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Cases from industry - academia collaboration

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Editorial: Cases from industry-academia collaboration

This special issue is entitled as "Compilation of good practices in industry - academia collaboration – practical examples from the Western Balkans". The articles are based on piloting projects and student works conducted within the KnowHub project.

KnowHub is a European Union (Erasmus+ Capacity Building in Higher Education) co-financed project aiming at developing new collaboration approaches between the industry and academia in Albania, Bosnia and Herzegovina and Montenegro. This project was designed to respond to the specific needs and problems in each country, and each involved region. In each region, a commercialization hub has been developed at the participating university as a one-stop-shop attracting enterprises, especially start-ups and SMEs, to the universities easing the access to the knowledge and skills of their faculty and students as well as the technology that they are operating.

Understanding the dynamics of successful Industry-academia collaboration is an important question of interest around the world and industries (Wohlin et al 2011; Gandhi 2014; Gersdorf 2019; Carver & Prikladnicki 2018). Each country and region have their own economic structure, prevailing industry types and characteristics and approaches should vary. The purpose of this special issue is to demonstrate how this kind of activity can be applied in the selected Balkan countries.

The curated results from the KnowHub project include the following cases which are described as good practices, the lessons learned from the project, which the PCUs proudly sharing:

(1) The first paper from European University of Tirana describes a case study of Enterprise Resrource Planning implementation in education context. The paper describes development of a specialized ERP module for management of students' contractual tuition fees.

(2) The paper from University of Vlora entitled "Development of a catalogue services for third partners. The case of Vlora University" describes the organization and operational structure how to organize academia-university collaboration from administrative point of view. These approaches demonstrate some decisions which academic units need to complete on building such services for the business.

(3) Two following papers conducted at University of Sarajevo describe interesting cases related to production and product design enabled by lean practices and additive manufacturing technologies. The first paper "Increasing manufacturing throughput using theory of constraints methodology and lean manufacturing tools" is showing how lean operations approach can be used in the local industry. The second paper "Design and development of an automated tire regrooving machine" is an example of a successful student project which created a startup company. Both cases are good examples of what higher educational and research institutes can do in applied engineering fields.

(4) University of Mostar has produced an illustrative case of enterprise collaboration with the local companies. The main application area is related to collaborative robots, cobots, which can operate in the same working spaces with human workers. This emerging technology is very promising, and university can spread this word as a technology ambassador.

(5) University of Montenegro is presenting then two case studies related to product design and use of rapid prototyping tools based on additive manufacturing. The first paper "Design of the universal calibration device for brake tester, pedal gauge force and axle load scale" is a collaborative product development case of a novel application. The second paper "Design of the blind corner cabinet mechanism for G shaped kitchen layout" presents a new type of cabinet design for kitchen products.

These papers describe some interesting applications of technology combined with fresh thinking and innovation. The cases have been done together with local companies, which have had real problems requiring advanced level technology and knowledge of novel tools. The works all include active participation from faculties and students have been involved in several roles ranging from participation in a project to all the way to actually founding a startup company around the new idea.

The works are shared as an example of what kind of fruits successful industrial academic collaboration can yield. All cases are related to the industrial environment of each country showing some characteristics related to PCUs, but we may extend the conclusions toward generalizations – this kind of approach should be successful also in many other places.

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Content

Implementing a specialized ERP module in education for an efficient management of students' contractual tuition fees

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Abstract

This article discusses the customization and implementation of an ERP system in a university to manage the financial details of student tuition fees, scholarships, and installments. The project involves creating a module that integrates with the university's existing student information system (SIS) and financial system to manage all contractual details for each student. The article emphasizes the importance of having a robust ERP system in a university to manage financial details accurately and efficiently. It covers the challenges encountered during the implementation process and how they were overcome. The benefits of the new ERP module include streamlined financial management, increased efficiency, and accuracy in financial reporting. The article serves as a useful guide for other universities looking to implement a similar solution.

Keywords: *ERP, University, OpenBravo, Albania, Best Practices*

1. Introduction

This article will discuss the process of customizing and implementing an ERP system, specifically Openbravo, in a university to manage the financial details of student scholarships, tuition fees, and contractual financial terms. The aim of this project is to create a ERP module that will manage all the financial contractual details for each student contract from the university's perspective. The project will involve integrating the ERP system with the university's existing student information system (SIS) to obtain all general data about the students, and the Financial System to send all students' fees and receive back all payments made by the students.The article will highlight the importance of having a robust ERP system in a university, especially in managing the financial details of students. It will also discuss the limitations of the university's current financial system, which cannot go into the specifics of students' financial contractual details, and the need for a more comprehensive solution.

The article will then dive into the process of customizing and implementing the Openbravo ERP system, including the steps involved in integrating it with the SIS and financial systems. It will also cover the challenges encountered during the implementation process and how they were overcome. ERP systems have incorporated best practice solutions since they are created in advance to fit a wide range of enterprises. Best practices don't necessarily reflect how the bulk of businesses conduct business because best practice solutions are frequently created in collaboration between the vendor and the most powerful clients. Sometimes an organization's operational processes must be restructured before an ERP system can increase performance. To harvest the improved performance of the new system, many firms undergo the complicated business process re-engineering (BPR) process(Hustad et al., 2016).

The article will conclude by discussing the benefits of the new ERP module, including streamlined financial management, increased efficiency, and accuracy in financial reporting. It will also discuss the potential for future enhancements to the system, such as incorporating automated payment reminders and allowing students to make online payments.

Overall, this article will provide valuable insights into the process of customizing and implementing an ERP system in a university setting, specifically for managing the financial details of students. It will serve as a useful guide for other universities looking to implement a similar solution.

2. Background

In today's fast-paced world, managing financial details of students in universities can be a challenging task. Inefficient financial management can result in incorrect invoicing, delayed payments, and difficulties in tracking student's financial records. To solve these problems, implementing an enterprise resource planning (ERP) system can be the solution.

ERP projects are complex and resource demanding. They tend to be flexible to different business's needs, but in the end they are as flexible as they are designed to be. On the other hand each business is different in how they compete in the market and what special internal and external procedures they adopted, created to increase their business efficiency. Matching business requirements with ERP features and functions is not an easy task and, more than often it requires dedicated resources, human and financial, to customize ERP functions that fits best the business processes.

A gap always exists between the business rules incorporated in the system and the practices and processes that are used in organizations, according to existing research that has studied how ERP systems fit to various businesses. Thus, tailoring may be a crucial step in the ERP deployment process, where the ERP is customized to meet the specific needs of the organization and its key business activities(Hustad et al., 2016).

In this article, we will discuss the customization and implementation of an ERP system in European University of Tirana (UET), an Albanian university, to manage all financial details and technicalities of student scholarships, tuition fees, installments, and other contractual details. The ERP system of choice for this implementation will be the Openbravo ERP.

The European University of Tirana (UET) has already two main systems in place that support other functionalities. The Student Information System (SIS) manages all academic data about students, and all students are registered there for the first time when they enroll in the university. The Financial System manages general financial bookkeeping for legal financial recording, but it cannot dig into all financial details of students' contracts like installments, different types of tuition fees, and other contractual details. All students' payments are recorded only in this financial system.

The proposed ERP module will be integrated with the SIS system to obtain all general data about the students. The integration will ensure that data related to students such as personal details, course registration, and academic performance is seamlessly synchronized across all university systems.

The ERP system will also be integrated with the Financial System to send all students' fees types to it and receive back all payments that the students make. This integration will ensure that all financial details of students are captured accurately, recorded, and reconciled in a timely manner.

The implementation of an ERP system at the university will have several benefits. Firstly, it will provide accurate financial data to the university's administration, allowing them to make informed decisions based on the data. Secondly, it will reduce manual errors and duplication of data entry, increasing efficiency and reducing operational costs. Finally, it will improve communication between different departments, enabling collaboration and streamlining processes.

In conclusion, implementing an ERP system at the university can help in managing all financial details and technicalities of student tuition fees, scholarships, and other contractual details. The proposed Openbravo ERP module will be integrated with the SIS system and the Financial System to ensure that all financial details of students are captured accurately, recorded, and reconciled in a timely manner. This implementation will not only increase efficiency and reduce operational costs but also provide accurate financial data to the university's administration.

3. Problem

European University of Tirana is a private university in Albania, established by decision of Council of Ministers decision no. 636, date 20.09.2006. Since then it has increased the level of studies to BA, MA and PhD, number of faculties, program of studies, specialization fields and number of students. It is currently the biggest private university in Albania with 5000 active students(*UET - Facts and Figures*, 2023).This increase in many dimensions increased the complexity of university management. One of them was the financial tracking system for students tuition fees and other contractual obligations.

The university have invested in implementation of several digital systems to support the academic and management needs. The financial solutions implemented never reached the required level of a detailed and efficient digital solution for the management needs. A financial system that has wide spread usage in Albania as it is build to be in compliance of Albanian legislation of bookkeeping was implemented at UET. This system, even though in compliance with the Albanian Laws, it was not a good fit for the university dynamic requirements concerning the flexibility and options the university offers to its students. All the dynamic and specific aspects couldn't be integrated in the existing financial system, so the finance staff members have to do a lot of manual work and data conciliation using MS Excel software with data collected from several digital and manual sources.

The workflow of the students contractual financial management, semi-manual is presents in the figure below:

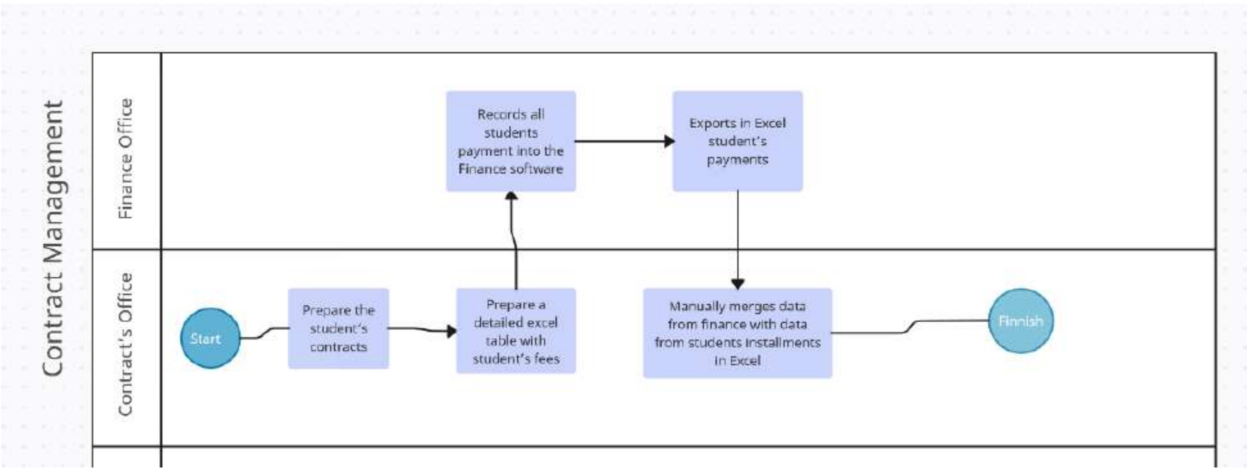


Figure 1: Existing financial workflow

A. THE EXISTING WORKFLOW

The problems that cause the existing workflow situation:

1- Double entries. The Contracts office has to make double entries to manage students records. The student information is first registered in the SIS platform. The same data like name, surname, faculty, registration year, program of study, etc. should be entered again manually in the excel file where all details of tuitions fees are recorded. Then the financial data for each student's contract is added like installments, dates, discounts.

2- Mistakes in recording student's payments into the excel file. Working in huge excel tables with thousands of students is a very tedious and with high risk of mistakes in data entry. Is very easy to record numbers in the wrong excel table row. Data integrity principle is not possible to be obtained when using excel files, especially when more than one employee are working of the same files. No data auditing features can be implemented in an efficient means.

3-Hard work with no real-time debtor list extraction. No dynamic report generation happens from data entered into the excel tables, spread in many different excel sheets, with enforced referential data system.

4-With no high data integrity in place, and as a result with not a good monitoring system, there is not an efficient way of enforcing contractual obligations to students.

There were some previous initiatives to build a custom solution for students tuitions fees management, including one solution based on Microsoft technologies tightly integrated with the existing SIS solutions that university is still using today. The same company that developed the SIS platform was contracted to build that solution. The process took place for one year and development and customization reached an advanced level of implementation. Nonetheless, because of some outside factors, the company had to withdraw from the agreement and eventually the solution was stopped. No other company could carry on their job.

UET started the implementation of the KnowHUB "Reconnecting universities and enterprises to unleash regional innovation and entrepreneurial activity" project on 2019 and as part of that project a Commercialization HUB was created(*CBHE Projects*, 2023). The HUB unit started a project to implement a solution that would customize a new solution in the new context of the university. Management and academic staff, together with students formed a specific team for this project. A crucial member of the team would be an external company with good experience in developing such platforms.

4. Methodology and solution

As the implementation of this tuition fee management system requires to fully understand business processes of the university then a qualitative research approach would be more of a fit.

The primary objective of this research would be to gather in-depth insights and understanding of the current tuition fee management process in the university and identify the specific requirements and challenges that need to be addressed through the implementation of the new system.

The qualitative research methodology involves collecting data through open-ended questions, observations, and interviews. The data collected through this methodology is subjective and allows for a deeper understanding of the phenomenon being studied.

A very important resource of information was the documents of the analyze done some years ago to build a similar platform. Nonetheless, this research had to repeated many steps of previous analysis since some staff have changed and also the legal framework in Albania had many changes in financial bookkeeping and invoicing of clients, including students.

This research involved conducting interviews with key stakeholders, such as the university high management, administration staff, finance staff, and students. The purpose of these interviews was to gather information on the current tuition fee management process and identify the specific requirements for the new system.

Additionally, observations of the current process and documentation of the existing systems was done very carefully. to better identifying the limitations of the current process. The data collected through the interviews, observations, and documentation of the existing systems was analyzed to identify key themes and patterns. The results of the analysis were then used to develop a requirements document that outlined the features and functionalities of the new tuition fee management system.

Overall, the qualitative research approach used in the methodology allowed for a deeper understanding of the business requirements. The data collected through this approach was subjective, allowing for the identification of specific requirements and challenges that needed to be addressed in the implementation of the new system.

A. SOLUTION

By identifying the key stakeholders and their roles, the project team was able to understand their specific needs and requirements for the system.

A requirements document was designed that outlined the key features and functionalities of the new system. This document was created based on the information gathered from the meetings with the university administration, identification of the key stakeholders, and analysis of the existing tuition fee management process. The requirements document included a detailed list of features and functionalities that the system would need to include to meet the specific needs of the university.

During the first phase of the analysis of the requirements, a new high level of the workflow of the students contractual financial management was designed. like shown in the figure 2 below:

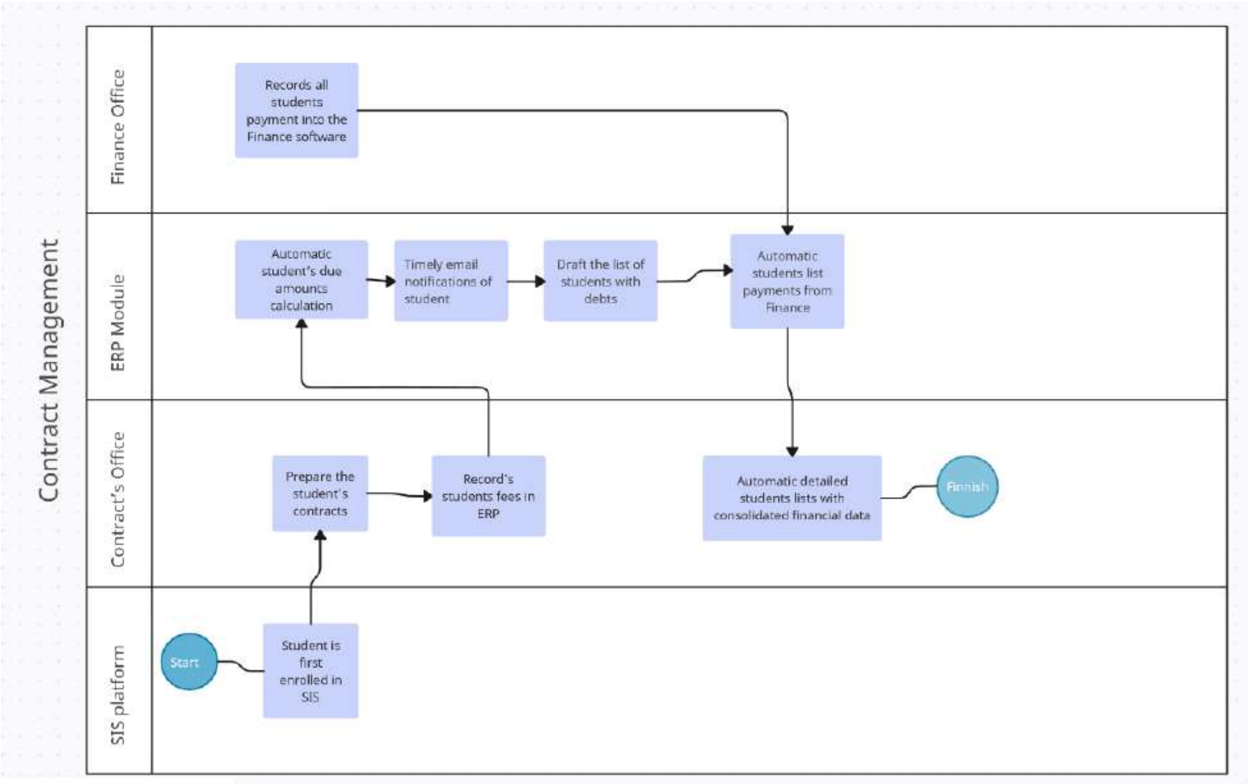


Figure 2: Proposed financial workflow of tuition fees management

The requirements document included functional requirements, which described the specific features and functionalities of the system, as well as non-functional requirements, which describe the system's performance, scalability, and security requirements.

Functional requirements might include features such as:

- Ability to create and manage student accounts
- Ability to assign fees and installments to students
- Ability to generate invoices and track payments
- Ability to generate reports on student payments and outstanding fees

Non-functional requirements might include:

- Performance requirements, such as the system's response time and scalability
- Security requirements, such as user authentication and access control
- Compliance requirements, such as data privacy regulations

B. ARCHITECTURE

The system will be built using a client-server architecture, with a web-based front-end and a back-end that manages the database and billing processes. The platform will be built on top of the well-known OpenBravo Open Source ERP Platform(Gómez-Llanez et al., 2020). The back-end of this ERP is built using JAVA programing language and Postgress database.

One of the benefits using a good ERP like OpenBravo is that the university for may functionalities it can use the ERP configuration options which allows to change settings within the ERP without modifying the source code. On the other hand, the other option would be the ERP Customization. ERP customization is a process in which business-specific functionalities are added or modified to an ERP system to meet the needs of a business. This process requires coding and/or special implementation.

Openbravo has the following modules: a) Master Data Management, b) Procurement Management, c) Warehouse Management, d) Sales Management and CRM, e) Production Management, Financial Management and Accounting, f) Business Intelligence and Project Management(Gómez-Llanez et al., 2020).

Database Schema: The database will be designed to store student information and tuition fees. The following entities will be included in the database schema:

- Students: stores student information, including name, address, email, and student ID.
- Tuition Fees: stores information about the different types of tuition fees that students are charged, including tuition, Photocopying, scholarships type. It will be flexible to include future other fee types.
- Installments: stores information about the different installments for each student, including the amount due and the due date.
- Payments: stores information about the payments made by each student, including the amount paid, the date paid, and the payment method.

C. INTEGRATION WITH EXISTING SYSTEMS

The new system should be integrated with the existing SIS platform and the Financial software. The system will pull student information from the SIS to populate the student database. The system will also send tuitions fees detailed information to the Financial System to record payments made by students. The payments, which will continue to be recorded in the financial software, will be synchronized back to the new tuition fee management system.

Security Measures: The system will implement security measures to ensure data privacy and protection. The system will use encryption to protect sensitive data, and will implement user authentication and access controls to ensure that only authorized users can access the system.

The system requirements for the platform to be implemented are:

1) Hardware

Table 1: Server Hardware requirements

Topology	Concurrent Users	Topology	Bandwidth	Hardware (single)
Single Server	<=10	64-bit (x86_64)	4Mbit/s	Quad Core 2.8 GHz Intel Xeon, 8GB RAM, 128 GB disk 10000rpm
Single Server	<=20	64-bit (x86_64)	10MBit/s	8 - Core 2.8 GHz Intel Xeon, 16GB RAM, 128 GB disk 10000rpm

2) Software

Table 2: OpenBravo Server Software requirements

Stack component	Supported versions	Recommended version	Notes
Java SE	11	Latest 11.x	OpenJDK and Oracle JDK supported

			• Java 11 supported starting with PR18Q2
PostgreSQL	10.x, 11.x, 12.x, 13.x, 14.x, Amazon RDS	Latest 10.x	With UUID support enabled (contrib) until PR18Q1 • PostgreSQL 10 supported starting with PR18Q1 • PostgreSQL 11 supported starting with PR19Q1 • PostgreSQL 12 supported starting with PR20Q1 • PostgreSQL 13 supported starting with PR20Q4 • PostgreSQL 14 supported starting with PR21Q3 • Amazon RDS supported starting with PR18Q1
Oracle	19c (LTS)	19c (LTS)	Oracle XE not supported
Apache Tomcat	8.5.x (x >= 24)	Latest 8.5.x	• Tomcat 8.5 supported starting with PR18Q2 • At least 8.5.24 is required (with Java11) starting with PR19Q1
Apache Ant	1.9.2 or higher	Latest 1.10.x	Starting from 3.0PR18Q2, lower than 1.9.2 is no longer supported Since 19Q1 1.10.6 is required. See changes list below for details. With Java>8 at least 1.9.4 is required. See changes list below for details.
Apache HTTP Server	2.4.x	Latest 2.4.x	Optional but recommended
Apache mod_jk connector	1.2.x	Latest 1.2.x	Optional but recommended
Apache Tomcat Native	1.1.x, 1.2.x	Latest 1.2.x	Optional but recommended

Table 3: list of supported/recommended browsers

Web browser		Minimum required	Recommended version	WebPOS and mobile applications	Backoffice
	Google Chrome	107	**111 or higher**	Yes	Yes
	Apple Safari	14	**16 or higher**	Yes	Yes

	Mozilla Firefox ESR	91	**102 or higher**	No	Yes
	Microsoft Edge (Chromium based)	107	**111 or higher**	No	Yes

5. Results

The partner company chose to work with for building this custom solution was DIAGNOSTICA. Their previous experience in customizing OpenBravo and previous good experience in collaboration with UET, made it a perfect candidate for this project. Students of the UET and a professor of programming languages were involved in the project design and implementation together with the DIAGNOSTICA company.

The HUB involved also the equipment provided by the KnowHUB project results of this cooperations. Students were working mostly from the HUB Commercialization centre office. Regular meetings were conducted with the development manager of DIAGNOSTICA and also the professor of UET.

The end result was a ERP Contract module for tuition management of the students integrated with the SIS platform and the Finance software. The ERP module, through integration solution developed, automatically reads students data from SIS platform, With these data it creates automatically student account in the ERP module itself and also in the Finance software. With this integration the student account is created identically on the 3 platforms, so no human error can happen anymore for that process. Then, the students payment are recorded correctly on the students account created in the software platform. This information can be synchronized back to ERP where the tuition fees detailed are first recorded first and financial data can be reconciled and summarized for each students.

Below are listed some sscreenshots from the ERP module platform developed.

I. ERP CONTRACT MODULE – MAIN PAGE

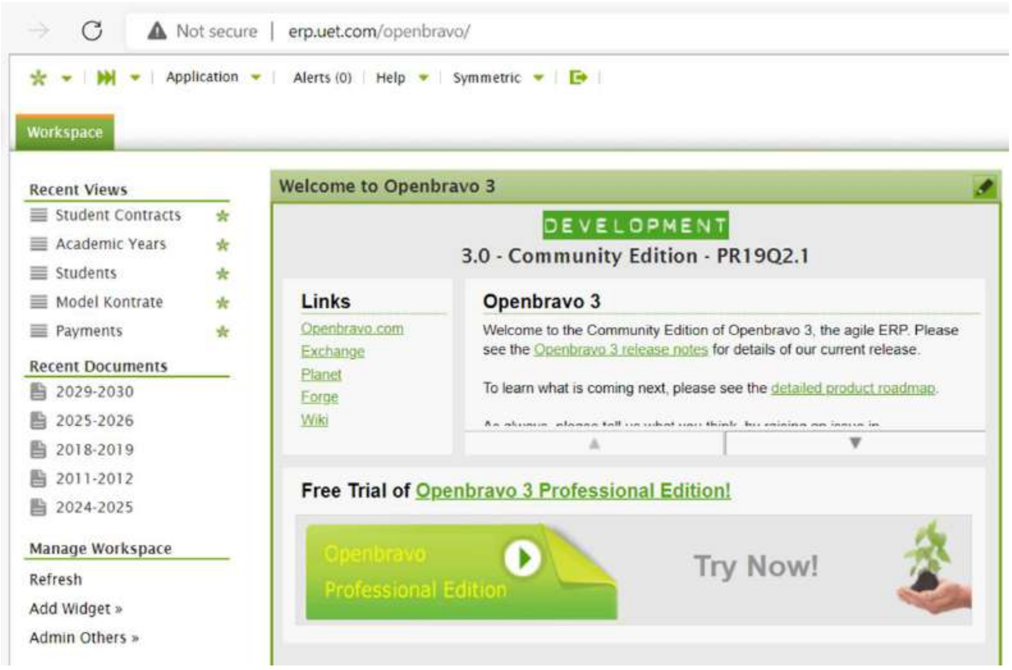


Figure 3: ERP Contract Module – main page

II. ERP CONTRACT MODULE – LISTING STUDENTS' CONTRACTS

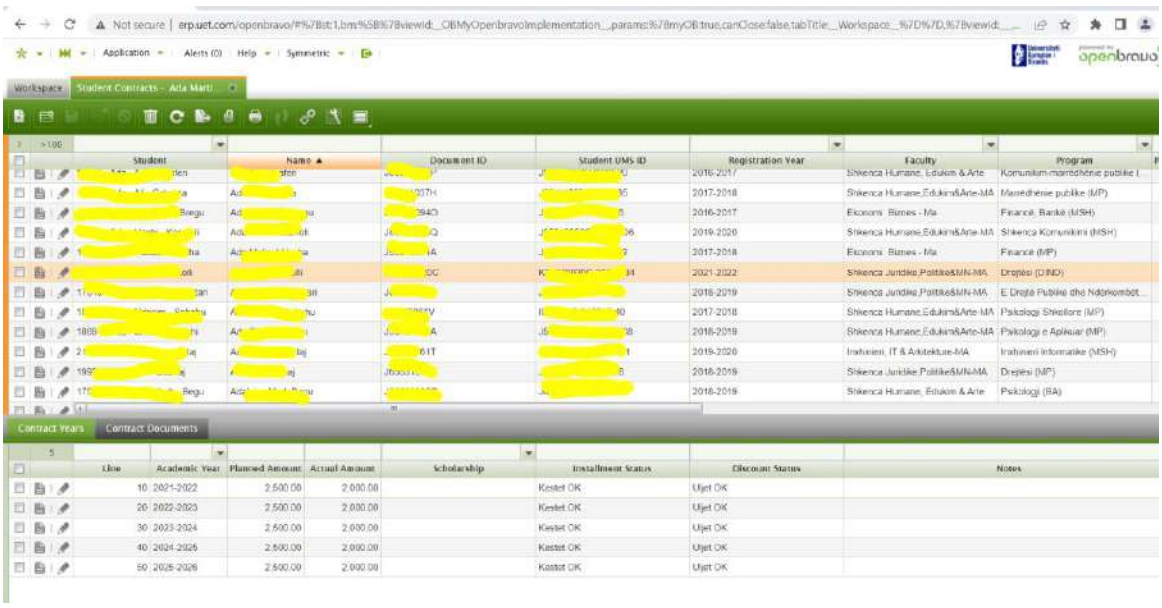


Figure 4: ERP contract Module – Listing students' contracts

III. ERP CONTRACT MODULE – LISTING STUDENTS' CONTRACTS

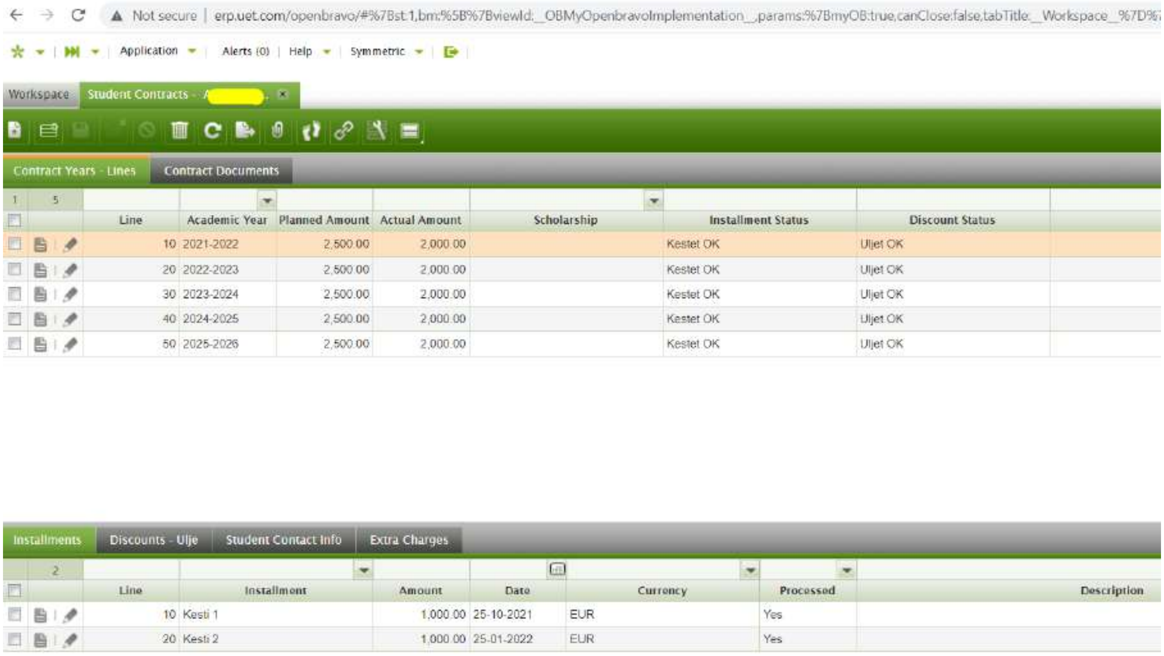
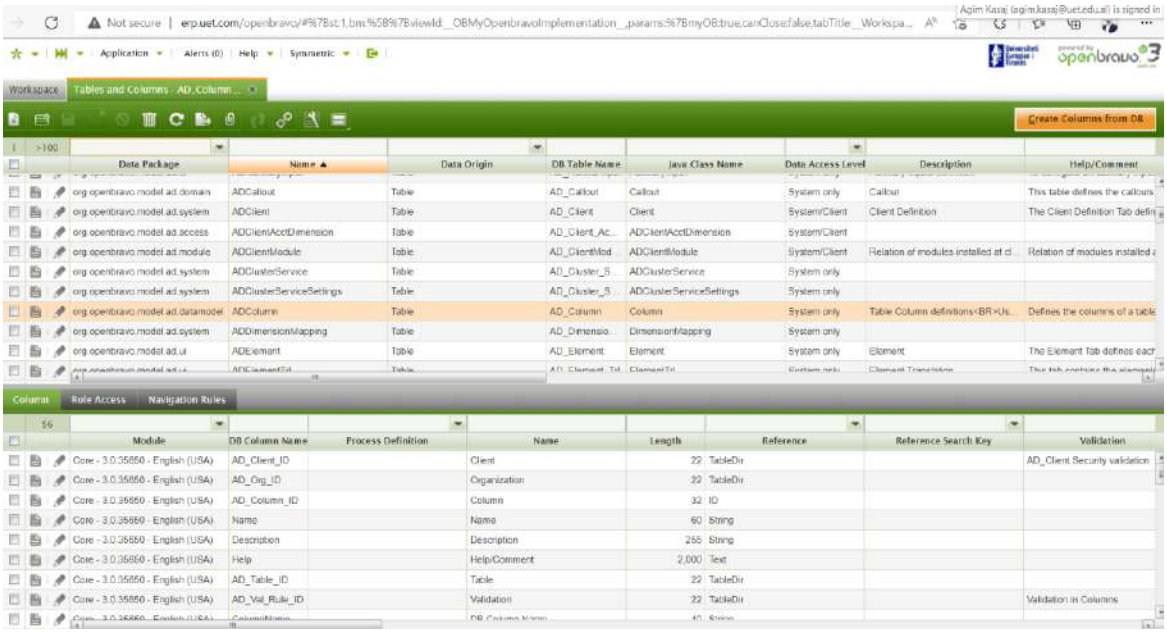


Figure 5: ERP contract Module – Listing students' contracts

IV. ERP CONTRACT MODULE CONFIGURATION



6. Discussion

The universities, like many other businesses need to stay competitive in the market. To face the competition it needs to implement latest technologies and solution by customizing them best suit their business processes and it requires a lot of resources.

Fortunately each university has a lot of internal resources that can be used to support it operations. Students and professors are the best resources and widely available to it. A carefully developed strategy of integrating those resources with other partner businesses can lead to a well desired synergy with very positive results.

The commercialization hubs are a very good strategy for the universities to go beyond traditional collaboration with the other businesses like internships, or open lectures. These HUBs can create a really strong and effective collaboration with high quality products that can serve to both parties.

UET designed and implemented successfully one commercialization HUB and managed to get good results with real product since the first year of implementation.

Nevertheless, there are many new obstacles and challenges for the university that needs to be overcome. A perfect fit with the product design requirements and development with the quality of students and professors is very difficult to achieve. The university management should exploit all the opportunities and choose the best way with the current resources and adapt to new, unforeseen situations that may come.

Is important that the lesson learned from this collaboration with the industry to be also implemented in the academic activity, so the students can learn more practical skills and be ready for the market even before they finish their studies.

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Development of a catalogue services for third partners. The case of Vlora University

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Abstract

University of Vlora "Ismail Qemali" (UV) is a public higher education institution established in 1994 with the Council of Minister’s decision no. 105 and located in the South of Albania in the city of Vlora.

The University of Vlora has a high qualified academic staff and students with high potential. However, there is a lack of formal collaboration with the companies/businesses in the Vlora region and the University. The collaboration has been sporadically and not formalized. Additionally, there is a lack of such kind of culture for this issue. This pilot project aimed to demonstrate all the possible services that the University of Vlora “Ismail Qemali” can provide to third partners (including here public and private institutions, SMEs, etc.). The pilot project was implemented by a multidisciplinary team that included academic and administrative staff and students. The pilot project was done in collaboration with the Vlora Chamber of Commerce and Industry. The final product included a service catalog that works as a central source of information on the main services delivered by UV. In total nine services are demonstrated in two languages (English and Albanian). This is a first step that can help the University of Vlora not just to complete its third mission but also to increase the University revenues.

1.1 Introduction

University of Vlora "Ismail Qemali" (UV) is a public higher education institution established in 1994 with the Council of Minister’s decision no. 105 and located in the South of Albania in the city of Vlora. University of Vlora started its activity with three established faculties: Faculty of Commerce (with the branches of Business and Tourism), Faculty of Marine Engineering and Faculty of Nursing. The selection of these faculties was made on the basis of the tradition that existed in Vlora for these disciplines. In 1919, the “High School of Commerce” was opened in Vlora. This good tradition was enriched when a branch of Economics of the University of Tirana was opened in Vlora, which operated between1970-1980. In 1960, A Navy Institution of Higher Education started operating in Vlora and it served as the basis for the establishment of the Faculty of Naval Engineering (Faculty of Technical Sciences). The Faculty of Nursing (today known as Faculty of Public Health) has been created in the tradition of the “Medical High School” (the only one of this kind in our country) which was opened in 1967. In the beginning, the name of the university was “Technological University of Vlora "Ismail Qemali ". Since 2007 the university changed its name into University of Vlora "Ismail Qemali", and its acronym is UV. The university started to increase the study programmes it offered along with the number of students and academic staff. In order to adapt to the demands of the community for the formation of various specialists, focusing mainly on the south of Albania where it is also situated, UV also started to offer a variety of study programmes including Foreign Languages, Teaching Education, Information Technology, Electrical Engineering, Navigational Sciences, Law, Mechanical Engineering, etc. The restructure of study programmes in accordance with the requirements of the Bologna process and ECTS credits began at UV during the academic year 2005-2006 (1).

The Institution for the first time was accredited in 2017. The accreditation period was for three years. The Accreditation Board of the Quality Assurance Agency of Higher Education, through Decision no.50 accredited and recognized UV with a positive Institutional Accreditation for a period of 5 years until 2025. The mission of UV focuses on a) Contributing to the promotion and dissemination of scientific knowledge through the provision of a wide range of teaching and research disciplines; b) Providing the necessary tools for a successful career for students and academic/administrative staff support; c) Meeting the social cultural and development needs of the country by providing a leading role in the local economy as well as in the cultural development. University of Vlora provides excellent and a wide variety of programs through the four Faculties (Faculty of Humanities AND Law, Faculty of Economy, Faculty of Technical and Natural Sciences; and Faculty of Health).

All UV Faculties have established a research center. In some cases, the research centers operate as main units (i.e., Faculty of Public Health) while in other cases as independent units within the faculty (i.e. Faculty of Economy or Faculty of Technical Sciences). Except the aforementioned centers, a multidisciplinary center operates also at the University. This center is named Regional Development Centre and the main aim of it is to bring national and international funded projects. The center provides also lifelong services to third parties (i.e., credits for teachers etc.). The university has made available to the teaching, pedagogical and academic activities, 53 auditoriums, 25 laboratories and other similar 20 facilities, 75 offices and administrative spaces, 16 technical and auxiliary offices, 3 computer and multimedia labs, 3 library halls and other infrastructures.

UV has defined internalization as one of the important points of its institutional development based on the Strategic Plan's line of Internationalization (2), International Strategy (3) of the university and the history of the mobility's in the framework of Erasmus+. The number of international mobility for both students and academic staff has increased significantly the last years at the University with more than 250 outgoing staff and more than 100 students. However, the number of incoming as increased, till improvements are needed.

The New Law in Higher Education in Albania was approved by the Parliament in July 2015 and since then came into force (4). The new law focuses on the three main missions of the Higher Education Institutions (education/teaching, research, and cooperation with third partners / third mission of the University). Despite the fact that the two first missions of the University are accomplished in a satisfactory level, the third mission is in its very first steps. The University of Vlora has a high qualified academic staff and students with high potential. However, there is a lack of formal collaboration with the companies/businesses in the Vlora region and the University. The collaboration has been sporadically and not formalized. Additionally, there is a lack of such kind of culture for this issue. However, due to the high human capacity and the infrastructure many services could be provided to the companies / industries of the Vlora region. On the other side, many companies / businesses are not aware of the possible services that they can receive from the University. Based on this, we decided to collaborate with the Vlora Region Chamber of Commerce and Industry and to develop a Specific Catalogue.

1.2 Background

The Chamber of Commerce and Industry of the Vlora Region is a public institution with functional autonomy which, in the territorial jurisdiction of the area, carries out important functions of general interest for the economic system. It is located in the south of Albania, in Vlora city. The Chamber promotes commercial and industrial activity in the territory of the district, as well as commercial and economic cooperation with other countries. The Chamber constantly exchanges information with the state administration, for business promotion and development. The Chamber of Commerce and Industry of the Vlora Region offers different possibilities to its members including (5):

- ❖ Attaining the Chamber of Commerce membership certificate is a mandatory requirement by law and one of the perquisites for obtaining a license to exercise the activity of your company;
- ❖ The certificate of membership in the Chamber of Commerce and Industry is the document that proves to local and foreign partners the seriousness of your company, increases your authority as a company and creates ease in your production, commercial and service activities;
- ❖ Through the Chamber of Commerce, members can get continuous information and create links with the worldwide businesses, offers, and demands and get the correct addresses of your possible partners in the world;

- ❖ With the possibilities it has and with the activities it develops, the Chamber creates opportunities for connection and direct contact with firms, companies and businessmen interested in establishing business relations in Albania;
- ❖ The Chamber of Commerce presents Albanian companies to international business institutions, with which it maintains many ties, and recommends potential partners from Albania to foreign companies.

The services that the Chamber of Commerce and Industry of the Vlora Region provides are:

- ➢ It offers interested local and foreign companies the possibility of cooperation in the form of joint ventures or other forms, which contributes positively to the increase of foreign investments in Albania;
- ➢ It organizes conferences, business missions, and business meetings, inside and outside the country, which serve as a link between Albanian and foreign businesses;
- ➢ Through the structures of the Chamber, develops international fairs. The Chamber creates the possibility of participation and exhibition of products, as well as of meetings with business owners for signing contracts and cooperation;
- ➢ Publish the monthly newsletters and the newspaper "The Business";
- ➢ It organizes courses and classes for the qualification and improvement of the business culture, for the recognition of the market economy and its special mechanisms;
- ➢ It ensures the registration of trademarks and patents of your products, in accordance with the "Industrial Property" law, which is the first step for their protection from speculators and counterfeiters.

The "Reconnecting Universities and Enterprises to Unleash Regional Innovation and Entrepreneurial Activity" – Know-Hub project was submitted in the context of KA2 – Cooperation for Innovation and the exchange of good practice - Capacity Building in the field of Higher Education Call for proposals 2019 – EAC/A03/2018. The main aim of the Know-Hub project is to address the University – Enterprises cooperation in western Balkan countries. The final objective is the development of commercialization hubs in all partner countries Universities (including UV).

This is a significant gap that comes to overcome this project with he establishment of the specific Hub. The University of Vlora aims to create a university in the service of the highest human values, promoter of developments in the territory, with quality and integrated services not only in the region of Vlora but throughout Albania. We aim to train and prepare promising students, quality professionals in line with the labor market trend, scientists in the service of dynamic developments not only in the national context but also in Europe and beyond, overcoming any barrier related to origin their social, economic or cultural.

The mission of the proposed Hub will be to bring together and to create synergies between the University of Vlora and local/regional entrepreneurships/businesses. The Hub will have as a key mission the promotion and technology transfer as well as the development of industrial innovation projects involving students, professors and businesses (6).

1.3 Problem

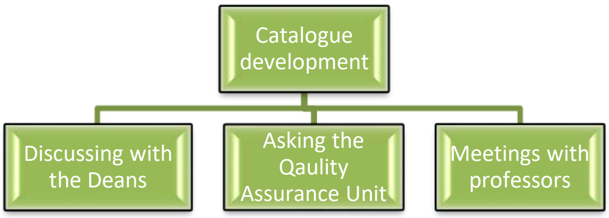
Till the beginning of the project, no concrete services were provided to third partners while they had no clear idea of possible services that they could benefit from the University. In the future, we aim to provide a number of services to industry / third partners as well as to have a specific offer for them. Based on this, and in order to make more available and achievable these services, in collaboration with the Chamber of Commerce and Industry to develop a catalogue services. As the Vlora Chamber of Commerce and Industry is the organization that has the daily contact with the businesses in the region, to our view, they were the best possible partners for implementation of this project. They are respected and with many years of experience in the field. Promotion of the catalogue services from them, increase the credibility to the third partners and make them less reluctant to ask for possible services.

The University of Vlora needed this catalogue in order to promote its services to the region. The catalogue was expected to be developed by University of Vlora Know Hub team in collaboration with all Faculties professors as well as some students that were included in this pilot project. The University of Vlora Services Catalog aims to disseminate all possible services that public/private institutions, small and medium entrepreneurship (SMEs), and other partners can receive from the University. These services can be offered in a very qualitative way as well as at a much lower price than can be offered by other private initiatives.

1.4 Methodology and solution

Based on all the aforementioned, we decided to develop a detailed catalogue of all possible services that could be offered to the different third partners. Initially, an agreement was signed with the Vlora Chamber of Commerce and Industry to make formal this collaboration. In order to develop this catalogue, we used a threefold approach (Figure 1). Initially, we asked from all the Deans of the Faculties of the University (4 Deans) during a Rectorate meeting to discuss with their staff and Heads of Research Centres about the services that they can offer. We waited two weeks for their response and contacted them again by phone call in order to remind them about this issue. Additionally, we contacted the Quality Assurance Unit in order to ask them for possible services that the University offer. This unit is responsible for accreditation process of the University and the study programs. During the accreditation process, usually the Faculties/Departments provide in their reports possible services that they can provide. Thirdly, we asked from different professors at the University that are active in projects and/or have a background in industry to inform us if they can provide specific services or if they know someone at the university that can do this.

Figure 1. Approach used to develop the catalogue



This work was done by the team members of the pilot project. However, other team members of the Know-Hub project contributed by providing different contacts. The role of students in this phase was limited as they couldn't do much. However, we asked them if they as students could provide different services that could be included in the final catalogue or if other students could do so. They provided us some ideas, but we considered not to include them in this first version.

After collecting all the available information, the Vlora team made two meetings in order to concretize the content and to start with its development. After finalizing the services that would be demonstrated at the catalogue a draft was prepared. During the whole process, the team members of the pilot project contacted regularly the responsible persons at the Faculty for more information and/or confirmation of the content included as well as for photos available. Initially, the catalogue was developed in Albanian language and after was translated in English. Translation was conducted by three members (2 of them students) of the pilot project team. Moreover, two persons participated in designation of the catalogue (including one student). The final draft was disseminated with the whole project members and the Head of the Vlora Chamber of Commerce and Industry for comments/suggestions. After approval, the final version of the catalogue was sent to the Work Package (WP) leader.

1.5 Results

The service catalog provides a central source of information on the main services delivered by our Institution. This ensures that all areas of the business can view an accurate, consistent picture of the IT and other services, their details and their status. It includes a customer-facing view (or views) of the IT services in use, how they are intended to be used, the business processes they enable, and the levels and quality of service the customer can expect for each service. Through the work of service catalog management, our institution can:

- *Ensure a common understanding of all the services and improved relationships between the customer and service provider by utilizing the service catalog as a marketing and communication tool*
- *Improve service provider focus on customer outcomes by correlating internal service provider activities and service assets to business processes and outcomes*
- *Improve efficiency and effectiveness of other service management processes by leveraging the information contained in or connected to the service catalog Improve knowledge, alignment and focus on the 'business value' of each service throughout the service provider organization and its activities.*

In total the catalogue included nine different possible services (Image 1 and Image 2) that could be offered to public/private institutions and SME. The catalogue is consisted of 40 pages in total (20 of them in Albanian and 20 in English language). These services are offered from the different faculties and research centers of the University. After development of the catalogue, it was published at the Vlora University website as well as at the website of Vlora Chamber of Commerce and Industry. However, both Institutions have disseminated it to all their partners via email for their information. The University of Vlora printed also both versions and disseminated them. Additionally, some copies are at the entrance of the Rectorate of the University. They are in a visible place and available to potential "customers". The catalogue contains also contact information in order to get more information about the services they can need. This is the first ever attempt that we have made to prepare a concrete product for third partners.

1.6 Discussion

To our best knowledge, this is the first ever attempt of Vlora University in its almost thirty years of life to develop such a catalogue in order to promote the possible services that can provide to third partners. The development of the catalogue by a multidisciplinary team and students in collaboration with the Vlora Chamber of Commerce and Industry is one of the strongest point of this work. This service comes at a very critical point where all Universities needs to better implement the New Law in Higher Education as well as the New National Education Strategy 2021-2026 (4, 7). In the Higher Education Law, article 25, point 9 is clearly mentioned that the department can offer services for third parties based on the legislation. This mission of the university is mentioned also in article 98 point 5 of the current law (4).

A very crucial point for the sustainability of the Universities are their revenues. Except the budget provided by the Ministry of Education, other possible financial sources of the University are students fees and revenues from services to third partners. This is clearly mentioned also in the Higher Education Law at article 109, point 1c and 1ç. In this issue, the University of Vlora is not doing so well and we hope that this catalogue can contribute also in increasing the revenues of the University.

1.7 Conclusion

This pilot project aimed to demonstrate all the possible services that the University of Vlora "Ismail Qemali" can provide to third partners (including here public and private institutions, SMEs, etc.). In the catalogue, possible services that could be offered for a fee are available for all interested partners. Through a long process that included professors, administrative staff, students and the Vlora Chamber of Commerce and Industry. The final result was the development of a detailed catalogue that included nine possible services that can be offered to third parties. The catalogue was developed in two different languages (Albanian and English) and is disseminated in both online and hard copy version. The Chamber of Commerce and Industry operates as a facilitator in this case and brings closer the different enterprises to the University through its legal status and its credibility. We aim to regularly enrich the catalogue with different services. This is a first step that can help the University of Vlora not just to complete its third mission but also to increase the University revenues.

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Appendices

Figure 2. Catalogue services in Albanian language

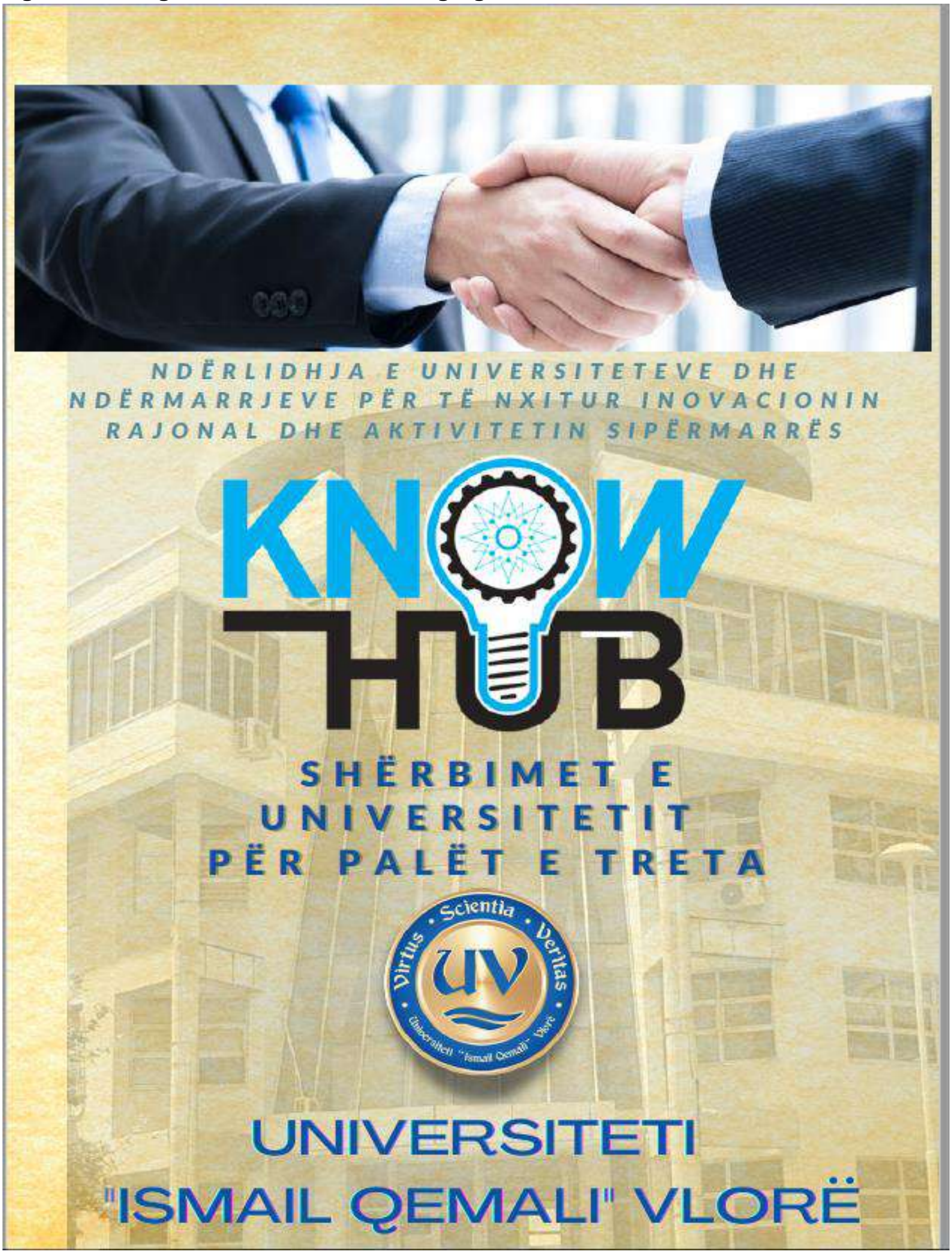

Figure 3. Catalogue services in English language

Increasing manufacturing throughput using theory of constraints methodology and lean manufacturing tools

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Abstract

In this paper production parameters such as throughput, cycle time, inventories in the production process, and idle time were investigated for a production system. The Lean Manufacturing methodology applied for elimination of identified waste in the production system. A more suitable layout of the production line was created, which reduces unnecessary movements. By Load Balancing, a reduction in the number of operators was achieved. One of the key elements of Lean Manufacturing, in addition to continuous improvement, is the respect of employees as key figures in product development. Therefore, the analysis also went in the direction of making production easier for employees. The Theory of Constraints (TOC) methodology was applied to investigate and analyse possible measures to alleviate the observed bottleneck of the system or completely remove that bottleneck in order to increase production capacity. In order to increase production capacity and reduce inventory between operations, the implementation of One-piece flow was analysed. With the Lean Manufacturing tools and Theory of Constraints methodology, the steps to achieve optimization were described and three solutions were offered for the Case Study. The first solution resulted in a cost reduction of €60,000 per year for the same production capacity. The other two solutions offered increases in production capacity by 21.62% and 46.15%.

Keywords: *theory of constraints, lean tools, process optimization*

Introduction

In modern times, it is a challenge for many companies to remain competitive in the market due to the impact of globalization. Caused by that pressure, it happens that companies orient themselves in large investments by purchasing sophisticated technologies, believing that this is the correct and only solution for improving the process and economic growth of the organization. First of all, it is necessary for an organization to ask what the measure of success is, and to do so it is imperative to know the difference between efficiency and effectiveness.

There are many parameters used to measure a company's performance. However, according to Goldratt (2014) only one parameter is crucial and that is profit. On the path to profit maximization, there is always a constraint, which at that moment is a critical factor for the performance of the organization. From this way of thinking of the mentioned author, the Theory of Constraints was created. The Theory of Constraints is an approach that explains the steps needed to remove the constraints that arise in the process of achieving a goal. A commonly used term for constraint in production management is a bottleneck and it represents any resource within a company whose capacity is insufficient to meet the demand required of it. Therefore, it can be stated that the tendency of this approach is to create a balanced production plant, with the desire to increase production capacity in order to satisfy the market and increase profits.

In addition to the Theory of Constraints, there is another customer-oriented approach that is discussed in this paper, the Lean Manufacturing approach. Aside from quality, customers are also interested in the price. Therefore, one of the goals of Lean Manufacturing is to eliminate all types of waste that do not add value to the product and for which the customer would not be willing to pay (Ohno, 1988). Using the so-called non-cost management principle, companies that operate according to the Lean Manufacturing approach manage to achieve the desired profit within the price set by the market, and they do this by reducing production costs.

The roots of Lean Manufacturing can be found in the Kaizen philosophy. Constant improvement, or Kaizen in Japanese, means taking small, incremental steps that lead to improvement instead of making sudden, big changes (Prošić, 2011). For that reason, the companies are able to make positive changes and improvements without large capital investments.

This research was created for the purpose of optimizing a production line at MANN + HUMMEL BA. MHBA[1] has a wide range of filter products and thus meets the needs of even the most demanding customers. The company is engaged in the production of air filters, fuel, oil, cabin and hydraulic filters for the automotive industry. Also, the company produces filters for industrial and construction machinery, and filters for wastewater treatment. This research paper was written to optimize a production line that produces one type of air filter.

In this research, the optimization was successfully performed by reducing waiting times and reducing the movements of employees. This was achieved by implementing new layouts and balancing the production line. Likewise, different production capacities are offered for different layouts, equipment and number of operators within the production line.

2. Study of existing processes in the production line b4

In this chapter, the description of the production line and the definition of its operations were carried out with the aim of achieving possible improvements, finding bottlenecks, and increasing production capacity.

2.1 Description of the production line B4

Production line B4 is just one of the production lines in the MHBA company. The task of the B4 line is significant because it produces air filters that are small in size, where the height of the finished filter is only 40.4 mm. Therefore, the production of these filters is challenging. This production line is adaptable because, in addition to the mentioned filters, if the market requires it, it is possible to produce slightly larger air filters. The number of filters per hour to be produced is 600. One shift lasts 7.5 working hours. The number of operators per shift is 9. The first goal is to maintain production line capacity of 600 units/h but at a lower operative cost. Then the second goal is to analyse an increase in production capacity in a case of the increasing demand for the filters.

The filter consists of five parts. The parts of the filter are as follows: Paper part of the filter (accordion), Upper lid, Gasket for the upper lid, Bottom lid and Gasket for the bottom lid. Figure 1 represents the initial layout of the production line. Operation and machine tags can be found inside the circles in Figure 1.

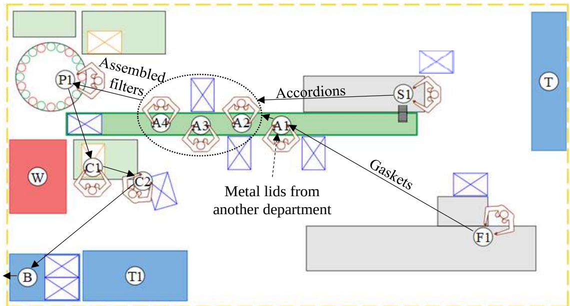

Figure 1. Sketch of the initial layout of the production line

The black arrows in Figure 1 represent the material flow. Tag S1 is an industrial stapler that staples the ends of the paper part of the filter (accordion). Operation F1 has the task of stamping gaskets. Operation A1 has the task of inserting the gaskets into the metal filter lids. Operations A2, A3, and A4 represent the assembling of the filter. They perform the joining

[1] *MANN+HUMMEL subsidiary in Tešanj, Bosnia and Herzegovina.*

of the lids inside which are the gaskets that come from operation A1 with the accordions that come from operation S1. Operation P1 represents the sealing of the filter using a press machine. Operation C1 represents the control of the diameter and height of the filter. Operation C2 represents the visual inspection of the filter and packaging. Tag B represents the buffer of the finished filters. The tag T1 represent shelves. Tag W represents a machine that is not in use.

Figure 2. The industrial stapler for joining ends of the paper filter

Figure 3. The stamping machine for the production of gaskets

The industrial stapler S1 is shown in Figure 2. One operator performs the operation of joining two ends of the paper filter using this machine. After operation S1, the paper filter has a cylindrical shape. After the stapling operation, the accordion falls onto the conveyor belt as illustrated in Figure 2. One can notice a large inventory of accordions on the conveyor belt. Operation F1 is also performed by one operator, who works on a stamping machine that produces filter gaskets. Operator F1 delivers gaskets manually to operation A1. The appearance of machine F1 is shown in Figure 3. Both of the mentioned operations S1 and F1 receive raw materials from the warehouse and perform their operations simultaneously without depending on each other.

A1 operation (see Figure 1) represents the joining of the gasket and the lid of the filter. Operation A1 depends on operation F1 from which it receives gaskets and depends on the delivery of finished lids that are manufactured in the metal stamping department. Since the metal stamping department does not belong to the B4 production line, it is not analysed.

After joining the gaskets and lids at operation A1, there remains the final assembly of the filter, which is performed at operations A2, A3 and A4. All three mentioned operations have the same task, which is to put the top and bottom lids with gaskets that come from operation A1, on the accordion that comes from operation S1. After assembly, the filters are on the conveyor belt as can be seen in Figure 4 and they are ready for the next operation P1.

Looking at Figure 4 one can get the impression that there is a large inventory of assembled filters on the conveyor belt. Excessive inventory in front of operation P1 indicates that operation P1 is a bottleneck in the production line. Operation P1 is shown in Figure 5.

Figure 4. The conveyor belt on which the filters are located

Figure 5. Circular press for pressing and sealing filters

Operation P1 is performed by the operator who inserts the assembled filters into the circular press. There are technical problems with the circular press, and only 12 compartments for filters are functional instead of 20. The circular press for sealing the filters uses temperatures of approximately 225 degrees Celsius, and it takes 70 seconds to complete one cycle, i.e. one rotation. This rotation time is adjusted to achieve sealing.

a) b)

Figure 6. a) Controlling internal diameters; b) Controlling the height of filters

Once the circular press completes its cycle, the filters are arranged on the table next to it, and after an average of 50 pieces, the operator who works on Control 1 comes and takes them to his worktable. Control 1, i.e. operation C1 represents the control of the diameter and height of the filter. The diameter is controlled using a go/no go gauge, and the height is controlled using height gauges as it is shown in Figure 6.

Operation C2 represents the last visual control and packaging of the filters in industrial crates. One industrial crate can hold 924 filters. Operation C2 is shown in Figure 7. After the crate is filled, it is placed in the place marked with the letter B (see Figure 2). This place represents the buffer of the finished filters and can be seen in Figure 8. From this area, employees in charge of transport take the finished filters to the warehouse.

Figure 7. Visual control of finished filters and packaging in industrial crates

Figure 8. The buffer of the finished filters

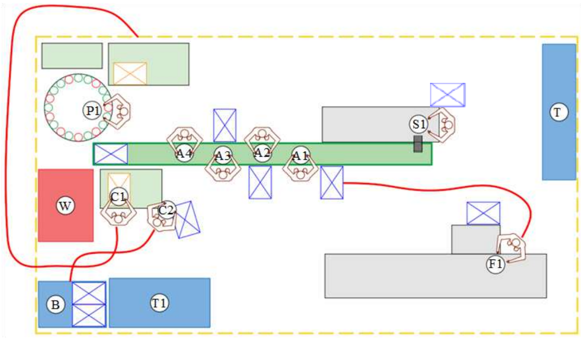

Figure 9. Spaghetti diagram for movement of the operators. The red lines represent the movement paths.

Figure 9 shows a Spaghetti diagram that graphically describes the path of employees' movement. As can be seen in Figure 9, operator C1 goes to the circular press in such a way as to leave the area of production line B4. During the employee's movement, the operator encounters other employees and transport equipment such as a manual fork, because the operator enters the movement zone that serves for the delivery of raw materials and the transportation of finished filters to the warehouse. Operator C1 needs an average of 23.3 seconds for both directions of movement and brings an average of 50 pieces to his desk. To fulfill the norm of 600 pieces per hour, operator C1 needs to walk to operation P1 for filters 12 times in one hour. In the course of one shift, the walk duration amounts to 34.95 minutes.

The duration of movement activities for the mentioned operation C1, as well as for operations C2 and F1 is presented in Table 1. The methodology according to Heizer and Render (2014) is used to obtain the number of necessary samplings in the time study. The variability of the operation times is not significant, so only the mean values of the measured times were used in further analysis.

***Table 1**. Movement duration times for the operations C1, C2, and F1*

Operation number	Walking time for both directions (seconds)	Times per hour	Per shift (minutes)
C1	23.3	12	34.95
C2	10.8	0.65	0.878
F1	11.6	12	17.4

Figure 10 presents a chart showing the times of all operations in production line B4. The goal of this type of chart is to perform Load Balancing in order to approximately equalize the operation times and thus eliminate waiting times between operations. In Figure 10 it can be seen that each operator's time is shown separately. As mentioned, the times shown represent the average duration of each operation.

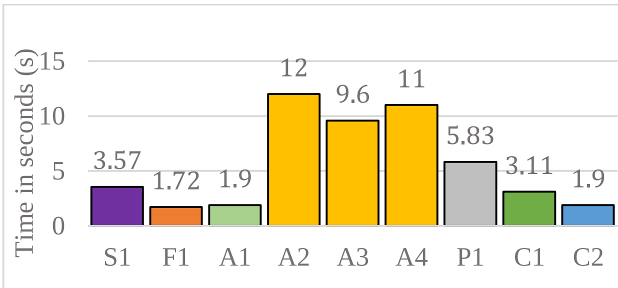

Figure 10. Visual display of the duration of all operations

Figure 11 is a new chart showing the filter assembling operations (A2, A3, and A4) as one operation, i.e. one time. This is done because operations A2, A3, and A4 have the same task.

The assembling time (A2, A3, and A4) in Figure 11 is calculated as the average time of A2, A3 and A4 operations, divided by the number 3 representing the number of operators. In this way, the average assembling time per filter is obtained. As can be seen in Figure 11, the pace is determined by the circular press (P1) which is the bottleneck, with a time of 5.83 seconds. This means that it takes 5.83 seconds for the production line B4 to produce one filter.

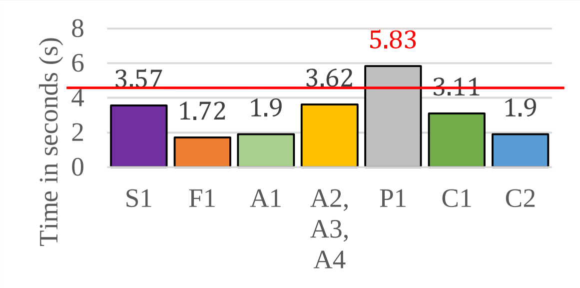

Figure 11. The duration of operations per piece

As can be seen in Figure 11, there is a significant difference in Cycle Times between the circular press operation (P1) and other operations. This will directly affect overproduction in operations before the circular press operation, leading to an inventory build-up. As mentioned, the accumulation of inventory before the circular press (P1) can be clearly seen in Figure 5.

Also, as seen in Figure 11 the controlling 1 (C1) and controlling 2 (C2) operations spend a lot of time waiting. This waiting time is used by operator C1 in walking to the circular press as presented in Figure 11 and Table 1. In addition to reducing the waste of time, the goal is to facilitate the work of operators.

As a result of the previous analysis, different types of waste are identified. To simplify the overview, the wastes are presented in the list, as follows:

1. A machine without a function in the production line that takes up space and does not contribute to the company, and at the same time hinders the operator's movements.
2. Manually moving accordions from the stapling operation (S1) to the assembling operations (A2, A3, and A4) due to the non-movement of the conveyor belt (see Figure 3). The conveyor belt does not move because there are many accordions and assembled filters on it.
3. Overproduction or waiting of operations S1, F1, A1 and operations A2, A3, A4.
4. The formation of excessive inventories before the operation of the circular press (P1).
5. Breakdowns on the circular press, as a result of which only 12 out of a total of 20 compartments for pressing filters are functional.
6. Waste of waiting on C1 and C2 operations.
7. Movements of operator C1 when bringing the filters.
8. Movements of operator F1 when delivering the gaskets.

In the next step these wastes are considered and the optimization of the production line is examined.

2.2 Optimization of the production line with maintaining the same production capacity

In this subchapter, the reduction of production costs while maintaining the same production capacity is analysed. As mentioned earlier, it can be seen from Figure 11 that the bottleneck of the production line is operation P1. The goal is to adjust the times of other operations to the time of the bottleneck if it is possible.

The first step taken is to balance the production line in such a way that operation C1 and operation C2 are combined, i.e. one operator (C) performs both control operations. The new chart after eliminating one operator from the control operation can be seen in Figure 16 (see Figure 11 and compare it with Figure 12).

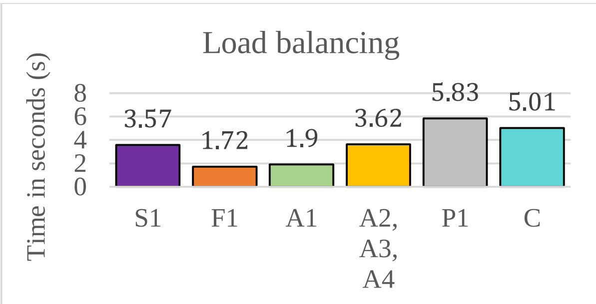

Figure 12. Load balancing of the control operations

However, it should not be overlooked that operator C1 uses his waiting time to move to the circular press, from where operator C1 brings the pressed filters to his work table (see Figure 11). Therefore, in order to achieve a reduction in the number of operators on control operations, a new layout within the production line must be carried out. Figure 13 shows a new layout that was created. In Figure 13, it can first be noticed that there is no machine that is marked with the letter W in the previous figures (see Figure 1 or Figure 9). The machine is removed because it does not contribute to the production line.

In Figure 13, it can be seen that the circular press has been moved from one side of the conveyor belt to the other, so that operator P1, after removing the filter from the circular press, will be able to place it in front of operator C. Thus resulting in the reduction of unnecessary movements. Operation F1 has been moved closer to operator A1, eliminating the movement of operator F1 to deliver gaskets. It is suggested to use sheet metal or gravity rolling conveyor to transport gaskets from operation F1 to the crate located next to operator A1. If these two solutions cannot fulfill the function, it is suggested to use a conveyor belt. The price of the conveyor belt in this case does not exceed €500.

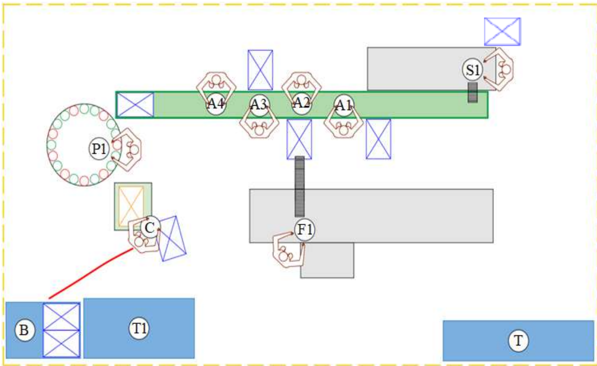

Figure 13. A new layout of the production line with one less operator in the control operations

However, according to Figure 12, it can be seen that there will still be an overproduction of assembled filters before the operation of the pressing filters in the circular press (P1) and that there is room for improvement. Therefore, the next step was to check if two operators (A2 and A3) instead of the initial three in the filter assembling operations can prepare a sufficient number of filters to fill all 12 functional positions in the circular press (operators A2 and A3 remain in the production line while operator A4 is removed). A new Load balancing chart was created, which can be seen in Figure 14.

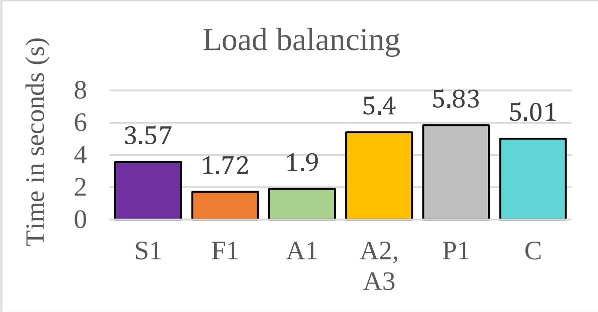

Figure 14. Load balancing of the filter assembling operations

According to Figure 14, two assembly operators (A2 and A3) are sufficient to meet the demands of the circular press (P1) because the assembled filter will be available every 5.4 seconds, and the circular press requires a new charge every 5.83 seconds.

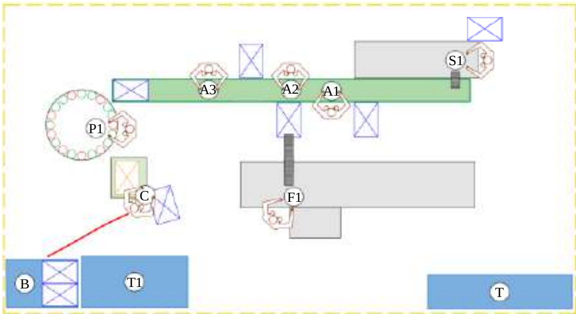

Figure 15. A new layout of the production line when removing one operator from the control operation and one operator from the assembly operation

Figure 15 shows the new layout of the production line, where there are 7 operators instead of the initial 9. Operators F1, S1, and A1 should not perform overproduction, but they will use their waiting time to be at the service of other operators when necessary. One operator costs approximately €10,000 for the company during the year. By eliminating two operators per shift, savings of €60,000 per year are achieved with negligible investments of €500, while the produced quantity of filters remained at the same level.

2.3 Optimization of the production line with the aim of increasing the production capacity

The increase in production capacity was analysed in several different ways. One of the ways is to increase production capacity by introducing a One-piece flow, and it is explained in this part of the research paper. One-piece flow is a method of production in which inventories between operations are eliminated. Firstly, a new layout of the production line can be seen in Figure 16.

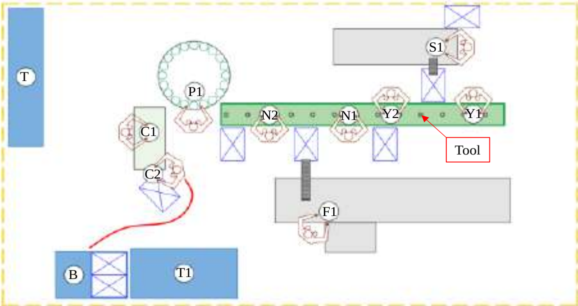

Figure 16. The layout of the production line in order to implement a One-piece flow. Operations Y1, Y2, N1, and N2 perform filter assembly in a new way.

In Figure 16, circles can be seen on the conveyor belt, and those circles represent tools that move along with the conveyor belt. The task of the tool is twofold, to facilitate assembly operations and to support the implementation of One-piece flow.

With the aim of implementing One-piece flow, the activities of operations on the assembly part of the production line were redistributed. Instead of the previous operations A1, A2, A3 and A4 (see Figure 9), there are operations Y1, Y2, N1 and N2, and what differs is the way in which the operators assemble the filters.

Also, the S1 operation has been moved so that accordions no longer fall onto the conveyor belt because they would block the tool function when they fall on the tool. According to the new layout, the accordions from operation S1 fall into the box between the Y1 and Y2 operators.

The activities performed by operation Y1 and operation Y2 are the same. Operators Y1 and Y2 take the accordions from the crate and stretch them in order to do their quick visual inspection. Then the operators make a cylindrical shape from the accordion and then insert such a cylindrical accordion into the tool that moves on the conveyor belt. The appearance of the mentioned tool can be seen in Figure 17, where the accordion is shown in brown, and the tool serves as its support. The design of the tool is planned so that it can be easily adjusted for several different dimensions of air filters that can be produced on this production line.

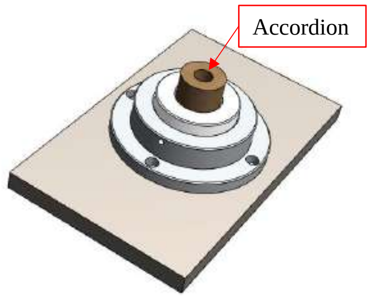

Figure 17. A tool for filter assembly operations

According to Figure 16, operators N1 and N2 are supplied with gaskets by operator F1. The gaskets are delivered to the crate located between these two operators. To the right of operator N1 and to the left of operator N2, there are crates containing lids, which are delivered from another department in charge of metal stamping, as mentioned in the previous chapters. Therefore, it is important to make a passable path to the crates at operators N1 and N2 when making the layout of the production line so that the crates can be filled.

Operator N1 inserts the gasket into the upper lid while waiting for the tool with an accordion to approach him on the conveyor belt. Then when the tool approaches, the operator takes the accordion that comes in the tool and places the mentioned upper lid on the accordion. Finally, the operator puts the accordion back into the tool.

Operator N2 inserts the gasket into the bottom lid, then takes the semi-assembled filter from the tool that approaches him and places the mentioned bottom lid on the filter. This completes the assembling of the filter. Operator N2 no longer places the filter in the tool, but next to the tool, and the filter continues to move towards operator P1 on the conveyor belt.

The task of operator P1 is known from before, which is to insert the assembled filter into the circular press. Next to the feet of operator P1, there should be a button with which the operator could stop the movement of the conveyor belt in case of need.

Figure 18 shows the duration of all operations according to the new redistribution of operation activities. As can be seen in Figure 18, the durations of operations Y1 and Y2 are shown separately. Therefore, the following Figure 19 presents a new chart when operations Y1 and Y2 are represented as one time because these two operations perform the same task. The time used for these two operations is 4.29 seconds. The time of 4.29 seconds represents the average time of 8.87 seconds and 8.27 seconds divided by the number two (number of operators). As seen in Figure 19, the bottleneck according to the new distribution of activities within the production line is operation P1. The reason for this is the fact that only 12 compartments for filters inside the circular press are functional instead of the total of 20. Therefore, in order to increase the production capacity of this production line, it is necessary to repair the remaining 8 compartments of the circular press that are not functioning. Using the 5 Whys technique, it is necessary to find the root cause of the problem and then work on its elimination. After collecting data on the frequency of occurrence of problems, causes of problems and so on, it should be considered whether these downtimes can be eliminated by preventive maintenance. If none of the above can be used, then it is necessary to find a new technical solution.

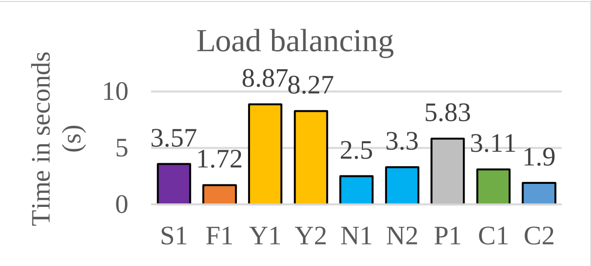

Figure 18. Display of time after redistribution of operations activities

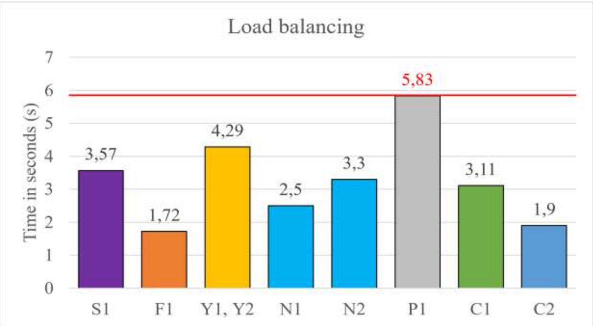

Figure 19. Operation P1 as a bottleneck

In order to be able to continue the analysis of the production line, it is used the information that all 20 compartments within the circular press are functional. This will provide insight into the new bottleneck that will emerge once the P1 operation can operate at full production capacity.

As can be seen in Figure 20, the time of operation P1 after the repair has been reduced from the previous 5.83 seconds to 3.5 seconds, making operation P1 no longer a bottleneck. The duration of operation P1 can be obtained by dividing one cycle of the press (70 seconds) by the number of functional compartments for filters inside the circular press (in this case 20). Even if the circular press is fully functional, it will not be able to operate at full capacity because it will not receive enough assembled filters from the filter assembling operations.

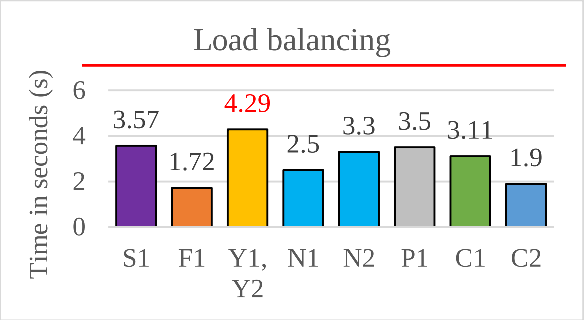

Figure 20. Operation times after repair of the circular press (operation P1)

The new bottleneck that determines the pace of production is operations Y1 and Y2 with a time of 4.29 seconds. This would mean that it is possible to produce approximately 839.16 filters per hour. According to Heizer and Render (2014), it is necessary to increase the duration of operations due to operators' fatigue, their personal needs, the frequency of downtime, and so on. In this case, 3% is added due to the operators' personal needs, 4% due to operators' fatigue, 3% due to monotony of work, and 5% due to possible downtime. Experience has proven that the production capacity in the B4 production line can fluctuate up to 15%. When 839.16 is reduced by 15%, the number of filters is 729.7. That means it is possible to produce 729 filters in one hour instead of the previous 600, which is an increase in production by 21.62%.

As can be seen in Figure 16, the conveyor belt is slightly shorter than in previous figures of the production line (see Figure 2 or 13). It is shortened by approximately 27% of the initial length, and the reason for this is that the layout of the production line is conditioned by limited space.

The times shown in Figures 24, 25, and 26 were obtained experimentally. First, the operators were familiarized with the new redistribution of operation activities, and after practicing the tasks, a simulation was performed. The process of preparing the simulation is shown in Figure 21. As a short solution, plastic rings were glued to the conveyor belt instead of tools, which served as an accordion holder.

Figure 21. One-piece flow simulation

It is necessary to return to the analysis of the state of the production line to remove the newly created bottleneck as much as possible. When reanalysing Figure 20, it can be seen that the operators doing the assembling of the accordions (Y1 and Y2) are the bottleneck. If one additional operator Y3 is included in the filter assembly operation, the operation time chart will look as shown in Figure 22.

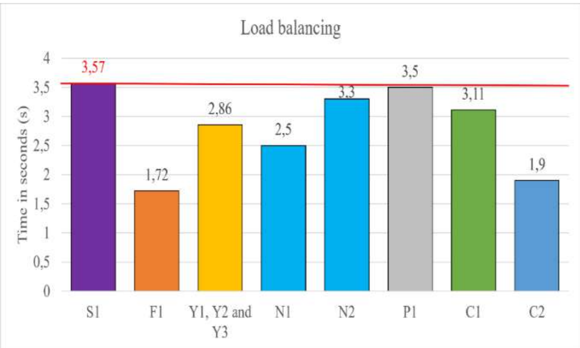

Figure 22. The industrial stapler as the new bottleneck

The new bottleneck becomes operation S1 as can be seen in Figure 22 with a time of 3.57 seconds. According to operation S1, which determines the pace of production, it is concluded that it is possible to produce 1008.4 filters in one hour in an ideal case. However, as mentioned, it has been proven empirically that up to 15% production capacity can be lower. When this information is taken into account, it turns out that it is possible to produce 876.87, that is, 876 filters in one hour. If this is compared to the previous 600 pieces per hour, the production of 876.87 filters per hour represents an increase in production capacity by 46.15%. However, the additional costs due to one more operator in the production line should not be overlooked, which amount to approximately €10,000 per year.

Figure 23 represents the layout of the production line when three operators Y1, Y2, and Y3 perform the accordion assembly operation. The change that was made and that should be mentioned is that in this case the conveyor belt was shortened by about 6 percent compared to the initial state (see Figure 11).

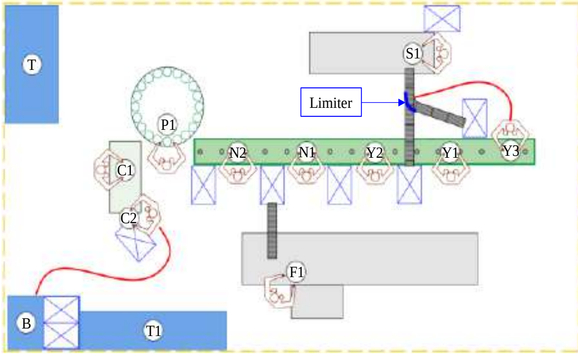

Figure 23. Layout with the additional operator (Y3) on accordion assembly operation

Given that operator S1 is a bottleneck and directly affects production capacity, it was a challenge to deliver accordions to operators Y1, Y2, and Y3. The plan that is proposed in this case is that operator S1 fills the crate between operators Y1 and Y2 via a small conveyor belt that goes over the production conveyor belt (see Figure 23), and this transport route is the main route for the delivery of accordions. After a certain time, operator Y3 arrives at the small conveyor belt close to operation S1 as indicated in Figure 23, where operator Y3 will place a limiter on the small conveyor and thus redirects the movement of the accordions to the crate located next to his operation Y3. After setting the limiter, operator Y3 returns to his place where he assembles the accordions.

With the time analysis from Figure 22, it is obtained that operations Y1, Y2, and Y3 in one hour will have a total waiting time of 35.85 minutes. The plan is that operators Y1 and Y2 will be constantly busy with the accordion assembly task so all the waiting time of 35.85 minutes will belong to operator Y3, as shown in Table 3. Also, in Table 3 can be seen that operation S1 needs only 10 minutes in one hour to prepare 147 pieces for the work of operator Y3. For operators

Y1 and Y2 not to run out of accordions when operator S1 prepares accordions for operation Y3, operators Y1 and Y2 must have a minimum of 141 accordions in the crate. According to Table 3, operator Y3 needs 24.15 minutes to assemble 147 accordions, and 35.85 minutes per hour remain free.

Table 3. Time analysis for operations Y1, Y2, and Y3

Opera-tor	Planned capacity utilization of the operator	Number of pieces per hour	Free time per hour
Y1	100%	365	0 min
Y2	100%	365	0 min
Y3	40.25%	147	35.85 min

By analysing the time of operations from Figure 22, it is obtained that operator F1 can produce a one-hour supply of gaskets for operators N1 and N2 in 28.88 minutes. The additional time of 15% is included in those 28.88 minutes. Therefore, operator F1 is free 31.12 minutes from performing the operation, as can be seen in Table 4.

Table 4. Time analysis for operation F1

Opera-tor	Planned capacity utilization of the operator F1	Number of pieces per hour	Free time per hour
F1	48.13%	876	31.12 min

According to the above, it is concluded that one operator (F1) can perform both operation F1 and operation Y3. In this way, the production capacity of 876 filters per hour is maintained with a reduction in production costs of approximately €10,000, which represent the costs for one additional operator (Y3).

As can be seen in Figure 24, the time of the operator performing operation S1 and the time of the operator performing operations F1 and Y3 are compared. The operator performing operations F1 and Y3 will have 6.97 minutes free in one hour. This means that operator F1 has enough time to switch to operation Y3.

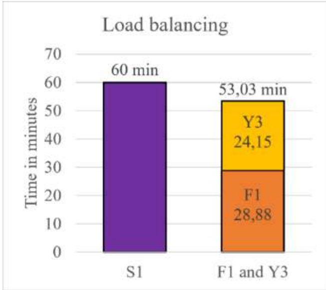

Figure 24. Comparison of the busyness of operator S1 and the operator working on operations F1 and Y3

The appearance of the Spaghetti diagram according to the new redistribution of operations activities would look as shown in Figure 25. In Figure 25, it can be seen that the task of operator P1 is highly demanding because of the movements he performs in an arc of 180 degrees. Therefore, the simplification of operation P1 by introducing another conveyor belt is discussed below.

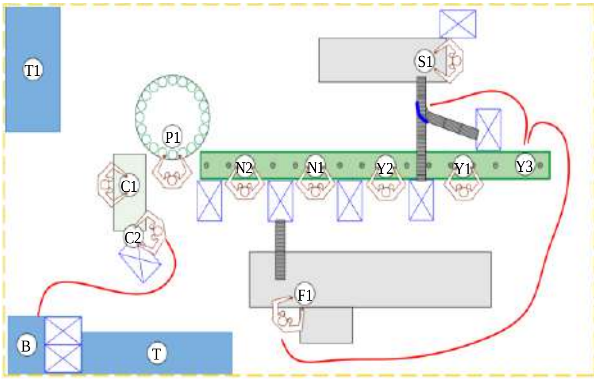

Figure 25. Spaghetti diagram for the new distribution of operations. The red lines represent the movement paths.

In Figure 25, it can be seen the new conveyor belt in front of operator P1. That way operator N2, after completing his operation, places the assembled filter onto the new conveyor belt that moves towards operator P1. The assembled filter comes in front of operator P1, he takes it and puts it in the circular press. Operator P1 then takes the pressed filter out of the circular press, puts it in front of him on the conveyor belt, and the filter goes to control operations C1 and C2. As can be seen, Figure 25 represents the implementation of the new conveyor belt in the case when two operators Y1 and Y2 do the accordion assembly.

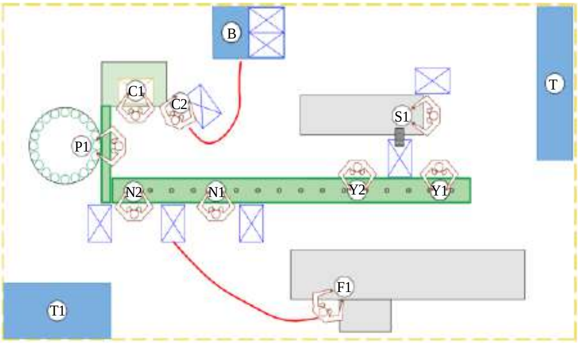

Figure 25. Facilitating the operation P1 when increasing the production capacity by 18.83%

The Figure 26 represents the implementation of the new conveyor belt in the case when the redistribution of activities was performed and when one operator performs operations F1 and Y3. As for operator F1 in Figure 26, no solution was found to avoid his movement to deliver gaskets to operators N1 and N2. The reason for not finding a solution is the lack of space in the production environment. Operator F1 spends approximately 10 seconds each way traveling to deliver gaskets to operations N1 and N2. If operator F1 delivers gaskets 6 times per hour, the time he will spend walking is 1 minute. If it is taken into account that operator F1 is free for 6.97 minutes, with the subtraction of that minute, the operator has 5.97 minutes available to perform other movements such as going to operation Y3.

One thing has not been mentioned so far, but it does not affect the previous analysis. Operation F1 needs to change material 5 times during one shift, and one material change takes 7 minutes. The total material change time in one shift is 35 minutes, and the F1 operator is free for 44.78 minutes in one shift. However, due to the large number of operations performed by operator F1, the task of changing the material in operation F1 is left to operator C1 because he has approximately 28 minutes of waiting time per hour. Operator C1 can always make up the missed work when he returns to his operation. The time analysis for operator C1 is shown in Table 5.

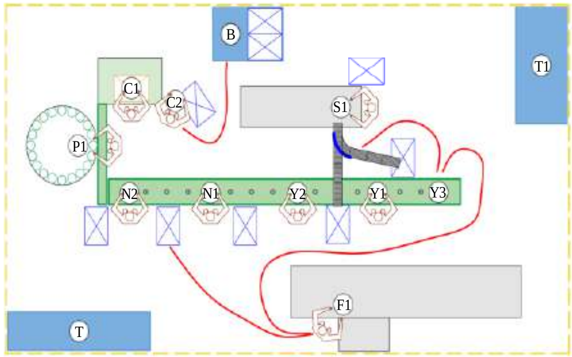

Figure 26. Facilitating the operation P1 when increasing the production capacity by 46.15%

Table 5. Time analysis for operation C1

Planned capacity utilization of the operator C1	Number of pieces per	Material changeover time of operation	Free time per shift
46.78%	876	35 min	204.47 min

One methodology was used in creating the layouts of the production line. It is about the aspiration to establish a U-shape in the arrangement of machines and people. However, due to the limited space, it was not possible to achieve a complete U-shape, and the L-shape of the production line was mostly achieved. Among the benefits of such forms of production lines is the facilitation of communication between operators, the operators are closer to each other, and in case of need, they can help each other in their work.

Also, special attention should always be paid to the bottleneck operation. If the operator representing the bottleneck needs to stop the operation due to some personal needs, that operator should always call one of the free operators to replace him. In this way, the reduction of production capacity will be avoided, and production will continue normally.

3. Conclusions

Every company strives to increase profits. However, a good approach is needed to identify bottlenecks and wastes and find appropriate solutions for them. Eliminating a problem that is not the cause of the stagnation deepens the stagnation in a way that exposes the company to additional costs and wasted time, while the real problem is still there. Approaches like the Theory of Constraints and Lean Manufacturing find the core of the problems that are the cause of the company's stagnation, or simply not achieving the desired progress, but also provide good guidelines for solving them.

The optimization of the production line started with the finding and elimination of seven types of waste. The elimination of waste can be seen as dominoes because by eliminating one waste, it becomes obvious to recognize new waste. By eliminating waste, the production line was optimized in order to reduce production costs. Production costs were reduced by €20,000 per year per shift by reducing two operators from the production line, while the production line kept the same production capacity. This means that for three shifts the savings are €60,000 per year.

Also, this research presents ways to increase production capacity by eliminating bottlenecks and introducing One-piece flow. In addition to increasing production capacity, the implementation of One-piece flow in this production line also has the task of facilitating operations. Also, thanks to the implementation of a One-piece flow, accumulation of WIP between operations is avoided. The pace of operations in the production line is adjusted based on the bottleneck operation. The research describes the steps by which the increase in production capacity was achieved. Two production solutions are proposed together with the layouts of the production line. The first proposed solution offers an increase in production capacity by 21.42%. The second proposed solution offers an increase in production capacity by 46.15%.

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Design and development of an automated tire regrooving machine

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Abstract

Tire regrooving is a technology for reusing tires. This technology provides benefits in the form of extending the life of the tire, as well as in the form of reducing the vehicle's fuel consumption.
Tire regrooving is currently done manually. Manual regrooving involves the use of a sharp, heated tool with which channels are deepened on the existing tire tread layer. The manual process of regrooving tires requires moving the tool by the operator. The quality of the manual regrooving process depends on the readiness and skill of the operator, and as such is subject to human-made mistakes.
In this thesis an automated tire regrooving machine was designed and built. The machine was tested and the results showed that a more precise tread pattern and less deviation from the desired pattern are achieved, with operating cost reduced by up to one-fifth of the manual regrooving process cost due to the tested machine capacity. In addition, the automated regrooving process enhanced the operator safety in comparison with manual regrooving.
This thesis assessed the impact of automated tire regrooving and fuel consumption reduction on the environment. Automated tire regrooving is beneficial for the user of the machine due to the lower operational cost and reduced consumption, but also for the environment due to the reduced environmental impact (reduced fuel consumption) of the vehicles with regrooved tires. Up to 400 kg of fuel can be saved on a 5-axle truck which uses regrooved tires.

Keywords: *automated tire regrooving, tire regrooving, life cycle assessment of a regrooved truck tire, regrooving automation, tire reuse*

1. Introduction

In recent times, the world witnessed accelerated development, population growth, globalization, and increased international transport of goods and people. One such trend followed the development of the automotive industry. Since cars and other means of transport contain many parts, the development of this industry has encouraged the development of many others. One of the industries that have developed with the growing demand for vehicles is the rubber (tire) industry. Like all other products, tires have a lifespan. Through different stages of life, they leave their mark on the environment. The environmental performance of tires can be enhanced by reuse technologies. One of the tire reuse technologies is regrooving. Tire regrooving extends tire service life and reduces its environmental impact in the usage phase. Currently, tire regrooving is done manually. The goal of this thesis is to develop a machine for automated regrooving. Given the fact that environmental awareness is growing significantly in recent times, and that regulations of various countries have been tightened, the design of tires, as well as the design of various equipment and machines to improve the environmental performance of tires are topics that will be present in the future.

2. Tire structure

A tire is a rotationally symmetrical object composed of several layers of rubber and reinforcements in the form of textiles and steel reinforcements (Leister, 2019). A tire is a composite product that consists of multiple main parts: sidewall, tread, belt plies, body ply, bead wires, chafer, and bead (Pelc, 2009). The tire structure is shown in Figure 1.

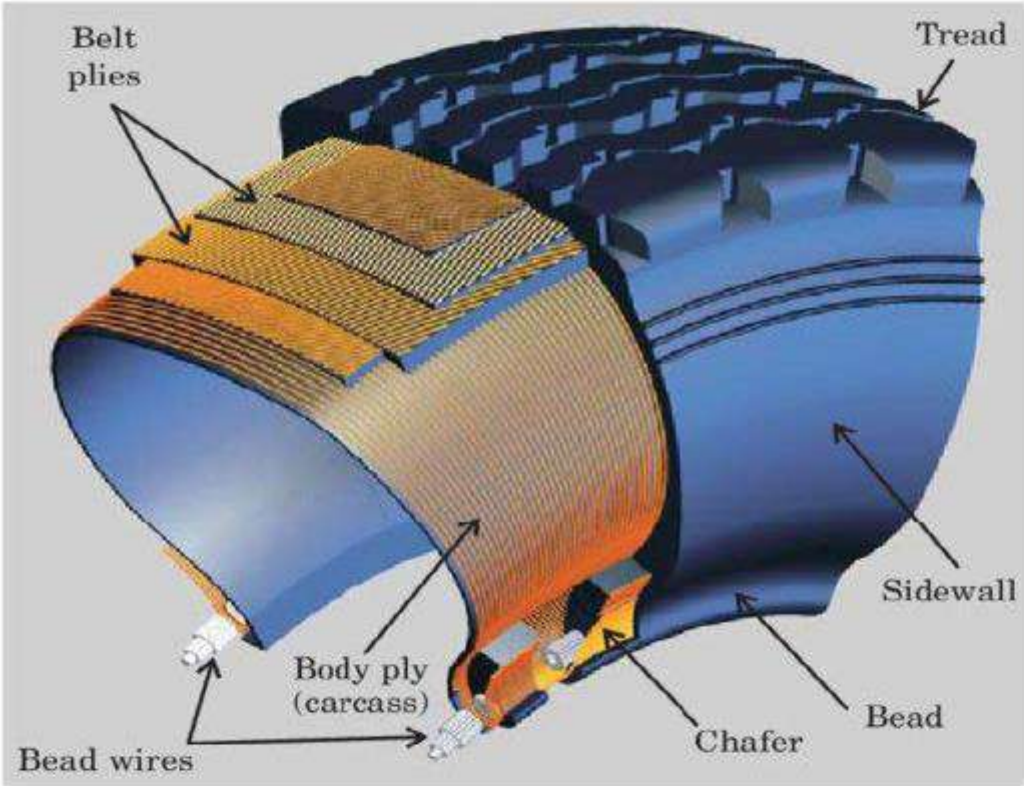

Figure 1. Tire structure (Pelc, 2009)

In addition to the mentioned tire parts, one more part of a tire is a bead wire. The role of this part is to keep the tire on the rim itself, according to the research conducted by Leister (2019). The structure of tires is mainly made of rubber, which is elastic by its nature. In order to keep the tire on the rim, it is necessary to introduce stronger materials for bead wire. Steel is used to make the bead stronger (Dong et al., 2021).

2.1 Tire materials

The first pneumatic tires were made of leather. Nowadays, the tire structure is different compared to the first ones. To overcome the low durability properties of leather, the rubber sheet was introduced. According to its structure, tires are a type of composite material. The input materials for the modern pneumatic tire production are natural rubber, synthetic rubber, carbon black, silicon dioxide, active clay, zinc oxide, stearic acid, processing agent, lubricating oil, fiber, and steel wire according to the study conducted by Dong et al. (2021). These materials are combined to produce the different tire parts mentioned in the previous section.

2.2 Manual tire regrowing

More recently, to increase sustainability and enhance environmental performance, tire manufacturers have introduced certain measures aimed at extending the life of tires intended for trucks. Namely, tire manufacturers, such as Michelin, Dunlop, Continental, leave a thicker wear layer of tires (tread), to enable tire reuse by regrooving, in other words deepening existing channels on the tire. Current methods for tire regrooving involve the use of hand heated cutting tools, which use heating and cutting mechanisms to deepen the channels on the tire manually. Tire regrooving is utilized by implementing simultaneous heating and cutting, while the operator moves the tool manually as shown in Figure 2.

Regrooving is one of the reuse alternatives that extends the life of the tire by up to 30%, and the cost of such a process represents 2.5% of the new tire costs (Beukering et al., 2000). According to Slyudikov et al. (2009), the cost of the regrooving process is 5% to 10% of the new tire costs.

Figure 2. Manual tire regrooving

2.3 Automated Tire Regrooving

The existing literature does not contain much information about the regrooving method, where the existing tread layer is deepened. By researching the Google Patent database, three relevant patents for the regrooving technology were found: Regroovable tread and regrooving method (Patent No. JP2004526625A), Tire regrooving device (Patent No. 5247983A), Tire regrooving tool and related methods (Patent No. 10894377B2).

The first two mentioned patents are expired, while the third patent has an active status. All of the patents do not contain any information about automated regrooving. The active patent called "Tire regrooving tool and related methods" patented by Moises Garcia and Antonio Mercado is related to the regrooving tool (cutter) shape, and this patent does not conflict with the automated tire regrooving machine developed in this master thesis because the developed machine uses standard cutters (blades) from other manufacturers.

Furthermore, a search on the Google Patent database did not find any current patents related to automated tire regrooving. The search was performed using the next keywords: automated regrooving, automated tire regrooving, automated tire regrooving, automatic regrooving, automatic tire regrooving, and automatic tire regrooving.

The lack of the available technology for automated regrooving, according to the research of the patent databases and the literature, imposed the motivation for the development of such a machine. The automation of regrooving process is required in order to enhance the regrooving process, decrease the human mistake risks, enhance operator safety, and enhance the environmental performance of the modern tires.

3. Design and construction of automated tire regrooving machine

The manual regrooving process itself is not fast enough, precise, and therefore not so profitable. It requires much higher operating costs compared to an automated process. When the tire is regrooved manually, the operator can miss the tread pattern, and damage the tire in that way. An example of the poorly manually regrooved tire is shown in Figure 3. This challenge of manual regrooving can be solved by implementing an automated regrooving machine that can overcome the risks of human-made mistakes.

Figure 3. Poorly regrooved tire using manual regrooving tool

The motivation and idea for the development of an automated machine are hidden in all the mentioned facts. In order to improve the regrooving process, the automated regrooving machine prototype is designed and constructed as the experimental part of this thesis. Firstly, the machine model is designed using CAD software. Secondly, the simulation is performed on the designed model. Finally, the real machine is made according to the model. The machine is tested and the performances of the machine are verified.

3.1 Machine Development

The development of the automated regrooving machine has been done through four different stages: a CAD design and simulation phase, design of the motion control system phase, manufacturing and assembling phase, and testing and validation phase. Different development steps are described briefly, and the main parts are explained without providing detailed drawings, calculations, and explanations because there is a patenting potential for the automated regrooving machine in the future.

The first phase of machine development is the CAD design and simulation. In the very beginning, the complete machine was designed using SOLIDWORKS software. 3D CAD modelling is performed because it allows fast and simple design of the machine. All of the parts can be designed, assembled, redesigned, and shown through the digital twin model. The critical parts such as shafts, bearing housings, and welded frames are examined on the maximum static and dynamic loading in the SOLIDWORKS Simulation software.

Even though SOLIDWORKS provides simulation tools, MATLAB is used to monitor the different parts kinematics, as well as the pneumatic and motion control system behavior. After the CAD model was done, different parts of the machine were put into MATLAB Simulink software to simulate the movement of the workpiece and the tool.

The Simulink simulation is needed to detect potential collisions and to test the design. Simulink software enables monitoring of the present forces and momentums in the different machine joints. The present forces and momentums are relevant for the motion control system design. Furthermore, Simulink ensures monitoring of the velocities and accelerations of the parts. In this way, the capability of the machine to regroove different tread patterns is assessed. Some of the activities done in the design and simulation phase are depicted in Figure 4.

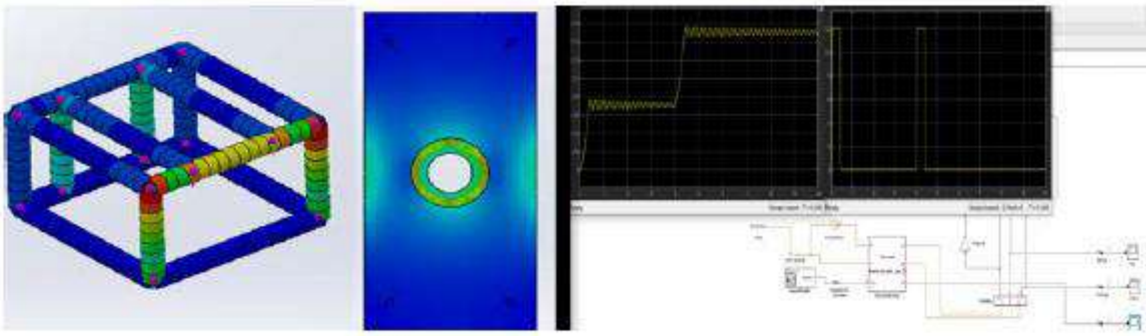

Figure 4. SOLIDWORKS static simulations for some critical parts (left), MATLAB Simulink simulation of the machine’s motion control system (right)

After the design is validated through the simulation, manufacturing of the different parts was performed. For the manufacturing of the automated machine for regrooving the next production technologies were performed: drilling, CNC turning, CNC milling, fiber laser cutting, plasma cutting, sheet metal bending, welding, and 3D printing. Some of the activities done in this stage are shown in Figure 5.

Figure 5. Frame welding, sheet metal bending, sheet metal cutting

Parallelly to the manufacturing step, the motion control system was designed. The motion control system design involves equipment choice, equipment wiring, as well as software development. The equipment is chosen concerning the loading condition obtained through the simulations.
The software is programmed using Python programming language. The software is used to generate the toolpath, as well as to transform the information about the toolpath to the physical outputs (signals for activators).
After the parts are manufactured, they are assembled with the motion control system parts such as motors and sensors. Some of the activities in this stage are shown in Figure 6.

Figure 6. Equipment testing and software development (upper left), control unit assembling and wiring (upper right), machine assembling (bottom left and right)

3.2 Machine Design

The automated tire regrooving machine uses a four-axis control system that is completely designed and programmed only for the needs of this machine. The machine specialization for the regrooving purposes ensures the simple operation with such a user-friendly interface.

The machine CAD model is shown in Figure 7. with the indicated functional parts.

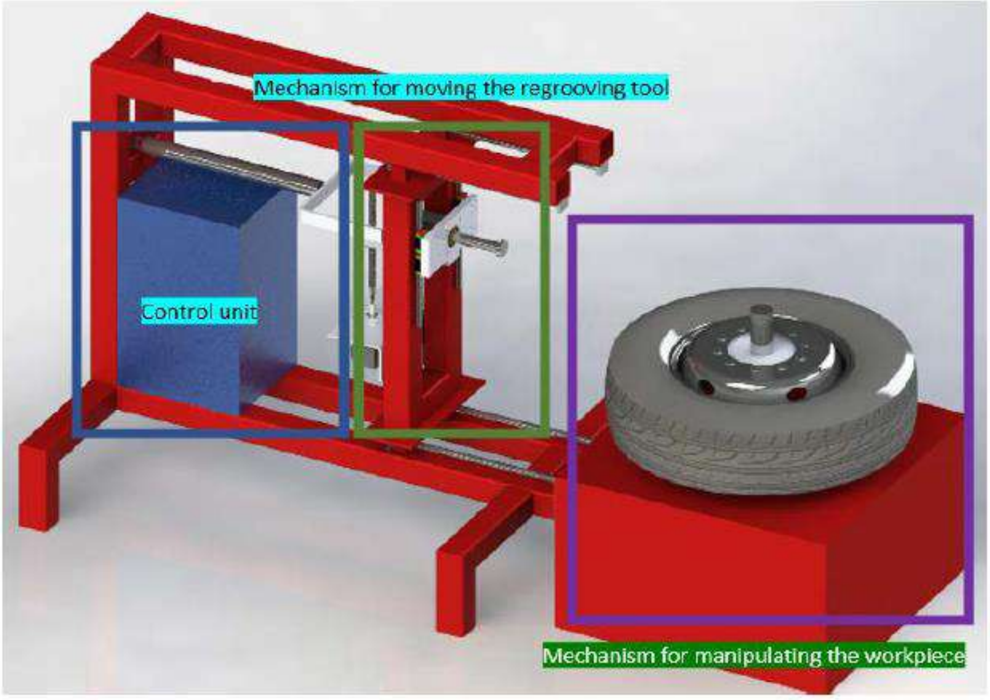

Figure 7. Main machine parts

Figures 8-10 show the manufactured parts indicated in Figure 7.

Figure 8. Mechanism for manipulating the workpiece

Figure 9. Mechanism for manipulating the regrooving tool (left), the regrooving tool (middle), the regrooving blade (right)

Figure 10. The machine control unit

3.3 Motion Control System

The motion control system contains three hybrid servo motors and a pneumatic actuator. These parts of the motion control system operate simultaneously to deepen the tire tread pattern. The scheme of the motion control system is shown in Figure 11.

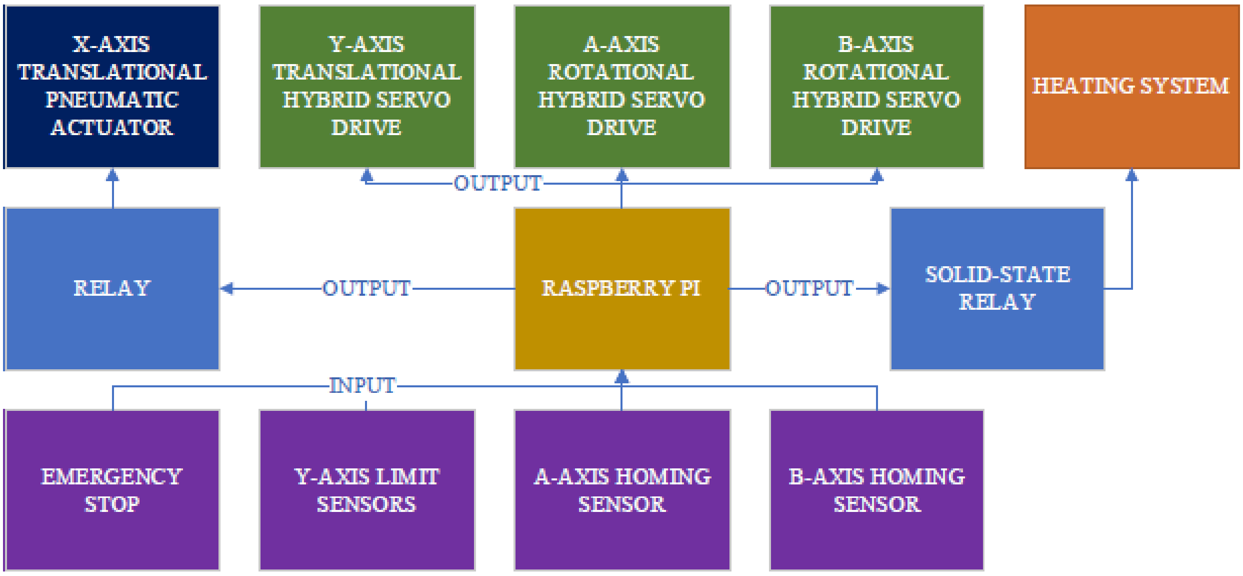

Figure 11. Conceptual scheme of electronical devices and actuator

The "brain" of the control system is the Raspberry PI controller. This device controls all other devices using input and output logical ports. This device operates on the Linux system and interprets the logic programmed in the Python programming language.

3.4 Software Design

In order to realize the stated activities of the motion control system, it is necessary to program the logic on the controller itself. For the needs of the regrooving machine, Python was used as a programming language because it is the most convenient solution for the Raspberry PI board. The architecture of the machine software is shown in Figure 12.

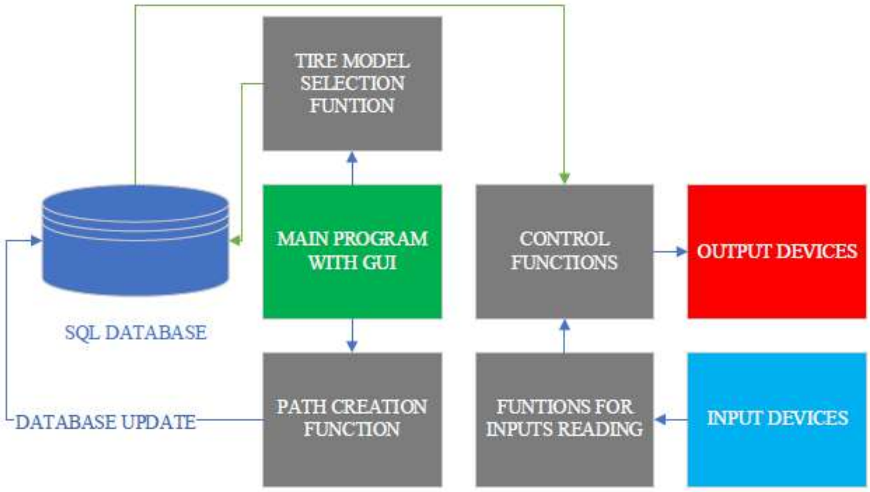

Figure 12. Software architecture

When the operator starts the regrooving process, the data about the tire tread pattern, according to the selected tire manufacturer and model, is fed from the SQL database to the control functions. The control functions are then combined with functions for input reading. The inputs from sensors are read through the input ports of the controller. The output devices (pneumatic system, hybrid servo drives, heating system) are controlled directly through the controller output ports according to the instructions from the control functions.

4. Productivity and quality analysis

In the performed experiment machine characteristics were analysed: machine productivity and regrooved tread geometrical quality. The regrooved tread geometrical quality (deviations of depth and width from the set values) is assessed in the experimental part of this thesis. It is required to test the hypothesis that automated regrooving can ensure better quality (lower deviations) than the manual regrooving process.

4.1 Productivity Analysis

One of the main properties of every machine is machine productivity. Machine productivity is usually expressed using the machine cycle time. The machine productivity is examined on the MATADOR tire, model FHR4 315/60 R22.5. Machine productivity (MP) requires the machine cycle time (t_c) for its calculation. The machine cycle time in the case of the automated regrooving machine consists of the average time needed for mounting (t_M), the time for regrooving which is t_R=228 s for the tested tire, and the average time for dismounting of the tire (t_{DM}). It is important to point out that the time required to regroove a single tire (t_R) is constant for one tire model.

t_M includes the time for elevating, clamping, and centering, and it is calculated as shown in Equation (1), according to the results of 30 tests.

$$t_M = \frac{\sum_{i=1}^{m} t_{M,i}}{m} = 43\ s\ (1)$$

t_{DM} includes the tire dismounting and tire lowering, and it is calculated as shown in Equation (2), according to the results of 30 tests.

$$t_{DM} = \frac{\sum_{i=1}^{m} t_{DM,i}}{m} = 32\ s\ (2)$$

The machine cycle time (t_c) is calculated as shown in Equation (3).

$$t_c = t_M + t_R + t_{DM} = 228 + 43 + 32 = 303\ s = 0.0842\ h\ (3)$$

The machine productivity is calculated according to the obtained cycle time as shown in Equation (4).

$$MP\left({}^{tires}/_{h}\right) = \frac{1}{t_c} = 11.88\ {}^{tires}/_{h}\ (4)$$

4.2 Quality Analysis

The quality of the regrooving process itself was assessed based on the geometric characteristics of the regrooved tire. The geometric characteristics that are measured in the experimental part of this thesis are the depth of the regrooved pattern and the width of the regrooved pattern. These characteristics were measured on a test tire model: Matador FHR4 315/60 R22.5. The measurements were performed with a Mitutoyo caliper, with a guaranteed resolution of 0.05 millimeters, shown in Figure 13.

Figure 13. Mitutoyo caliper

The comparison between the geometrical properties of the manual and the automated regrooving process is shown in Figure 14.

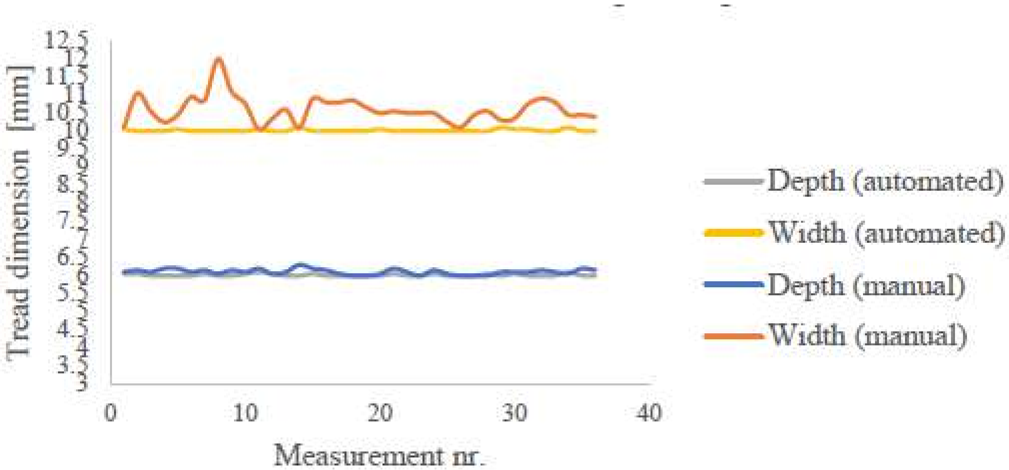

Figure 14. Results of the experiment: comparison between manually and automatically regrooved tread layer

A visual comparison between a tire grow that was manually produced, and one that was produced using the developed automated machine are presented in Figure 15.

Figure 15. Comparison between manual and automated regrooving processes

5. Parts of the final machine

The final machine is depicted in Figure 16.

Figure 16. Final machine

6. Conclusion

Large requirements for transportation of goods, resources and people have placed a significant strain on the production, usage and all activities associated with the tire industry. As a result, during this project an approach for automated tire reproving is developed. The main work consists in developing a novel machine for tire regrooving. This development included extensive design work, software development, complex part manufacturing, development of mathematical models to run the controls and finally assembly of everything into one usable package.

The developed machine was extensively statistical tested, and its use was validated on real tire examples. Besides this the result of the automated tire regrooving was compared to those generated by manual labor. This analysis showed that the regrooving pattern is significantly improved both in the dimensions of the grove (width and depth) but also in its adherence to a proper shape in general.

This work proved the feasibility of such an approach and opened a large amount of potential for further optimization, material use reduction, large financial savings, and most importantly reduction of environmental impact of the tire industry and of any companies' logistic chain that decides to adopt such an approach.

7. Equipment and software purchased by knowhub used for the project

The following table involves project activities that were accomplished with use of equipment and software purchased from the budget of KnowHub project.

Table 1. Used equipment

No.	Equipment / Software	Project activities
1.	SolidWorks	3D modelling of the machine parts
2.	3D printers	3D printing of plastic parts of the machine

8. References

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3. *Dong, Y. et al. (2021) "Life cycle assessment of vehicle tires: A systematic review," Cleaner Environmental Systems, 2(100033), p. 100033. doi: 10.1016/j.cesys.2021.100033.*
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Transfer of knowledge in the field of 3d printing, reverse engineering, and metrology

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Introduction

Examples of transfer of knowledge in the field of 3D printing, reverse engineering, and metrology will be presented in this paper Also, examples of transfer of knowledge in the field of collaborative robotics will be presented in this paper. The first chapter contains the description of the concept of the Learning Factory, within which knowledge is created and transferred to the economic entities in the environment. Technologies of 3D printing, reverse engineering, and metrology are subsequently described and various examples of development projects for the local industry are presented. A conclusion regarding the realized activities is given at the end.

Background

The Learning Factory at the Faculty of Mechanical Engineering, Computing and Electrical engineering (FSRE) has the basic goal of enabling students to experience many problems that will be present in the production facilities where they will soon be operating. At the same time, the Factory also provides engineers from local companies with the opportunity to get acquainted with new technologies that were not present at the time they were studying.

The set goals are achieved through several projects: "Reconnecting universities and enterprises to unleash regional innovation and entrepreneurial activity" (KnowHUB) and "Increasing competitiveness of micro, small and medium-sized enterprises through digitalization" (IC SMED). The main goal of the KnowHUB project is to build HUBs as a link between higher education institutions, the business environment and the wider community. The main goal of the IC SMED project is to increase the competitiveness of micro, small and medium enterprises with the help of digitalization. Through these projects, conditions have been established to help and support local businesses in the areas of 3D printing, reverse engineering, and metrology. Students, assistants, and engineers from local companies are introduced to 3D printing, 3D scanners and 3D scanning through practical examples. Also, they can actively participate in the development and adjustment of materials for the implementation of training and laboratory exercises, as well as in the organization of training, laboratory exercises and exercises on real examples. The practical work of printing and scanning objects is done in the premises of the Learning Factory.

1.1 3d Print, Reverse Engineering and Metrology

1.1.1 2.1 Rapid prototyping - 3D print

Several 3D printers were procured at FSRE through the project.

• Stratatys F 270 is an industrial type of F123 series printer with FDM technology. It uses materials for model/support: PLA, ABS-M30, ASA, TPU, 92A/QSR.

• MakerBot Method X Carbon Fiber Edition uses carbon fiber reinforced material, ABS, ASA, SR30, PLA, PVA.

• Zortrax M200 Plus uses LPD/FFF printing technology. It uses dedicated M series material.

• Ultimaker 2+ is a small 3D printer that is programmed within the Cura software package. The software is easy to use and allows you to move objects, load multiple objects for printing, and change resolutions and other settings.

1.1.2 Reverse engineering in general

Modern manufacturing companies that want to maintain and improve competitiveness in the global market are forced to systematically update existing and find new ways to reduce operating costs in all aspects of their operations.

The process of transforming an idea into a functional product consists of a series of steps that in some cases can be iterated several times. Such a setting implies a significant expenditure of time and financial resources during the product development process, without a guarantee of a positive outcome of the entire process. These reasons were sufficient to try to find ways and methods of shortening the time of product development and spending financial resources related to the product development process in everyday engineering practice. One of the ways of reducing the time and cost of the new product development process is reverse engineering.

In a narrower sense, reverse engineering can be defined as the process of duplicating an existing component, assembly, or product, without the aid of a drawing, technical documentation, or computer model (Figure 1). In the context of the aforementioned, the technique of reverse engineering can be applied to analyze and study the internal working parts of the machine, for example, to compare the current device with the performed analyzes in order to obtain suggestions for improvement.

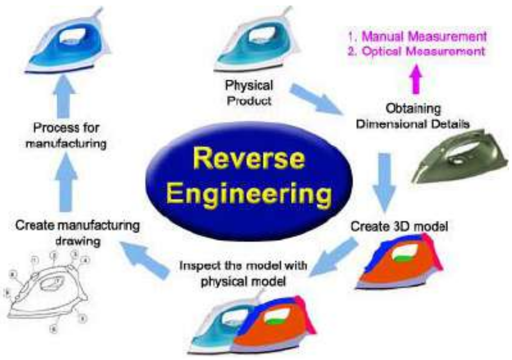

Figure 1. Reverse engineering process

Unlike "classical" engineering design that starts from the abstract - the idea implies its elaboration through conceptual and then detailed CAD design, design based on the principles of reverse engineering begins with a physical object which is then translated into a CAD model, possibly adapted or refined and in the end manufactured by one of the CNC, that is, RP technologies [2].

1.1.2.1 Reverse Engineering and Metrology at FSRE

In the "Learning Factory" at the Faculty of Mechanical Engineering, Computing and Electrical Engineering, within the KnowHUB project, several tasks related to the topic of reverse engineering were performed. 3D digitization, for example, scanning of workpieces is performed using the scanner GOM ATOS Compact Scan 8M. Processing is done within the GOM Inspect Suite 2020 software package, and CAD model generation is done using the reverse engineering tool Geomagic for SolidWorks.

1.1.2.2 GOM ATOS Compact Scan.

A new class of compact 3D scanners for 3D metrology and control (Figure 2). Light, compact construction of the trigger probe opens new areas of application and provides adaptability for three-dimensional measurement of components such as cast and injection molded parts, cores and models, interiors, prototypes, and similar. Adopts blue light technology, combines scanning and measurement, adjustable measuring range, complete and portable measuring system, compact trigger probe with integrated control unit, etc.

Figure 2. 3D scanner within the FSRE Learning Factory

1.1.2.3 GOM Inspect Suite.

GOM Inspect Suite is a comprehensive software package for simple or complex measured tasks during the entire quality control process - from 3D product scanning, polygon network editing, CAD model import, GD&T analysis, statistical trend analysis, digital editing, etc. (Figure 3)

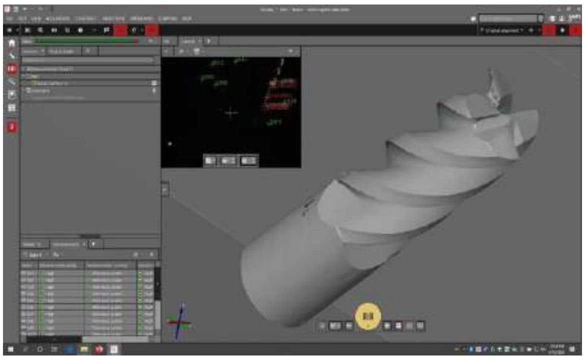

Figure 3. The appearance of the workspace inside the GOM scanning module

1.1.2.4 Geomagic for SolidWorks.

Represents a set of software tools for reverse engineering that provides advanced capabilities for point clouds and polygon networks to become usable in the product construction and redesign process. Data can be imported or scanned directly into SolidWorks. Supports all major scanners and portable CMMs as well as importing standard point cloud and network formats.

1.1.3 Metrology in general

Metrology is a scientific discipline that deals with measurement in all its theoretical and practical forms. Basic metrology deals with the scientific assumptions of measurement, technical metrology covers the procedures and methods of measurement, and legal metrology covers the applications prescribed by law. Metrology includes all theoretical and practical aspects of measurement, deals with methods of measuring physical quantities, realization, and maintenance of standards of physical quantities, development and production of measuring instruments, and analysis of measurement results. Metrology has been developed to the level of applied science.

1.1.4 Integration of rapid prototyping and reverse engineering processes

With the help of the characteristics of the process of rapid prototyping and reverse engineering, the possibilities provided by their combination and adequate application provide numerous advantages that are primarily reflected in the ability to reduce time and reduce costs of product development/redesign, and in certain conditions in the production of tools and ready-to-use products. The integration of these approaches ensures the transition of the problem of transformation, that is, the translation of a virtual product from a digital form stored in the appropriate CAD software into a real tangible form-object and vice versa (Figure 4). Namely, reverse engineering ensures the generation of 3D CAD models based on a real object, and the model is transformed into a suitable real prototype/product relatively quickly and without significant human involvement by applying the process of rapid prototyping.

Figure 4. Integration process

1.2 COLLABORATIVE ROBOTICS IN GENERAL

The relationship between humans and robots in a collaborative working environment has been classified from a number of different points of view. Shared workspace refers to an environment where a human and a robot work in the same workspace without any physical or virtual barriers between them. Direct contact refers to whether there is direct contact between a human and a robot in the process of performing a task. A joint work task represents a situation in which a human and a robot work on the same operation and strive towards the same work goal. This task can be simultaneous or sequential. According to these characteristics, the relationship between man and robot differs, so there is:

1. Coexistence – a situation in which a human and a robot are placed in the same space, but without mutual investment in the other's workspace. There is no direct contact between man and robot, the work object can be exchanged between them, but they perform work processes separately and simultaneously.

2. Interaction - happens if a human and a robot sharing the same workspace communicate with each other. This is the situation when a human controls a robot or when there is any physical contact between them. A human and a robot can work on the same task, but they work sequentially, step by step.

3. Cooperation - can develop between participants (human and robot) who have their own autonomy. With the aim of mutual gain, the participants in the cooperation will occasionally share physical, cognitive or computer resources, even though they pursue their own interests. Participants may share a workspace with partial overlap, but direct contact is not typical.

4. Collaboration – joint activity of humans and robots in the same workspace with a specific goal to be achieved by performing a series of tasks together. This usually requires coordinated and synchronized activity of all parties where physical contact is also allowed. Collaboration means joint, focused, goal-oriented activity of participants who share their different abilities, competences and resources.

Different types of collaborative robots are defined by their safety and programming features, i.e. the way they avoid potentially dangerous encounters with human workers. Each type of collaborative robot applies unique methods and technologies to maintain a safe workspace - this difference defines which environments they are best suited for. According to ISO 10218, four types of collaborative robots are defined as safety-monitored stops, speed and separation, power and force limitation, and manual guidance:

- Safety Monitored Stop: Collaborative robots defined as Safety Monitored Stop are intended for applications that have minimal interaction between the robot and human workers. Usually, these types of collaborative robots are actually industrial robots with a series of sensors that stop the robot when a human enters the robot's workspace.

- Speed and Separation: These types of collaborative robots are similar to the first type of collaborative robots in the fact that they are also industrial robots with sensors. However, collaborative speed and separation robots use more advanced vision systems to slow down operations when a human approaches and stop operations altogether when a worker is too close to the robot.

- Strength and Force Limiting: These types of collaborative robots are built with rounded corners and an array of intelligent collision sensors to quickly detect contact with a human worker and stop work. These collaborative robots also have force limits to ensure that collisions do not result in injuries.

- Manual guidance: these collaborative robots are equipped with a manual guidance device through which the operator directly controls the movement of the robot during automatic operation. While in automatic mode, a robot performing collaboration with manual guidance only responds to direct operator control input. This allows the robot, for example, to support the weight of a heavy workpiece while the operator manipulates it into position, reducing the risk of injury to the operator. Similar capabilities can be used to "teach" or program the robot, but properly speaking, manual guidance as a collaborative operation occurs while the robot is in automatic mode, during normal production, while programming is not done in automatic mode or used during production.

1.2.2 Collaborative robots vs. Classical industrial robots

Classic industrial robots are automatically controlled, reprogrammable, multipurpose manipulators that can be programmed in three or more axes, and which can be fixed in place or mobile. They can automate an extremely wide range of processes. Multiple robots can be integrated for fully automated production lines that completely remove human operators from unsafe environments and provide a significant return on investment for high-volume processes. Improvements in safety technologies now allow industrial robots to be used in collaborative operations, providing many of the same benefits as a cobot, while increasing payload and speed and reducing the cost of traditional automation. The new program interfaces are very intuitive and easy to learn and use.

Cobots, on the other hand, are designed to be used within a defined workspace to collaborate with human workers and usually have some built-in security mechanisms to support this use. Cobots typically perform tasks that are repetitive or have an increased chance of injury, such as machine maintenance or palletizing, while a human worker performs higher-value manual tasks. Cobots mimic human actions and complete tasks at similar or slower speeds, with payloads and reach that are also human-like.

Table 1 shows a comparison of Collaborative Robots and Classic/Traditional Industrial Robots:

Application	Cobots	Traditional Robots
Education and learning about robotics	**Good fit:** They reduce risk of injury, typically don't need guarding, and tend to have a shallow learning curve.	**Mediocre Fit:** More time consuming to learn, will require appropriate safety rated sensors and/or guarding, higher risk of injury.
High speed work (e.g. case packing or pick and place)	**Poor Fit:** Lower speed will reduce cycle time and limit the benefits of automation for high-volume products.	**Good fit:** These systems are designed to run at high continuous speeds.
Very high accuracy work (e.g. assembling micro circuit boards)	**Mediocre Fit:** Accuracy varies with cobot models, but in general it is harder to get very high accuracy in a cobot.	**Good Fit:** Traditional robots are about speed, payload and accuracy so finding one that meets the requirements is frequently much simpler.
High payload work (moving heavy parts)	**Not possible with cobots:** As of this writing, cobots range between 3 and 35 kg.	**Good fit:** Traditional robots have payload capacities up to the weight of a car, so payload is usually not a problem.
Force sensitive work	**Good Fit:** Some Cobots have built in force control which can be integrated into the control loop without extra sensors.	**Mediocre Fit:** Traditional robots can have force control devices added between the tool flange and the end effector, but this is a separate unit and only gives force control at the tool.
Processes in which the robot is working close to a human	**Good fit:** Safety and risk assessments must still be considered, but this is a distinguishing cobot feature.	**Poor Fit:** Not possible without safety systems (e.g. guarding and safety rated switches and sensors) in place.
Explosive environment (e.g. painting)	**Not possible for cobots:** Currently no explosive environment rated cobots.	**Good Fit:** Paint robots are readily available for this application.

Table 1. Cobots vs. Traditional robots

1.2.3 Applications of Collaborative Robots

Collaborative robots can be used for assembly, gluing, painting, polishing, machine maintenance, sorting and packaging, quality control, welding and many other industrial processes. Some of the industries where these robots are used are [4]:

• Car industry

Although the automotive industry is highly automated, there remains enormous opportunity for continued growth. Collaborative robots are driving new efficiencies across the industry, in applications including machine loading, inspection and assembly in powertrain, electronics and interior manufacturing. Cobots can work side by side with human workers, improving their performance.

• Education and science

These robots are used in the educational, scientific and research communities to create the foundation for accurate information collection and analysis, for the development of new technologies and for the education of future generations. Safe near students (after risk assessment), intuitive and easy to program, cobots are used in vocational and technical programs to teach valuable and modern automation skills to teenagers and adults to address the manufacturing skills shortage. Small, lightweight cobots are cost-effective to deploy and can fit in small labs and on classroom desks. Intuitive, flexible programming allows even non-robotics students to easily take advantage of automation.

• Electronics

Safe alongside workers (after risk assessment), cobots can handle precise tasks such as inserting, dispensing, screwing or marking with high repeatability. Collaborative robots are also an ideal way to remove workers on production lines by fulfilling upstream or downstream processes. Even in competitive electronics manufacturing, cobots can pay for themselves in less than a year.

• Food and drink

Cobots are used throughout the food and beverage supply chain in a wide range of secondary processes such as packaging and machine maintenance. Collaborative robots can work 24 hours a day, without interruption, in the conditions of humid greenhouses, refrigerated rooms or next to hot ovens, freeing employees from repetitive tasks that can cause injuries in unfavorable environments. They are even useful for meeting the specific needs of customers when it comes to stacking methods and product labeling, which is often a very important item in this industry.

• Medicine

Cobots help reduce the risk of human contamination in sensitive processes and clean environments. collaborative robotic arms can be used for sterile, precise handling and assembly of medical devices or implants.

• Metal processing

Cobots are ideal for maintaining machines used for metalworking. Cobots are at the heart of collaborative welding systems that cost a fraction of traditional automated systems and can fit into standard welding work cells. By automating the welding of repetitive and small products that are undesirable for welders and moving skilled welders to more complicated products, better quality and more satisfied workers are achieved. Collaborative automation is affordable and flexible, and robots can be moved from one task to another as needed.

1.3 COLLABORATIVE ROBOTS AND ACCESSORIES

1.3.1 The collaborative robot Universal Robots UR5e

Within the Learning Factory is the collaborative robot UR5e manufactured by Universal Robotics. The basic features and its capabilities are shown below:

The UR series of robots is a group of collaborative robots manufactured by Universal Robots that meet different user needs and are suitable for automating various industrial processes, as shown in Figure 5.

Figure 5. UR-e series of robots and their applications

The UR5e is a medium-sized robot, ideal for automating light weight machining tasks with its 5 kg payload and 850 mm reach radius. Easy to program and quick to set up, the UR5e strikes the perfect balance between size and power. The UR5e is a collaborative robot, i.e. a robotic arm with 6 axes of movement that allow it to rotate all joints in a range of 360 degrees. The UR5 series is the most versatile cobot from the Danish manufacturer Universal Robots. It has a maximum deviation when repeating the task of +/- 0.03mm. Compared to its predecessor, the UR5, the UR5e differs in that it has a built-in force and torque sensor in the rear joint. Using this sensor, the robot is able to control the force and moment in the direction of all 3 axes in the range of 50 N and 10 Nm with a precision of 4N and 0.3 Nm, respectively. In addition to the already mentioned ability to rotate all joints in the range of 360 degrees, the rotation of the joints can reach a maximum speed of 180 degrees per second, while the usual speed of the tip of the tool is 1m/s. It has a consumption of 200W, and produces noise less than 65dB, and as for the safety aspect, it has 17 different safety functions that guarantee safe collaboration. The robot weighs 20.6 kg and its stand occupies a surface with a diameter of 149 mm. The parts are made of aluminum, steel and plastic, and the robot comes with a 6m long connecting cable. The complete table of specifications of the robotic arm can be seen in Table 2.

Performance

Power consumption	Approx. 200 W using a typical program	
Safety System	All 17 advanced adjustable safety functions incl. elbow monitoring certified to Cat.3, PL d. Remote Control according to ISO 10218	
Certifications by TUV Nord	EN ISO 13849-1, Cat.3, PL d, and full EN ISO 10218-1	
F/T Sensor - Force, x-y-z		
Range	50 N	
Resolution	2.5 N	
Accuracy	4.0 N	
F/T Sensor - Torque, x-y-z		
Range	10 Nm	
Resolution	0.04 Nm	
Accuracy	0.30 Nm	

Specification

Payload	5 kg / 11 lbs
Reach	850 mm / 33.5 in
Degrees of freedom	6 rotating joints DOF
Programming	Polyscope graphical user interface on 12 inch touchscreen with mounting

Movement

Pose Repeatability	+/- 0.03 mm, with payload, per ISO 9283	
Axis movement robot arm	Working range	Maximum speed
Base	± 360°	± 180°/s
Shoulder	± 360°	± 180°/s
Elbow	± 360°	± 180°/s
Wrist 1	± 360°	± 180°/s
Wrist 2	± 360°	± 180°/s
Wrist 3	± 360°	± 180°/s
Typical TCP speed		1 m/s / 39.4 in/s

Features

IP classification	IP54	
ISO Class Cleanroom	6	
Noise	Less than 65 dB(A)	
Robot mounting	Any Orientation	
I/O ports	Digital in	2
	Digital out	2
	Analog in	2
	Tool communication	RS-485
I/O power supply in tool	12V/24V 600mA continuous, 2A peak	
Ambient temperature range	0-50°C*	
Humidity	90%RH (non-condensing)	

Physical

Footprint	Ø 149 mm
Materials	Aluminium, Plastic, Steel
Tool (end-effector) connector type	M8 | M8 8-pin
Cable length robot arm	6 m / 236 in
Weight including cable	20.6 kg / 45.4 lbs

Table 2. UR5e Specifications

The UR5e robot has the possibility of various extensions in the form of different grippers, sensors, software, mobile and work platforms, etc.As for grippers, the UR5e robot is compatible with grippers from various manufacturers such as: Robotiq, Zimmer, J. Schmalz, OnRobot, Weiss Robotics and others. As for the types of grippers, it is possible to install classic mechanical electric or pneumatic grippers with 2 or 3 fingers, magnetic grippers, various vacuum grippers, soft grippers intended for sensitive objects and "Festo" adaptive gripper of variable shape. Figure 6. shows some of the accessories for the UR5e robot.

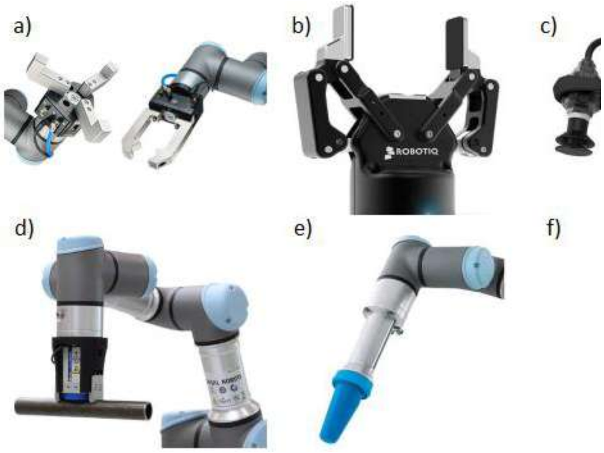

Figure 6. Examples of accessories for the UR5e: a) pneumatic mechanical gripper b) electric-mechanical gripper c) vacuum gripper d) magnetic gripper e) adaptive gripper f) gripper for sensitive objects

One of the main features of the collaborative robot UR5e highlighted by the manufacturer Universal Robots is safe collaboration. As a basis for safe cooperation, the user is obliged to comply with the rules on safe use of the robot. The security features can be configured through the security configuration settings and are particularly relevant to address specific risks in the integrator's risk assessment:

• Limitation of force and power: It is used to reduce clamping forces and pressures exerted by the robot in the direction of movement in the event of a collision between the robot and the operator.

• Torque limiting: Used to reduce high transient energy and impact forces in the event of a collision between the robot and the operator by reducing the speed of the robot.

• Limiting the position of joints or tools: It is especially used to reduce the risks associated with certain parts of the body. For example to avoid movement towards the head and neck.

• Tool Orientation Constraint: Specifically used to reduce risks associated with specific areas and features of the tool and workpiece. For example to avoid pointing sharp edges at the operator

• Speed limit: It is especially used to ensure a low speed of the robot arm.

So that the safety of the collaboration does not depend only on the user and his vigilance, the Universal Robots e-series robots are equipped with a series of built-in safety functions and safety inputs and outputs, digital and analog control signals to or from the electrical interface, for connection with other machines and additional protection devices.

Programming of the UR5e robot is done using a device called Teach Pendant. Taech Pendants are handheld devices that can be wired or wireless. They may contain several buttons or switches or have a touch screen as is the case with newer models. They also have a screen that displays the robot's commands and allows editing of those commands. Additionally, the display can be used to read the robot's command history. The pendants use a keyboard for entering tasks and simple programming. Another common feature of the pendants is the large red button, which is the emergency stop button of the robotic system. It can be used in the event of an industrial robot malfunction and will immediately stop working once activated, ensuring the safety of any workers or production equipment around the robot. Teaching robot pendants allow the robot operator the ability to program applications and remotely control the robot's movements. The remote control capability allows operators to safely program or control the robot out of reach of their workspace or hazardous environments. In addition to programming and controlling robots, the pendants can be used to test and troubleshoot robotic systems. The Teach Pendant from UR5e is shown in Figure 7.

Figure 7. UR5e Teach Pendant

1.3.2 Gripper Robotiq 2F-140

The Robotiq 2F-140 gripper is shown in Figure 8.

Figure 8. Gripper Robotiq 2F-140 [8]

The basic specifications of this gripper are shown in Table 3.:

Stroke	140 mm	5.5 in
Grip Force	10 to 125 N	2 to 25 lbf
Form-fit Grip Payload	2.5 kg	5.5 lbs
Friction Grip Payload*	2.5 kg	5.5 lbs
Gripper Weight	1 kg	2 lbs
Closing speed	30 to 250 mm/s	1.2 to 9.8 in/s
Ingress protection (IP) rating	IP40	

*Calculated for the use of silicon covered fingertips to grip a steel object, at a low robot acceleration.

Table 3. Basic specifications of this gripper Robotiq 2F-140 [8]

2 APPLICATION OF 3D PRINT, REVERSE ENGINEERING AND METROLOGY

Various examples of the application of 3D printing, reverse engineering, and metrology will be presented in this chapter.

2.1Reverse engineering applied on metal joints for FSRE

The task aims to generate a CAD model (original geometry or redesign) of metal couplings with the intention of small series production (3D printing technology) for the needs of the "Learning Factory" if the prototype satisfies during testing (Figure 9).

All aforementioned elements were made with 3D printing technology after scanning and processing (Figure 10).

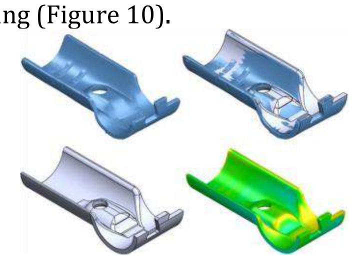

Figure 9. Reverse engineering on G-1S connector (polygonized mesh - scanned piece and CAD model - CAD model - deviation display)

Figure 10. Scanned elements made with 3D printing technology

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Igor Bošnjak, Luka Šaravanja, Eva Čuljak
Students: Marijana Marušić, Kristina Čović, Kata Kukulj, Tomislav Antolović

1.2 Reverse engineering on the example of a pulley for the local company "ZEC"

This task aimed to use reverse engineering to obtain the geometry of the pulley profile using a CAD model to make an equal part since the original part is frayed (Figure 11).

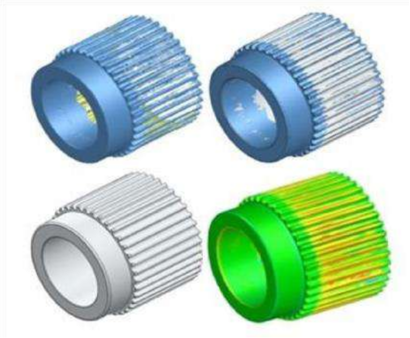

Figure 11. Scanned pulley, 3D model of the pulley and deviation display

Project team:
FSRE employees: Željko Stojkić, Luka Šaravanja,

1.3 Reverse engineering on the example of a part of a plastic injection tool for a local company "Weltplast"

The task aims to generate a 3D model of a part of a plastic injection tool since the original part is frayed (Figure 12).

Figure 12. Reverse engineering on a part of a plastic injection tool

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Igor Bošnjak, Luka Šaravanja, Eva Čuljak
Students: Marijana Marušić, Kristina Čović, Kata Kukulj, Tomislav Antolović

1.4 Reverse engineering on the example of dental spoons for the local company "MA-COM"

This task aims to create a CAD model (and technical documentation) of dental spoons for taking dental impressions (Figure 13).

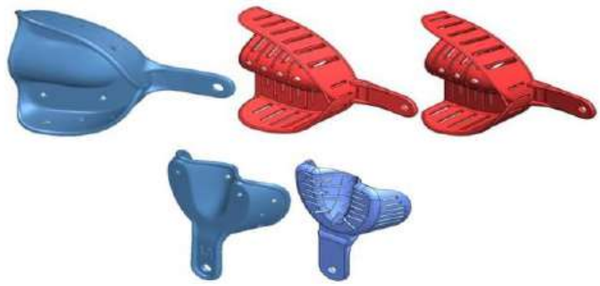

Figure 13. Scanned spoons U1 and U4 and redesign of the spoon

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Igor Bošnjak, Luka Šaravanja, Eva Čuljak
Students: Marijana Marušić, Kristina Čović, Kata Kukulj,

1.5 Reverse engineering applied on a lever for the company "SIK"

The task aims to create a new lever with 3D printing technology using the process of reverse engineering (Figure 14).

Figure 14. Reverse engineering on a lever

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Luka Šaravanja

1.6 Reverse engineering applied to the pool shutter

The task aims to create documentation based on a damaged shutter and then create a new part by reverse engineering and 3D printing.

In this specific case:

- No spare parts on the market

- No shutter drawing

- No tools for making shutters

Shutter requirements:

- Must be made with 3D printing

- The material must be elastic due to the installation requirements

- The material must be resistant to sunlight

A drawing of the shutter in SolidWorks and a prototype of the shutter obtained by 3D printing are shown in Figure 15.

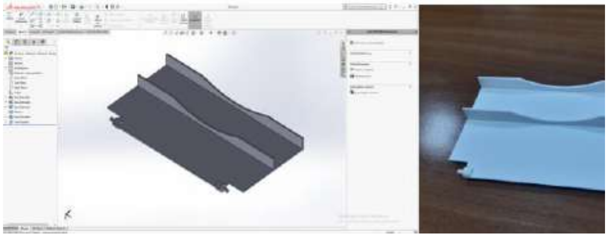

Figure 15. Drawing of the shutter on the pool and a prototype of the shutter made by 3D printing

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Luka Šaravanja

1.7 Metrology applied on a milling cutter for the company "Škutor"

In the FSRE Learning Factory, several tasks related to the topic of metrology were performed.

The objects that have to be measured were first subjected to a scanning process performed using a GOM ATOS Compact Scan 8M scanner. The measurement process itself is performed within the GOM Inspect Suite 2020 software package within the measurement module [4].

The task aims to determine the dimensions of cutters with a diameter of Ø20 and Ø12 and to prepare accompanying documentation ((Figure 12).

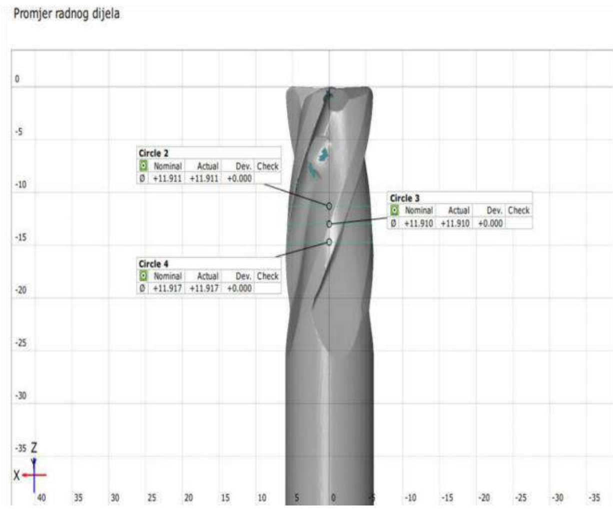

Figure 16. Display of the measurement report page

Project team:
FSRE employees: Željko Stojkić, Remzo Dedić, Igor Bošnjak, Luka Šaravanja, Eva Čuljak
Students: Marijana Marušić, Kristina Čović, Kata Kukulj,

1.8 Application of a collaborative robot UR5e in the process of stacking and packing plastic bags for the company "Weltplast" /Case 1.: Bags with suspenders/

This case for the company "Weltplast" was done as part of the diploma thesis of candidate Tomislav Antolović, a student of mechanical engineering, majoring in Mechatronics. This thesis describes a project that aimed to obtain results that wil demonstrate the cost-effectiveness of implementing the UR5e collaborative robot in a plastic bag stacking and packaging withing the company Weltplast. All the steps that were represented in the process itself are described in detail. Starting from the initial analysis and selection of the appropriate process, writng the entire program, making the gripper, all the way to the analysis of the final results. In addition to describing the entire project in detail, the graduate thesis also introduces the history of robotics and its progress, as well as the collaborative robot UR5e used in this project. All its specifications, possibilites, modes of operation and the way in which programming is performed on such and similar types of collaborative robots are presented.

The entire process was recorded, from the first point and placing the roll on the machine to the moment when the bags are placed in the boxes, and the boxes further on the pallets, and now it was important to go through all the points of the process and come to the most expedient solution that will satisfy all parties involved in the project . The first challenge occurs right at the very beginning. Since the Faculty owns only one robot, it was not possible to move the robot to its own plant within the company for a long period of time because it was also part of other projects. Furthermore, the Gripper, which was owned by the Faculty, was not designed to perform these types of operations and it was necessary to start looking for a new one. The solution was found in the form of making a new gripper, and also had to change the material used. Through this project, a new metal extension was made for the existing gripper, which made it impossible to manipulate the bags without hindrance.

The robotization solution offered through this project and the ROI for that case are shown in Figure 17.

Figure 17. Proposed solution for the application of a collaborative robot in the bag stacking process for the company "Weltplast"

The most important information about the new solution is the enormous time savings. Compared to the first solution, this approach would bring numerous benefits and improvements. The big problem that arose due to the high speeds with which the robot moves in the first solution would be solved in such a way that the speeds could return to normal limits, while there would still be a significant saving in time thanks to the absence of two full circles that the collaborative robot during one download it no longer has to work from the conveyor belt. In addition, this gives the possibility to increase the speed of the conveyor belt, which would automatically speed up the entire stacking process, which would lead to an even more significant step forward. In relation to the first solution, the difference is enormous, but unfortunately this solution still remained only on paper and there was no opportunity to test it when writing this thesis. Figure 18 shows the process of stacking and packing bags using a collaborative robot in experimental conditions inside the Learning Factory at the Faculty.

Figure 18. Process of stacking and packing bags using a collaborative robot in experimental conditions inside the Learning Factory at the Faculty

The project, carried out in collaboration with the Weltplast company, offered confirmation of the previously mentioned positive claims about collaborative robots. In a very short period of time, a solution was reached that could ultimately prove to be very profitable in the long term for the Weltplast company itself. The solutions have not been fully implemented and it is possible to further work on each of them and improve them, which leaves an additional possibility of progress. The main goal of this project was to show that collaborative robots really belong in the operation of such companies and that this is the direction in which to start thinking.

The task aims to generate a CAD model (original geometry or redesign) of metal couplings with the intention of small series production (3D printing technology) for the needs of the "Learning Factory" if the prototype satisfies during testing.

Project team:
FSRE employees: Boris Crnokić
Students: Tomislav Antolović

1.9 Application of a collaborative robot UR5e in the process of stacking and packing plastic bags for the company "Weltplast" /Case 2.: Rolled bags/

This case for the company "Weltplast" was done as part of the diploma thesis of candidate Marin Perić, a student of mechanical engineering, majoring in Mechatronics. This thesis shows how fast and simple it can be to implement a robot in the packaging process in serial production and how the programming process itself is very easy and does not require too much prior knowledge about it. It has been successfully proven that the introduction of cobots only improves the efficiency of the production process. The space for upgrading is very wide, and with additional investments, the process can be brought to perfection. Such robots are suitable for many different operations and are highly adaptable, i.e. the program is relatively easy to create for each different operation. Thus, for example, the robot can pack products for a period of time and then switch to the welding department. The disadvantage of such robots is their small payload, they are not suitable for heavy loads, but that is why they have a great advantage over other robots when it comes to small and sensitive objects. With the ability to control force and speed, these robots can easily handle sensitive objects such as microchips or glass objects without fear of damaging them.

All in all, collaborative robots have proven to be very high-quality investments in terms of efficiency, safety, costs and quality, and because of this, they are slowly becoming an integral part of every modern factory every day, and the real flowering of this branch of mechanical engineering will only come in the coming years, and it will be interesting. to see what further improvements the future holds.

The company Weltplast has a large number of products on which it is possible to apply a collaborative robot, but for this work the choice fell on plastic bags in rolls. Specifically, these are garbage bags (type Gea Supreme) with dimensions 53x60 cm and a volume of 35L. It is necessary to program a robot to buy bags packed in a roll (15 bags) from a conveyor belt and pack them into packages, a process that is currently done by humans. In order to successfully implement the application of a collaborative robot, it is necessary to carry out certain preparatory phases before the actual programming. In the existing system, the bags packed in rolls come on a conveyor belt with rollers and go to a container where they fall and accumulate before a person puts them in a box (Figure 19.).

Figure 19. Layout of the existing system of production and collection of bags in rolls

In the new improved system, the bags at the end of the line will be waiting for the UR5 robot and put them in the appropriate box. It is possible to program the robot to buy bags directly from the belt, however in this case this is not an option due to the irregular position of the products on the belt, and since the robot is not equipped with robotic vision, it is not able to recognize the object to be picked up, but moves according to the provided coordinates. The deviations of the bags along the rollers are not too great, but they can be enough that the robot does not catch the roll in the right way and thus interrupts the entire packaging cycle. On such a strip, the bags always have the same orientation, which greatly facilitates their final positioning. The only problem remains the uneven positioning of the bags along the rollers, and without additional orientation of the bags it is impossible to construct a kind of dispenser in which the bags will always be positioned in the same way without error. In order for the robot to work without error, it is necessary to direct the products so that each production cycle, the roll bag ends up in the same place in space. The main challenge is to create such a piece that, without any sensors or auxiliary equipment, will position the product and prepare it for the robot, just by its geometric shape. After considering a couple of options, it was decided to design a dispenser that will have certain stops that will be located immediately on the belt and direct the product to slide on the rollers and thus turn it towards the stacker that will be installed instead of the existing trough. The dispenser is shown in Figure 20.

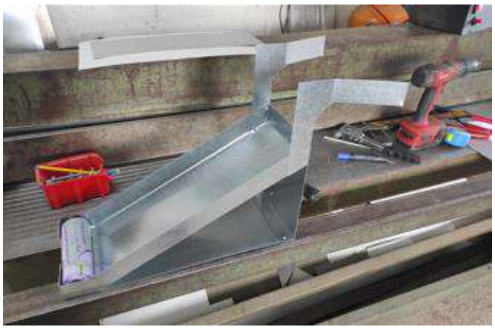

Figure 20. Dispenser for roll bags

A collaborative robot that picks up and stacks bags in rolls, under experimental conditions at the Faculty, is shown in Figure 21.

Figure 21. Collaborative robot picks up and stacks bags in rolls

Project team:
FSRE employees: Boris Crnokić
Students: Marin Perić.

6. Conclusion

The technology of rapid prototyping with 3D printing in combination with a 3D scanner and appropriate software using reverse engineering can significantly speed up the path to the finished product, which is extremely important for relevant companies.

Industrial robots as an integral part of the production plant are already a standard story in the more developed countries of the world, but in the last few years the percentage of collaborative robots in production companies has been increasing. Some predictions say that in the next 10 years, collaborative robots will make up 30% of the robots in the world. This growing trend of implementing cobots in production is the result of numerous advantages that cobots bring, but certainly the biggest advantage that collaborative robots have in relation to industrial safety and ease of programming. Collaborative robots are conceived as machines that will not take away a person's work, but will make it easier, relieve them from difficult, monotonous and boring jobs and give them space to do something more creative and interesting. In the previous cases, it was shown how fast and simple it can be to implement a robot in the packaging process in serial production, and how the programming process itself is very easy and does not require too much prior knowledge about it.

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Design of the universal calibration device for brake tester, pedal gauge force and axle load scale

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Abstract

Periodical vehicle inspection is mandatory throughout the world, ensuring that vehicles are safe, reliable and that they meet all the required standards set by national and international regulations. Mandatory vehicle inspections relate different vehicle functions, including braking system. Inspection of braking system includes: inspection of braking force on vehicle wheels, inspection of force acting on brake pedal of braking system and inspection of vehicle axle load. In order to guarantee validity of inspection results, equipment in vehicle inspection stations must meet the required standards set by national regulations, which is proven by equipment calibration which could be mandatory periodical calibration or voluntary calibration conducted, usually, after failure of crucial parts and assemblies and its repairs. This paper deals with design and manufacturing of universal calibration device for equipment used in inspection of braking system.

Keywords: braking system, calibration device, design

1. Introduction

Brake safety of vehicles is the most important performance for vehicle safety. To output the right brake force from vehicle brake system, the brake performance should be inspected by brake tester periodically [1]. Periodic brake system inspection is a part of mandatory periodic vehicle inspection throughout the world, ensuring that vehicles are safe, reliable and that they meet all the required standards set by national and international regulations. The roller brake tester is the commonly used equipment to inspect brake performance of vehicles [2]. In the inspection process, a vehicle, whose transmission is in neutral position, is tested on the rotating rollers with rough surfaces. The wheels of the vehicle are driven by the rollers. When the driver steps the brake pedal, brake forces are transferred from the left and right wheels to the rollers and then to the force sensors connected to the rollers. Simultaneously the pedal gauge force is used to inspect the force acting on brake pedal and scale is used to inspect axle load of the vehicle.

Calibration is the effective way to ensure the precision of the brake tester, pedal gauge force and axle load scale directly and enhance the brake performance of the vehicle indirectly. Calibration could be mandatory periodical calibration or voluntary calibration conducted, usually, after failure of crucial parts and assemblies and its repairs. Calibration methods should be static ones if the calibration force is performed on a few points of the dynamic calibration curve [3] or dynamic ones if the calibration force is performed continuously along the dynamic calibration curve [4-5].

Uncertainty of the calibration results could be determined according to the procedure explained by Lau and Kallgren [6].

This report deals with design and manufacture of universal calibration device for equipment used in inspection of braking system. Design task is defined by the company Pro Tool doo from Podgorica, Montenegro. The scope of this company is maintenance of equipment for vehicle inspection.

2. Design Task

Universal mechanical calibration device for brake testers, brake pedal force gauges and axle load scales for motor vehicles should be designed.

List of requirements:

1. Device is used for static calibration of the following brake testers manufactured by the company Hofmann:
   - -Brekon 131-4
   - -Brekon 141-3
   - -Safelane 204-RP
   - -Safelane Truck N SC – 13t
   - -Safelane Truck N SC – 16t
   - -Safelane Bike PC B-WV
2. Device is used for static calibration of the following brake pedal force gauges:
   - -PD07 manufactured by the company Hofmann
   - -PK2.1 manufactured by the company HKM Messtechnik
3. Device is used for static calibration of axle load scales up to 2000 kg
4. The overall dimensions of the calibration device are limited by the dimensions of the transport vehicle trunk being 1046 x 1130 x 1094 mm
5. The calibration device should be designed for harsh field working conditions
6. Assembly / Disassembly of the device during calibration should be as simple as possible
7. Maintenance of the calibration device should be as simple as possible
8. The calibration device should be made of as many standard parts as possible in order to reduce manufacturing and maintenance costs
9. Non-metal parts of the calibration device should be manufactured by 3D printing

3.Overview Of Equipment For Inspection Of Vehicle Breka System

3.1 Roller brake tester

In order to design calibration device for roller brake testers one must know principles of their operation and calibration, as well as, their structural details.

3.1.1 Principles of operation and calibration

Roller brake tester design is shown in the following figure. In the inspection process, a vehicle, whose transmission is in neutral position, is tested on the rotating rollers with rough surfaces. The wheels of the vehicle are driven by the rollers connected to electromotor by chain transmission. When the driver steps the brake pedal, brake forces are transferred from the left and right wheels to the rollers and then to the force sensors connected to the rollers. Gradual increase of break force finally causes blocking of rollers rotational motion.

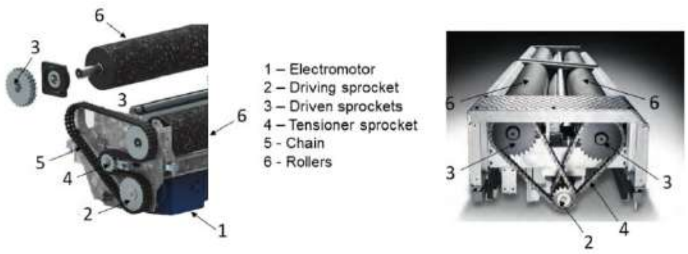


Fig.1: Roller brake tester

The calibration of break tester is performed in such a way that a force is applied to the lever attached to the shaft of the drive sprocket and thus simulates the effect of the braking force on the rim of the rollers as shown in the following figure. The magnitude of the braking force corresponding to the force exerted on the lever during calibration can be determined according to the expression:

$$F_B = 2 \cdot F_0 = 2 \cdot L_B \cdot \frac{z_3}{z_4} \cdot \frac{1}{d_2} \cdot F \qquad \textbf{(1)}$$

where is F_B breaking force, F calibration force, L_B brake tester lever length, d_2 roller diameter, z_3 and z_4 teeth number of driving and driven sprocket.

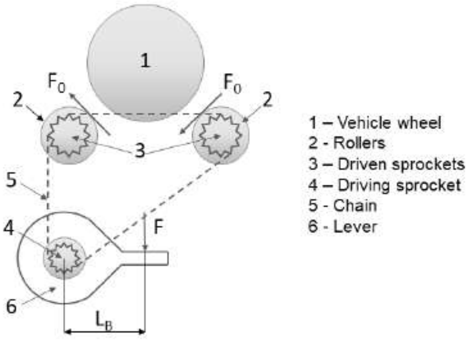


Fig.2: Brake tester calibration principle

3.1.1 Brake tester characteristics

During the tour of the stations for vehicle inspection, all the information on the characteristics of the brake testers necessary for the design of the device for their calibration was collected.

In the following figures are shown brake tester for vehicles with a maximum mass of up to and over 3500 kg. The figures also show characteristic elements of the break testers stucture, such as: acting point of the calibration device on the brake tester lever, chain transmission...

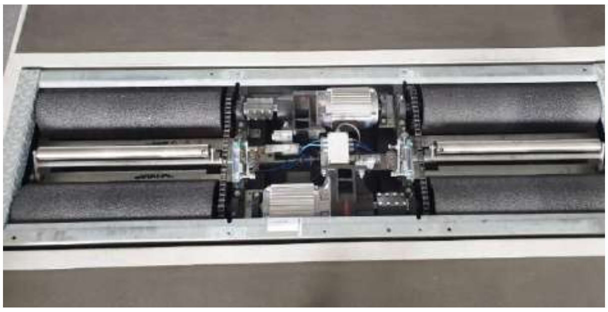


Fig.3: Brake tester Hofmann Safelane 204-RP

Fig.4: Brake tester Hofmann Safelane Truck N SC - 13t

The following table provides an overview of the structural characteristics of the brake tester that would be calibrated with the device to be designed.

Table 1.Brake tester characteristics

Model	$F_{B,max}$ [N]	d_2 [mm]	z_4	z_3	L_B [mm]	F_{max} [N]
Brekon 131-4	6000	204	24	24	320	1913
Brekon 141-3	6000	175	24	24	240	2188
Safelane 204-RP	8000	216	24	24	178	4854
Safelane Truck N SC 13t	30000	204	17	22	204	11590
Safelane Truck N SC 13t	30000	204	15	22	204	10228
Safelane Truck N SC 13t	30000	204	13	22	204	8864
Safelane Truck N SC 16t	40000	255	13	22	357	8442
Safelane Bike PC B-WV	3000	206			90	3434

Maximal calibration force that has to be exerted during brake tester calibration equals to F_{max}≈11600N.

3.2 Break pedal force gauge

Brake pedal force gauge, being an additional part of the brake tester, is shown in the following figure. In the inspection process brake pedal force gauge is placed directly on the brake pedal, which is inspected simultaneously with the inspection of the brake tester. Driver steps on the brake pedal force gauge and the pedal itself. During the entire process, the brake pedal force gauge monitors the change of the force exerted on the brake pedal.

Fig.5: Brake pedal force gauge

Brake pedal force gauge calibration mimics driver stepping on the brake pedal force gauge during inspection of the force on the brake pedal. Maximal calibration force that has to be exerted during brake pedal force gauge calibration equals to F_{max}=1000 N.

3.3 Axle load scale

Axle load scale, being an additional part of the brake tester, is shown in the following figure. Axle load scale is attached to the bottom side of support structure of the brake tester, directly below the bearings of the rollers of brake tester. In the inspection process of brake system, a vehicle is tested on the rotating rollers. Vehicle weight is transferred from the left and right wheels to the rollers and then to the force sensors of axle load scale connected to the support structure of the brake tester.

Fig.6: Axle load scale

Axle load scales of brake testers for vehicles up to maximal mass of 3500 kg, listed in design task, are with maximal range of 2000 kg.

Axle load scale calibration can be done simply by pressing on the surface of the supporting structure of the brake tester located directly above the axle load scale. Maximal calibration force that has to be exerted during axle load scale calibration equals to F_{max}≈20000 N.

4.Conceptual Design

According to design task calibration device has to be mechanical one. Therefor calibration force, whose maximal magnitude is equal F_{max}≈20000 N, would be generated based on principle of the lever.

Conceptual design of calibration device, based on principle of the lever, is shown in the following figure. Such a device can generate force needed for calibration of brake tester, brake pedal force gauge and axle load scale by means of weights of reasonable mass. By putting weights on the tray of calibration device a calibration force is generated on threaded spindle of calibration device which exerts on calibrated device.

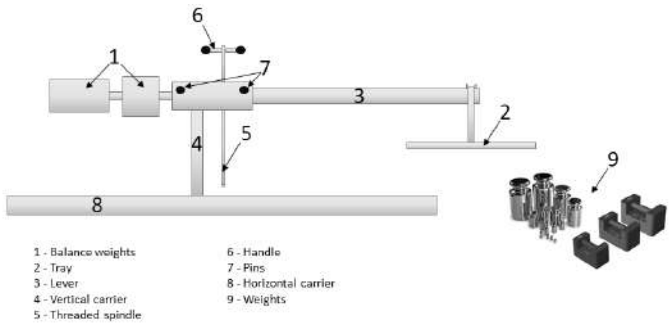


Fig.7: Conceptual design of calibration device

5.DETAILED DESIGN

In the following part of the paper some details of detailed design of calibration device would be introduced.

5.1 Selection of rolling bearings at the supports of the vertical carrier

A scheme of vertical carrier assembly is shown in the following figure. At the same time vertical carrier carries the lever and the threaded spindle of calibration device and enables their rotational motion in vertical plane. Achievement of these functional requirements is enabled by the rolling bearings placed in the supports of vertical carrier.

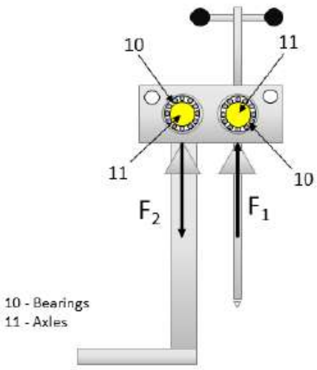


Fig.8: Vertical carrier assembly

Threaded spindle is by means of axle shaped nut supported on the rolling bearings. Bearings are symmetrically arranged regarding threaded spindle. Therefor calibration force on threaded spindle exerts at the middle of bearings distance loading them equally.

Calibration device is used regularly not longer than 2 hours weekly. Axle shaped nut rotates negligibly around its axis during calibration. Hence, the rolling bearings are infrequently loaded and mobile, therefor the selection of the rolling bearing would be done based on their static basic load ratings C_0, which must fulfill the following requirement:

(2) $$C_0 \geq S_0 \cdot \frac{F_{max}}{2}$$

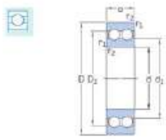
where is S_0 static safety factor and F_{max} maximal calibration force. The rolling bearings are selected from the ball bearings category, whose static safety factor equals C_0=0.4 according to the table from SKF catalogue shown in the following figure. Thus, required static basic load rating of the rolling bearings equals $C_0 \geq 4000$N.

Guideline values for the static safety factor s_0 – for continuous and/or occasional loads – ball bearings

Certainty of load level	Continuous motion Permanent deformation acceptance Yes	 Some	 No	Infrequent motion Permanent deformation acceptance Yes
High certainty For example, gravity loading and no vibration	0,5	1	2	0,4
Low certainty For example, peak loading	≥ 1,5	≥ 1,5	≥ 2	≥ 1

Fig.9: The static safety factor for ball bearings

To select as small rolling bearing as possible selection would be done from the double raw ball bearings. Double raw ball bearing 4202 2RS is selected according to characteristics from SKF catalogue shown in the following figure (d=15mm, D=35mm, B=14mm and C_0=7500N).



Principal dimensions d	 D	 B	Basic load ratings dynamic C	static C_0	Fatigue load limit P_u	Speed ratings Reference speed	Limiting speed	Mass	Designation
mm			kN		kN	r/min		kg	–
10	30	14	9,23	5,2	0,224	40 000	22 000	0,049	4200 ATN9
12	32	14	10,6	6,2	0,26	36 000	20 000	0,052	4201 ATN9
	37	17	13	7,8	0,325	34 000	18 000	0,092	4301 ATN9
15	35	14	11,9	7,5	0,32	32 000	17 000	0,069	4202 ATN9

Fig.10: Characteristics of double raw ball bearings

The same ball bearings would be used in the supports of the lever regarding negligible smaller force acting these bearing compared to ones supporting the threaded spindle.

5.2 Calculation of the lever

Scheme of the lever of calibration device is shown in the following figure. Distance of the supports of the lever and the threaded spindle should be l=36mm according to the minimal needed distance for assembly of ball bearing 4202 2RS.

Calibration device lever length L should be calculated according to requirements that maximal calibration force equals F_{max}=20000N should be generated by means of weights whose total mass equals m=65kg.

(3) $$G = m \cdot g \approx 640\,\text{N}$$

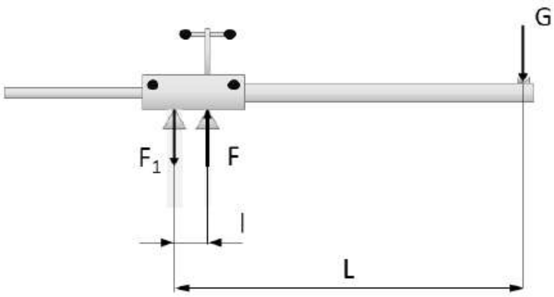


Fig.11: Loadings of the lever of calibration device

Equations of static equilibrium of the lever of calibration device:

($$\sum M = 0 \rightarrow F_{max} \cdot l - G \cdot L = 0 \rightarrow L = \frac{F_{max}}{G} \cdot l \approx 1100m$$

($$\sum F = 0 \rightarrow F_{max} - F_{1,max} - G = 0 \rightarrow F_{1,max} = F_{max} - G \approx 19000N$$

Bending moment diagram of the lever of calibration device is shown in the following figure.

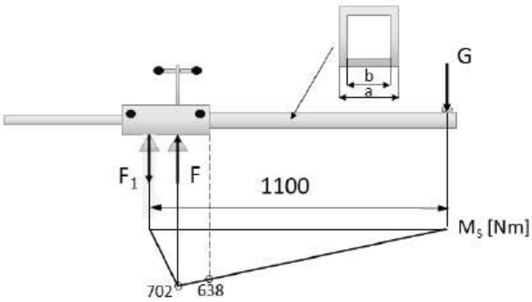


Fig.12: Diagram of the bending moment of the lever of calibration device

The lever is manufactured from the square steel tube 40x40x3 EN10219 (a=40mm, b=34mm). Section modulus of square tube should be calculated according the following equation:

(6) $$W = \frac{a^4 - b^4}{6 \cdot a} \approx 5100mm^3$$

Maximal bending stress of the lever of calibration device should be calculated according to the following equation:

(7) $$\sigma_{S,max} = \frac{M_{S,max}}{W} \approx 125 \frac{N}{mm^2}$$

Steel for tubes S275J2H with minimum tensile yield stress equals σ_T=275 N/mm[2] according to data from table shown in the following figure satisfy requirements regarding bending of the lever since corresponding yield stress equals:

(8) $$\sigma_{Ts} = 1.2 \cdot \sigma_T = 330 \frac{N}{mm^2}$$

Steel grade		Minimum yield strenght ReH		Tensile strenght Rm		Minimum elongation A	Minimum impact energy KV
Steel name	Steel number	MPa		Mpa		%	J
		Specified thickness		Specified thickness		Specified thickness	at test temperature of
		mm		mm			
		≤ 16	> 16 ≤ 40	< 3	≥ 3 ≤ 40	≤ 40	
S235JRH	1.0039	235	225	360-510	360-510	24	24
S275J0H	1.0149	275	265	430-580	410-560	20	27
S275J2H	1.0038						
S355J0H	1.0547	335	345	510-680	470-630	20	27
S355J2H	1.0576						
S355K2H	1.0512						

Fig.13: Characteristics of steels for tubes EN10219-1

Safety factor for plastic deformation of the lever of calibration device equals:

(9) $$S_T = \frac{\sigma_{Ts}}{\sigma_T} \approx 2.6$$

5.3 Calculation of the threaded spindle

Threaded spindle should be manufactured with metric coarse thread M24 (d=24mm, P=3mm, d_2=22.051mm, d_3=20.319mm, A_3=324.3mm[2], H_1=1.624mm and □=2.48[0].

Section modulus of threaded spindle should be calculated according the following equation:

(10) $$W_{p3} = \frac{d_3^3 \cdot \pi}{16} \approx 1650mm^3$$

Coefficient of friction for metric threaded spindle made of steel should be calculated according to the following equation:

(11) $$\mu_n = 1.155 \cdot \mu = 0.1155$$

where is μ=0.1 coefficient of friction of steel. The friction angle of metric threaded spindle should be calculated according the following equation:

(12) $$\rho_n = arctg(\mu_n) \approx 6.6^0$$

Torque to overcome friction between threads of threaded spindle and its nut should be calculated according to the following equation:

(13 $$T_n = F_{max} \cdot \frac{d_2}{2} \cdot \tan(\varphi + \rho_n) \approx 34540 Nmm$$

Axial and torsional stress of threaded spindle should be calculated according to the following equations:

(14) $$\sigma = \frac{F_{max}}{A_3} \approx 61 \frac{N}{mm^2}$$

(15) $$\tau = \frac{T_n}{W_{p3}} \approx 21 \frac{N}{mm^2}$$

Equivalent stress of threaded spindle should be calculated according to the following equation:

(16) $$\sigma_i = \sqrt{\sigma^2 + (\alpha \cdot \tau)^2} \approx 67 \frac{N}{mm^2}$$

(17) $$\alpha = \frac{R_e}{\tau_T} = \frac{R_e}{0.8 \cdot R_e} = 1.25$$

Threaded spindle should be made of steel 42CrMo4 (R_e=750 N/mm^2) and factor of safety for plastic deformation equals:

(18) $$S_T = \frac{R_e}{\sigma_i} \approx 11$$

Radius of inertia of threaded spindle should be calculated according to the following equation:

(19) $$i_{min} = \frac{d_3}{4} \approx 5mm$$

Lifting height of threaded spindle equals h=500mm and effective length of threaded spindle should be calculated according to the following equation:

(20) $$l_{red} \approx 0.7 \cdot h \approx 350mm$$

Buckling resistance should be calculated according to the following equations:

(21) $$\delta = \frac{l_{red}}{i_{min}} = 70$$

(22) $$\sigma_k = \frac{\pi^2 \cdot E}{\delta^2} \approx 400 \frac{N}{mm^2}$$

Factor of safety for buckling equals:

(23) $$S_T = \frac{\sigma_k}{\sigma} \approx 6.6$$

6. Cad Modelling And Engineering Drawings

When detailed design was finished, CAD model of the calibration device and engineering drawings of all parts, shown in the following figures, were generated by CAD software SolidWorks,.

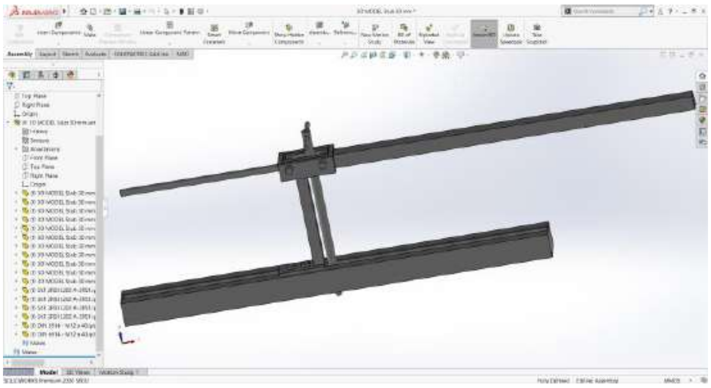


Fig.14: CAD model of the calibration device

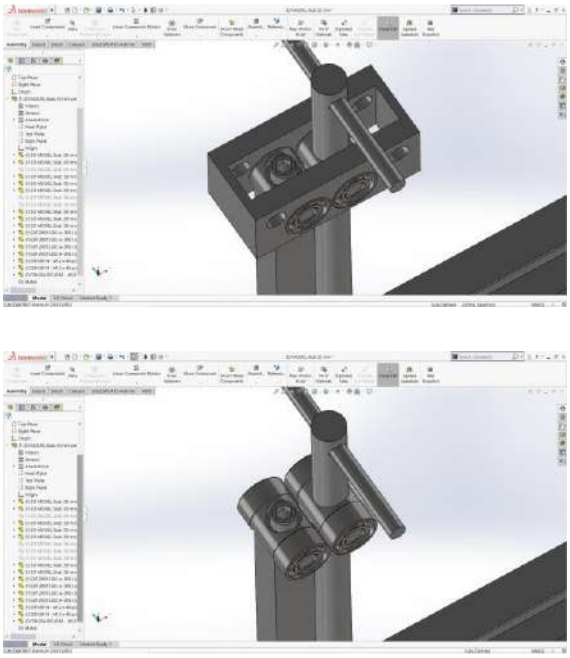


Fig. 15: Details of the calibration device

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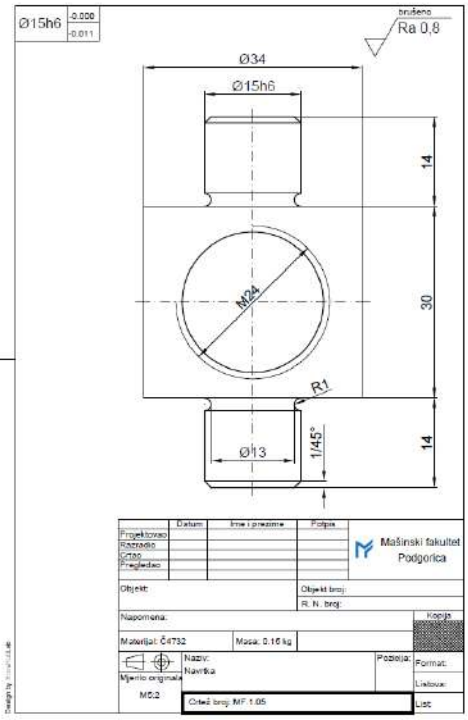

Fig. 16: Engineering drawing of the axle shaped nut

7. Rapid Prototyping And Manufacturing

Based on engineering drawings several parts of calibration device were manufactured by 3D printing as shown in the following figure.

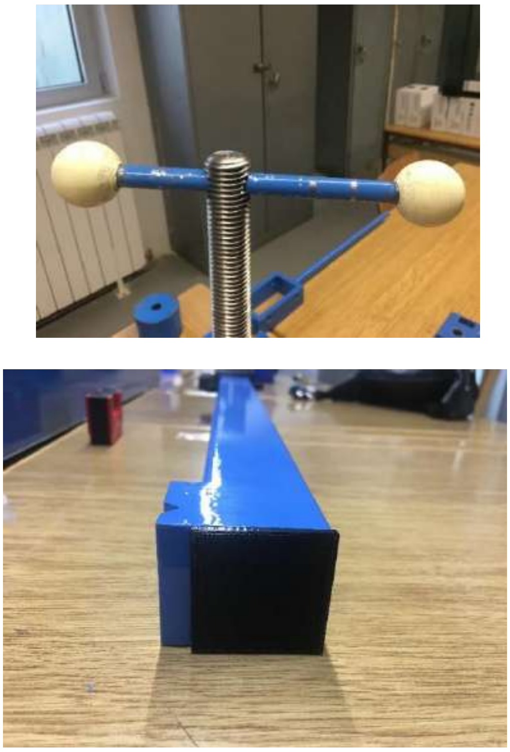

Fig.17: 3D printed parts of calibration device

Other non-standard parts of calibration device, shown in the following figures, were manufactured by conventional manufacturing processes.

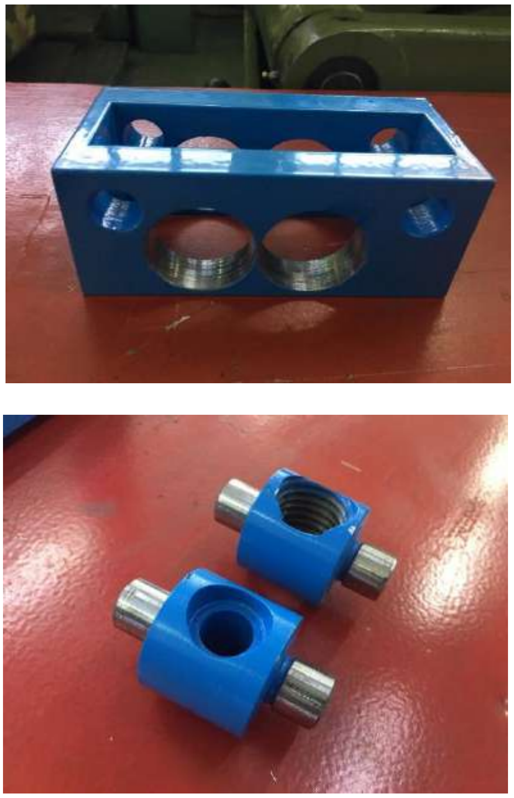

Fig.18: Parts of calibration device manufactured by convenional manufacturing processes

6. Assembly And Testing Of Calibration Device

After rapid prototyping and manufacturing of the mechanism parts their assembly and testing were conducted as shown in the following figures.

Fig.19: Brake tester calibration

Fig.20: Axle load scale calibration

Fig. 21: Brake pedal force gauge calibration

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Design of the blind corner cabinet mechanism For g shaped kitchen layout

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Abstract

Kitchen cabinets are the built-in furniture installed in kitchens for storage of pots, pans, dishes, cutlery, food, etc. Design of the functionality of the kitchen cabinets must provide adequate utilization percentage of the cabinets, as well as, the access for the user to the storage space. In order to fulfill these design requirements for the kitchen cabinets special mechanisms must be designed to provide access for the user to the storage space of the blind corner kitchen cabinets. This mechanism is usually used to pull out the shelf of the blind corner kitchen cabinet enabling easy access for the user to the stored pots, pans, dishes, cutlery, food, etc. This report deals with design and rapid prototyping of the blind corner cabinet mechanism for G shaped kitchen layout.

Keywords: blind corner cabinet, mechanism, design

1. Introduction

Ergonomics and human comfort are among the most important aspects of the furniture design. Therefor improvement of the current mechanisms, which are used in the widely produced types of furniture, is gaining momentum every day. Design of sliding mechanism to pull out the shelf of the kitchen cabinet is presented by Wu et all [1]. Design of new sofa bed mechanism to open and close sofa bed in order to transform sofa bed from sitting to lying position and vice versa is presented by Mutlu et all [2].

The design of the mechanisms that provide the desired function is considered within the kinematic synthesis of the mechanisms [3-4]. The kinematic synthesis of mechanisms is consisted of three main categories: function, trajectory and motion synthesis. It is expected that mechanisms follow the desired trajectory throughout their movement simultaneously utilizing available area and/or volume.

Kitchen cabinets are the built-in furniture installed in kitchens for storage of pots, pans, dishes, cutlery, food, etc. Design of the functionality of the kitchen cabinets must provide adequate utilization percentage of the cabinets, as well as, the access for the user to the storage space. In order to fulfill these design requirements for the kitchen cabinets special mechanisms must be designed to provide access for the user to the storage space of the blind corner kitchen cabinets. This mechanism is usually used to pull out the shelf of the blind corner kitchen cabinet enabling easy access for the user to the stored pots, pans, dishes, cutlery, food, etc.

This paper deals with design and rapid prototyping of the blind corner kitchen cabinet mechanism for G shaped kitchen layout. Design task is defined by the company Rekant doo from Podgorica, Montenegro. The scope of this company is furniture manufacturing.

2. Design Task

Mechanism to pull out the shelf from the blind corner kitchen cabinet for G shaped kitchen layout should be designed.
List of requirements:

1. The mechanism should be as simple as possible in terms of number of parts
2. Non-metal parts of the mechanism, except the shelf made of MDF plate, should be designed so that they can be manufactured by FFF or SLA technologies of 3D printing
3. The mechanism should be as simple as possible in terms of assembly and disassembly
4. The body and shelf of the blind corner cabinet should be made of 18 mm thick MDF plate
5. The internal dimensions of the blind corner cabinet equal 1160 x 560 x 680 mm
6. The angle of opening the blind corner cabinet door equals 90^0
7. The dimensions of the blind corner cabinet opening with the door in the open position equal 550 x 680 mm
8. The load capacity of the blind corner cabinet shelf equals 30 kg
9. The mechanism should be rapid prototypedc

3.Conceptual Design

3.1 G shaped kitchen layout

G shaped kitchen layout, as well as, position of blind corner cabinet is shown in the following figures.

Fig.1: G shaped kitchen layout

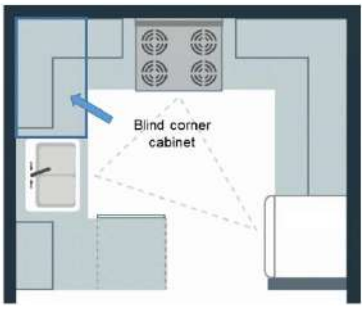


Fig.2: Blind corner cabinet position

3.2 Blind corner cabinet

For the sake of development of the mechanism for the blind corner cabinet of G shaped kitchen, the company Rekant doo from Podgorica which defined the design task, manufactured blind corner cabinet and delivered it to the 3D Centar of the Faculty of Mechanical Engineering. Delivered blind corner cabinet is shown in the following figure.

Fig.3: Blind corner cabinet of the G shaped kitchen

Based on the manufactured blind corner cabinet of G shaped kitchen the accurate key dimensions for the mechanism design were measured. These dimensions are shown in the following figure.

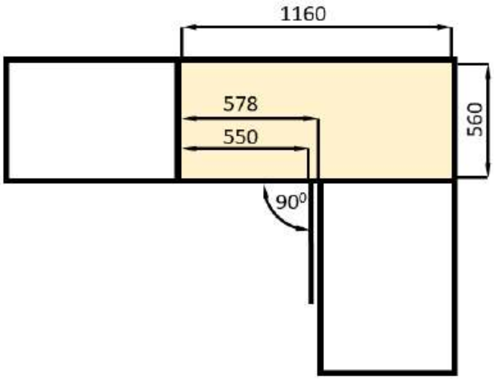


Fig.4: Key dimensions of the blind corner cabinet

3.3 Mechanism type and its main characteristics

Regarding the requirement of design task related to as simple mechanism design as possible, after consideration of possible types of mechanisms that could be used to pull out the shelf from the interior of blind corner cabinet, the three bar linkage mechanism, shown in the following figure, was selected.

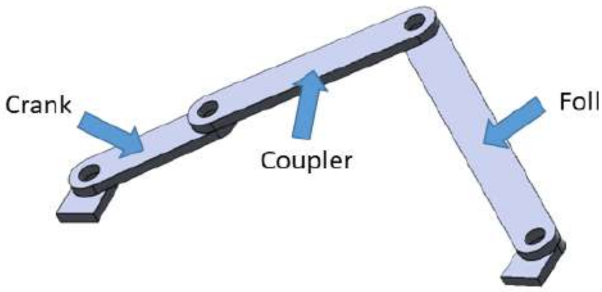


Fig.5: Three bar linkage mechanism

Mechanism fixed joints, shown in the following figure, should be fixed to the body of blind corner cabinet.

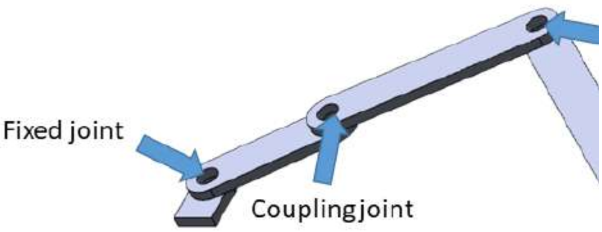


Fig.6: Joints of the three bar linkage mechanism

Crank and follower should be curvilinear in order to enable shelf of the blind corner cabinet to be pulled out as much as possible from its interiority. The shape of shelf, having a role of coupling element of mechanism, is irregular which enables its pullng out of the blind corner cabinet. Conceptual design of the mechanism is shown in the following figure.

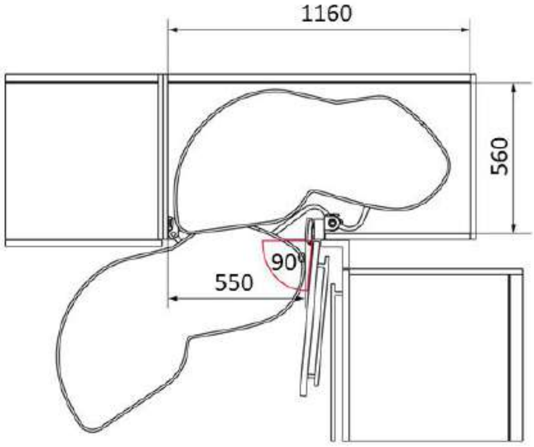


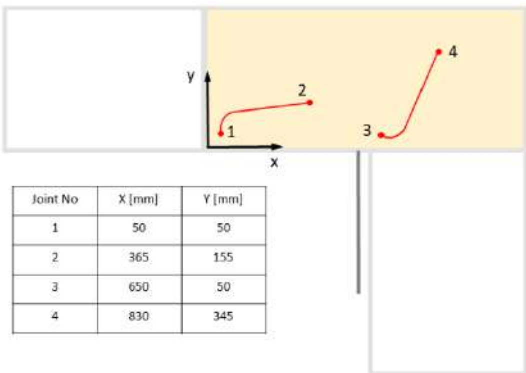
Fig.7: Conceptul design of the blind corner cabinet mechanism

4.Detailed Design

In the following part of the paper some details of detailed design of the blind corner cabinet mechanism would be introduced.

4.1 Positions of the mechanism joints

Based on the mechanism motion analysis for different positions of the mechanism joints, the fixed joints positions were selected in order to enable proper connection of crank and follower of the mechanism to the body of blind corner cabinet. The coupling joints positions were also selected in order to enable mechanism motion resulting into pulling out the shelf from blind corner cabinet interiority. The mechanism joints positions corresponding to the innermost position of the shelf of blind corner cabinet are shown in the following figure.



Joint No	X [mm]	Y [mm]
1	50	50
2	365	155
3	650	50
4	830	345

Fig.8: Positions of the mechanism joints

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4.2 Determination of shape of the coupler

The shape of the coupling element of the mechanism, which is simultaneously the shelf of the blind corner cabinet, must satisfy the mechanism motion requirement regarding pulling out the shelf from the blind corner cabinet interiority.

Therefore, in order to find the final shape of the coupling element of the mechanism it is necessary to conduct a detailed mechanism motion analysis from the starting to the ending position. This analysis starts from the initial shape of the coupling element that corresponds to the shape of the interior of the blind corner cabinet, which is gradually reshaped during the mechanism motion analysis in order to find the shape of the coupling element which enables its pulling out from the blind corner cabinet interiority during the mechanism motion.

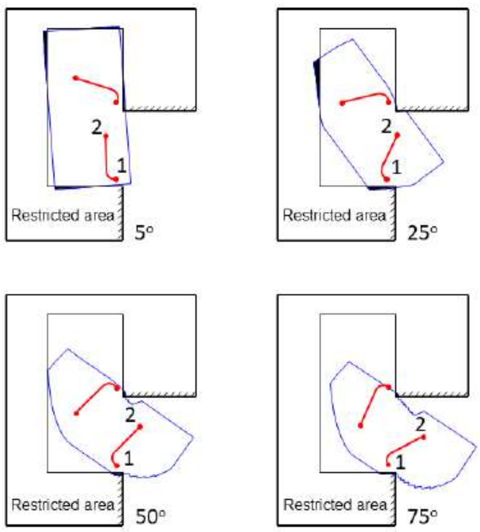


Fig.9: Gradual shape detrmination of the coupling element in the chosen mechanism positions

The mechanism motion is analysed through series of succesing positions of its elements corresponding to the gradual rotational movement of the crank element of the mechanism from initial position with angular step of 5°. In each of the analyzed positions, sections of the coupling element entering into the restricted area are gradually removed as shown in the figure 9.

Finally, after rotational motion of the crank element of the mechanism corresponding to the angle of 130° the mechanism is in its the outermost position which results into the coupling element being the mostly outside the blind corner cabinet and being accesible to the kitchen user.

The shape of the coupling element of the mechanism determined by the previosly described procedure is shown in the following figure.

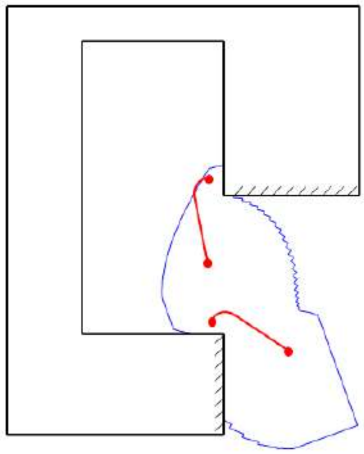


Fig.10: Shape of the coupling element of the mechanism

Shape of the coupling element, shown in the previous figure, due to its extremely irregularity represents only the design space within which the final shape of the coupling element, ie the shelf of the blind corner cabinet must be designed. The final shape of the coupling element of mechanism is defined in accordance with the requirements of functionality and aesthetics. The final shape of the mechanism coupling element is shown in the following figure.

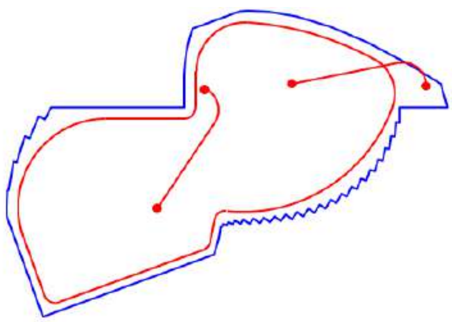


Fig.11: Final shape of the coupling element of the mechanism

The mechanism of the blind corner cabinet in its innermost and outermost positions is shown in the figure 12. Space utilization of the blind corner cabinet mechanism is 55.5%.

The mechanism coupling element, ie the shelf of the blind corner cabinet is made of 18 mm thick MDF plate.

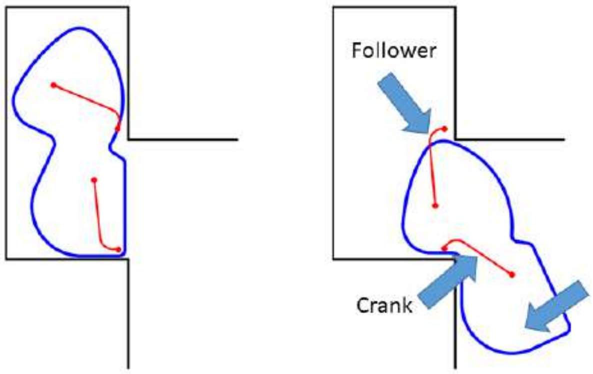


Fig.12: The mechanism in its innermost and outermost positions

4.3 Determination of the shape of crank and the follower

Dimensions of the crank and the follower of the mechanism are determined in accordance with the joints positions. Crank and follower are manufactured from square tubes of the following dimensions 40x40x2 mm, made of stainless steel X6CrNi18-10KT. Shape of the crank of the mechanism is shown in the following figure.

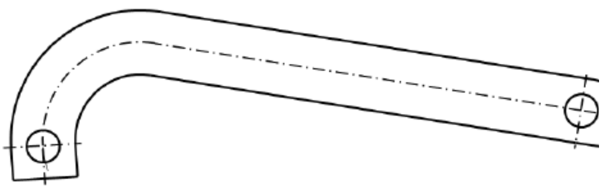


Fig.13: The crank of the mechanism

4.4 Calculation of the screw connections

Connection between the mechanism and the body of the blind corner cabinet is realized by means of the mechanism support shown in the following figure.

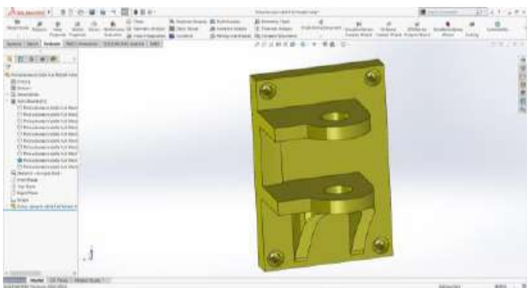


Fig.14: CAD model of the mechanism support

The mechanism support is screwed to the body of the blind corner cabinet with 4 countersunk screws M8x25 shown in the following figure.

Load analysis of screws connecting the mechanism to the body of blind corner cabinet is realized by finite element method. Maximal load of 30 kg is applied.

Maximal load of single screw in innermost position of the mechanism, which connects the mechanism support to the body of blind corner cabinet is 326 N (axial component F_a=309 N, radial components F_{r1}=52 N and F_{r2}=90 N).

Maximal load of single screw in outermost position of the mechanism, which connects the mechanism support to the body of blind corner cabinet is 392 N (axial component F_a=134 N, radial components F_{r1}=236 N and F_{r2}=282 N).

Fig.15: Countersunk screw M8x25 with internal / external threaded nut

Dimensions of metric coarse thread M8 are as follows: major diameter d=8 mm, pitch P=1.25 mm, pitch diameter d_2=7.188 mm, minor diameter d_3=6.466 mm, minor cross section area A_3=32.84 mm^2, thread depth H_1=0.677 mm, thread angle ⍰=3.17°.

Screw stresses corresponding to maximal single screw load in innermost position of the mechanism are caused by tension and shear:

$$\sigma = \frac{F_a}{A_3} \approx 9.4 \frac{N}{mm^2} \quad \text{and} \qquad (1)$$

$$\tau = \frac{\sqrt{F_{r1}^2 + F_{r2}^2}}{A_3} \approx 3.2 \frac{N}{mm^2}$$

Equivalent stress of screw, made of steel 4.8 (R_e=340 N/mm^2, ⍰$_T$=200 N/mm^2) should be calculated according to the following equation:

(2)
$$\sigma_i = \sqrt{\sigma^2 + (\alpha \cdot \tau)^2} \approx 10.9 \frac{N}{mm^2} \quad \text{and}$$
$$\alpha = \frac{R_e}{\tau_T} = 1.7$$

Screw stresses corresponding to maximal load of single screw in outermost position of the mechanism are caused by tnsion and shear:

(3)
$$\sigma = \frac{F_a}{A_3} \approx 4.1 \frac{N}{mm^2} \quad \text{and}$$
$$\tau = \frac{\sqrt{F_{r1}^2 + F_{r2}^2}}{A_3} \approx 11.2 \frac{N}{mm^2}$$

Equivalent stress of screw, made of steel 4.8 (R_e=340 N/mm², τ_T=200 N/mm²) should be calculated according to the following equation:

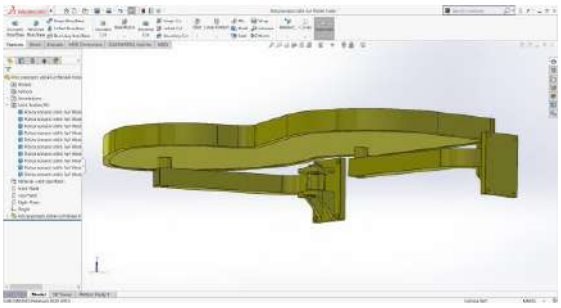
(4)
$$\sigma_i = \sqrt{\sigma^2 + (\alpha \cdot \tau)^2} \approx 19.5 \frac{N}{mm^2}$$

Factor of safety for plastic deformation of screws equals:

(5)
$$S_T = \frac{R_e}{\sigma_i} \approx 17.5$$

5. Cad modelling and engineering drawings

When detailed design was finished, CAD model of the blind corner cabinet mechanism and engineering drawings of all parts, shown in the following figures, were generated by CAD software SolidWorks,.



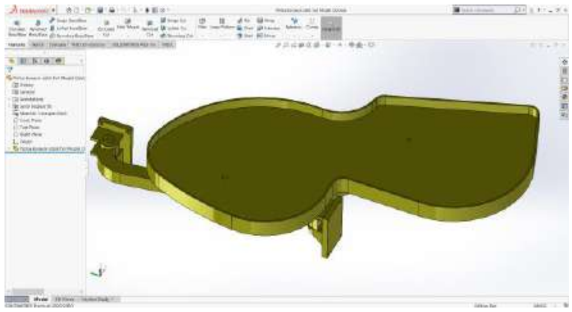


Fig.16: CAD model of the mechanism

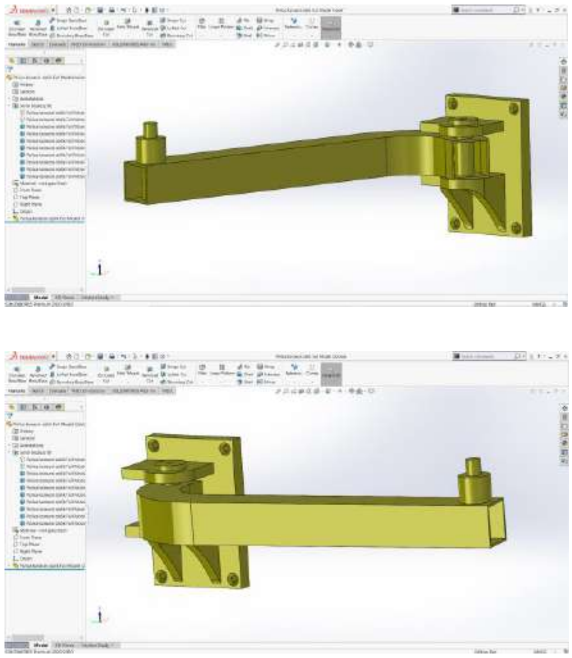


Fig. 17: CAD model of the follower and the mechanism support

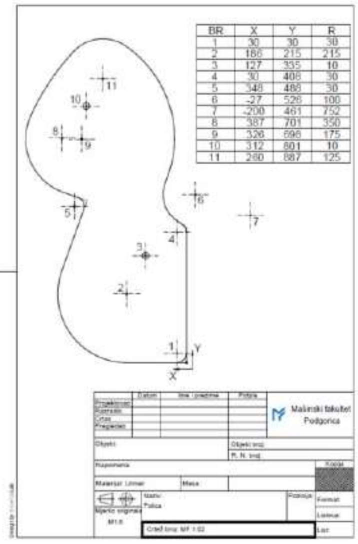


Fig. 18: Engineering drawing of the coupler (the shelf of the blind corner cabinet)

5. Rapid Prototyping

Based on engineering drawings the most of parts of the mechanism were manufactured by 3D printing as shown in the following figures.

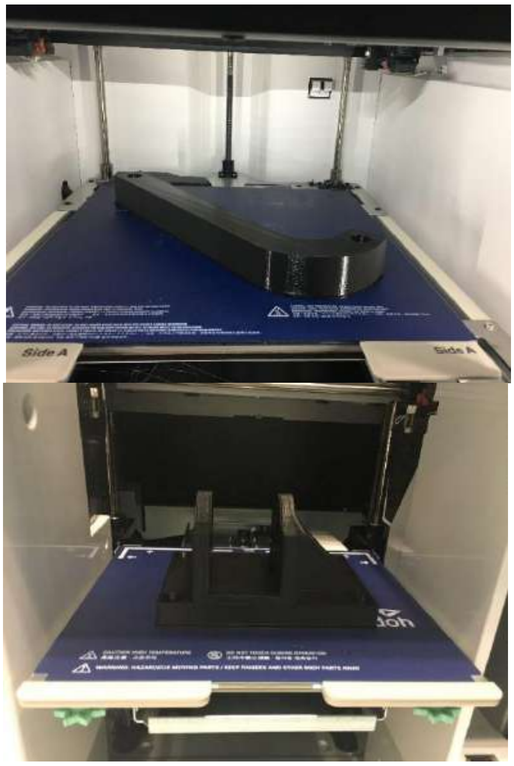


Fig.19: 3D printing of the mechanism parts

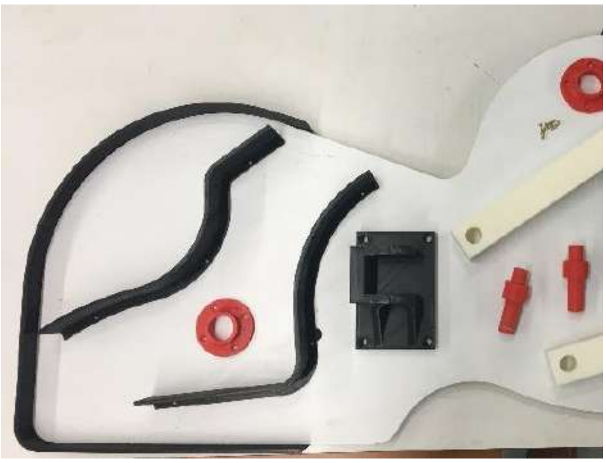


Fig.20: 3D printed parts of the mechanism

6. Assembly And Motion Testing Of The Mechanism

After rapid prototyping of the mechanism parts their assembly and motion testing were conducted as shown in the following figures.

Fig.21: The crank and the follower after assembly

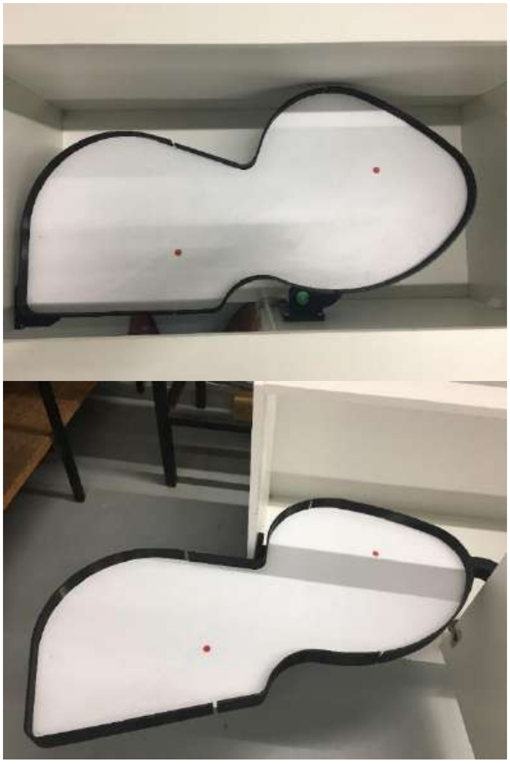


Fig. 22: Mechanism in the innermost and the outermost positions

Fig.23: Mechanism in the midd position

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