Production of spare parts for custom braking systems installation

Andrei Akinshin

Bachelor’s thesis
May 2022
Production, purchasing, entrepreneurship
Bachelor's Degree Programme in International Logistics

Jyväskylän ammattikorkeakoulu
University of Applied Sciences

jamk

Description

Akinshin Andrei

Production of spare parts for custom braking systems installation

Jyväskylä: JAMK University of Applied Sciences, May 2022, 40 pages

Production, purchasing, and entrepreneurship, Degree Programme in International Logistics, Bachelor's Thesis.

Permission for open access publication: Yes

Language of publication: English

Abstract

It is well known that a car's braking system is one of the most critical components for the driver's safety, driving, and life preservation in case of emergency occurs during the driving. Nowadays, many stock cars are equipped with powerful engines with more than 250 horsepower and a maximum speed of more than 200 km/h. Still, at the same time, these cars are fitted with single-piston floating brake systems, which sometimes are not enough to prevent an emergency. Drivers who care about their safety would prefer to replace the stock brakes with more efficient ones, which often cannot be installed without additional intervention in the design.

The primary purpose of the work was a theoretical description of the processes and actions aimed at creating a business to produce spare parts for the installation of non-standard (custom-made) braking systems on any cars. The term non-standard refers to braking systems that exist but cannot be installed on stock models due to technical design features. Therefore, spare parts such as brackets, hub parts, and protective shields are required.

The main research questions were those related to purchasing and production:

1. Which equipment and raw materials are needed for production, and where to order them? It was necessary to analyze the technical component and choose suitable suppliers to solve this problem.
2. How should space be used and minimize production costs, which is extremely important for the regular profitable production operation?

The research was conducted based on information collected by reviewing the technical literature necessary to properly select materials and equipment, interviewing professionals involved in this activity, and analyzing websites and reviews of potential suppliers.

Based on the answers to 2 previous questions, conclude how to organize and maintain the life cycle of such production.

Keywords/tags (subjects)

Purchasing management, Production management

Contents

1 Introduction

The car’s brake system is a complex technical unit that consists of a set of details. As it has been earlier written in the abstract for today, most of the stock cars are equipped with not the most reliable brake systems, which is not enough for complete confidence in the ability of the vehicle to brake in case of an unforeseen emergency. Today many motorcar manufacturers save the cost of the car by installing single-piston floating brake systems, or as in the case of the Toyota Land Cruiser 300, installed brake rotor size 354 mm and a two-piston floating caliper **(Toyota Inc., 2022, LC300 section)**, which is categorically not enough for a vehicle with unloaded weight in 2320 kg.

Many motorists retrofit their cars with more high-tech brakes to solve such problems. Still, those solutions that manufacturers offer are often too expensive and many times cheaper to put the brake system from another vehicle with the necessary characteristics. Implementing such solutions requires small technical changes in the design of the car brake system, namely the design and installation of adapter brackets to install calipers and the design and installation of transition hub parts for installing the brake rotor.

As known, a car is a high-risk vehicle. Therefore, the final product is primarily aimed at meeting the demand of those drivers who want to feel confident in the car and in the case of an unforeseen situation on the road, for example, a wild animal like an elk suddenly running onto the road, to be fully confident that the vehicle will be able to slow down immediately and save the driver's life.

To paint all these aspects and choose the suitable material and manufacturing method for each detail, it is necessary to do the research regarding materials, equipment, and special programs that will allow all this to be done because the technical characteristics of every aspect are one of the most important criteria for choosing the suitable suppliers.

2 Purpose and objective of the thesis

The primary purpose of the work is a theoretical description of the processes and actions aimed at creating a business to produce spare parts for the installation of non-standard/custom-made braking systems on any car. The term non-standard refers to braking systems that exist but cannot be installed on stock models due to technical design features. Therefore, spare parts such as brackets and hub parts.

This topic is relevant because many drivers face this problem, but not many companies provide practical solutions today. Almost none of them supply it to a mass-market segment. Usually, this is done only to order.

The main research questions are those related to purchasing and production:

1. Which equipment and raw materials are needed for production, and where to order them? It was necessary to analyze the technical component and choose suitable suppliers to solve this problem.

2. How should space be used and minimize production costs, which is extremely important for the regular profitable production operation?

3. The profitability of the business idea. To evaluate profitability, it is necessary to calculate the cost of production, considering all expenses, such as prices for materials, wages, rent, equipment, and other production expenses. And calculate the price of sale of the final product, considering all taxes. Also, it is essential to consider the costs of equivalent offers in the market, to understand whether this business can be profitable in Finland.

Since prices for each specific type of solution may vary, several particular cases should be used for evaluation.

3 Research methods and implementation

Based on the goals and questions of the thesis, the conclusion is that this work is a "development work" whose primary goal is the production of the final product in the form of a business.

For this type of work, the best solution for implementation would be "2.7 Development of a service, product or production" because, based on the description of this type of implementation, "A thesis produced through a service, product or production provides the student with an opportunity to delve into and focus on solving a specific practical problem" **(JAMK.fi, n.d., Opinnaytetyo - Thesis, 2.7 section)** it is clear that this type of implementation appropriate for these questions and goals.

Both qualitative and quantitative research methods were used to careful collecting of information during the research work.

Quantitative methods include the following observations:

A review of technical literature and Internet sources allowed to compile a list of raw materials necessary for the production. Proven and respected sources of information, such as textbooks and scientific papers on materials science, were used to obtain the data necessary for writing the work.

The overviewing of the official websites of potential raw materials and equipment suppliers. For the correct selection of raw materials and equipment, only the official websites of suppliers and specific marketplaces were used, which made it possible to find the best options and accurate technical characteristics of the purchased raw materials and equipment.

A review of other research data to identify salaries and rents in Finland. In order to select these parameters, statistical data that are publicly available were studied

As a qualitive methods were used interviewing with specialists.

First, there was an interview with a highly qualified Russian engineer was conducted, during which the necessary information about the production as a whole was obtained. During the interview conducted in the format of a telephone conversation, the necessary data regarding the actual production of products, such as recommended dimensions and maximum permissible errors of equipment were obtained. And also, advices on the organization of the production process itself were received.

In order to identify the current prices for raw materials and equipment, requests to suppliers which were selected as the most suitable options during the market analyzing process were sent.

Among other methods the own knowledges gained during study at the university and work experience in production were applied.

4 Literature review

The brake caliper is one of the essential parts of the brake system. The safety of driving in the car depends on the serviceability of this part.

The caliper circuit is not complicated and is the same in most car models. Pressing the brake pedal leads to pressure in the brake line, acting on the calipers' pistons. This pressure leads to the displacement of the caliper pistons, which in turn push the brake pads to the brake disc mounted on the wheel, pressing them against it from both sides. The resulting friction causes the braking effect of the car.

Only this part is a movable part of the car’s braking system, so the system’s performance greatly depends on the serviceability of this element.

Brake calipers are of two types — fixed and floating.

In a floating type caliper, when braking, the piston, under the influence of fluid pressure, presses the inner pad against the brake disc of the wheel. The caliper moves the guide fingers opposite, equalizing pressing the inner and outer pads.

Fixed calipers are an earlier development of automakers. A caliper of this type often includes a metal body with two working cylinders arranged symmetrically. The body is rigidly fixed to the brackets of the car, usually on the swivel member of the front or rear suspension.

To attach a non-native caliper to the brake system installation system (swivel member), a bracket is required that will be linked with standard bolts to the design and have holes for mounting the caliper; that is, in this case, the bracket acts as an adapter for connecting a non-standard caliper for a specific car model to the standard swivel member of this model.

The most popular materials for this kind of fastener are those alloys and metals with high strength and anti-corrosion qualities. It can be stainless steel, titanium, aluminum alloy, or galvanized steel.

The brake rotor is the most thermally loaded part in a car (with aggressive use in a separate part of the brake disc, the temperature can reach more than 500C). And at the same time, one of the most critical for security. Thus, it turns out that the brake disc has two primary characteristics – it must be strong (not deformed by repeated heating and cooling, not cracking) and well cooled (ventilated, for which there are ventilation channels inside the brake disc). Secondary but also necessary qualities of a good brake disc are weight (brake discs are part of unsprung masses, the reduction of which has a positive effect on dynamics, suspension performance, fuel efficiency) and additional features to improve the efficiency of the disc in combination with brake pads.

The main categories are as follows:

- Ventilated and non–ventilated - the first consists of two "plates," between which cavities run from the disk's center in the outside direction, and the second is just one "plate."
- Integral and composite brake discs are made of a single material processed into the appropriate shape. The second consists of two parts (hub and ring) made of different materials and connected by small bolts.

A hub element is needed to attach a non-standard brake rotor to the available braking system to connect the swivel member’s hub and the rotor using bobbins with a screw and nut.

4.1 Materials

4.1.1 Stainless steel

Stainless steel is a suitable material not only due to its anti-corrosion properties but also due to its variety of physical properties. Modern corrosion-resistant steels are produced by adding various impurities to the steel.

The physical properties of the finished steel depend on the amount and type of impurity.

It is necessary to highlight the main physical properties of stainless steel, which qualitatively distinguish it from other metals. Such properties include:

1. High strength. Products made of stainless steel are characterized by increased power compared to analogs. Due to the resistance to physical stress, the products are not damaged and do not lose their initial shape. High-quality steel retains reliability for more than ten years.

2. Resistance to the aggressive external environment. Such steel is practically not subject to changes due to environmental conditions. This allows for maintaining the product's functional properties for a long time.

3. Heat resistance. Stainless steel products are resistant to high temperatures, even when exposed to open fire, without changing their shape, size, and properties at significant temperature differences.

4. Anti-corrosion properties. The main property possessed by such steel is an obstacle to rust. Moreover, the alloy does not rust even after exposure to acids or alkalis.

5. Appearance. The appearance of stainless steel products is qualitatively different from other materials. The steel has a clean, shiny appearance that does not change after long service life.

6. Pliability. Such an alloy is easy to process, and making an object of the desired shape is not difficult.

The chemical composition of stainless steel depends on the type and grade of the alloy. The main features that characterize stainless steel are the presence of at least 10.5% chromium and low carbon content. Carbon is essential in manufacturing steel, as it gives the necessary strength. The percentage component in the anti-corrosion alloy should not exceed 1.2%.

Also, Titanium, Phosphorus, Molybdenum, Sulfur, Nickel, and Niobium can be included in stainless steel composition.

Stainless steel marking depends on the finished material's chemical composition, properties, and internal structure. Based on this, steel is divided into the following types:

1. Ferritic. This group of steels is characterized by a high chromium content, usually more than 20%. Therefore, sometimes this type is called chronic. This chemical composition contributes to increased resistance to an aggressive environment. Alloys of this group have magnetic properties.

2. Austenitic. A group of anticorrosive alloys is characterized by a high chromium and nickel content. Due to this, they are characterized by increased strength and flexibility compared to analogs. They are also easy to weld and resistant to corrosion. They belong to non-magnetic metals.

3. Martensitic. A particular type of stainless alloy. It is characterized by increased strength and wears resistance. They are not exposed to high temperatures, and they contain a minimum of harmful components that do not emit vapors during intense heating. This group includes heat-resistant corrosion-resistant steel.

4. Combined. A particular type of steel combines the properties of the above groups.

(AZO materials, 2001, Stainless steel classification section)

Austenitic stainless steel grades are divided into five types:

“1. A1 is steel containing a significant part of sulfur, so it is more susceptible to corrosion than the rest.

2. A2 is the most widely used brand. It is easy to weld without loss of physical properties. Frost-resistant but subject to corrosion in an aggressive acidic environment.

3. A3 is a derivative of A2 but with stabilizing components. It is characterized by increased resistance to high temperatures and an acidic environment.

4. A4 is an alloy with molybdenum (up to 3%). It is characterized by resistance to the acidic environment.

5. A5 – similar to the A4 brand. Differs only in the ratio of stabilizing components. It was produced for increased resistance to high temperatures.” **(Metallurgical plant Elektrostal, 2021, stainless steel classification, austenitic stainless steel section)**

Due to their chemical composition, Group A anticorrosive steels are easy to weld. That is why this type is widely used in industry. It is possible to produce parts of almost any shape from such steel with a strong connection of the components.

The resistance of steel to corrosion depends on the amount of chromium: the more significant its part, the more stable the alloy. Classic stainless steel, used under normal conditions, contains 13% chromium. To resist an aggressive environment, the proportion of chromium should exceed 17%.

For resistance against more vital acids, the percentage of nickel increases in the composition, and other components are added in small quantities.

Types of stainless steel are not limited to the above types since even the slightest change in the percentage of components can significantly affect steel properties.

4.1.2 Aluminum alloys

The most common elements in the composition of aluminum alloys are copper, manganese, magnesium, zinc, and silicon. Alloys with titanium, beryllium, zirconium, and lithium are less common.

Aluminum alloys are conditionally divided into two groups: foundry and deformable.

For the manufacture of casting alloys, molten aluminum is poured into a mold corresponding to the resulting product's configuration. These alloys often contain significant silicon impurities to improve casting properties.

“Deformable alloys are first poured into ingots, then given the desired shape. This happens in several ways, depending on the type of product:

1. By rolling, if necessary, to obtain sheets and foil.

2. By pressing if needed to get profiles, pipes, and rods.

3. Molding to obtain complex shapes of semi-finished products.

4. Forging, if it is required to obtain complex shapes with increased mechanical properties.”

(Beletskiy, 2005, Aluminum Alloys, Basics section)

Aluminum-magnesium alloys.

These plastic alloys have good weldability, corrosion resistance, and specific strength levels.

Aluminum-magnesium alloys contain up to 6% magnesium. The higher its content, the stronger the alloy. Increasing the magnesium concentration by each percentage increases the tensile strength by about 30 MPa, and the yield strength by about 20 MPa. Under such conditions, the elongation decreases slightly, remaining within 30-35%. However, with a magnesium content of more than 6%, the mechanical structure of the alloy in the carbonized state becomes unstable, and corrosion resistance deteriorates. **(Beletskiy, 2005, Aluminum Alloys, Aluminum-magnesium alloys section)**

Chromium, manganese, titanium, silicon, or vanadium are added to the alloys to improve their strength. Admixtures of copper and iron, on the contrary, negatively affect alloys of this type — reducing weldability and corrosion resistance.

Aluminum-manganese alloys

These are solid and ductile alloys with high corrosion resistance and good weldability.

To obtain a fine-grained structure, alloys of this type are alloyed with titanium, and manganese is added to maintain stability in the carbonated state. The main impurities in Al-Mn alloys are iron and silicon. **(Beletskiy, 2005, Aluminum Alloys, Aluminum-manganese alloys section)**

Aluminum-copper alloys

The mechanical properties of this type of alloy in a heat-strengthened state sometimes exceed even the mechanical properties of some low-carbon steels. Their main disadvantage is low corrosion resistance because they are treated with surface protective coatings. **(Beletskiy, 2005, Aluminum Alloys, Aluminum-copper alloys section)**

Aluminum-copper alloys are alloyed with manganese, silicon, iron, and magnesium. The latter has the most significant influence on the properties of the alloy: magnesium alloying significantly increases the yield strength and strength. The addition of iron and nickel to the alloy increases its heat resistance.

Aluminum-zinc-magnesium alloys

Durable and well-processed. A typical example of a high—strength alloy of this type is B95. Such strength is explained by the high solubility of zinc and magnesium at a melting temperature of up to 70% and up to 17.4%, respectively. Upon cooling, the solubility of the elements decreases markedly.

The main disadvantage of these alloys — low corrosion resistance during mechanical stress — is corrected by copper alloying. **(Beletskiy, 2005, Aluminum Alloys, Aluminum-zinc-magnesium alloys section)**

Avial

Avial is a group of aluminum—magnesium-silicon system alloys with minor elements (Mn, Cr, Cu). The name is formed from the abbreviation "aviation aluminum.»

Avial began to be used after the discovery by D. Hanson and M. Geiler of the effect of artificial aging and thermal hardening of this group of alloys due to the isolation of Mg_2Si.

These alloys are characterized by high elasticity and good corrosion resistance. The copper content is sometimes reduced to 0.1% to increase corrosion resistance.

“Physical properties

- Density — 2712 kg/m3.
- Melting point — from 658°C to 660°C.
- Specific heat of melting — 390 kJ/kg.
- Boiling point — 2500 °C.
- Specific heat of evaporation — 10.53 MJ/kg.
- Specific heat capacity — 897 J/kg·K.
- Electrical Conductivity — 37·106 Cm/m.
- Thermal conductivity — 203.5 W / (m · K).”

(Beletskiy, 2005, Aluminum Alloys, Avial section)

4.1.3 Galvanized steel

Before an ordinary steel sheet turns into galvanized steel, it must be subjected to a particular treatment. For this purpose, the hot-dip galvanizing steel coils have been successfully used in factories for a long time.

The specially prepared steel roll passes through liquid zinc in continuous galvanizing units. The devices allow adjusting the speed of galvanizing and the quality and temperature of molten zinc.

After annealing and uniform coating of the steel sheet with zinc, a smooth profile sheet is obtained. In this way, galvanized steel is produced, later into various products.

Classification of galvanized steel

Galvanized steel, like any other product, has its classification:

- general-purpose galvanized steel;
- cold-stamped galvanized steel;
- cold-polished galvanized steel;
- galvanized steel for further painting.

(Montos, 2022, Galvanized steel)

4.1.4 Titanium alloys

The basic mechanical properties of titanium alloys determine their wide distribution. If ignore the chemical composition, then all titanium alloys can be characterized as follows:

1. High corrosion resistance. Titanium is less susceptible to humidity than iron.

2. Cold resistance.

3. Titanium and titanium alloys have a relatively low density, significantly reducing weight.

4. High specific strength and low density are characteristics that are rarely combined

These primary advantages of titanium alloys have determined their rather large distribution. However, as previously noted, much depends on the specific chemical composition. For example, the hardness varies depending on which substances are used in alloying.

The classification of titanium alloys is carried out according to a sufficiently large number of features. All alloys can be divided into several main groups:

1. High–strength and structural-durable titanium alloys also have sufficiently high ductility. Due to this, they can be used to manufacture parts that have a variable load.

2. Heat-resistant with low density is a cheaper alternative to heat-resistant nickel alloys, taking a specific temperature range into account. The strength of such a titanium alloy can vary in a sufficiently large capacity, which depends on the particular chemical composition.

3. Titanium alloys based on a chemical compound represent a heat-resistant structure with a low density. Due to a significant reduction in thickness, the weight is also reduced, and the heat resistance allows the material to be used in the manufacture of aircraft. In addition, high plasticity is also associated with such a brand.

The marking of titanium alloys is carried out according to specific rules that allow determining the concentration of all elements.

Considering the most common grades of titanium alloys, it’s necessary to pay attention to VT1-0 (grade 2) and VT1-00 (grade 1). They belong to the class of technical titans. The composition of this titanium alloy includes a sufficiently large number of various impurities that determine the decrease in strength. However, due to a reduction in force, plasticity increases significantly.

The OT4-1 alloy is also widely used. Compared to the previous one, it has higher strength and heat-resistant qualities. Unique operational rates were achieved by adding a large amount of aluminum and silicon to the composition. It should be borne in mind that the maximum temperature at which this titanium alloy can be operated is about 500 degrees Celsius.

VT5-1 (grade 6) alloy is quite common, using aluminum exclusively as an alloying element. It is important to note that aluminum is considered the most common alloying element in titanium alloys. This is due to the following points:

1. The use of aluminum can significantly increase the elastic modulus.

2. Aluminum also allows an increase in heat resistance value.

3. Such a metal is one of the most common of its kind, due to which the cost of the resulting material is significantly reduced.

4. The index of hydrogen fragility decreases.

5. The density of aluminum is lower than the density of titanium, due to which the introduction of the alloying substance in question can significantly increase the specific strength. **(Il'in, 2009, titanium alloys)**

4.2 Equipment

4.2.1 Milling machine

Milling machines are designed for processing metal workpieces using a milling cutter. The milling operation involves the rotational movement of the cutting tool, the main one, and the translational movement of the workpiece or milling head, which is called the feed movement. In this case, this machine will be used to manufacture hub units.

Almost all milling machines work on the same principle. The differences can only be in their functionality.

The main structural elements of such machines are a load-bearing bed, a work table, clamping parts, a collet and a collet chuck in which the working tool is fixed, and a portal with a spindle set to it, which can move, an electric drive motor. **(Bagdarasov, 2015, Milling machine technology)**

The working tool of any milling machine is a milling cutter; the design and dimensions depend on the configuration of the part to be processed. The working tool is fixed in the collet chuck using a shank, and the rotation is transmitted to it from the drive motor through the transmission system. The primary purpose of the milling cutter is to remove an excess layer of metal from the workpiece, which is the essence of processing on such a machine.

The machine spindle is placed on a movable portal, which special controllers control if we are talking about CNC equipment. The electronic system of such equipment includes CNC controllers (numerical control), auxiliary elements of the system, and connecting parts. The principle of operation of models of CNC machines is as follows: a unique program reads the drawings of the amount to be obtained as a result of processing. It generates electronic commands transmitted to the machine's working body.

Particular attention should be paid to wide-universal machines, a hybrid of horizontal and vertical models. Their design also has a collet, collet chuck, and clamps, but the gearbox of such engines transmits all movements from a single electric motor. Their distinctive feature is the presence of a manual mode, with which you can control the operation of the running unit.

There are three types of milling machines

By control method:

- With CNC
- Without CNC

According to the plane of performance of the work:

- Vertical
- Horizontal

From the kind of its versatility:

- Drilling and milling
- Universal

To perform the tasks set, it is also necessary to understand the positioning accuracy and repetition accuracy when processing a milling machine and the indicator of the maximum diameter of the disc type product since these indicators depend on the manufacturer and the type of machine.

As follows from my interview, the positioning accuracy of a numerically controlled machine (CNC) is an indicator of positional accuracy, which is achieved by moving each coordinate axis of the device under the influence of a digital control system. In other words, it is the accuracy of the mechanism's movement. The positioning accuracy shows how significant the positioning error can be on one or another axis.

Repeatability is an indicator of the machine's error at the same position.

Let's say the control system gave the command to the machine to move to a certain point, then return to the starting position and go back to the specified place. Suppose this route needs to be repeated several times. The machine will arrive at the specified point with a spread. This is repeatability.

Since it is about the execution of parts for a rather complex structure, these two indicators should be minimal, so the positioning accuracy should be at least +-0.007 mm, and the repetition accuracy +- 0.005 mm for the manufacture of high-quality hub elements. **(Ivanov, personal communication, May 4, 2022)**

The indicator of the maximum processing diameter means that a workpiece can be installed in the machine no more than this indicator in diameter. Based on market observations, the diameters of brake rotors that are suitable for improving the braking system on average range from 320 mm to 430 mm, which means that the diameter of the hub part will not exceed 286 mm (2/3 of rotor diameter), which allows concluding that a machine with a maximum diameter of the disc type product of 300 mm is suitable for almost all types of orders.

Another important parameter when choosing a machine is the presence of a drive unit that will allow operating drilling holes for mounting of the hub unit.

4.2.2 Vertical machining centers

A metalworking center is a multifunctional machine with numerical program control. Performing the entire complex of necessary technological operations using various cutting tools, the machining center produces a three-dimensional product with all the pre-set technical parameters.

The machines allow roughing and finishing of profile surfaces of workpieces with the following operations:

- boring of cylindrical surfaces (external and internal)
- milling of planes, grooves
- drilling holes and their processing (deployment, countersinking, etc.)

Structurally, the center is a frame with a horizontally positioned working table for fixing the workpiece. A spindle headstock with a cutting tool clamped in a rotating spindle moves along vertically arranged guides.

The vertical arrangement of the spindle in machining centers is a logical continuation of drilling machines.

With this arrangement of the working bodies, high rigidity of the entire structure is ensured. Reducing the impact of bending forces on the spindle significantly increases processing accuracy. Due to this, it becomes possible to process parts of a large mass.

The processed part is installed on the desktop in a vise or fixed with clamping devices. Also, an additional coordinate can be installed on the desktop - a rotating table capable of rotating the workpiece at a certain angle with high positional accuracy. This is necessary for carrying out technological operations on various planes of the workpiece, cutting different screws, and forming molds.

Electric servos controlled by CNC provide the accuracy of the movements of the workpiece and the working tool. The presence of laser or contact systems for measuring the workpiece and optical rulers for positioning control also increases processing accuracy. It reduces the time to bind the part to the coordinate axes. **(Haas Automation Inc., n.d., Vertical machining center manual book)**

Thus, it can be concluded that this machine is a combination of turning and milling equipment that will allow performing two primary operations for the manufacture of brackets - this is giving the part the desired shape and drilling technological holes for mounting.

The most critical indicators which should pay attention to when choosing this machine are maximum turning processing diameter, positioning accuracy along the axes, and repeatability of the axis.

In the 3.2.1 part was mentioned the positioning and repeatability accuracy indicators along the axes were. These indicators should stay the same in this machine as well.

Most machines' maximum turning processing diameter is 300/450/600 mm; since the bracket will not reach an indicator of more than 450 mm, a 600mm machine is unnecessary. When choosing a device with a hand between 300 and 450 mm, it is better to take 450 since, if necessary, this will allow producing a suitable part. **(Ivanov, personal communication, May 4, 2022)**

4.2.3 3D scanners

A 3D scanner is a device that examines an object, digitizes it using sensors, and uses the information obtained to create a three-dimensional model. A 3D scanner makes a digital copy of a physical object of any configuration and degree of complexity.

The scanning process itself can occur in different ways - depending on the type of 3D device and the technology used and on which object needs to be processed with its help — moving or static.

3D scanners are divided into two groups: laser scanners and optical scanners.

For the most part, 3D laser scanners work on the principle of triangulation, when the camera finds a ray on the surface of an object and measures the distances to it, after which a cloud of points is created, each of which has its coordinates in space, and a 3D model is built.

Another type of laser scanner works by measuring the response time of the beam from the surface of the object — the so-called laser rangefinder. It is impractical to use them at short distances since, in such cases, the response time is fast, and the accuracy of the data is reduced.

Optical 3D scanners shoot an object illuminated by a particular projector with one or several cameras from different angles. Based on the resulting image, a three-dimensional image is constructed.

Furthermore, laser 3D scanners might be contact and contactless; contactless scanners are the most practical decision for scanning in hard-to-reach places like a swivel member. And in turn, this type of scanner can be hand-held or static, that is, not movable. **(Oskin, n.d., CADmaster journal, to be 3D or not to be…)**

4.3 Other expenses

Salaries

For this enterprise, it is also necessary to have personnel whose salary is considered in the price of the final product. According to statistics presented on the resource "salary explorer," the average monthly salary of an engineer in Finland is 3960 euros and varies between 1260 and 8370 euros per month.

To create and design projects, one design engineer will need an average salary of 4 170 euros. Maintenance Engineer responsible for the operation of the equipment with 3 810 salaries and Fabrication Specialists accountable for the direct production of parts whose average salary is 2 720 euros, sales manager with average salary 7 470 euros and a laborer with 1280 euros average salary. **(Salary explorer, 2022, Average Salary in Finland, 2022)**

Taxes

According to the data provided in "Vero Skatt," the Corporate Income Tax Rate is 20%, while the Share of Revenue from Corporate Income Tax is 5%.

VAT for these products is the standard Finnish rate of 24% if sold in the EU; if exported outside the EU, this product is not subject to VAT; the rate is 0%. **(Vero Skatt, 2022)**

Rent

Another component of expenses is the rent of industrial properties. The approximate cost of rent per square meter found in central Finland is 8-9 euros. **(Commercial properties 24, 2022, central Finland)**

5 Suppliers and equipment

It is possible to select suppliers for raw materials and equipment based on those technical parameters obtained during the study of the main varieties of materials and equipment.

5.1 Materials

First of all, it should be noted which material is most suitable for the production of the hub part; this material is titanium alloy OT4-1 in addition to the fact that it has high strength and corrosion resistance, like other alloys and metals that have been disassembled. This titanium alloy stands out favorably due to its heat resistance; as noted earlier, it can continue to work for a short time without losing its basic properties even at a temperature of 500 degrees Celsius, which is the limit of heating of the carbon-ceramic brake rotor. For the hub element, this indicator is significant since it is located near the heat due to the friction force of the brake rotor. Choosing a less heat-resistant material may lead to the deformation of this part.

To produce the hub part, it needs 180 – 320 mm diameter titanium round bars that might be supplied from a German producer “Auremo GmbH.” The price per 1 kilo is 36.9 euros, including shipment. **(Auremo GmbH, 2022, price list)**

For bracket production, stainless steel alloy Aisi 304 is suitable. This steel belongs to the A3 group, and the top distinguishing quality that distinguishes it from other variants is its oxidation resistance. Since in winter public roads are sprinkled with sand with various impurities, this quality is essential since the oxidation of this element of the installation can lead to consequences for the caliper, which in no case should be allowed. It is necessary to purchase this raw material in the form of Square bars because this is the most similar form to the final product should be. The price per kilo is approximately 11 euros; this price includes the shipment. The supplier is the same as for titanium alloy.

Auremos' critical lead time is four weeks, equal 20 business days.

5.2 Equipment

5.2.1 Vertical machining centers

It was possible to find several variants of almost identical machines from different manufacturers that would meet the above criteria in market research.

First of all, this is the machine of the "Haas Automation Inc." - VC 400 company; this company has a big name in its field both due to the quality of the equipment and the presence of its racing team performing in Formula 1. The machine combines two machines of the same brand, VF and EC 400, which allows it to complete all the necessary processing functions. The maximum detail diameter of 508 mm, and the positioning accuracy meet the requirements. The cost of this device is 113 000 euros, excluding delivery. **(Haas Automation Inc., 2022, VC400)**

The second machine that was noticed is a product of the German company "EMAG Group" VMC 450 **(EMAG Group, 2022, VMC450).** The maximum processing diameter is 450 mm, and the positioning accuracy is 0.005mm. This machine has been discontinued by "EMAG," so the only option is to buy it through a reseller; the cost varies from 62 000 to 64 000 euros.

Another option is the products of a Chinese companies' "Taian Yuzhuo Machinery Ltd." VMC 450; like the "EMAG Group" machine, the maximum diameter is 450 mm, but the main drawback of this machine is its positioning accuracy, which varies from 0.01 to 0.02 mm **(Taian Yuzhuo Machinery Ltd., 2022, VMC450)**, which does not fully meet the specified parameters. In contrast, this machine has the lowest of all options price of 18 500 dollars, which is approximately equal to 17,800 euros at the exchange rate of the Central Bank **(European Central Bank, May 15, 2022, USD- EUR rate),** as well as almost four times cheaper than the "EMAG Group" machine and nearly 6.5 times cheaper than Haas.

Based on the data obtained, the best solution both in price and quality will be the VMC 450 of “EMAG Group” companies. Unlike its Chinese counterpart, this sample fully meets the requirement and has a more attractive price than “Haas Automation Inc.” The only drawback of this machine is that it is designed for processing disc-type material, so it is also not suitable. But at the same price, an apparatus of the company “Halkan Ltd.” model HV 450 A was found that meets absolutely all requirements. The positioning accuracy is 0.007, the maximum processing diameter is 450 mm, and it is designed for processing square bars. **(Halkan Ltd., 2022, HV450A)**

5.2.2 Milling machine

As the equipment for creating the hub part, the Russian machine of the Tver Machine Tool Plant is best suited. Since this machine has all the functions and characteristics that are necessary. As follows from the description of the device on the official website of the production:

“TS1720F4 lathe machine with milling function, designed for the following processing of flanges, shafts, and bar parts:

- automatic processing of internal and external cylindrical, cone-shaped, radius and end surfaces;
- turning of grooves and recesses of shafts and disks;
- cutting metric, inch, and cone threads;
- performing drilling and milling operations in radial and axial directions.”

(Tver Machine Tool Plant, 2022, TS1720F4)

To date, there are no restrictions on the purchase and delivery of this equipment to the territory of Finland. The price of this machine is approximately 47 500/ 50,000 euros, depending on the conversion rate. This price already includes the cost of customs clearance.

The maximum diameter of the processed disc-type product is 320 mm, and the claimed positioning accuracy and repeat accuracy are 0.005 and 0.003, respectively.

5.2.3 Cutting machine

The principle of operation of the cutting machine practically does not differ from each other. The only indicator that is worth paying attention to is the maximum diameter of the part that it can cut.

The product of the Swiss company “JET” model HBS-1319V is suitable for this machine. This is a band saw with an indicator of the maximum diameter of the workpiece in- 330mm when processing the part at 90 degrees and a price of 8,000 euros. **(JET, 2022, HBS-1319V)**

5.2.4 Design program

To design spare parts, it is necessary to have a design program. Because both machines are equipped with a CNC with Siemens 828, the best option is to use a program that is entirely suitable for this CNC - this is Siemens NX.

Unlike conventional CAD programs, this program also combines systems such as CAM and CAE, which, in addition to directly designing, allows to immediately from this program upload all tasks on turning and milling equipment.

A monthly subscription to “NX Core Designer” will cost 242 pounds, and in addition, it’s needed to purchase a subscription to “NX CAD/CAM 2.5-Axis Milling & Turning”, which costs 529 pounds **(Siemens, 2022, Siemens NX)**.

In total, the monthly maintenance of the programs will amount to 771 pounds, which is equivalent to 913 euros. **(European Central Bank, May 16, 2022)**

5.2.5 3D scanner

Based on the data obtained in Part 3.2.3, the most suitable option for 3D scanners is a hand-held 3D scanner operating on the principle of triangulation. There are many variants of this type of scanner on the market. Still, based on the information obtained during an interview with a specialist **(Ivanov, personal communication, May 4, 2022),** it was concluded that the most suitable product would be “Scanform” L5, which gives an excellent combination together with the Siemens NX design system and also has a relatively small price of 4 000 euros compared to scanners with the same characteristics since it is instead a new company in this market. **(Scanform, 2022, L5)**

The most critical indicator to pay attention to is the measurement error. As the manufacturer claims, this model has an error of only 0.006mm, which is undoubtedly suitable for carrying out such types of work.

Also, during research, this company's products obtained the data that "Forward-auto" engineers whose racers won the FIA international Drifting Cup in 2018 and 2019 use "Scanform" products to design their cars, which certainly indicates the high quality of this product.

6 Production

Based on the available data, it is possible to draw up a production process plan and calculate the space required to produce and store finished products and raw materials.

6.1 Production processes plan

First of all, it is necessary to configure the step-by-step production processes needed for the production of finished products:

1. Order raw materials for production. As stated in Part 4.1, the critical lead time of the supplier is four weeks. This time is a supplier's production time, excluding the delivery time equal to 1 extra week. This means that the order must be placed no later than five weeks before the planned time of receiving raw materials.

2. Good acceptance. As soon as the cargo arrives at the factory, it must be checked for compliance with the order. After that, it should be sent to the production warehouse.

3. Billet. From the warehouse, as orders are received, raw materials are sent to the procurement post. With the help of a cutting machine, it is cut into the necessary diameter discs or bars along the length.

4. Distribution by workshops. After pre-processing, the billets are distributed to its workshops. Disk type billets s are sent to the production shop of hub elements and square bars to the production shop of brackets.

5. Production of front elements. The billets that have arrived at their workshops get on the production line. After that, one by one, they are fixed in the machine holder, and their direct processing begins according to the parameters preset by the machine. The average production time of one hub element is about 5 minutes, depending on the set parameters; the brackets are 4.25 minutes.

6. Preliminary collection of the kit. After carrying out all the necessary production operations, that is, machine processing, the finished products are sent to the distribution center, where they are pre-distributed into sets. The front brackets go into groups to the front hub elements.

7. Production of rear elements. Since the technical solutions for the front of the car and the rear may differ, this step completely duplicates step 5 but with other technical parameters.

8. Final assembly of the kit. After producing the rear parts, they are sent to the distribution center, where the gears are completed. A ready-made rear set of spare parts is added to the finished front set. Thereby forming the necessary group of spare parts for retrofitting the car with a new braking system.

9. Storage. After all the actions are performed, the finished kits are sent to the finished product warehouse, where they are later shipped for sale.

In addition to this equipment, which has already been painted, auxiliary elements are required for production, such as:

Pallet transfer truck for transportation of raw materials and finished products that could be ordered in “Alibaba” for 854 euros for each. The loading capacity of 1 500 kilograms and the lift height of 115mm. **(Alibaba, 2022, Flexible 1.5 ton Mini Pallet truck hydraulic pallet truck lifting pallet truck)**

ERP system for internal use. It will allow tracking the balance in the warehouse more accurately, form orders, and, in principle, ensure the normal functioning of production. As such a system, SAP Business One ERP, which is not the most complex in terms of functionality, with a cost of 1,300 euros per installation and monthly maintenance of 37.5 euros, will be suitable. **(SAP, 2022, SAP Business One)**

Shelves are also needed for a raw material warehouse, a finished product warehouse, workshops, and a distribution center. The shelves can be purchased at any hardware store like the K-Rauta.

6.2 Production calculations

6.2.1 Raw material dimensions

The most appropriate length for stainless square bars is 900 mm because, with such a length, it leaves no residue if it is cut into pieces of 450 mm and 300mm, which is the most common length for this type of part.

The length of the titanium alloys circle bar must be 1000 mm because it would be equal to 100 titanium disks with an average width of 10mm.

6.2.2 Weekly consumption

Suppose the production works at total capacity during an 8-hour working day, of which lunch takes an hour. In that case, it turns out that in 7 hours (25 200 seconds), it is possible to produce 98 brackets (25 200 seconds/4.25 minutes) and 84 hub elements (25 200 seconds/ 5 minutes) in ideal production conditions, excluding the human factor and the possibility of equipments' error. In 5 working days, it is equal to 490 brackets and 420 hub elements.

Based on that data, it is possible to calculate the maximum weekly consumption of raw materials. It is equal to 246 (490 brackets multiplied by 450 mm of materials needed for that and divided by 900mm) stainless steel 900 mm square bars if the size of the bracket is 450mm, which is the absolute maximum size that might be produced in manufactures equipment, and 4.2 (420 hub elements multiply by 10 mm of materials needed for that and divided by 1000mm) titanium alloy 1000 mm length circle bars.

6.2.3 Two weeks of consumption

If ordering raw materials every two weeks, which is the most convenient option for production, then the warehouse for raw materials should contain an indicator of 2 weeks production-consumption with a surcharge of 20% in case of unforeseen circumstances. It is equal to 8 titanium alloy 1000 mm in length and 320 mm diameter (the maximum parameter) and 1 with the same diameter but with a size of 400mm circle bars and 492 stainless steel 900 mm x 35 mm x 35 mm square bars.

Considering the load-bearing capacity of 1500 kg and the dimensions of the euro pallet 800mm by 1200 mm, it turns out that 86 stainless steel square bars with a weight of 17.42 kilos each will fit on one pallet. It is equal to 7 pallets.

The weight of one titanium alloy 1000 mm length and 320 mm diameter circle bar equals 362.31 kilograms. Still, due to its dimensions, the only possible option for storing and transporting it is by three pieces on the pallet, two from the bottom and one from the top. It is equal to 3 pallets.

The total capacity of the raw materials storage should be sufficient space for storing ten pallets permanently.

6.2.4 Monthly capacity

The finished product storage, in its turn, must accommodate the maximum possible monthly production rate of units with the same parameters as for the raw materials warehouse used.

The maximum amount of brackets that might be done in one month is 2058 brackets (98 daily multiplied by 21 business days in a month) and 1764 hub elements (84 daily multiplied by 21 business days in a month). This is equal to 441 sets of finished. And 294 extra brackets that would be divided into 73/74 only brackets kits.

They must be placed in boxes with dimensions sufficient to fit the largest possible product for storing and selling products. This means that four brackets with a length of 450mm, a width and height of 35 mm, and four hub parts with a diameter of 320mm and a width of 10mm must be fit. The box should have the following dimensions:

- Length- 450 mm
- Width- 390 mm
- Heigh- 70 mm
- Weight- 31.88 kilos

Fifty boxes with finished products will fit on one pallet, which means that 8.82 pallets (9) will be required for the whole amount of the final products.

6.3 Production space calculations

After all the production process steps have been formed during the research, data on the size of the purchased raw materials have been obtained. There is a clear understanding of what equipment will be used in production, including its brand and model. It is possible to draw up a production layout and calculate the area needed for production since the rental price will depend on it, which will affect the cost of the final product.

6.3.1 Storage space

According to the data obtained, the conclusion is that for the storing of raw materials, there should not be any racks; the materials should be stored right in pallets on the floor. The raw materials storage should be enough place for storing 10-euro pallets equal to 9.6 square meters, and to have a place for passages and loading, the area should be increased to 15 square meters.

There should be enough place to store boxes in the racks and enough place for pallets formed before the shipment date in final product storage. The shelves should have enough space to store 441 big kit boxes and 74 small boxes with only brackets and dimensions 450x70x70 mm. For this purpose, a 4-tier metal shelving with dimensions of 1850x920x500 will fit 64 boxes (16 in 1 row at the rate of 2 in width, 8 in height) which means that the required number of such racks is precisely

8. And it is equal to 3.68 square meters plus space for nine pallets (8.64 square meters), which equals 12.32. it means that the storage space should be around 20 square meters.

6.3.2 Production workshops space

First of all, it is worth noting the sizes of each machine.

Milling machine TS1720F4 has the following dimensions:

- “length 2290 mm
- width 1930 mm
- height 1780 mm.”

(Tver Machine Tool Plant, 2022, TS1720F4)

It is equal to 4.42 square meters plus one metal shelving with size 1850x700x400 mm 0.28 square meters and area needed to work activity, that’s in total gave approximately 15 square meters.

Vertical machining centers “Halkan” model HV 450 A:

- “length 2260 mm
- width 2346 mm
- height 2610 mm.”

(Halkan Ltd., 2022, HV450A)

According to the previous calculations needed for the VMC, the workshop should be one square meter bigger due to the bigger size of the machine itself. It is equal to 16 square meters.

Cutting machine “JET” model HBS-1319V:

- “length 2030 mm
- width 750 mm
- height 1280 mm.”

(JET, 2022, HBS-1319V)

Even though the dimensions of the machine itself are smaller than those of the rest of the equipment, the area of this workshop should be slightly larger than the rest of the workshops for a more convenient and faster execution of the material preparation process. The site is equal to approximately eighteen square meters.

One more essential workshop is the distribution center, where the final products are packed in boxes according to sets. For that purpose, one metal shelve and table are required for more comfortable work. The area should be approximately six square meters.

6.3.3 Other spaces

Also, the office for the design and maintenance engineers should be at least 10 square meters, non-production spaces such as a toilet and a staff room would add 15 extra square meters, sales manager office and director office – 10 square meters.

6.3.4 Total

After calculating the required production area, a result equal to 125 square meters was obtained after carrying out the procedure. This indicator is the absolute minimum necessary for the organization of such production.

7 Profitability

7.1 Expenses

All of the expenses might be divided into two groups:

- Regular
- Disposable

7.1.1 Disposable

Disposable expenses include the purchase of equipment and other inventory. According to the data obtained, the total price is 124 954 euros. It contains 62 000 euros VMC, 47 500 euros milling machine, 8 000 euros cutting machine, 4 000 euros 3D scanner, 854 euros pallet truck, 1 300 euros SAP installation, and 13 metal shelves by 100 euros each. This is the price that should be returned with a net profit within one year of production operation.

7.1.2 Regular

Regular expenses are a more complicated part. The maximum possible amount of production output would be used to count it.

First of all, it is the price of raw materials. For more convenient calculations, the yearly expected maximum statistics would be used. Stainless steel bars' yearly consumption is 1 219 218 euros (consumption for 1 part is 4.35 kg), titanium alloy circles 2 917 343 euros per year (consumption for 1 part is 3.62 kg), 266 040 euros for personal salaries, 10 956 per siemens NX maintenance, 444 per SAP maintenance and 13 500 rent payments.

At the same time, regular prices must be divided by independent and dependent expenses. Independent includes salary, maintenance for apps, rent bills, and other costs. Dependent cost is the cost of raw material that depends on such factors as actual consumption and dimensions of supplied materials because this parameter might vary due to technical parameters of the concrete project.

7.2 Calculations

To calculate the price of one concrete product, it is needed to divide the sum of material cost, half of the independent expenses, and the disposable price cost (price of a particular machine, half of the other fees) by the number of products that might be produced yearly and also taking into account two weeks of downtime that caused by public holidays non-working days per year that is equal to 3.856% out of 52 weeks a year.

According to the “calculations” appendix, the hub part price for one unit equals 142.80 euros. The bracket price per one unit is equal to 56.57 euros.

The price of one complete kit that includes four hub elements and four brackets is 797.48 euros, not including VAT but considering the return of the equipment cost for one year. Including VAT, it is 996.88 euros.

The price for one only brackets’ set (only four brackets) is 226.28 euros, not including VAT but considering the return of the equipment cost for one year. Including VAT, it is 282.86 euros.

8 Analysis and assessment of the output, conclusions, and applicability

During the analysis of the work done, it can be concluded that this work provides all the necessary theoretical knowledge and practical solutions to create a business for the production of high-quality spare parts that are necessary when changing the standard car brake system to a more reliable type of brake system, which in turn will cost less for the end customer than replacing those options that were initially provided by design the car.

Research outlines the specific production steps necessary to create this type of production. The production areas are calculated based on the actual dimensions of equipment and materials. The best ways to solve problems related to procurement were found - these are suppliers of raw materials and suppliers of necessary equipment. All expenses that affect the cost of the final product are calculated. And the price of the product with the largest possible sizes was formed.

This work gives the prospect of organizing profitable production in the territory of central Finland and creating at least six workplaces for residents based on the data set out in the material. Due to the data presented, it can be concluded that this will also improve the region's economic situation due to the taxes that will be paid.

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Full interview transcripts are presented in Appendix 3 (Ivanov- interview)

Appendices

Appendix 1. Calculations

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Appendix 2. Research plan

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Appendix 3. Ivanov- interview

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