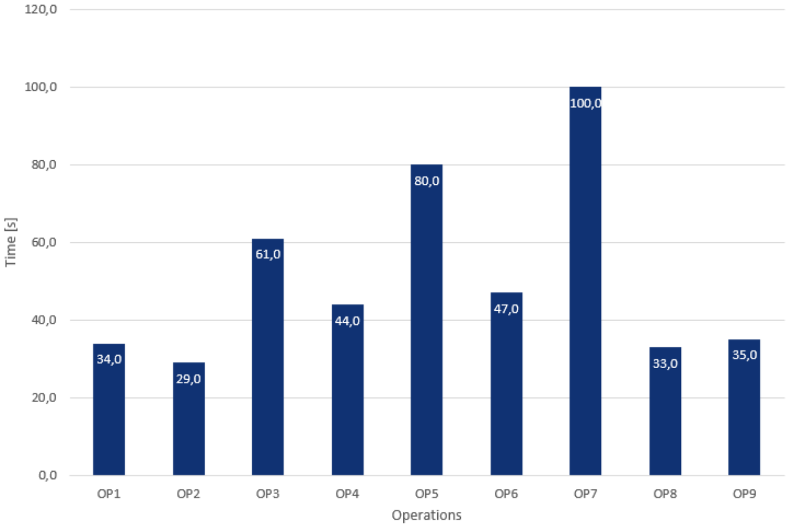


Figure 25 - Time for manual operations [s].

Apart from these operations, there is also a quality control test performed every 20 parts for each different part (which takes about 6 minutes total), and set-up. The latter only involves changing the gabarit's stoppers, as the NC part programs are already downloaded to the machine and just need to be selected (there are many folders on the CNC controller by model and model size). This gabarit set-up takes about 10 minutes total, and all the stoppers are in the storage next to the CNC centers as shown in Figure 10 (page 14). As for the quality control tests, they are done to ensure the geometry of the holes on the DT are correctly done and placed (tested in control gabarit present in Figure 20, page 18), to ensure that the SS's geometry fit and align on the ST and Dropout (Figures 21, page 18, and 23, page 19), that the CS's geometry fit and align on the Dropout and MB (Figure 22, page 18), as well as the nominal dimensions of the frame (Figure 24, page 19).

3.6 Machining operations in the CNC machining cell

Many operations take place in these machining centers, which are mainly used for milling work. They are described in detail in this subsection of the report.

The overall sequence of operations on Ralc 6 is present in Figure 26 and will be further detailed below.

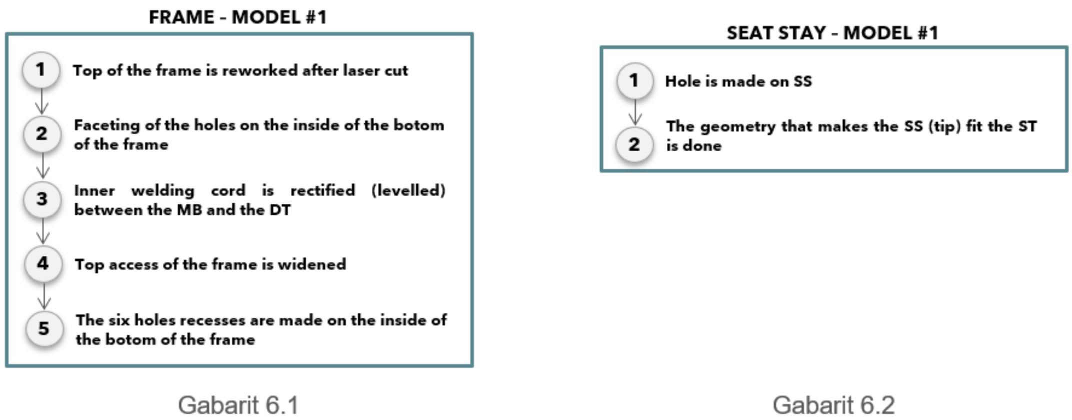


Figure 26 - Machining sequence for Ralc 6.

The overall sequence of operations on Ralc 7 is present in Figure 27 and will also be further detailed below.

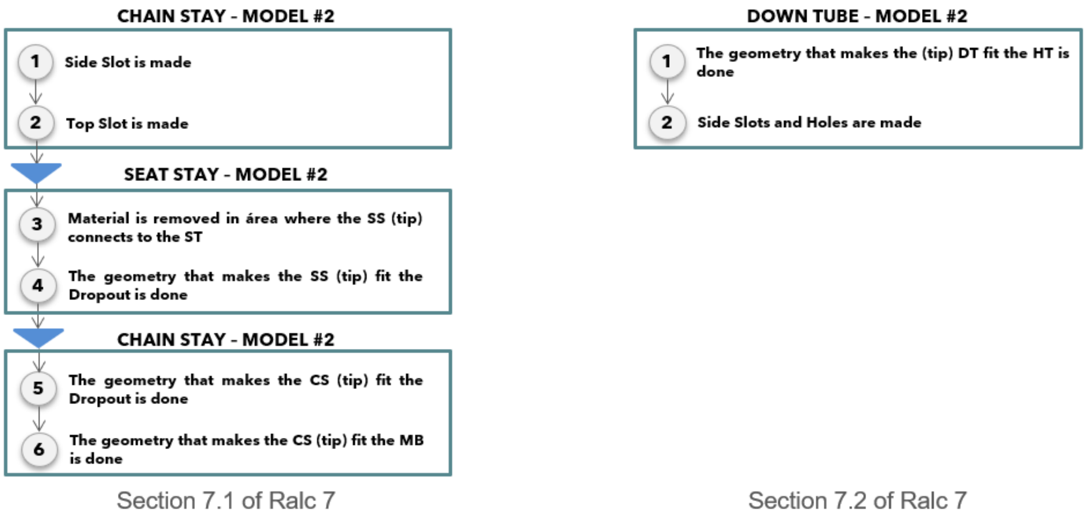


Figure 27 - Machining sequence for Ralc 7.

The machining operations will now be described, per machine and per zone. These are the operations done by the CNCs on the different parts of models #1 and #2, mentioned in Figures 26 and 27.

- **Ralc 7**

- **Zone 7.1**

  - This CNC starts with making the first slot on the CS's side, followed by the slot on the top, which is to the left on the same gabarit (Figure 11, page 15). Both operations are carried out with the 6 mm mill. The described operations are the ones marked in Figure 28.

Figure 28 - Slots on the CS on Model #2.

  - Then the CNC goes to the SS, trims the excess that is not needed and creates the geometry that connects the SS to the ST with a 10 mm mill (done on the gabarit present in Figure 12, page 15, however the parts look different between these figures because they are different sized models). The described operation is the one marked in Figure 29.

Figure 29 - Machining of the SS to fit the ST on Model #2.

  - Then, the geometry of the area where the SS connects to the Dropout is machined with a 16 mm ball end mill to match the geometry of the Dropout (gabarit in Figure 12, page 15). The described operation is the one marked in Figure 30.

Figure 30 - Machining of the SS to fit the Dropouts on Model #2.

  - Machining is done to create the geometry of the CS's connection to the Dropout with a 20 mm custom-made mill (gabarit in Figure 11, page 15). The described operation is the one marked in Figure 31.

Figure 31 - Machining of the CS to fit the Dropout on Model #2.

- Machining is done to create the geometry of the CS's connection to the MB with a 20 mm custom-made mill (gabarit in Figure 11, page 15). The described operation is the one marked in Figure 32.

Figure 32 - Machining of the CS to fit the MB on Model #2.

After completing these machining operations, the machine moves to the second station, where another gabarit is located.

- **Zone 7.2**
  - Here, the CNC machine will machine the surface of the DT's joint area to fit the design of the HT, using a 20 mm custom mill (gabarit in Figure 13, page 15). The described operation is the one marked in Figure 33.

Figure 33 - Machining of the surface of the DT on Model #2.

  - The CNC proceeds to make the side slots and the holes that can be seen in Figure 34 with a 6 mm mill. These holes are for the inserts that will also be brazed later (gabarit in Figure 13, page 15).

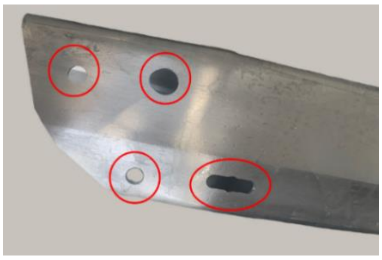


Figure 34 - Machined slots and holes on the DT on Model #2.

- **Ralc 6**
  - **Zone 6.2**
    - Machining on this CNC begins with the first hole drilled in the SS for an insert that will be brazed later, using an 8 mm to 7 mm step drill (gabarit in Figure 14, 15). The described operation is the one marked in Figure 35.

Figure 35 - Machined hole for the SS on Model #1.

- The geometry of the SS to be adapted to the ST is made with a 10 mm mill (Figure 14, page 15). The described operation is the one marked in Figure 36.

Figure 36 - Machining of the SS to fit the ST on Model #1.

After these processing steps have been completed, the machines move to the second station, where the final gabarit is.

- **Zone 6.1**
  - The top of the frame is reworked with a 20 mm mill (gabarit in Figure 15, page 15) after the laser cut, previously performed in the cutting section of the layout (Figure 3). The described operation is the one marked in Figure 37.

Figure 37 - Machining of the top of the DT's surface.

  - Then the faceting of the holes that will have the screws on the MB, with a 20 mm mill. The inner welding cord is rectified (levelled) between the MB and the DT with a 20 mm mill (gabarit in Figure 15, page 15). The described operations are the ones marked in Figure 38.

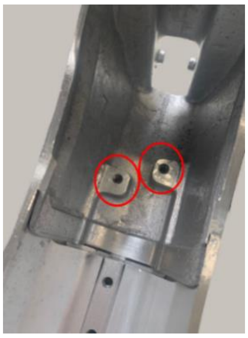


Figure 38 - Machining of the slots on the DT.

  - After this process, the access is widened so that the battery will fit into the frame with a 20 mm mill (gabarit in Figure 15, page 15). The described operation is the one marked in Figure 39.

Figure 39 - Widening of the access to the battery on the DT.

- The six holes (and for each, a small recess) are made, meant for M6 screws, with a 5.5 mm to 6.5 mm combination mill (gabarit in Figure 15, page 15). The described operations are the ones marked in Figure 40 and 41.

Figure 40 - Four of the six holes to be drilled on the DT.

Figure 41 - Two of the six holes to be drilled on the DT.

The process described earlier has been transferred into a diagram for better understanding and interpretation. It is divided into 4 main zones, corresponding to the gabarits, and for each there is a sequence of processes. The most complex processes are those in zones 7.1 and 6.2, as can be seen in Figure 42.

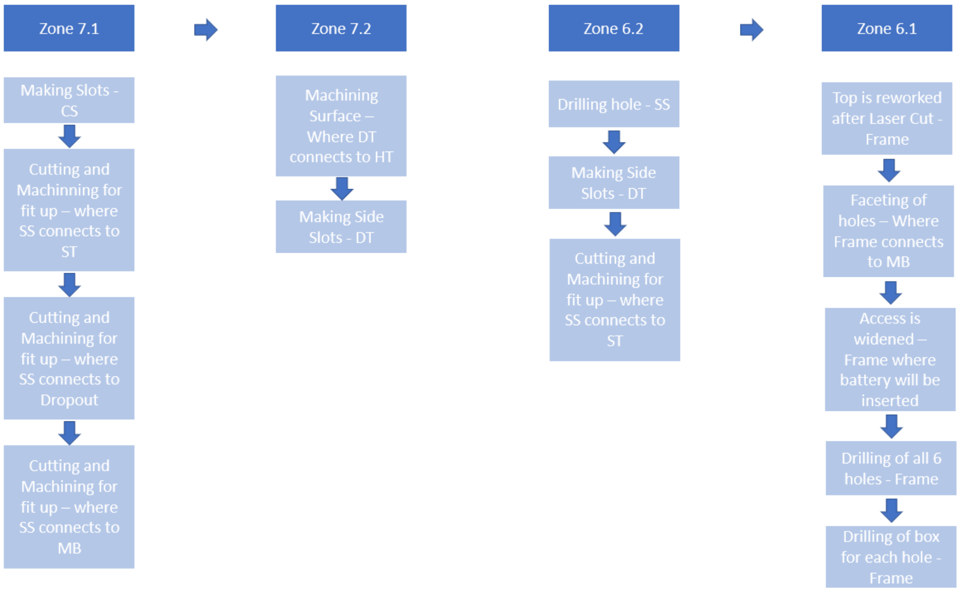


Figure 42 - Machining operations on Ralcs 6 and 7.

The machine times corresponding to the programmed operations on the CNC machines of the cell under study are listed below, again by section on the diagram in Figure 43. Section 7.1 machines the SS and the CS for Model #2, section 7.2 the DT for Model #2, Section 6.1 the SS for Model #1, and Section 6.2 the frames for Model #1, as can be seen in Figure 10 (page 14), presented earlier in this report. The most time-consuming machine sequence is the one in section 7.1 (corresponding to the SS and CS of Model #2).

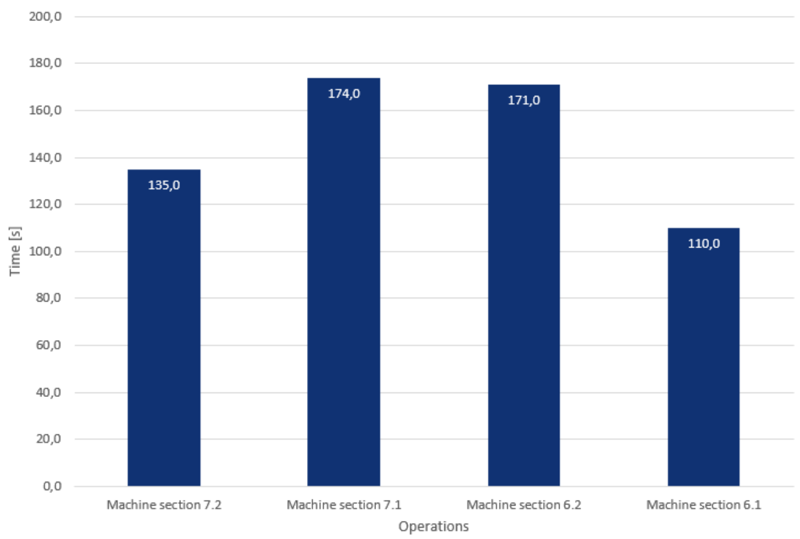


Figure 43 - Time for the machining operations for the cell under study [s].

3.7 Analysis of the current situation

As shown in Figure 44, the percentage of time spent in muda tasks (tasks with no added value) for all the machining centers (machining sections 1 and 3), which correspond to Ralcs 1, 2, 3, 4, 5, 6 and 7 is about 80% and the percentage of tasks with added value is about 20%. Within these 80% of muda tasks, the percentage of time spent overprocessing (operations that do not add the quality, functionality, or performance to the part) is about 82%, time spent moving (by the operators) is nearly 10% and the time spent in transportation (of materials) is about 8%.

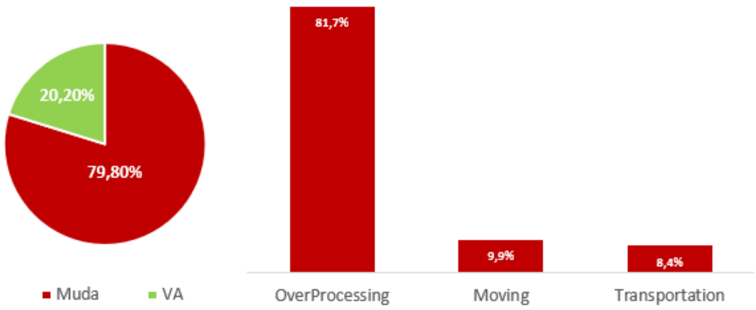


Figure 44 - Description of the current operator tasks for the CNC's under investigation.

As can be seen in Figure 45, 43% of the tasks that are done for the set-up of all the Ralcs have added value and 58% of the tasks are muda. The muda for the CNC's is decomposed in about 56% for overprocessing, 35,7% for movement (of people), 5% for waiting and 3,4% on transportation (of materials).

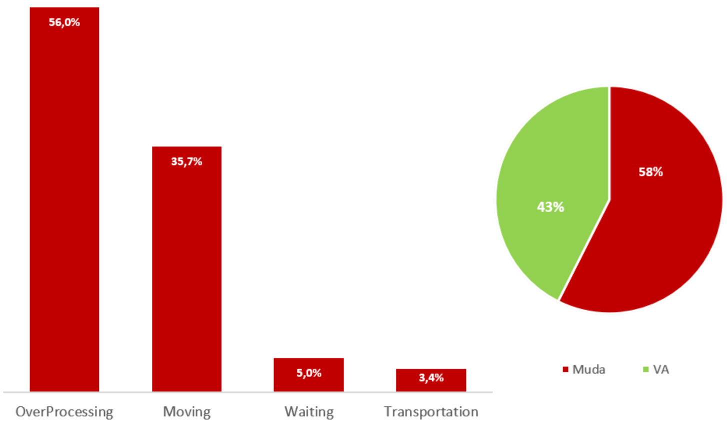


Figure 45 - Machining set-up.

The sum of the machine times (per Ralc) compared to the sum of the operator times (per operator) can be found in Figure 46, along with the takt time of 432 s. This takt time was calculated by dividing the amount of time each machine is working (80% of two 7.5-hour shifts, which is 12 hours) by the amount of frames that are supposed to be machined, per Ralc (100 frames), imposed by the client's demand:

$$Takt\ Time = \frac{12 * 3600\ s}{100\ frames} = 432\ s$$

Only 80% of the time per shift is accounted since the rest is considered time for set-up, transportation and cleaning/maintenance operations. As such, in this machining cell, a frame (or various parts in an amount corresponding to one) must leave each Ralc every 432 s, to keep up the intended production values.

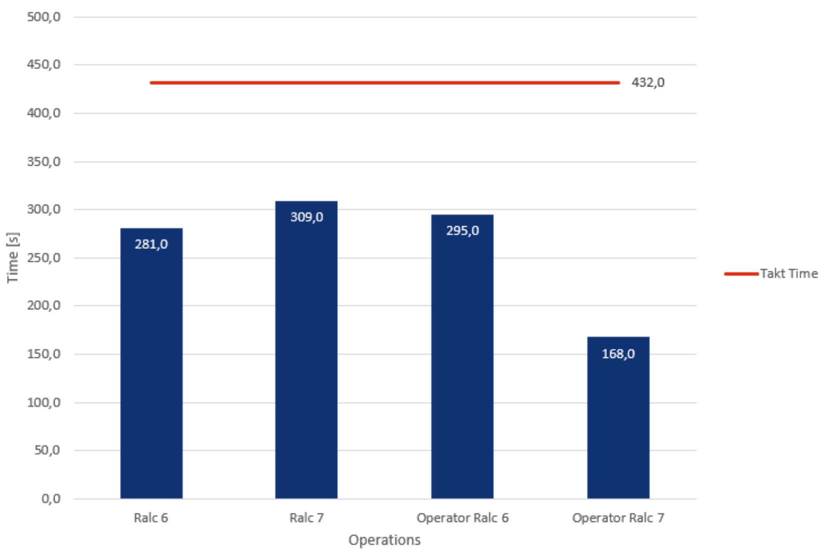


Figure 46 - Initial scenario: manual operation time [s] vs. machine operation time [s].

As can be seen by the graph, takt time was being kept, which meant production was assured. However, both operators were very unbalanced (one had significantly more load than the other).

3.8 Improvement oportunities

The main improvement options considered for this machining cell are listed and briefly described below:

1. Monitoring the pressure on the pneumatic gabarits: The gabarits that fix each part on the Ralc are pneumatic. This raises a safety issue if possible faults in the pneumatic system are not automatically detected/monitored. A suggestion to reduce this possibility would be to monitor the pressure as soon as the machine is activated and set a minimum pressure that allows it to work only when this value is met. If the pressure of the compressed air drops, the machine should be stopped immediately.

2. An automatic and centralized tool warehouse that could act as a small supermarket for the CNC machines: The entire CNC machine department currently has about 124 tools on site. These tools have a high rotation period (they last for about 2500 frames) and need to be replaced regularly in order not to compromise the quality of the parts. The goal is to ensure that these tools never run out of stock, as zero stock would lead to a production stop. As such, there could be a small stock of tools that, once reduced to the minimum stock, would trigger the automated warehouse that is able to get in touch with suppliers. The warehouse would place an order, by email, for the quantity that would be set as the purchasing lot. These quantities could be calculated based on the suppliers' delivery times and tool wear per frame, in order to get to the tool's life spam value. The current tool life can be automatically obtained from the CNC controller. With a network connection, it should be possible to send this information directly to the storage unit, to be compared with the tool's life spam.

3. Additional lubrication or adjustment of the machining parameters of the NC part program: currently, an operator applies additional lubrication by hand with a gun because the lubrication provided by the CNC is not sufficient. The problem could be solved by either reducing the cutting parameters (i.e., feed speed) of the CNC program so that the oil can better cover the part, or by ensuring an external source of lubrication on the part. By doing this, perhaps burr formation would also be reduced, improving machining quality.

4. Include the execution of the tapping operation as an operation at the CNC: tapping is performed manually on the frames. Since one of the goals agreed upon by Kaizen and Company

X is to increase productivity, an effort was made to reduce the number of operators in this machining cell from 2 to 1. To achieve this, a reduction in operator time would be critical. By tapping the frame on the CNC machine instead of doing manual tapping, operator time would be reduced, allowing for 1 operator to have enough time to attend to both Ralcs.

5. Machining an opening in the upper part of the DT: Currently, Company X's customers have asked for an inside weld on frame model #2, for quality reasons. To make it more convenient for the welder to reach the inner areas of the DT, an upper opening should be machined on the DT of this model. This would improve the product quality (for the welding section).

6. Optimize machine set-up: currently the CNC machine set-up time is about 10 minutes. This set-up time only applies to size changes on a specific model, as all CNC Ralc machining centers have a specific model. This set-up includes changing the stoppers for each gabarit to the stoppers corresponding to the new size of the part to be machined. A possible improvement would be to have pneumatic stoppers (with many positions, each position for each size or set-up) so that the set-up could be almost instantaneous.

7. Development of a manufacturing plan that explains step by step how to perform a set-up (changing stoppers and selecting the NC part programs), how to operate in the machining cell, how to perform the quality tests needed and how to do the set-up operations for the quality control gabarits, so that anyone reading it will be able to perform it. Also making a set-up sheet for tools on the CNC so that programmers can change them and know their parameters, per operation.

8. Changing the tools used in the CNC's, especially the mills, more regularly, to decrease burr formation. This would lead to a smaller operator time and better part finish. However, a compromise must be made between tool life, surface finish requirements, and production efficiency, as changing tools more often will mean tool investment and more machine down-time.

The proposed improvements to be implemented in this work are points 4, 5 and 7 in the list above. They were chosen since they were the easiest, fastest and with the most potential. The threading operation was implemented because it served the main objective of improving productivity. The upper opening because part quality is a fundamental aspect for the factory and needed to be improved as fast as possible. Finally, the manufacturing plan did not have such potential (when only applied to one machining cell) however, it would be a fast implementation, that could be taken as an example to be implemented for all CNC machines, to make an impactful result.

4 Implementing the chosen measures

In this chapter, the reasons for implementing the previously suggested measures will be explained, as well as the possible challenges and constraints these measures hold. A plan for implementation of each measure will be made, with a more technical approach, as well as a description of the method to be followed for the new machining operations in terms of tool choices, of gabarit/support choices, of inclusion in the machining sequence and any auxiliary decision-making points for any of these topics. Finally, the implementation process will be shortly described, with an overview of what was implemented among the choices that were previously made. Following this, the performance indicators will be chosen and explained. This is how the success or failure of these implementations will be measured. This section is also where the main objectives for each measure are specified. Finally, the results of each implementation individually and collectively will be analyzed, having assessed the previously defined indicators and the original objectives, for each measure. A conclusion relating to the implementation of said measures will be drawn, having all these points in mind.

4.1 Reasons for implementing the chosen measures

Measure number 4 (to be applied) consists of threading a hole with an M6 thread, on the CNC machine. This operation was being done manually with a tabletop thread tapping machine (this can be seen in Figure 18 (page 17, previously shown). This measure will free up the operator's time. As such, the idea is that if enough time is spared, an operator might be able to attend to both machines instead of having one operator per machine. This would increase productivity (the number of frames made per working hour per person) and decrease the number of people working on this machining cell, saving the equivalent to an operator's salary.

The takt time was calculated for this machining cell (operating time in a day divided by the number of frames per day that need to be made). To uphold the deliveries that need to be made, the takt time must be complied with. This value was attained by calculating the number of hours the machining cell is working (two shifts of 7,5 h with an OEE, Overall Equipment Efficiency, of 80%, which is 12 h) and dividing it by the amount to be produced (100 frames), which comes to 432 s. This takt time would not be followed if the machining cell were to switch to one operator instead of two with the initial scenario. For the takt time to be bigger than the cycle time, manual operation time must decrease 31 s and the machining time in Ralc 6 can improve up to 151 s, as can be seen in Figure 47.

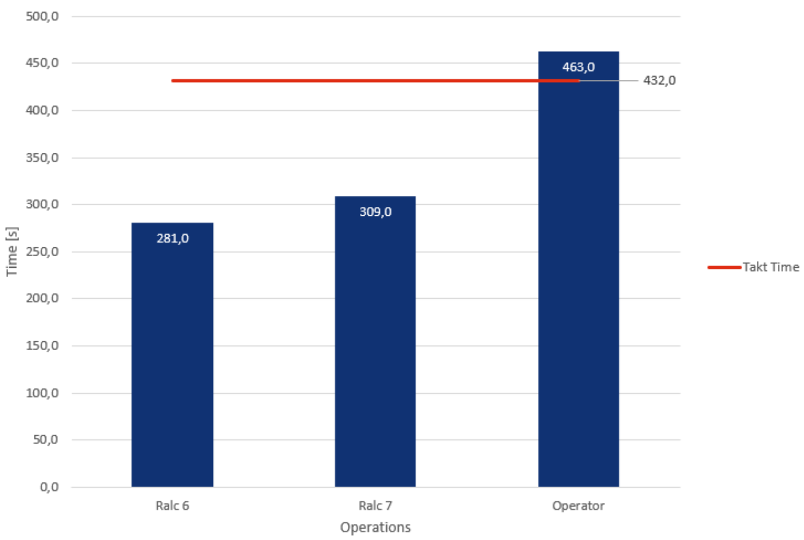


Figure 47 - Initial scenario: manual operation time [s] with one operator vs. machine operation time [s].

Measure number 5 (to be implemented) comes due to the necessity of quality improvement in a station further ahead in the production process. To improve welding quality, the decision to start welding both from outside and inside the frame was made, since only welding from the outside was not yielding the expected results quality wise. To start welding from the inside of the frame as well, a hole had to be made in each DT, big enough for the manual welder to comfortably weld. This process would have to be done in the CNC machining process, and because the CNC machining centers are dedicated per model, and this quality problem came to be on Model #2, the machining cell under study would now have to take on this extra machining operation. As such, an opening on the top part of the DT will be made on section 7.2 of the machining cell.

Once again, this will increase machining time, and must not make the cycle time higher than the calculated takt time of 432 s (leaving only 123 s to do so). With two machining operations to be added to the machining cell, there is a high importance in the efficiency of the NC part program to be made, to allow for the number of operators in this machining cell to be decreased, while still complying with the needed production rates for the company.

Measure number 7 (to be implemented) will allow any operator currently working in the machining cell to perform various set-up tasks on the CNC machining centers. This measure will free up the programmers' time (which is more qualified and more expensive) to perform other tasks that cannot be performed by other people. It also speeds up set-up operations, as the operator must no longer notify the programmers, who then must go to the machining cell (which wastes set-up time). This way, when the manufacturing order is completed, with the help of the manufacturing plan and training, the operators will not have to leave the machining cell. This is because all the stoppers for the gabarit are in the storage present in the same cell and the programs have already been transferred to the CNC machine and only need to be selected.

It will also explain how to operate the machining cell, so that anyone who reads it is equipped to work in the machining cell. Another goal would be for the programmers to be able to change tools in all machines, consulting the set-up sheet, since they only did so in the machines they programed themselves.

4.2 Plan for implementation of tapping operation (measure 4)

When it comes to tool choice, the tools that were already in use for this section of the NC part program are presented in Table 4.

Table 4 - Tools already in use for the Frame machining on Ralc 6

5.5 mm diameter to 6.5 mm diameter combination mill
20 mm diameter medium mill with 3 flutes

However, since no thread-cutting tool for the required diameter was already in use, a new tool had to be chosen. A crushing tap was decided upon, bearing in mind how soft and ductile the material was.

Crushing taps can be used to displace the material rather than remove it to create a thread. This method is suitable for blind holes (which was the case) or situations where chip evacuation is difficult as it reduces the possibility of chip formation. Because the material displaced during tapping can work-harden and increase the thread's resistance to tearing or pulling out, the thread produced with a crushing tap usually has greater strength. In addition, crushing taps may be more economical in terms of manufacturing speed and tooling (longer tool life). Compared to thread cutting, it also results in a smoother inner surface of the thread [19, 20]

As the required diameter corresponded to an M6 screw, the tool selected was an M6 crushing tap.

As for the orientation and fixture for the part, the previous method is maintained. The original fixture (Figure 15, page 15) already displays the top plane to be processed, since it holds the part from its sides, so there is no problem in keeping this method. After the simulation on Mastercam, this will be verified since it is possible that the conjugation between the tool and fixture is not compatible.

When it comes to the insertion of this operation in the operation sequence the main factor considered was that the threading operation could only be done once the holes were created. Because the holes were the last operation done on the frames, this operation was put in last. The new sequence of operations is present in Figure 48, with the added machining operation marked in red.

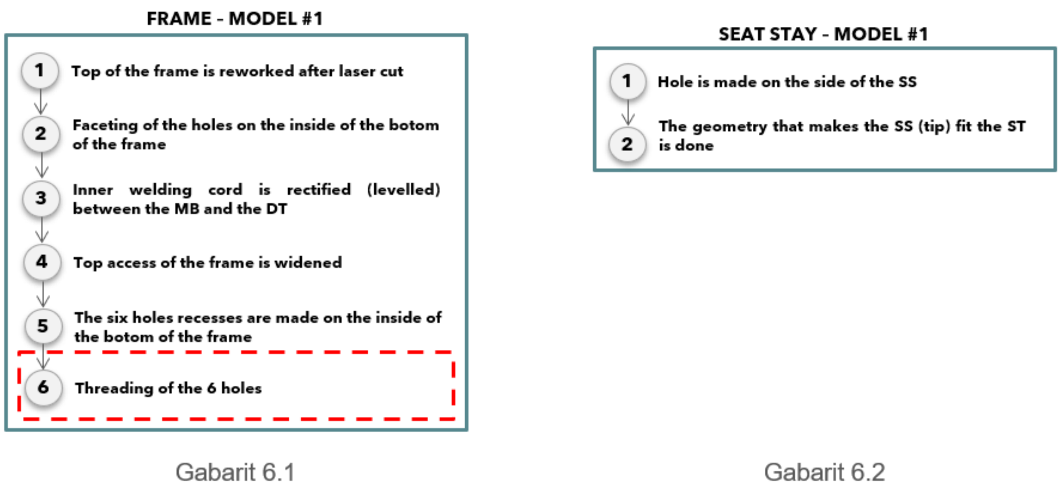


Figure 48 - New machining sequence for Ralc 6 with threading operation.

4.3 Plan for Implementation of Upper Opening (Measure 5)

When it comes to tool choice, the tools that were already in use for this section of the NC part program are presented in Table 5.

Table 5 - Tools already in use for the DT machining on Ralc 7

20 mm diameter medium mill with 3 flutes
6 mm diameter mill with 1 flute

Since the upper opening was very wide, there was no immediate restriction on the diameter enforced by the geometry. Because each automatic tool change can take up to 20 seconds, tool optimization was necessary. As such, the 20 mm mill was chosen instead of a new tool to save machine time and to keep the tool reference list as short as possible (to make it easier to order these tools). An alternative, if these points were not a concern, would be a 20 mm diameter short mill or a 10mm diameter mill, so that it could tolerate a higher feed rate and the machining time could be decreased. The mill is medium in length due to the length of the area on the tip of the DT that is machined in a previous operation (Figure 33, page 22, and Figure 50).

As for the fixture for the part, once again, the areas to be machined (holes) are already exposed in one of the previously used orientations (marked in red in Figure 49), so it should not be a problem to keep this method (especially since the trajectory for tapping is the same as for making the hole, which has already been done with this fixture). However, this must be verified in the simulation on Mastercam with the selected tool.

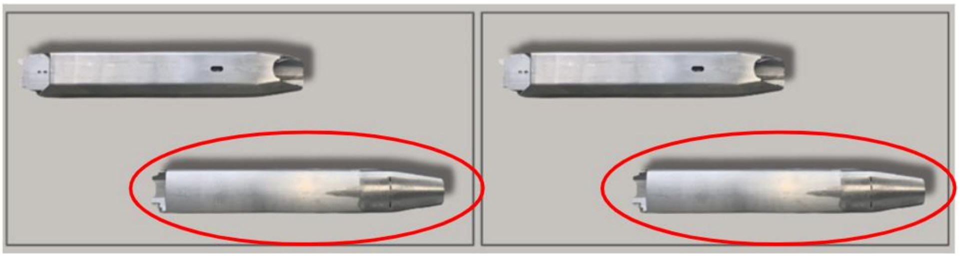


Figure 49 - Chosen orientation for upper opening operation.

As for the insertion of this operation on the sequence of machine operations, this was placed in as the first operation. As such, the top opening was put first and is followed by the fitting operation of the DT to the HT (Figure 33, page 22) with the same tool, but at a different tool plane (angled), that can be seen in Figure 50.

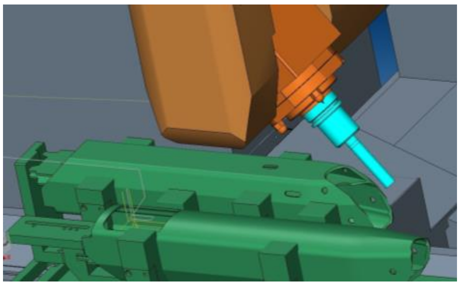


Figure 50 - Machining simulation for Ralc 7 of the DT fitting to the HT.

These two operations would always have to be in sequence since they share the same tool. The new sequence of operations is present in Figure 51, with the added machining operation marked in red.

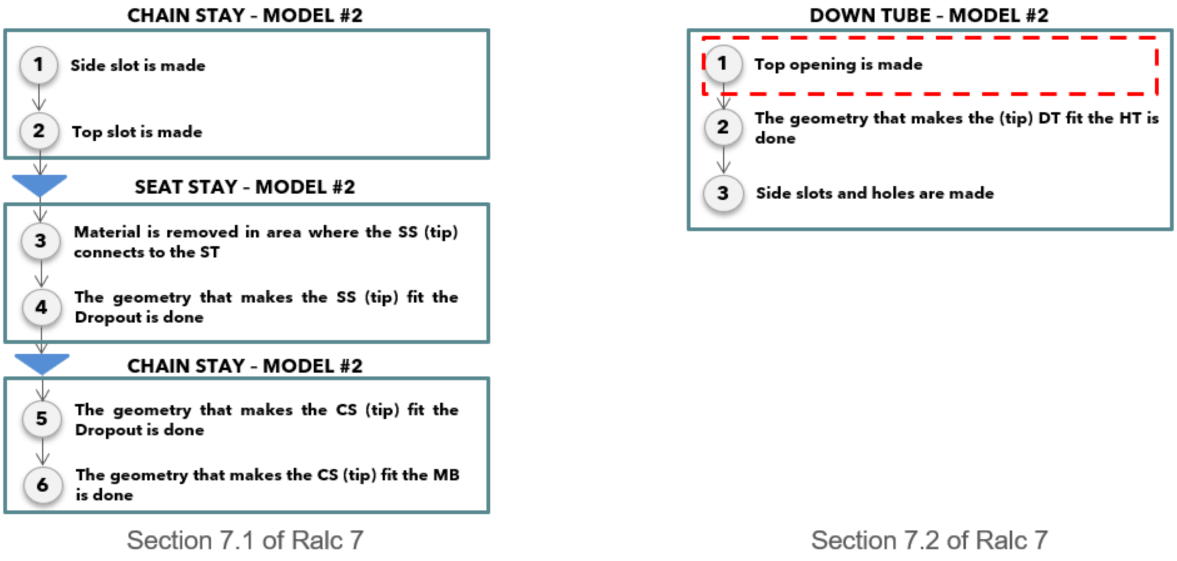


Figure 51 - New machining sequence for Ralc 7 with top opening operation.

4.4 Plan for implementation for manufacturing plan (measure 7)

This had to be the last implemented measure because it was necessary for the machining cell to be working with the previously mentioned measures (4 and 5). It was also necessary to know whether the machining cell would be working with either one or two operators. Tasks would also have to be balanced between operators.

The plan for this implementation would be to accompany the work in the machining cell, take pictures and categorize every set-up, quality control and normal operating procedure/action.

After this, they would have to be timed and sequenced, consulting the operators and using good judgement.

Finally, the company's working instruction template would be used as a base, and a manufacturing plan would be made for each of the two models in the machining cell and each of the parts or gabarits, except of course for the normal machining operations (as they would include the whole machining cell).

As for the programmer's set-up sheet, this would be exported from Mastercam after all editing and simulations of the NC part programs had been done.

The operator's manufacturing plan would be divided into four different documents: the quality control procedure per part, the normal operating procedure for the machining cell, the set-up for the machines (per part), the set-up of the quality control gabarits (per part). The set-up sheet (for the programmers to use) would be a separate document.

After being completed, they would be confirmed by the main responsible of the machining section, the programmer and confirmed visually (accompanying the operator's usual work). When validated, they would be printed, put in covers and fixed on the machining cell.

4.5 Implementation of tapping operation (measure 4) and of upper opening (measure 5)

The new model files created in the Creo software were received from the project office as a STEP (Standard for the Exchange of Product model data) file. These files already contained the new implementations (both the upper opening and the thread) as well as the gabarits and stoppers. The NC part programs were first created for the largest and smallest model sizes (after these are validated, all other sizes are programmed and imported into the machine). All auxiliary lines/axes and unnecessary solids are hidden or deleted in the file that is opened in Mastercam. Then, the gabarit and everything in it is positioned in the correct orientation (top plane upward). Then the zero point for the NC part program is usually selected (in both cases the previous ones were maintained). Then, all auxiliary planes/lines needed for programming the trajectories were created, the trajectories and tools were selected. These three steps are iterative and simultaneous, as they are all interdependent. For this, the notion of where the gantry comes from (right or left) and where the gantry goes (right or left) is fundamental. The orientation in which the part is fixed has been previously defined by the project department in the Creo file, and in both cases, there was no need for adjustment. Each tool also has associated standard machining parameters that have been previously defined in consultation with the tool manufacturer and based on the experience from previous NC programs. In many cases, the parameters defined by the manufacturer were developed for blocks and not for tubes (as is the case for all machining operations in this company), so many iterations are often required when defining these machining parameters.

After defining the previously chosen tools, machining operation sequences, fixtures for the parts, trajectories and machining parameters, a simulation was run in Mastercam to evaluate possible collisions and adjust the trajectories if necessary.

Upon this simulation a problem was encountered with the threading operation of the Frame in Ralc 6. The CNC was colliding with the part on the threading operation, as can be seen in Figure 52.

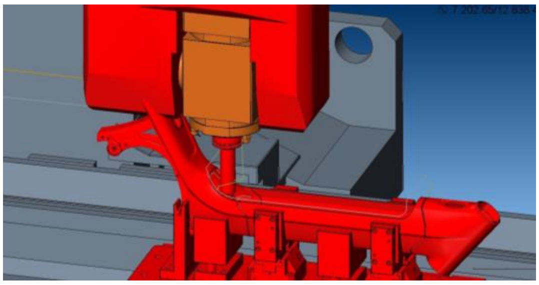


Figure 52 - Simulation of threading operation on a Frame on Ralc 6.

To solve this, the C-axis had to be rotated 90°, so that the CNC’s gantry would not collide with the frame when threading the holes.

After this, both simulations showed no problems. If the gabarits for production and for quality testing were different this would be the stage where they would begin to be produced internally. In this case no alterations to the gabarit had to be placed since the fixtures for the parts were not altered. For the tool location, the nearest vacant location to the previously used tool was chosen so that the tool changer would have to turn as little as possible (to not waste machining time). The NC part program was, then, generated by Mastercam using the respective postprocessor and revised by the programmer. The origin point/zero point of the program was inserted manually and corresponds to the one previously defined on Mastercam (that had no alteration as it is a fixed point in the CNC machine’s worktable). Finally, the code was transferred to a USB drive and copied into the appropriate folder. All NC programs are organized on the CNC controller by size (for model #1 there are 6 sizes and for model #2 there are 4 sizes). Overall, there is a NC program for model and for each different size (6 on Ralc 6 and 4 on Ralc 7).

The first tests on the CNC machine were performed with the default parameters for tool processing. These parameters were then adjusted, and the tests were assessed in the gabarit for quality testing. Once the parameters were adjusted and the control gabarit approved the tested parts, they were sent for further internal testing and approval by the customer. Once both approvals were received, the final version of the NC program was transferred to the machine. After this, the NC program was adjusted to the remaining sizes of the model.

After all sizes were transferred and placed in the appropriate folders on the CNC controllers, production began, and the CNC machine line continued with the implemented alterations.

The implemented threading operation on Ralc 6, corresponding to Measure 4, is shown in Figure 53 below.

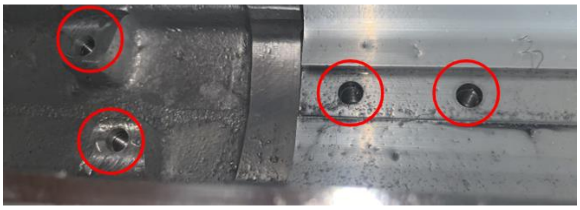


Figure 53 - Implementation of Measure 4.

The implemented top opening operation on Ralc 7, corresponding to Measure 5, is shown in Figure 54 below.

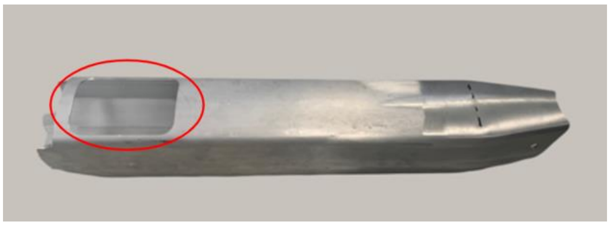


Figure 54 - Implementation of Measure 5.

As for machining parameters, the threading operation was done with a feed rate of 1000 mm/min and the upper opening with 2500 mm/min. The spindle speed for the threading operation was 17500 rpm and for the upper opening was 1000 rpm. To reach these values, the programmer started with the indicated parameters for the specified tools, given by the tool manufacturer. Once testing began, they were adjusted to improve part quality.

4.6 Implementation of manufacturing plan (measure 7)

The operator's work instruction for the machining cell, the machining set-up, the quality control set-up and the quality control work instruction documents would together make up the operator's manufacturing plan. An example will be show of a manufacturing plan implemented for the SS of Model #2 and a set-up sheet for the CS of Model #2. The cover for the manufacturing plan for the SS can be seen in Figure 55.

COMPANY X CODIFICAÇÃO

PLANO DE FABRICO DO OPERADOR

PEÇA: SEAT STAYS

MODELO: MODELO #2

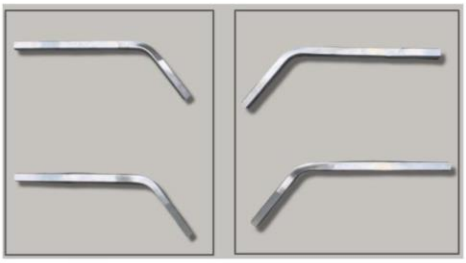


Figure 55 - Operator's manufacturing plan cover for the SS of Model #2.

The cover has a field to write the part name and model. The manufacturing plan was divided by part, for all sizes of the model.

The implementation of this measure required that the previously mentioned measures (4 and 5) be carried out so that the work instructions would be as up to date as possible. It was also necessary to check if it would be possible to work with only one operator or if this manufacturing plan still had to count on two operators for the machining cell.

After concluding that only one operator was needed with the changes made, the manufacturing plan was created. An example of each document is presented for the manufacturing plan. They are all in Portuguese since the factory is in Portugal. As for the regular workflow for the machining center, the instructions for operating are included in Figures 56, 57 and 58. This document is 3 pages long, however, a conscious effort was made to keep the number of pages to a minimum so that it is not too visually overwhelming.

On this document there is some initial information regarding the objective and application field for the document, the necessary equipment (for protection and for work) and the procedure. In the end of the document, there is a field to fill out regarding responsibility, registration, and other notes. These fields are common to all documents except the set-up sheet, as they are part of the template provided by the company for work instructions.

Initially, on the procedure section there are two schemes that show the overall flow of the operator from gabarit to gabarit and the locations of each task they perform. For the locations, the number of the operation is used on the machining cell scheme to show where the task is performed. If a task is performed in more than one place, then the number used on the scheme will appear as n.1 for the first location, n.2 for the second location and so on, being n the number of the operation present in the table. The table has the following fields: Number (of the operation, to indicate order), description, tool, localization, time (how long this task should take to perform) and figure (for a graphic representation of the operation).

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Operação - Maquinação Ralc 6 e 7

1. Objetivo e campo de aplicação

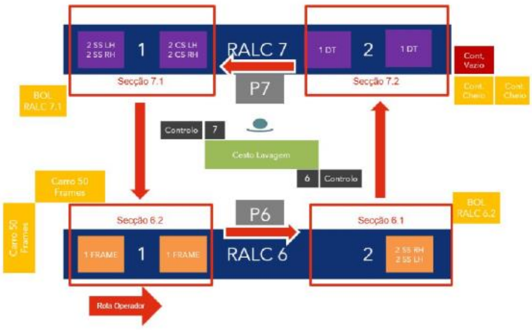
Linha de Maquinação da Ralc 6 e 7.

2. Equipamento Necessário

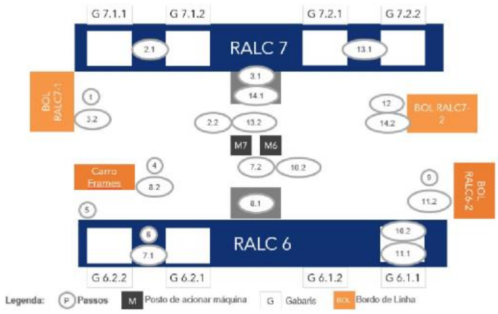
Auscultadores industriais, luvas de proteção, sapatos de segurança, tira-rebarbas, pistola de lubrificação e pistola pneumática.

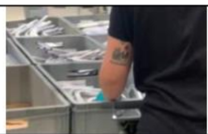
3. Modo de Proceder

Fluxo do operador:



Passos a seguir – Passo 1 a 14:



Nº	Descrição	Ferramenta	Localização	Tempo	Figura
	Todas as operações			**363 s**	
1	Pegar nos 2 Chain Stays e nos 2 Seat Stays	-	RALC 7 (Posto 1): BOL RALC7 - 1	10 s	
2	Retirar os artigos maquinados, fixar os artigos por maquinar nos gabaris e acionar a máquina	-	RALC 7 (Posto 1): G 7.1.1 e G 7.1.2	51 s	 

Mod.003.00

Página 1 de 3

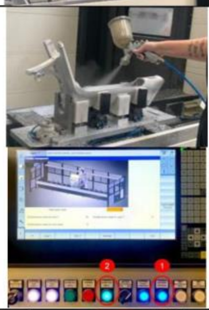
Figure 56 - Manufacturing plan example: operations in Ralc 6 and 7 (page 1).

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Operação - Maquinação Ralc 6 e 7

Nº	Descrição	Ferramenta	Localização	Tempo	Figura
3	Rebarbar os artigos maquinados e colocar na zona de saída	Tira-Rebarbas	RALC 7 (Posto 1): BOL RALC7 – 1; P7	44 s	
4	Pegar nos 2 Frames que estão na zona de entrada	-	RALC 6 (Posto 2): Carro Frames	10 s	
5	Soprar os Frames maquinados	Pistola pneumática	RALC 6 (Posto 2)	6 s	
6	Retirar os Frames maquinados, colocar os freios nos Frames por maquinar e fixá-los no gabari	-	RALC 6 (Posto 2): G 6.2.1 e G 6.2.2	56 s	
7	Lubrificar os Frames por maquinar com pistola e acionar a máquina	Pistola de Lubrificação	RALC 6 (Posto 2): G 6.2.1 e G 6.2.2	8 s	
8	Rebarbar os Frames maquinados, soprá-los e colocá-los na zona de saída	Tira-Rebarbas; Pistola pneumática	RALC 6 (Posto 2): P6; Carro Frames	47 s	

Mod.003.00

Página 2 de 3

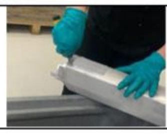
Figure 57 - Manufacturing plan example: operations in Ralc 6 and 7 (page 2).

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Operação - Maquinação Ralc 6 e 7

Nº	Descrição	Ferramenta	Localização	Tempo	Figura
9	Pegar nos 4 Seat Stays que estão na zona de entrada	-	RALC 6 (Posto 1): BOL RALC6-2	7 s	
10	Retirar os artigos maquinados, fixar no gabari os artigos por maquinar e acionar máquina	-	RALC 6 (Posto 1): G 6.1.1	26 s	
11	Rebarbar os Seat Stays maquinados, soprá-los e colocá-los na zona de saída	Tira-Rebarbas; Pistola pneumática	RALC 6 (Posto 1): P6; BOL RALC6-2	35 s	 
12	Pegar nos 4 Down Tubes que estão na zona de entrada	-	RALC 7 (Posto 2): BOL RALC7-2	10 s	
13	Retirar os artigos maquinados, fixar no gabari os artigos por maquinar e acionar máquina	-	RALC 7 (Posto 2): G 7.2.1 e G 7.2.2	24 s	
14	Rebarbar os Down Tubes maquinados, soprá-los e colocá-los na zona de saída	Tira-Rebarbas; Pistola pneumática	RALC 7 (Posto 2): P6; BOL RALC7-2	29 s	

1. **Responsabilidade**

2. **Registos**

NA.

3. **Notas**

NA.

Elaborado:

Aprovado: Data de aprovação:

Mod.003.00 Página 3 de 3

Figure 58 - Manufacturing plan example: operations in Ralc 6 and 7 (page 3).

Another document made was the set-up instruction for the machining equipment. This document explains how to change the stoppers and select a new NC part program on the machine’s controller. The overall structure of the document remains the same and the table used to describe the process also maintains the same fields as the ones mentioned previously. No set-up is necessary regarding the zero point for the NC part program, since this point never changes and is located on the CNC machine's worktable. This document has 2 pages, and they are shown in Figures 59 and 60.

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Set up de Maquinação: Seat Stays da Ralc 7

1. Objetivo e campo de aplicação

Set up para a Linha de Maquinação de Seat Stays na RALC 7.

2. Equipamento Necessário

Auscultadores industriais, luvas de proteção, sapatos de segurança, tira-rebarbas e pistola de lubrificação.

3. Modo de Proceder

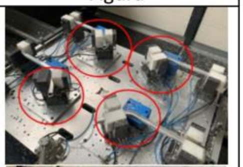
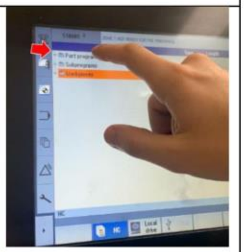
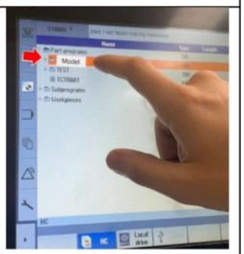
Nº	Descrição	Ferramenta	Localização	Tempo	Figura
1	Realiza-se a troca dos batentes. Para a troca desapertam-se os parafusos de cada e coloca-se o batente correspondente (identificado com o tamanho) e coloca-se na disposição marcada na mesa com a identificação desse mesmo tamanho (identificação assinalada com círculo e orientação com seta).	Chave Allen	RALC 7 (Posto 1): G 7.1	180 s	 
2	Realiza-se a troca de programas. Seleciona-se a pasta Workpieces.	Controlador Ralc 7	7	3 s	
3	Seleciona-se a pasta correspondente ao modelo desejado.	Controlador Ralc 7	7	3 s	
4	Seleciona-se a pasta correspondente ao tamanho desejado (Main): _MAIN_*modelo#2*_tamanho	Controlador Ralc 7	7	3 s	

Figure 59 - Manufacturing plan example: machining set-up for SS in Ralc 7 (page 1).

COMPANY X CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Set up de Maquinação: Seat Stays da Ralc 7

1. **Responsabilidade**

2. **Registos**

NA.

3. **Notas**

NA.

Elaborado:
Aprovado: Data de aprovação:

Figure 60 - Manufacturing plan example: machining set-up for SS in Ralc 7 (page 2).

Another document was the set-up instruction for the quality control equipment. This document explains how to change the stoppers for the control gabarit. The overall structure of the document remains the same and the table used to describe the process also maintains the same fields as the one mentioned previously. There is a scheme used to mark the important locations, that are later mentioned on the table. This document has 1 page that can be seen in Figure 61.

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Set up Qualidade – Seat Stays da Ralc 7

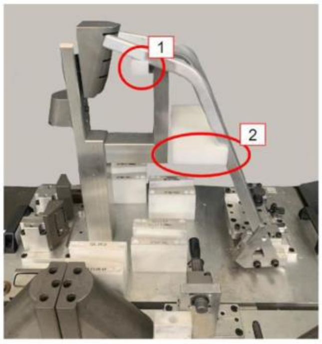
1. Objetivo e campo de aplicação

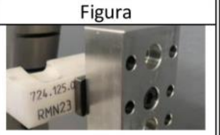
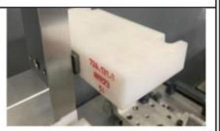
Set up do Gabarit de qualidade para os Seat Stays da Ralc 7.

2. Equipamento Necessário

Auscultadores industriais, luvas de proteção, sapatos de segurança, tira-rebarbas e pistola de lubrificação.

3. Modo de Proceder



Nº	Descrição	Ferramenta	Localização	Tempo	Figura
1	Trocar a peça 1 pela peça que que está identificada com o tamanho correto: desapertar parafusos, substituir por nova e apertar parafusos.	Chave Allen	Posto de Controlo 7: 1	40 s	
2	Trocar a peça 2 pela peça que que está identificada com o tamanho correto: desapertar parafusos, substituir por nova e apertar parafusos.	Chave Allen	Posto de Controlo 7: 2	40 s	

1. Responsabilidade

2. Registos

NA.

3. Notas

NA.

Elaborado:

Aprovado: Data de aprovação:

Mod.003.00 Página 1 de 1

Figure 61 - Manufacturing plan example: quality control set-up for SS in Ralc 7.

Finally, the last document made was the quality control instruction. This document explains how to execute the quality control for the parts machined in this section. The overall structure of the document remains the same, however, the table used to describe the process only has the fields “Tool”, “Location” and “Time” since there is only one operation described in this document. This document has 1 page and can be seen in Figure 62.

COMPANY X

CODIFICAÇÃO

INSTRUÇÃO DE TRABALHO

Qualidade – Seat Stays na Ralc 7

1. Objetivo e campo de aplicação

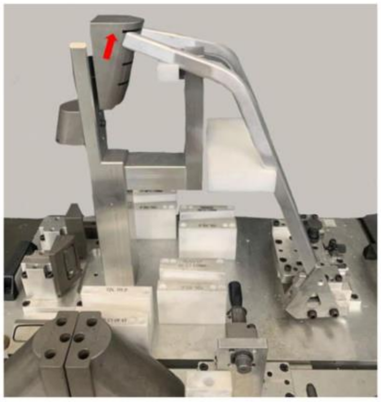
Verificação de qualidade para os Seat Stays da Ralc 7.

2. Equipamento Necessário

Auscultadores industriais, luvas de proteção, sapatos de segurança, tira-rebarbas e pistola de lubrificação.

3. Modo de Proceder

- Colocam-se os pares de Seat Stays como mostra a Figura. Se estiver abaixo da linha com o tamanho do Seat Stay assinalado, então passou no teste de qualidade.



Ferramenta	Localização	Tempo
Gabarit de Qualidade dos Chain Stays e Seat Stays da Ralc 7	Posto Controlo 7	20 s

1. Responsabilidade

2. Registos

NA.

3. Notas

NA.

Elaborado:

Aprovado: Data de aprovação:

Mod.003.00 Página 1 de 1

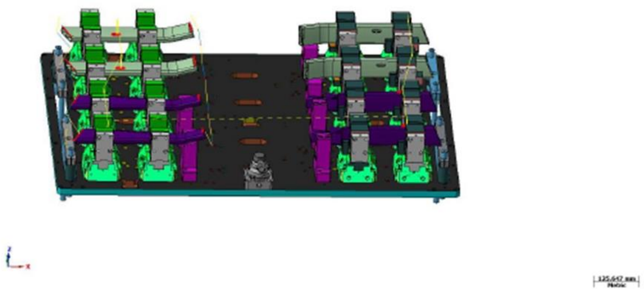
Figure 62 - Manufacturing Plan Example: quality control for SS in Ralc 7.

Besides the operator's manufacturing plan, a set-up sheet was also exported and adapted from Mastercam to help the programmers with tool changing, for instance. In this document, machining parameters, tools, holders, and machining times per operation are shown, as can be seen in the Figures below. This document has 7 pages and an example of a set-up sheet for the CS of Model #2 can be seen in Figures 63 to 69. Each set-up sheet would correspond to a part and size (corresponding to part of an NC program, identified in the cover of the sheet). The fields "project name" (NC part program's name), "customer name", "programmer", "drawing" (Creo file in STEP format), "date", and "time" must be filled out. The fields "part", "model" and “size” identify the part being machined. Any comments can be written on the comment section present on page 1 of this document.

Mastercam Setup Sheet Report

GENERAL INFORMATION

PROJECT NAME: CS_*model#2*_53	PART: CHAIN STAY
CUSTOMER NAME:	MODEL: MODEL #2
PROGRAMMER:	SIZE: 53
DRAWING: CS_*model#2*_53	
DATE:	
TIME:	



COMMENTS

The drawing corresponds to the Creo file in STEP format used to make the NC part program.

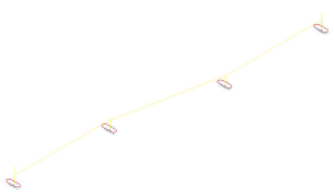
Figure 63 - Set-up sheet made in Mastercam for CS of Model #2 (page 1).

OPERATION LIST

OPERATION INFO 1 - Contour (2D)

CYCLE TIME:	0 HOURS, 0 MINUTES, 13 SECONDS
COMMENT:	

PROGRAM NUMBER:	0
SPINDLE SPEED:	18000 RPM
FEEDRATE:	1500.0 mm/min
CLEARANCE PLANE:	30.0
RETRACT PLANE:	20.0
FEED PLANE:	1.0
DEPTH:	-5.0
STOCK TO LEAVE:	0.0
COMP TO TIP:	YES
WORK OFFSET:	0



TOOL INFO 6 Flat Endmill

TYPE:	Flat endmill
NUMBER:	6
DIAMETER:	6.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	6
DIAMETER OFFSET:	6
MATERIAL:	Carbide
NUMBER OF FLUTES:	1
FPT: 0.072	SFM: 339.303
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C4F0016 C:
TIME:	00:00:13

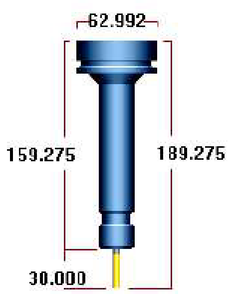
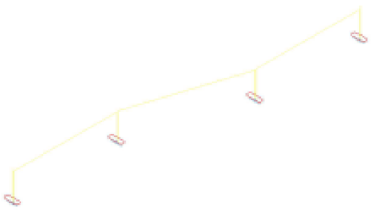


Figure 64 - Set-up sheet made in Mastercam for CS of Model #2 (page 2).

OPERATION INFO	2 - Contour (2D)
CYCLE TIME:	0 HOURS, 0 MINUTES, 14 SECONDS
COMMENT:	

PROGRAM NUMBER:	0
SPINDLE SPEED:	18000 RPM
FEEDRATE:	1500.0 mm/min
CLEARANCE PLANE:	50.0
RETRACT PLANE:	50.0
FEED PLANE:	1.0
DEPTH:	-5.0
STOCK TO LEAVE:	0.0
COMP TO TIP:	YES
WORK OFFSET:	0



TOOL INFO	6 Flat Endmill
TYPE:	Flat endmill
NUMBER:	6
DIAMETER:	6.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	6
DIAMETER OFFSET:	6
MATERIAL:	Carbide
NUMBER OF FLUTES:	1
FPT: 0.072	SFM: 339.303
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C4F0016 C:
TIME:	00:00:14

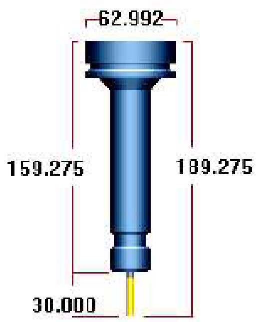
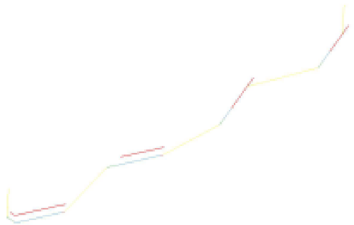


Figure 65 – Set-Up sheet made in Mastercam for CS of Model #2 (page 3).

OPERATION INFO	3 - Contour (2D)
CYCLE TIME:	0 HOURS, 0 MINUTES, 9 SECONDS
COMMENT:	

PROGRAM NUMBER:	0
SPINDLE SPEED:	17500 RPM
FEEDRATE:	2500.0 mm/min
CLEARANCE PLANE:	50.0
RETRACT PLANE:	0.0
FEED PLANE:	-22.0
DEPTH:	-22.0
STOCK TO LEAVE:	0.0
COMP TO TIP:	YES
WORK OFFSET:	1



TOOL INFO	20 Flat Endmill
TYPE:	Flat endmill
NUMBER:	1
DIAMETER:	20.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	1
DIAMETER OFFSET:	1
MATERIAL:	Carbide
NUMBER OF FLUTES:	5
FPT: 0.029	SFM: 1099.592
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C3F0032 C:
TIME:	00:00:09

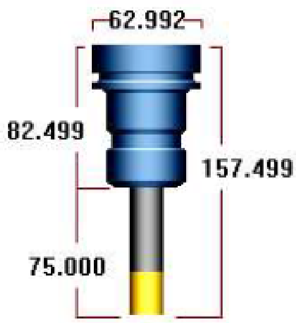


Figure 66 - Set-up sheet made in Mastercam for CS of Model #2 (page 4).

OPERATION INFO	4 - Contour (2D)
CYCLE TIME:	0 HOURS, 0 MINUTES, 7 SECONDS
COMMENT:	

PROGRAM NUMBER:	0
SPINDLE SPEED:	17500 RPM
FEEDRATE:	2500.0 mm/min
CLEARANCE PLANE:	50.0
RETRACT PLANE:	0.0
FEED PLANE:	-40.0
DEPTH:	-40.0
STOCK TO LEAVE:	0.0
COMP TO TIP:	YES
WORK OFFSET:	2

TOOL INFO	20 Flat Endmill
TYPE:	Flat endmill
NUMBER:	1
DIAMETER:	20.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	1
DIAMETER OFFSET:	1
MATERIAL:	Carbide
NUMBER OF FLUTES:	5
FPT: 0.029	SFM: 1099.592
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C3F0032 C:
TIME:	00:00:07

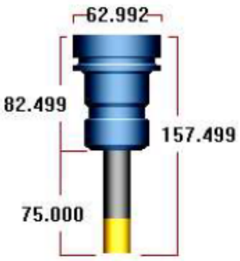
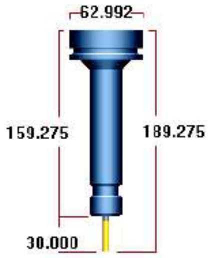


Figure 67 - Se-up sheet made in Mastercam for CS of Model #2 (page 5).

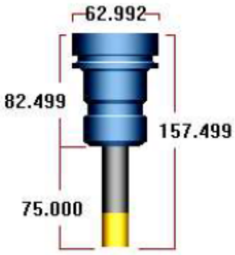
TOOL LIST Sorted: NO

TOOL INFO	6 Flat Endmill
TYPE:	Flat endmill
NUMBER:	6
DIAMETER:	6.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	6
DIAMETER OFFSET:	6
MATERIAL:	Carbide
NUMBER OF FLUTES:	1
FPT: 0.072	SFM: 339.303
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C4F0016 C:
TIME:	00:00:28



USED BY OPERATION:	# 1	1 - Contour (2D)
USED BY OPERATION:	# 2	2 - Contour (2D)

TOOL INFO	20 Flat Endmill
TYPE:	Flat endmill
NUMBER:	1
DIAMETER:	20.0
CORNER RADIUS:	0.0
LENGTH OFFSET:	1
DIAMETER OFFSET:	1
MATERIAL:	Carbide
NUMBER OF FLUTES:	5
FPT: 0.029	SFM: 1099.592
MFG CODE:	
ASSEMBLY:	
HOLDER:	H4C3F0032 C:
TIME:	00:00:17



USED BY OPERATION:	# 3	3 - Contour (2D)
USED BY OPERATION:	# 4	4 - Contour (2D)

Figure 68 - Set-up sheet made in Mastercam for CS of Model #2 (page 6).

WORK OFFSETS

OFFSET INFO

NUMBER: 0	PLANE: Top	ORIGIN: 0.0, 0.0, 0.0
USED BY OPERATION:	# 1	1 - Contour (2D)
USED BY OPERATION:	# 2	2 - Contour (2D)

OFFSET INFO

NUMBER: 1	PLANE: CS_DROP_OUT	ORIGIN: 0.0, 0.0, 0.0
USED BY OPERATION:	# 3	3 - Contour (2D)

OFFSET INFO

NUMBER: 2	PLANE: CS_MB	ORIGIN: 0.0, 0.0, -0.0
USED BY OPERATION:	# 4	4 - Contour (2D)

Figure 69 - Set-up sheet made in Mastercam for CS of Model #2 (page 7).

4.7 Performance indicators for the selected measures

To evaluate the performance of the implemented measures, some indicators are presented and explained in this section.

Productivity is used to evaluate the threading operation inclusion (measure 4). The reason is that the main objective of this measure is to reduce the number of operators in the machining cell. As such, in comparing the original productivity with the one after these measures, a conclusion will come about its success. The number of operators in the machining cell is also a good indicator of this success. The time for manual operations will also be a good indicator (the smaller the better), as is the machining time (the goal is for it to not have increased much). Cycle time (time to complete a work cycle for the operator), with one operator being below takt time is also a good indicator that the ideal production pace is being maintained.

Productivity is calculated in frames, per man per hour (frames/man/hour). Thus, it is the number of frames (or parts corresponding to a frame) divided by the number of hours worked and the number of operators who were in that processing cell during that period.

To evaluate the upper opening procedure (measure 5), the machining time (before and after) must be compared to determine if the increase was large or small. Also, the welder's ability to weld the inside of the frame without problems will qualitatively appraise this change.

Finally, to assess the manufacturing plan and set-up sheet (measure 7), the average of time saved for the programmers because of this measure (this would be the time spent in set-ups per month or year, for example, for both machines set-ups and quality control gabarit set-ups). Overall operator understanding of what to do is also a qualitative measure to consider.

4.8 Results of implementation of chosen measures

After implementing measure 4, the machining time and operator time were measured for calculations and comparisons. The baselines and current machining and operator times for threading for Ralc 6, Section 6.2 are shown in Table 6. Both the loading and unloading times and the deburring times suffered no change.

Table 6 - Time comparison before and after Measure 4

Operation	Time [s] before Measure 4	Time [s] after Measure 4
Machining of frames (machining operation)	171	285
Threading of frames (manual operation)	100	-

The baselines and current machining times for Ralc 7, Section 7.2 are listed in Table 7 after the top opening of the DT was added (Measure 5). Both the loading and unloading times and the deburring times suffered no change.

Table 7 - Time comparison before and after Measure 5

Operation	Time [s] before Measure 5	Time [s] after Measure 5
Machining of DT (machining operation)	135	161

In this way, Figure 70 shows a chart with machining times compared to operator times and a takt time reference.

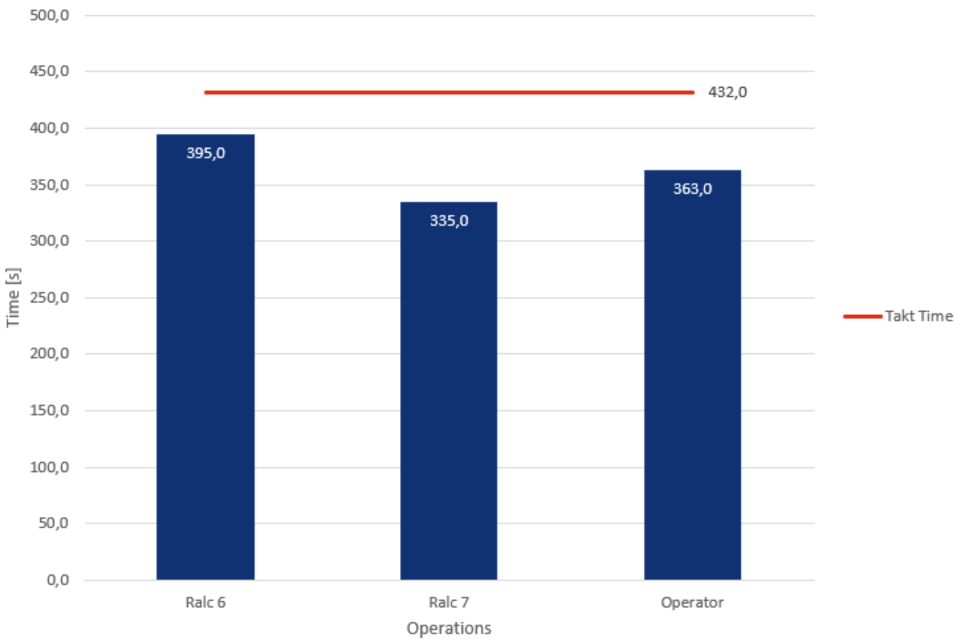


Figure 70 - Final scenario: manual operation time [s] with one operator vs. machine operation time [s].

From this chart, it can be concluded that the machining cell under study can have one operator per shift, and as such, this change was implemented as well. In the original scenario, there was one person per machine in the processing cell, each working a 7.5-hour shift and producing 100 frames during that time. Now there is only one person working on both machines (0.5 person per machine), with each machine still producing 100 frames in a 7.5-hour period. The instructions for the machining cell are to produce no more than 100 frames so as not to generate stock in the factory. This is because the customer's demand did not change and the only goals for this machining cell were to increase productivity by reducing the number of operators. The calculation for the productivity per machine base line is shown below.

$$Productivity = \frac{100}{7{,}5*1} = 13.33 \text{ frames/hour/person}$$

The calculation for the current productivity per machine after this measure was implemented is shown below:

$$Productivity = \frac{100}{7{,}5*0{,}5} = 26.67 \text{ frames/hour/person}$$

As can be seen, productivity has doubled because of these interventions.

The cycle before these measures was equal to the operator's time (463 s) and after these measures was equal to the Ralc 6 machining time (395 s).

The consequences of measure 5 were the intended ones: the overall quality of the frame (in the welding section) increased, which increased the quality of the final frame, due to the additional welding on the inside. This was made possible by the upper opening done in this machining cell, which gave the welders access to the area to be welded.

A summary can be found in Table 8. As can be seen, the number of operators decreased, the overall machining time increased and the operator time decreased. As a result, cycle time decreased, and productivity doubled. So, these measures were very positive and achieved their objectives.

Table 8 - Summary table for Measures 4 and 5

Scenario	Nr. of operators	Ralc 6 machining time [s]	Ralc 7 machining time [s]	Operator time [s] (1 operator)	Cycle time [s]	Productivity [frames/hour/person]
Before Measures	2	281	309	463	463	13,33
After Measures	1	395	335	363	395	26,67

Regarding measure number 7: The time saved for the programmers is about 40 minutes per month (4 set-up operations). This means a time saving of about 8 hours per year for a programmer (who is more expensive and more qualified for the company than an operator). The overall feedback from the operators was also positive, as it became clearer what tasks are to be performed.

5 Conclusions and future work

As expected, CNC machines are an essential part of bicycle manufacturing worldwide and in this factory alike. After analyzing one machining cell in particular, several opportunities for improvement stood out, some of which have been implemented and from which the main conclusions of this thesis have been drawn.

By moving the threading operation to the CNC machines, the operator gained enough time to load and unload both machines and deburr all parts coming out of this machining cell. This allowed the cell to operate with only one operator, doubling the productivity value per machining center.

By performing the upper opening on the DT of Model #2, the welders were able to weld the inside of this part, improving the quality of the frame and meeting the customer's requirements. This action increased the machining time. However, this increase was not a concern as the takt time was met and production values were not affected.

By implementing manufacturing plans and set-up sheets for all parts, the work on the machining cells became more organized, standardized and clearer for everyone. This also enabled the operators to perform set-ups on both machining centers, freeing up the programmers that used to do these tasks (which is relevant since they are more qualified and expensive for the company). It standardized tool switching and set-up (done by programmers) and enabled any programmer to attend to any machine’s tools and machining parameters, even if they are not familiar with this machine.

Overall, the implemented measures were successful, and the machining cell was generally improved. However, some of the measure’s results or implementations were not as successful as others. Passing the set-up operations to the operators did not result in a great difference of time spared as they were “quick” and not done very often, resulting in only 40 minutes of time saved per month for the programmer, which is not very significant. However, if the same principle were to be applied to all CNC machines, then the time spared for the programmers would be far greater.

But, as previously mentioned, not all measures were implemented. As such, there are some improvements that would be interesting to apply to this machining cell in the future. Suggestions for this would be air pressure monitoring for the gabarits in the machining centers. If the value is below a set value, the machine should not operate. Another would be to have an automatic tool warehouse for the CNC section. This would provide a stock of tools. If that stock were to reach a minimum stock value, the warehouse would be equipped to place an order with the supplier. Another improvement could be to improve the lubrification in the machining centers by optimizing machining parameters or adding external lubrification. This would improve tool wear and part quality. Another suggestion would be to improve set-up time with the use of pneumatic stoppers, that could adjust to any reference selected, reducing the 10-minute-long set-up time. A final improvement could be changing the tools in the CNCs more often to improve part quality and decrease time spent deburring (less manual operation time).

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