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MASTER'S THESIS

Analysis and improvement in design and production of labelling machines parts

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Prohlášení o autorství

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STRUČNÝ POPIS (MAX 10 ŘÁDEK) **ZAMĚŘENÍ, TÉMA, CÍL POZNATKY A PŘÍNOSY**	Diplomová práce se zabývá analýzou a racionalizací částí etiketovacích strojů ve společnosti Krones AG. Se zaměřením na vodící systém nádob. Výstupem jsou návrhy zlepšení, které zlepšují celkovou ergonomii v určitém pracovním úseku.
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BRIEF DESCRIPTION **TOPIC, GOAL, RESULTS AND CONTRIBUTIONS**	This Master’s thesis analyses and suggest some improvements on part of the label machine in the Krones AG company. The focus point is the container guiding system. In conclusion are suggestions for improvements of the ergonomics.
KEYWORDS	improvements, analysis, ergonomics, industrial engineering, mechanical engineering

Table of Contents

List of Figures

List of Tables

Abbreviations

5S - A shorthand expression for principles of maintaining an effective and efficient workplace

ABC - Items overhead cost directly to a giving product, it stands for “Activity-Based Costing)

AG - Is the short form of a joint-stock company from the German term “Aktiengesellschaft”

BOM - Bill of materials or product structure (parts list of contents)

CAD - A computer technology that designs a product and documents the design's process, it stands for “Computer-aided design”

CNC - Computer Numerical Control, a computer converted CAD design into numbers (code)

F3 messages – Error messages reported by the assembly department

IE - Industrial engineering

KLT - Euro containers, it the short form “Kleinladungsträger” ("small load carrier")

LCS - It stands for “Life circle service”

LI - Lift index

ME - Mechanical engineering

NIOSH - National Institute of Occupational Safety and Health

OEE - Overall equipment effectiveness shows the overall efficiency of manufacturing or production facilities

QM - Quality management

RULA - Rapid Upper Limp Assessment

RWL - Recommended mass limit

SAP - A German software for data management, it stands for “Systems, Applications and Products”

SMED - Single Minute Exchange of Die, an industrial engineering method for opalization of all kind of exchanges in manufacturing

TAB - Technische Abteilung (Technical division)

TPM - Total Productive Maintenance, a system of maintaining and improving the production and the whole organisation

1 Introduction

The main task of this master's thesis is to analyse the process of design and production of labelling machines in the German company KRONES AG. All the analysists will be around the three main pillars of the current project in consists of design, production and assembly.

There are three important aspects to look in these analyses. Rising quality through time due to the improvement of current technologies. Level of transparency in the different departments. Globally, as this company is represented in the major regions in the world and within the firm. The last aspect is to define all the benefits of those taken steps.

The second part of this thesis are suggestions for improvements in the assembly division. Those improvements should be accomplished through suitable optimisation methods within industrial engineering, specifically ergonomics methods. At the end of this part are valuations and conclusions of these suggestions.

Structure of the thesis

Derived from the purpose, this master's thesis will be structured as follows:

Theoretical Review introduces the evolutionary theories, relevant models and methods used in industrial engineering. This section is divided into two separate subsections "Definition of industrial engineering" and the application of ergonomics in this field. The first subsection will define industrial engineering itself, importantly all the tasks in this engineering profession. Included are also definitions of lean manufacturing and the most importing task in industrial engineering. The second subsection will define one of the most used methods in this profession ergonomic analysts.

Analysis of the current state gives an overview of the whole process for the "label machine" project. The focus is on the three main departments (design, production and assembly). Important is to showcase the past, presence and if possible, the future of the workflow by each department to show the increase of quality and transparency.

Suggestions for improvements provides value and improvements, based on the analysis of the current state. These suggestions should be practicable and improve the overall ergonomics.

Evaluations will prove the benefits of these suggestions, by comparison, the current state and the improved working process.

The conclusion gives a summarization of this thesis and shows the results of this paper.

2 Theoretical Review

Since mentioned, this chapter should provide all the theoretical background on this subject. The first part will showcase "Industrial Engineering" in theory and lean manufacturing. The second part is based on various methods, used in industrial engineering and the ergonomics side in particular.

2.1 Industrial Engineering

Industrial engineering embraced the ideas of scientific management theories and principles (for exp. by Frederick Taylor, later expanded by Frank and Lillian Gilbreath). The core industrial engineering applications and tools to define and significantly improve operations include time and motion study, workplace and floor layout, simplification, constraint management, flow process, materials handling, and standard costing. Many successful modern methods and practices have been developed from the Japanese Toyota Production System. [1]

Basics of industrial engineering principles apply widely beyond manufacturing or industries. Recent applications of industrial engineering techniques have been used to increase efficiency and productivity in the office, lab, maintenance shop, warehouse, military, medical services or construction. All those practices across the spectrum tend to reinforce and transform into another. Work measurement for an example is based on previous layout, methods study and flow process, and sets a ground for standard costing and constraints management. In the end, all these tools create a continuous loop of improvement for optimum benefit. [1]

Classic industrial engineering tools to define and improve operations include work measurement, constraints management, balanced workload, facility planning, workplace and facility floor layout, flow process simplification, materials handling and standard costing. The major goal at the end is cost reduction. Basic tools as The Pareto Principle, ABC or 80/20 rule, are most used. Pareto for example, suggests that an insignificant number of problems will have a large impact. Therefore, a few actions will contribute to the largest improvement.

[1]

2.1.1 Primary function

The goal is to reduce cost throughout the organisation through consistent and sustaining programs

1. Work measurement
2. Methods
3. Manning
4. Cost reduction
5. Capital
6. Layout
7. Standard Labour Cost
8. Capacity
9. Engineered Budgets
10. Cost Analysis of Specification Changes
11. Automation
12. Administer specialised management tools

[1]

2.1.2 Industrial Engineering tools, terms and concepts

Through history, information has been added to classic theses, modern tools and concepts, to form a list of industrial engineering methods. Important are references to Lean, operation management and terminology. These tools are designed to support 21th-century Scientific Management practised by industrial engineers, the management or other disciplines.

[1]

Here are some methods, tools, terms and concepts:

- 5S – Shorthand expression for principles of maintaining an effective and efficient workplace
- Six sigma – Business strategy (originally developed by Motorola)
- Activity-Based Costing (ABC) – Items overhead cost directly to a giving product
- Lean six sigma – Combination between 6 sigma and lean speed
- Benchmarking – Process to compare business processes
- Ergonomics – The study of designing equipment and devices that fit the human body
- Fishbone diagram – Identification of potential factors causing an overall effect
- Just in Time (JIT) – Production scheduling – time optimisation
- Kaizen – Specific philosophy that combines different tools as 5S, spaghetti chart, ...
- Pull and push system – communication of actual real-time need from downstream op.
- Single Minute Exchange of Die (SMED) – quick Change capability JIT
- Toyota Production System

[1]

2.2 Manufacturing

Manufacturing is an application of different guidelines and management tools in the manufacturing department. In general, is the term “manufacturing” responsible for generating profit through creating (assembling) materialistic or nonmaterialistic matters. Production of goods is a process with a distinct entrance and because of transformation processes are those entrances transforming into profitable economic exits. The transformation process, also known as a manufacturing process, depends on human resources. These human resources are in cooperation with tools, gear and other resources responsible for the transforming process. To provide economic profitability, is it important to keep all the cost of production under the final selling price.

[2]

The manufacturing process is generally divided into three basic phases, and these include creating the design for the products, sourcing raw materials, processing the raw materials, production and quality control. The first thing to be considered in manufacturing is creating the design of the products. It should fulfil the end purpose of the product for the consumers. Sourcing the raw materials are depending on the kind of those specific products. Raw materials are acquired through internal resources or by importing from external resources. External resources neither locally situated nor located abroad. Processing the raw materials also depends on the kind of the product. The outcome of the third process should be the final product.

[3]

2.2.1 Types of manufacturing

The degree of standardisation has a major influence on the type of manufacturing process. It differentiates the organisation structure of manufacture, according to Mr Kavana [4] are manufactures divided into these types:

Project-oriented

This kind of manufacture is based on an elastic production line and is individual on the project.

[4]

Unit production

Producing a small number of products for a customer. Unit productions are specific for the technological arrangement of the production process.

[4]

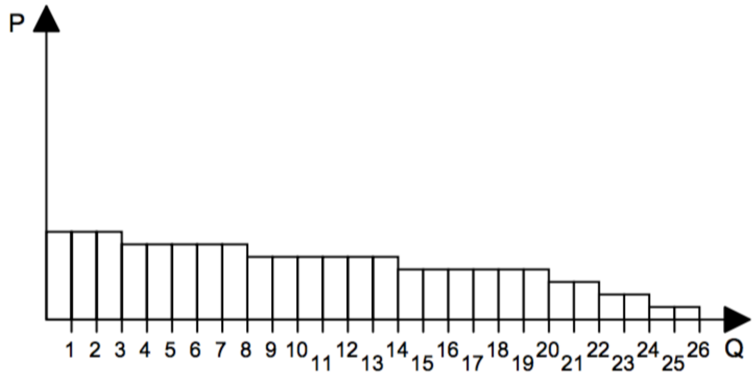


Figure 1: Unit production [5]

Batch production

This production evolves through the repetitive production of one or more products. Batch productions are based on batches, also referring to series. It reaches the highest step of efficiency with a high standardisation. In this production type, are specialised machinery with a degree of flexibility.

[4]

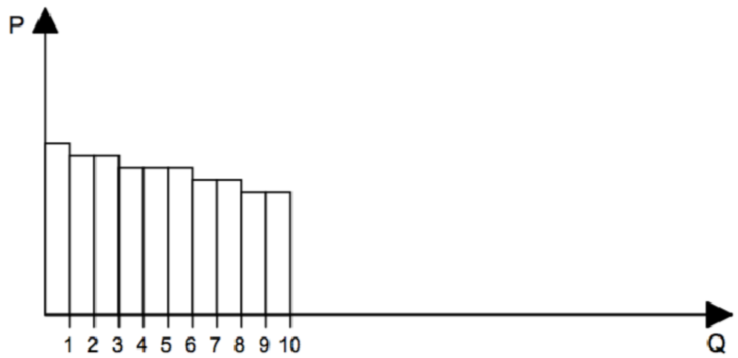


Figure 2: Batch production [5]

Mass production

Is used for simple products with a moderate size, for the highest efficiency and standardisation. The level of automatization doesn't allow flexibility. The typical usage of this kind of manufacture is manufacturing lines with highly specialised machinery.

[4]

Figure 3: Mass production [5]

2.2.2 Production layout

According to professor Basl and Horváth [5] are the manufacturing layouts divided into four basic layouts.

Technological position layout

Technologically oriented layouts depend on the similarities of technological characteristics. All the machinery is ordered into the manufacturing section. Those sections are identified after the usage, for example, machining, press or forge. These layouts are mainly used in smaller productions and unit productions.

[5]

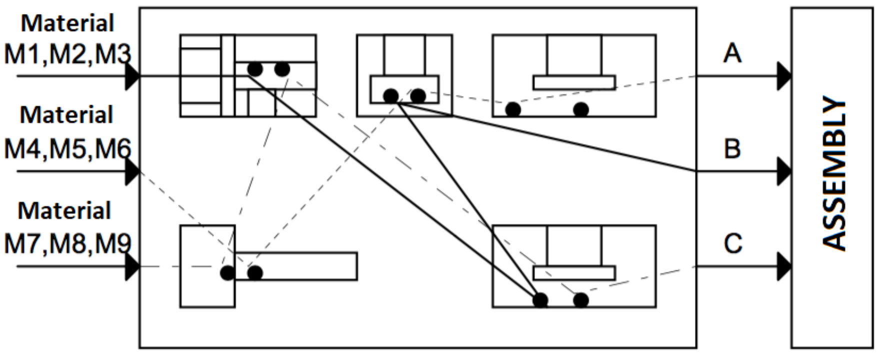


Figure 4: Technological oriented [5]

According to professor Basl and Horváth [5] are the greatest advantages:

- Little sensitivity to changes in the manufacturing program
- Possibility usage of free capacity
- The possibility of cooperation
- Easily replicable or reparable of machinery

But also, some disadvantages:

- More demanding needs of manufacturing space
- Large intermediate stocks
- The serious difficulty of preparing and managing the manufacture

[5]

Objective position layout

The objective-oriented manufacturing layout is one of the most used layouts. This type is mostly used in the automobile industry. All the technological stations are ordered in a specific order with specific duties. Therefore, the ordering depends on the product and the current program. Typically, is the production and manufacturing at the beginning of the process and the assembly station at the end. The optimal usage of this layout is a mass production with little variability.

[5]

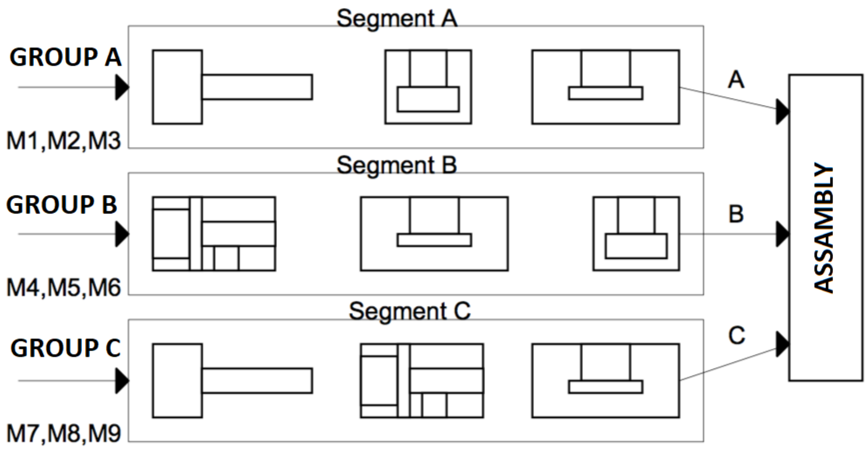


Figure 5: Objective oriented [5]

Advantages of the objective position layout:

- Uncomplicated preparing and managing of the manufacturing
- Relativity quick manufacturing processes
- The little requirement of the plane space
- Short transport of the product between the workstations

Disadvantages of the objective position layout:

- The High sensitivity of manufacturing program changes
- High requirements for maintenance and repairing of the machinery
- Impossibility usage of free manufacturing capacity

[5]

Cellular position layout

Cellular manufacturing layout is an application of group technology with similar machines or processes that have been aggregated into "*cells*". Each of these cells are dedicated to the production of a part of the whole product family (or a limited group of families). The objectives in cellular manufacturing are like the objectives of the group technology.

[6]

By reducing setup, product part handling, waiting times and batch size are the manufacturing times significantly shortened. Smaller batches are leading to product part process inventory reduction. Due to the similarity among part in the family, are the complexity of production scheduling also reduce, and this factor simplifies the production schedule. By specialising each cell in producing a smaller number of different parts (variation reduction), is the overall quality improved.

[6]

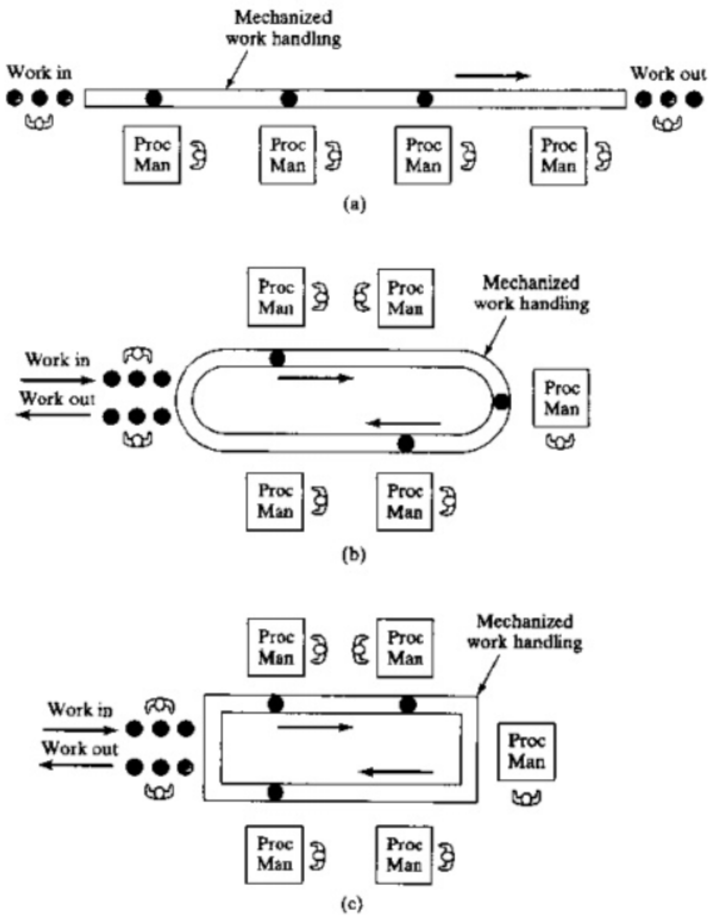


Figure 6: Machine cells [6]

Description for the "***picture 6***": *Machine cells with semi-integrated handling: (a) in-line layout, (b) loop layout and (c) rectangular layout. (Key: "proc" = processing operation (e.g., mill, lathe, etc.), "Man" = manual operation; arrows indicate the workflow.)*

[6]

Fixed-position layout

The fixed manufacturing layout is the least important and used in today's manufacturing industries. In this type of layout is the major component or product in a fix location due to the size of the component or product. Other materials, parts, tools, machinery, human resources and other supporting equipment are brought to the current location of the main component. This layout is used as previously mentioned for large component or a product like aeroplanes and large ships. The main component or body of the product remains a stationary (fixed) position.

[7]

Advantages of the fixed position layout:

- Material movement reduction
- Minimalization of capital investment
- The least involvement of materials
- The possible flexibility of changes in product design, product mix and production volume

Disadvantages of the fixed position layout:

- The requirement of highly skilled human resources
- Low content of work in progress
- High equipment handling costs
- Low utilisation of labour and equipment

[7]

2.3 Ergonomics in Industrial Engineering

The impact of ergonomics in this anthropocentric focused time is an essential part of production and non-production companies. This subchapter will discuss the benefits of ergonomic analysts, specific methods and tools to achieve the optimal result for this matter. In the ergonomic field are a lot of specific methods. This thesis will mainly focus on the methods of RULA and NIOSH.

The constant expansion of science and technology brings new and innovative possibilities of work procedures. There is a certain imbalance between a person's abilities, skills and limits, and the requirements for the activities and demands that the new technology necessitates. It is very important, not to overlook the mentioned imbalance because all these new technologies and methods must be performable and practicable. Neglections may cause an overdrawn of person physic, which leads either to fatigue, failure or even to the crash of the whole physiological system with possible health damage. The main task in ergonomics is to focus on the person's limits and to respect all his abilities and limitations in the designing process of a certain workplace.

[8]

According to the definition of the International Ergonomics Association (IEA) [9], " *Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design and optimize human wellbeing and overall system performance.* "

Ergonomics and its roots go back to the period of human origin. At first, it was mainly about adapting the tools to the human body, like hand-shaped equipment. According to Mr Matoušek [10], humans has always tried to adapt work tools and machines to their physical, sensorial and mental abilities. He also states that only in recent decades are systematic studies of the interactions between man and the technical tools viable. Ergonomics is a systematic approach to problem-solving.

[10]

The most important features of the systematic approach include stability and reliability. This means that the system can implement its function in a given process within given tolerances and at a certain time. It quantifies with the probability of trouble-free operation. Furthermore, the system can be divided according to the complexity of origin and taken to the environment. According to Mr Chundely, is this system a set of several elements and components. They are functionally interconnected and between which some links allow the intended inputs to achieve the intended outputs - results, within the given limiting conditions. This system is known as 3M: man, machine and medium.

[8]

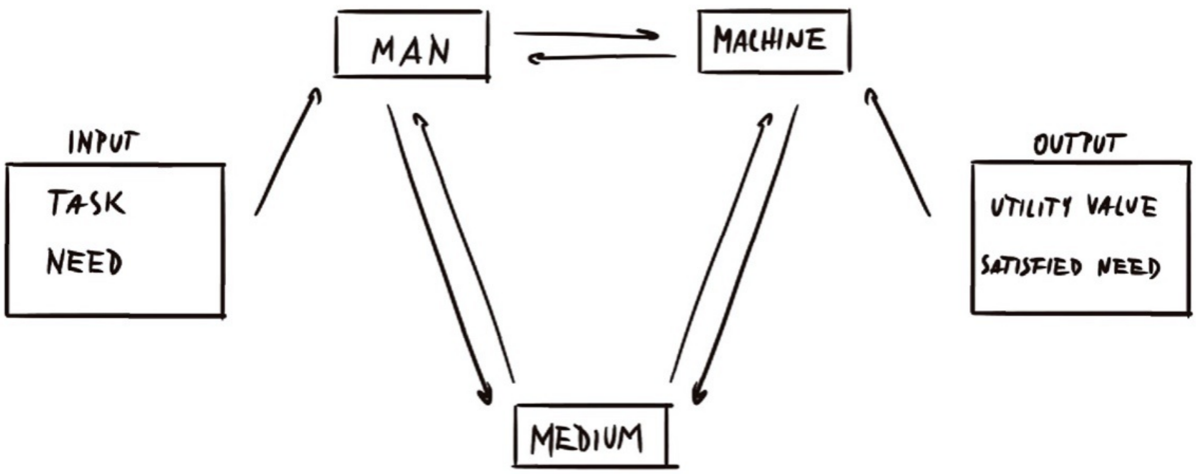


Figure 7: The 3M system (man-machine-medium)

As pictured in *Figure 7* is the man component an important specification in this ergonomics system. Humans are thus understood as a decisive and limiting part of the system that affects his final behaviour. As a result, are ergonomic systems reliability depending not only on technical elements but also on the human part.

2.4 Ergonomics analysis

In the following text are described some of the most used ergonomic analysis, they will be also in the practical part of this thesis.

2.4.1 RULA method

The Rapid Upper Limb Assessment (RULA) method has been proposed by Dr Lynn McAtamney and Professor Nigel Corlett, two ergonomists from the University of Nottingham in England Great Britain. RULA is a postural targeting method for estimating the risks of work-related upper limb health issues. A RULA assessment gives a fast and systematic assessment of the postural risks to a worker. The analysis can be conducted before and after an intervention to demonstrate that the intervention has worked to lower the risk of a work-related injury.

The strain on the worker's upper limbs, neck and torso are expressed by a scoring according to an action level. It also determines whether the position is acceptable, or changes will be needed to be made. Another possibility is to pay more attention to different tasks. For example, to perform an analysis that calculates the risk factor from the angle of the joint, the rotation of the arms, wrists, neck and legs. The RULA action levels provide the urgency about the need to improve a person working process to minimise the degree of injury risk. And like most ergonomics analysis methods, RULA's results are not absolute.

[11]

Action level	RULA score	Interpretation
1	1-2	The person is working in the best posture with no risk of injury from their work posture.
2	3-4	The person is working in a posture that could present some risk of injury from their work posture, and this score most likely is the result of one part of the body being in a deviated and bad position, so this should be investigated and corrected.
3	5-6	The person is working in a poor posture with a risk of injury from their work posture, and the reasons for this need to be investigated and changed shortly to prevent an injury
4	7+	The person is working in the worst posture with an immediate risk of injury from their work posture, and the reasons for this need to be investigated and changed immediately to prevent an injury

Table 1: RULA action level [11]

The RULA method is mostly used to assess position, force and movement associated with sedentary tasks. The four main applications of RULA analysis include:

1. Measure musculoskeletal risk, usually as part of ergonomic analysis
2. Compare musculoskeletal strains of current and modified workplaces
3. Evaluate results such as productivity or equipment suitability
4. Educate employees about the risks caused by various bad work attitudes

[12]

Since the RULA method is based on observation and analysis of the human body at work, are some of the ergonomic standardisation necessary. These standardisations are based on specific limits are recommended for the minimising the strain on the physiological body. As pictured in *Figure 8* could be the standardisation incorporated into checklists or instructions. As the acronym RULA suggests, the main body parts for analysts are two arms, which are analysed separately. This analogy is practised also on the neck, torso and legs.

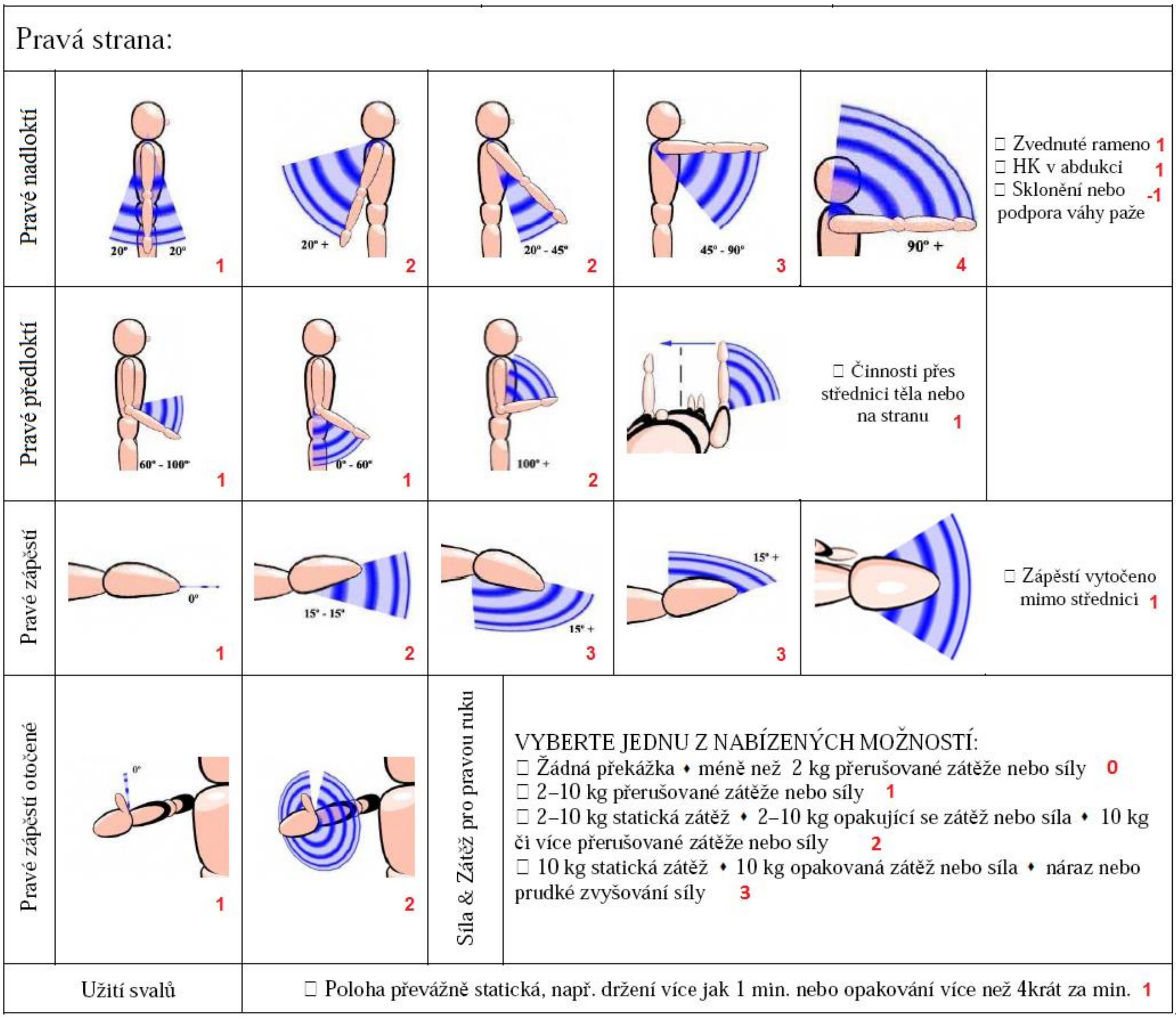


Figure 8: Evaluating the posture of the right arm following the RULA method [13]

2.4.2 NIOSH method

NIOSH stands for National Institute for Occupational Safety and Health. In 1981, this institute proposed a method for the analysis of lifting operations. In 1991, it was reworked. They extend the number of procedures. This method is based on a combination of epidemiological, biomechanical, physiological and psychological researchers.

Different studies have shown, that pressure force in the spine has a significant effect on lumbar spine pain and back injuries may occur. For this reason, a geometric model of the torso was created, on which various types of strains, movements and the reaction force of the muscles are analysed. This is necessary for understanding the stabilization of the spine under strain.

[14]

The NIOSH method can only be used if there is no disjointed lifting. Both hands must work at the same time, the posture must not be restricted in any way and also good conditions for power transmission must be provided (gripping properties, quality floor). The result of the method is the so-called recommended mass limit (RWL) calculated by multiplying the weight constant (23 kg) by different coefficients. RWL represents the maximum weight of a strain that can be lifted or laid by at least 75% of female workers and up to 99% of male workers. The NIOSH calculation also determines the degree of relative physical stress called the lift index (LI), which is the ratio between the lifting weight (L) and the RWL.

[14]

The recommended mass limit (RWL) and the lift index (LI) is calculable with these formulas:

$$RWL\ [kg] = LC \times HM \times VM \times DM \times AM \times CM \times FM$$

LC ... mass constant (LC = 23 kg)

HM ... horizontal multiplier - the distance of the load from the body.

VM ... vertical multiplier - the height from the ground in which the load is gripped and placed.

DM ... distance multiplier - the height of the ongoing manipulation.

AM ... asymmetric multiplier - the angle of rotation from the sagittal plane (a plane parallel to the median plane) when lifting a load.

CM ... connection multiplier - describes the gripping conditions of a load.

FM ... frequency multiplier - the frequency of lifting operations within one minute

$$LI = \frac{L[kg]}{RWL\ [kg]}$$

[14]

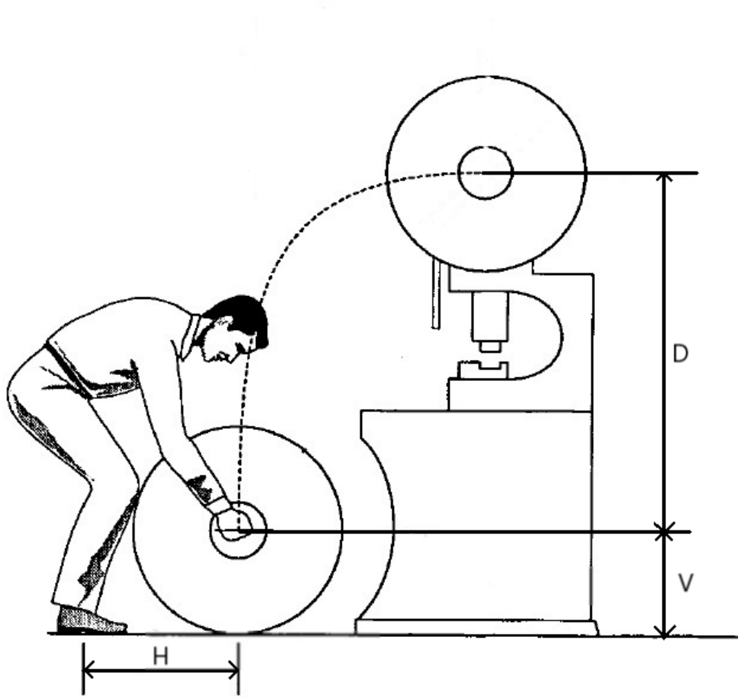


Figure 9: NIOSH illustration [14]

2.5 Load manipulation

As mention in the previous subchapter, specifically at the NIOSH method is the load manipulation one of the most preferred topics in ergonomic optimization of the workplace. Although manipulation with effective automation is rising, it is still estimated that up to 50% of spinal damage in the industry is caused by improper handling of loads. According to Mr Bureš, does the manipulation of loads depends on ergonomic factors:

- Condition of the subject (constitution, gender, age, experience, etc.)
- Load characteristics (weight, dimensions, shape, gripping possibilities, etc.)
- Environment (physicochemical environmental factors, etc.)
- Conditions of self-handling (working position, path, frequency of movements, etc.)

Due to the complexity of the maximum load calculation, are some of these weight limits in *Table 2* fairly used. Occasional lifting and transmission refer to intermittent work that is less than 30 minutes per shift in total. Frequent manipulation is the opposite, and its more than 30 minutes per shift in total. Cumulative permissible weight is countable for 8 hours of work per shift.

[15]

	Occasional manipulation	**Frequent manipulation**	**Work at a sitting position**	**Cumulative weight**
Man	Max. 50 kg	Max. 30 kg	Max. 5kg	Max. 10 000 kg
Woman	Max. 20 kg	Max. 15 kg	Max. 3kg	Max. 6 500 kg

Table 2: Weight limits [15]

Like for the lifting of loads, is pushing and pulling limited as well. The permissible hygienic limit for pushing and pulling forces, when handling a load, using a simple non-motorized trolley is visualised in *Table 3*.

	Pushing force	**Pulling force**
Man	Max. 310 N	Max. 280 N
Woman	Max. 250 N	Max. 220 N

Table3: Pushing and pulling limits [15]

These limits should minimise the risk of work-related injuries. Referring to Mr Bureš, three basic mechanisms of musculoskeletal damage can be identified:

- **Damage caused by an accident** - work-related injuries that can't be foreseen, like slipping
- **Damage by overload** - this type is more expected. It arises under conditions of excessive forces or repeated loads. It is manifested by damage to soft tissues (muscles and ligaments) and the lumbar spine.
- **Damage due to cumulative load** - In this case, it is a long-term load that slowly causes damage to joints, ligaments, muscles, etc.

[15]

3 The application area

This chapter should provide a brief introduction of the submitter of this thesis, the company Krones AG. Followed by that introduction is information about labelling technology and the guiding system. This chapter also uncovers information, that is important for the understanding of the further chapters.

3.1 Krones AG

The company Krones AG, based in Neutraubling, is planning, developing, producing and installing machinery and complete facilities for filling and packaging. Among the greatest consumers are involved in the food industry, chemical industry, pharmacy industry and the cosmetic industry. The most important market is the food industry because of the heavy consumer base. Krones AG delivers complete solutions for the whole factory. They can build the factory with the required properties basically on a green field. After the facilities, they also deliver all the equipment for the whole filling and packaging process.

[16]

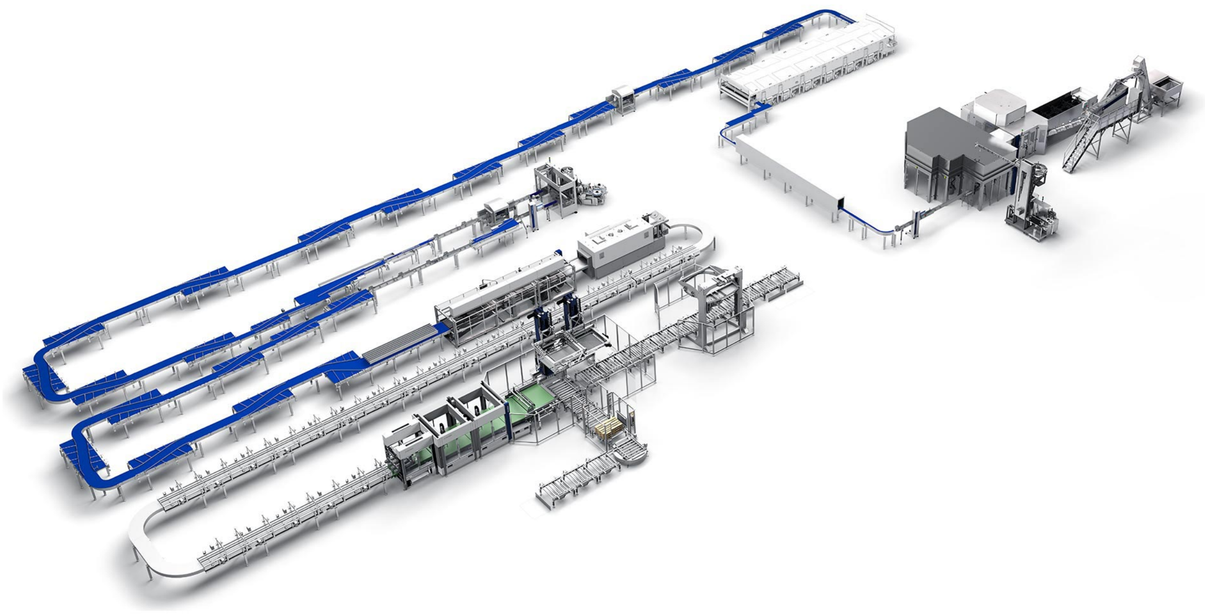


Figure 10: Filling and packaging lines [16]

Essential parts of the filling and packaging line

- Stretch blow moulding
- Filling and capping
- Inspection
- Labelling
- Packing
- Palletising

[17]

3.2 Label machines

Labelling is an essential step for the finishing of the whole liquid filling process. Labels are responsible for recognition of the product, the listing of ingredients and all important information due to the legislation for the current market.

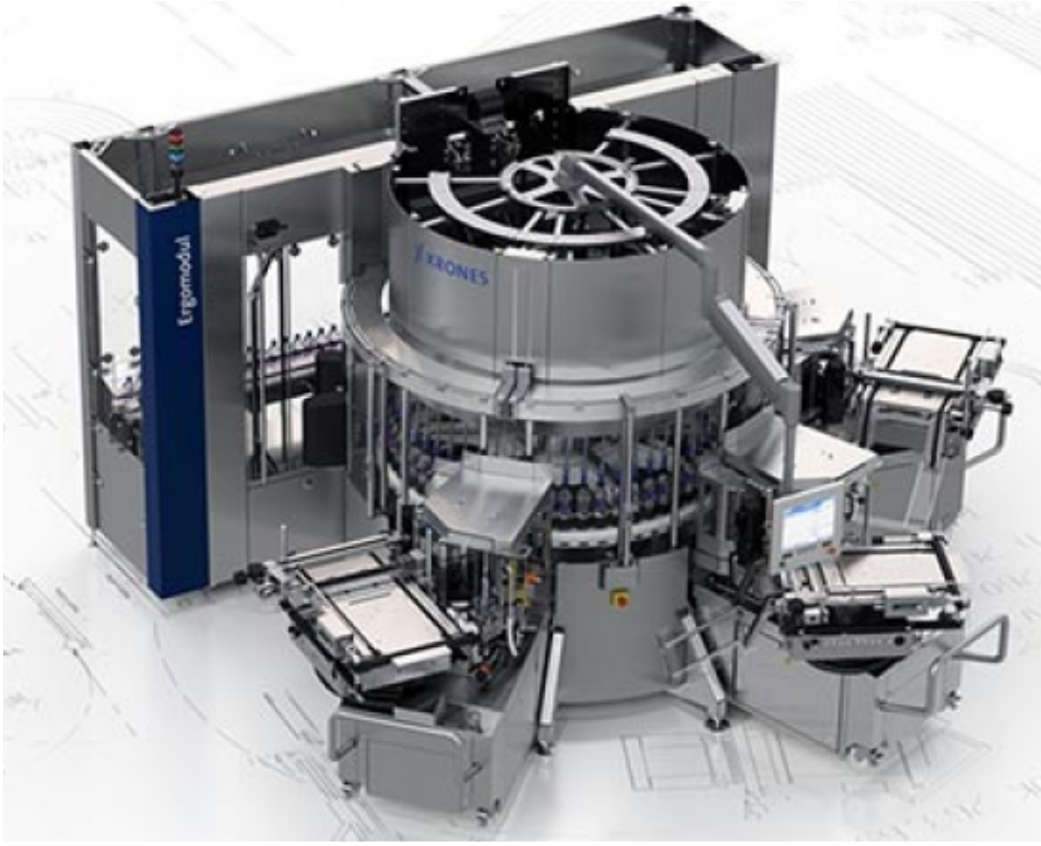


Figure 11: Fully equipped label machine

Krones AG can provide labelling technology for the needs of specific consumers. The labelling station consist just a few main parts, the labelling star and the conveyor transportation belt. The labelling star (covered by a cylindrical case in the centre) is surrounded by different machines. Some are responsible for correctly installing and gluing of the labels. The conveyor transportation belt is responsible for transportation of beverage through the station. All the parts are in several different variations and combinable.

Their bottle handling direction defines the most used label machines, and there are parallel, straight (a straight version is visualised in *picture 2* above) and frontal machines. In combination with the bottle guiding system (in German "*Behälterrustteil*"), it's possible to make numerous variations.

This company provides a great variety of label machines, and it depends on the different factors, like layout capabilities, beverage technology or just the specific needs of the customer. In general, are 50 % of all label machines represented in three basic label machine layouts (in German "*Einstelllehre*"). These Einstelllehre are in various sizes and modifications to satisfy customer. The main three Einstelllehre are:

- Frontal
- Straight (in German "*Gerade*")
- Parallel

This Einstelllehre builds from different parts (elements). Those elements are completely variable and are chosen for the specific need of the customer and are also combinable. The basic Einstelllehre elements are:

- Transportation ground element (or "*Transportbahn*")

Transportbahn is usually 110 mm in width and different length. The length depends on the machine layout, and most of the elements described below are installed on the first Transportbahn.

- Snail gear adjusting element (or "*Schneckenverstellung*")

This element is installed on the Transportbahn and is responsible for the snail gear adjusting. It provides variability for different bottle diameters. In *Figure 12* visualised in blue colour.

- Snail drive (or "*Schneckenantrieb*")

Snail drives are used for moving the bottles through the Transportbahn. This element is in sync with the main label machine for the flawless movement and must keep the programmed pace.

- Torque arm (or "*Drehmomentstütze*")

As the name says, this element prevents any torque in the snail gear and locks the gear in its predefined position. Torque arms are connected at two points, at the snail drive and the snail clamp.

- Snail clamps (or "*Schneckenklemmung*")

Snails clamps are mainly securing the second connect point of the torque arm and securing the snail gear itself.

- Bottle guider (or "*Flaschenführung*")

Bottle guider is directly connected to the snail drive and is in contact with the fluid container. This element leads the bottle further into to the system.

- Bottle barrier (or "*Flaschensperre*")

This element is on the opposite side of the snail gear and displays in *Figure 12* as yellow collared. Flaschensperre is integrated into the guiding system while a part of the base Einstelllehre.

- Clamping stars (or "*Sternklemmung*")

These stars are holding the entry stars (in German "*Einlaufstern*") and the exit star (in German "*Auslafstern*"). The entry and the exit stars are responsible for dividing the bottles and leading them further into the system.

- Star column (or "*Sternsäule*")

Star columns just provide support and stability for the clamping stars and everything above.

- Overshift (or "*Überschub*")

Überschub traces the tangent of the Sternklemmung and leads the bottle into the machine.

3.2.1 Frontal Einstelllehre

Since previously mentioned, are Frontal Einstelllehre one of the most used machine layouts that is produced. These Einstelllehre takes usually a large footprint, so they're not suitable for smaller factories. The most distinct parts of this Einstelllehre from the others are "transportation ground" (in German "*Transportbahn*") and the "overshifts" (in German "*Überschub*"). These elements are pictured in "*Figure12*" for Transportbahn – green and Überschub – light grey. This layout also consists of four clamping stars (in German "*Sternklemmung*") that are moving bottles further into the system.

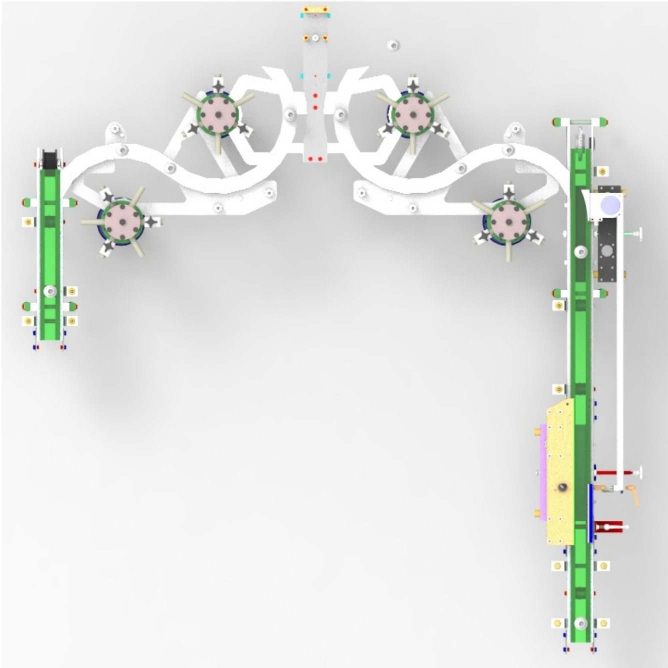


Figure 12: Frontal Einstelllehre

3.2.2 Straight Einstelllehre

This Einstelllehre takes a tremendously smaller footprint. The production pace is lower, but the versatility is higher by the given size. This version is the simplest to build, based on the consisting elements. The bottles are going through one Transportbahn and two Sternklemmung.

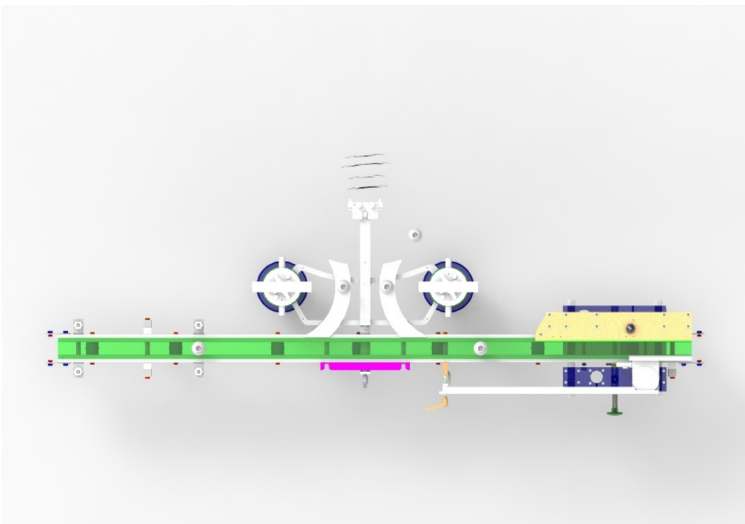


Figure 13: Straight Einstelllehre

3.2.3 Parallel Einstelllehre

The last Einstelllehre is unfolding into a parallel layout. This version is a combination of the Einstelllehre above and covers a middle ground. The Bottles are entering the system sideways and leaving in the same direction. The number of elements is slightly less than in a frontal version. Parallel Einstelllehre consists of two Transportbahn and three Sternklemmung.

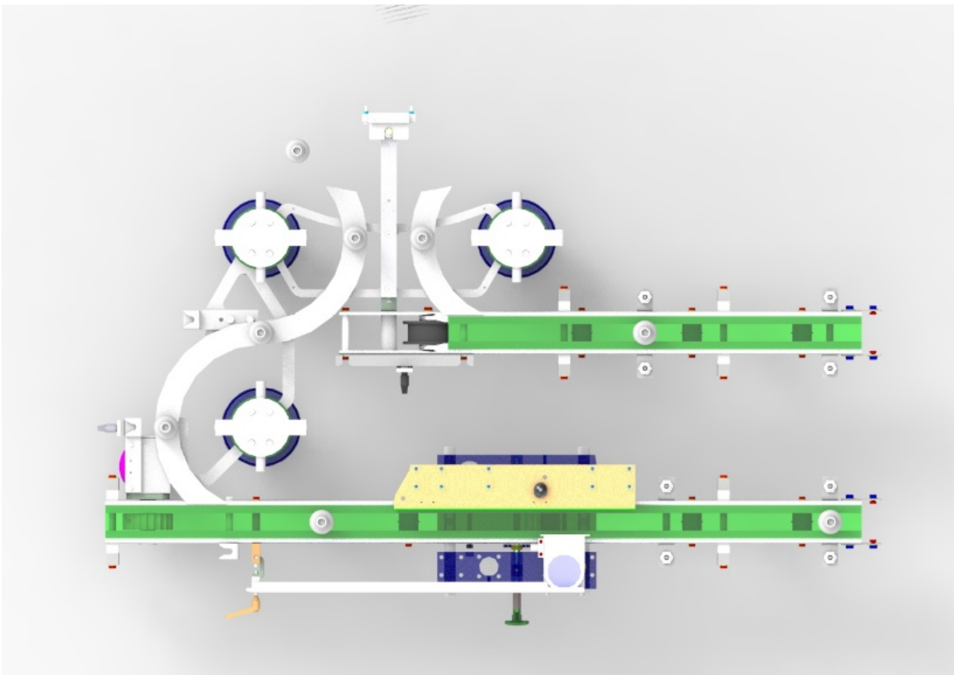


Figure 14: Parallel Einstelllehre

Those elements are creating the base of the machine and are preparing the ground for the guiding system. The baseline defines the type of "fluid container", and the guiding system is specifically configurated for the current bottle (or another fluid container). Important are specifics of the container as diameter, high, weight or just the shape of the bottle.

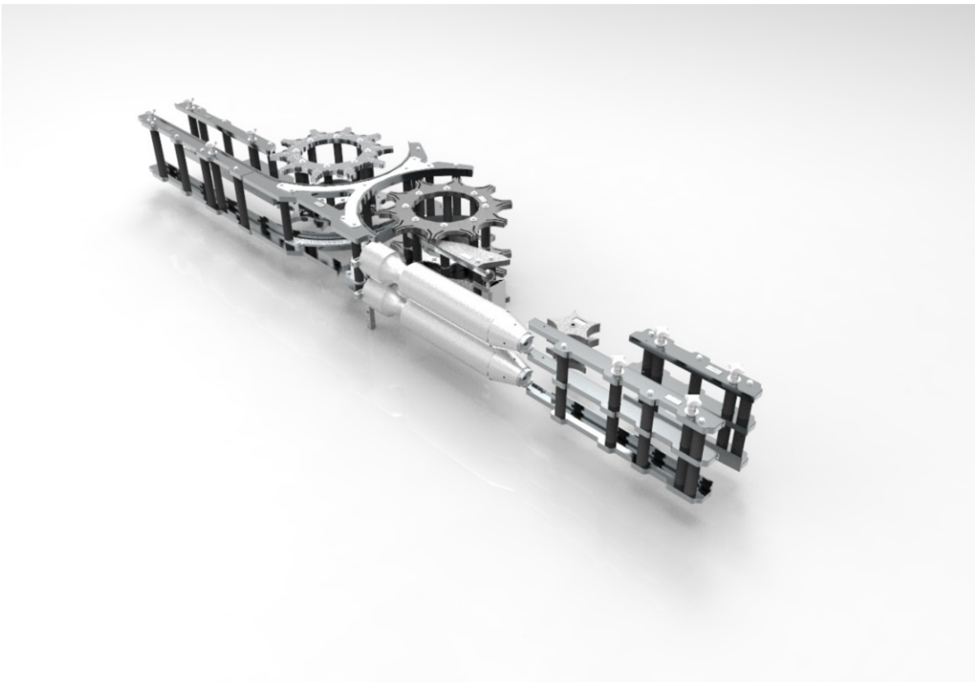


Figure 15: Bottle Guiding system

3.3 Guiding system

The bottle guiding system (in German “*Behälterrustteil*”) is responsible for guiding the bottle further into the system, for a flawless manipulation in the system. All the different parts are listed in ***Supplement1***. A complete guiding system visualised in *Figure15* is fully adjustable. All those parts vary with the specific needs of the customer.

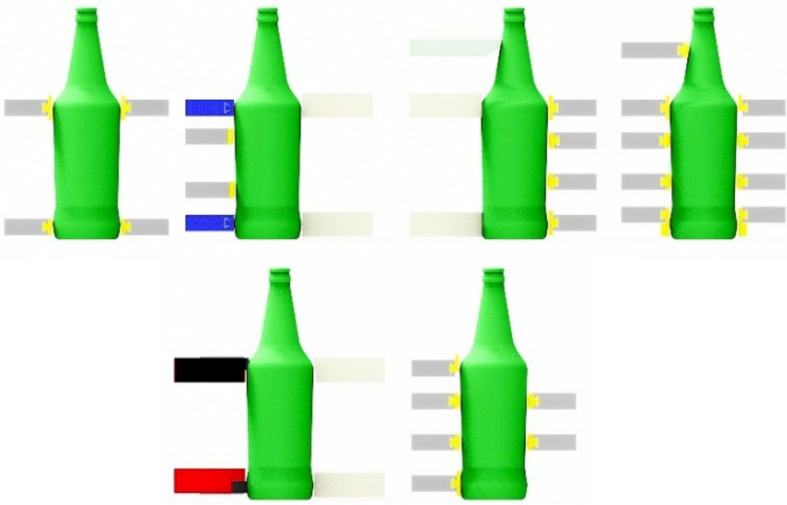


Figure 16: Cross-section view through the bottles

As mentioned previously is the guiding system fully customised for the one specific bottle (or another fluid container). Since pictured in a cross-section view through bottles in *Figure 16* are all the sections in the guiding system adjusted for the current bottle (in *Figure 16,* a 0.5 litters glass beer bottle). Like Einstelllehre base are also guiding systems divided into subsections. The position is based on the technical drawing and properties are based on the bottle. For example, is the label machine number *K810-D65 – 12.1* pictured in *Figure 17* composed from 11 sections.

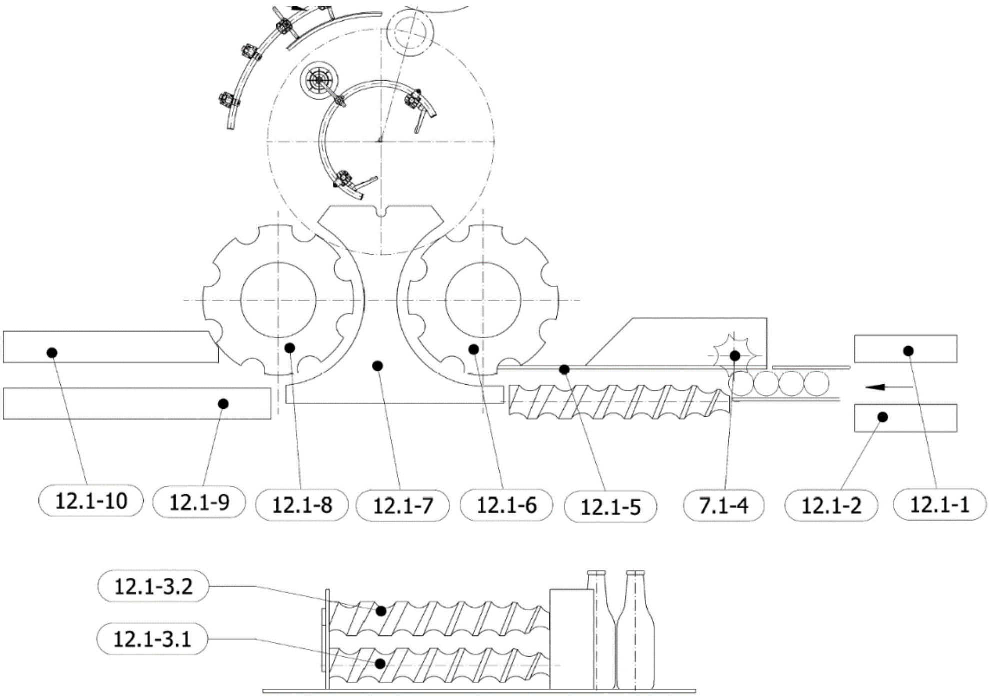
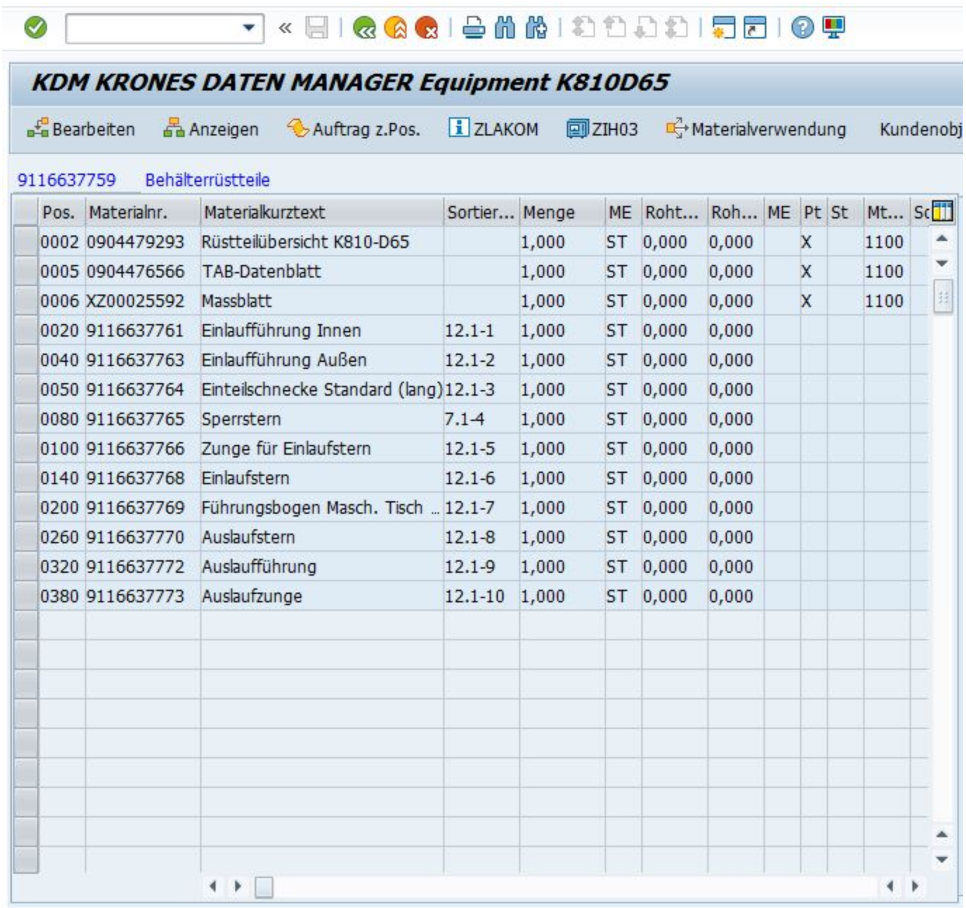


Figure 17: Technical drawing for the positioning of the guiding sections

These numbers correlate with the parts list (BOM) of the current project, in this case, the label machine number *K810-D65 – 12.1*. The parts list is available in the company intern database (SAP) and searchable under the commission (its ID a K-number). The specific part list is pictured in *Figure 18.* As displayed in the parts list are the most important elements in the guiding system:

- Internal entry guide (or "*Einlafführung Innen"* with the position number *12.1-1*)
- External entry guide (or "*Einlafführung Außen"* with the position number *12.1-2*)
- Snail gear (or "*Einteilschnecke Standard"* with the position number *12.1-3*)
- Locked star wheel (or "*Sperrstern*" with the position number *7.1-4*)
- Tongue to the Entry star (or "*Zunge fur Einlafstern*" with the position number *12.1-5*)
- Entry star wheel (or "*Einlafstern*" with the position number *12.1-6*)
- Guide arch (or "*Fuhrüngsbogen*" with the position number *12.1-7*)
- Exit star wheel (or "*Auslaufstern*" with the position number *12.1-8*)
- Exit guide (or "*Auslaufführung Innen"* with the position number *12.1-9*)
- Exit tongue (or "*Auslaufzunge"* with the position number *12.1-10*)



Pos.	Materialnr.	Materialkurztext	Sortier...	Menge	ME	Roht...	Roh...	ME	Pt	St	Mt...	Sc
0002	0904479293	Rüstteilübersicht K810-D65		1,000	ST	0,000	0,000		X		1100	
0005	0904476566	TAB-Datenblatt		1,000	ST	0,000	0,000		X		1100	
0006	XZ00025592	Massblatt		1,000	ST	0,000	0,000		X		1100	
0020	9116637761	Einlaufführung Innen	12.1-1	1,000	ST	0,000	0,000					
0040	9116637763	Einlaufführung Außen	12.1-2	1,000	ST	0,000	0,000					
0050	9116637764	Einteilschnecke Standard (lang)	12.1-3	1,000	ST	0,000	0,000					
0080	9116637765	Sperrstern	7.1-4	1,000	ST	0,000	0,000					
0100	9116637766	Zunge für Einlaufstern	12.1-5	1,000	ST	0,000	0,000					
0140	9116637768	Einlaufstern	12.1-6	1,000	ST	0,000	0,000					
0200	9116637769	Führungsbogen Masch. Tisch ...	12.1-7	1,000	ST	0,000	0,000					
0260	9116637770	Auslaufstern	12.1-8	1,000	ST	0,000	0,000					
0320	9116637772	Auslaufführung	12.1-9	1,000	ST	0,000	0,000					
0380	9116637773	Auslaufzunge	12.1-10	1,000	ST	0,000	0,000					

Figure 18: Parts list of the Guiding system

Note: these elements are pictured in ***Supplement 1***.

4 Analysis of the current state

This chapter gives an overview of the whole process of “label machine” project. The focus is on the three main departments (design, production and assembly). Important is to showcase the past, presence and the future of the workflow by each department. To show the increase of quality and transparency. The quality is crucial for the consumer experience and the image of this company. Transparency of the project is impactful in different ways. Internally is this factor integrated into standardisations, every task should be understandable across the departments. This helps for higher quality and fewer mistakes. Another factor is transparency across establishments of the Krones AG crosswise the globe, as this company is represented in the major regions in the world (for example in North America, Asia and Africa). Transparency helps the standardisations and international cooperation within the firm.

4.1 The design

The following text will provide an overview of the current and future state of the new “drawing design software” project for automatization of technical drawings. All data listed in this subsection are given by KRONES [18] and specific numbers (cost) could be modified, due to the classification of this matter.

Starting position

These bullet points represent the past/current state.

- The bottle guiding system (in German “*Behälterrustteile*”) are made in the CAD system Solid Edge in 2D through height plan drawings and further in SAP transactions documented
- Errors in the parts lists are found only by experienced designers or in the assembling department
- Already produced parts are difficult to repair with a high potential of errors. Older parts, the great variety of parts and incomplete part lists causes misinterpretations, several of F3 messages (these messages are reported by the assembly department) and reclamations from the consumers

Exit position

These bullet points represent the desired future, after the implementation of the new standardisation software (this new ME software will be described in the following text).

- Create the basis for a group-wide solution
- Quality improvements and assembly simplification (less F3 and reclamations)
- By deriving a clear assembly drawing, are errors in the assembly department avoidable (e. g. collisions)
- Functional tests already in the construction (interface problems are easily recognizable in 3D). A “100% functional test” in the assembly is no longer necessary
- No more problems with duty payment clearance and packaging (could be calculated automatically)
- Very important for internationalisation (all designers who are familiar with Solid Edge can quickly learn and use this working method (no unique knowledge is necessary)

Prognosis of the new ME software

Based on the data provided by the quality division, are reclamations divided into two sections. The first side are reclamations from the end consumer. These consumers are major companies in the food industry worldwide. Secondly are reclamations made internally through the sharing of information. If an error is found in the assembly or production, an F3 message appears. Yearly reports of reclamations and F3 massages are available. Based on the provided numbers, are reduction of reclamations and thus cost of these possible. As showed in *Table 4* bellow are reclamations by the customer reducible by 40% and F3 massages even by 90%. As a result, the return of the investment of this project is calculated for approx. 1,5 year.

Utilisation	Reclamations	F3 massages
Reduction through automatization	40%	90%

Table 4: Utilisation of the new design software [17]

One of the major problems in the past was an inconvenient technical drawing that caused the number of errors in the production and assembly department. A long time they have been using drawings named "*Medusazeichnungen*". These drawing didn't show crucial parameters, so the assembly department had to do some guesswork, or the factory would send incomplete machines to the end customer. One of these Medusazeichnung is pictured in *Figure 19*.

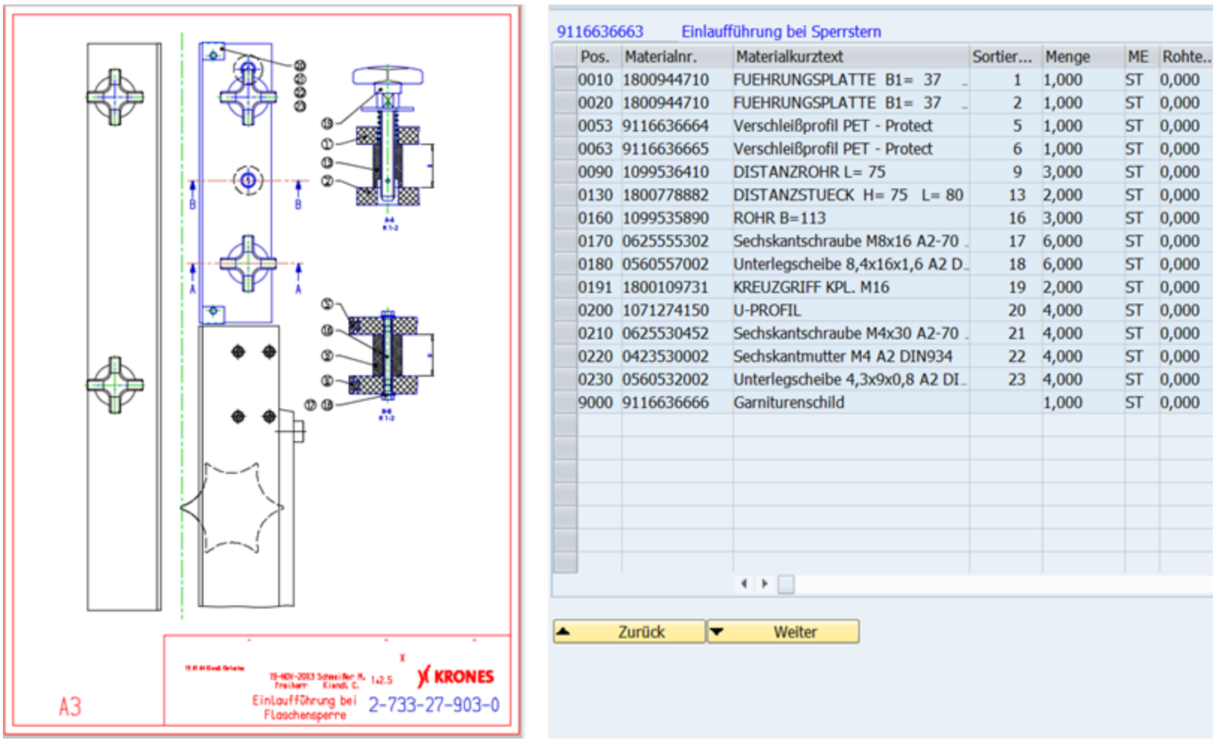
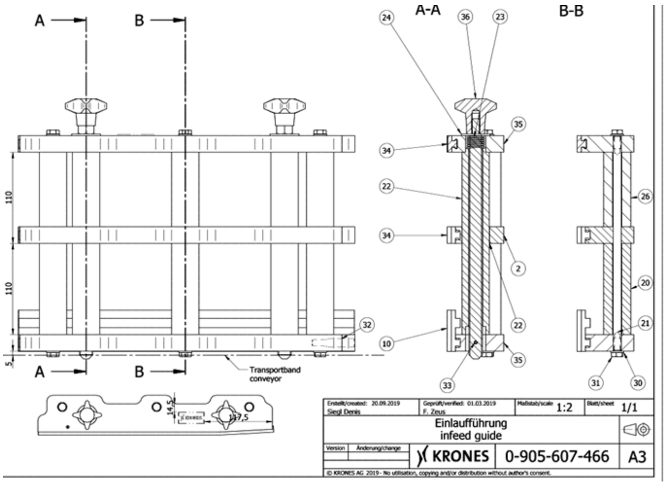
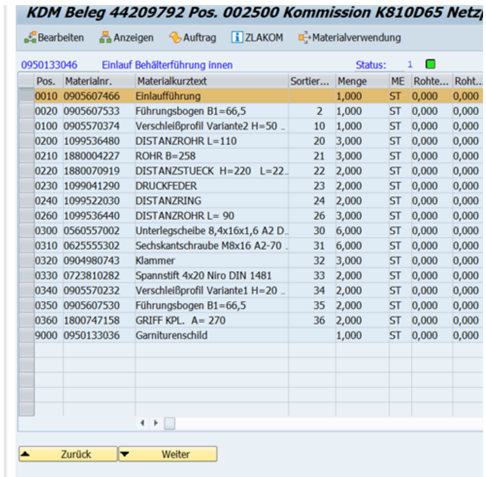


Figure 19: Medusazeichnung of an Einlaffführung (2003)

4.1.1 Design department – the past

Medusazeichnungen are noticeable because of the red frame and description. In the future should be all of these drawing replaced by a new drawing. One of these new drawings is pictured in *Figure 20*, those drawing are more detailed and hold more information. These two drawings are made by two different technologies, while Medusazeichnungen is made in 2D, the newer version is made in 3D, so the employees can double-check the information in the CAD system.





KDM Beleg 44209792 Pos. 002500 Kommission K810D65 Netz

Bearbeiten Anzeigen Auftrag ZLAKOM Materialverwendung

0950133046 Einlauf Behälterführung innen Status: 1

Pos.	Materialnr.	Materialkurztext	Sortier...	Menge	ME	Rohte...	Roht...
0010	0905607466	Einlaufführung		1,000	ST	0,000	0,000
0020	0905607533	Führungsbogen B1=66,5	2	1,000	ST	0,000	0,000
0100	0905570374	Verschleißprofil Variante2 H=50 ...	10	1,000	ST	0,000	0,000
0200	1099536480	DISTANZROHR L=110	20	3,000	ST	0,000	0,000
0210	1880004227	ROHR B=258	21	3,000	ST	0,000	0,000
0220	1880070919	DISTANZSTUECK H=220 L=22...	22	2,000	ST	0,000	0,000
0230	1099041290	DRUCKFEDER	23	2,000	ST	0,000	0,000
0240	1099522030	DISTANZRING	24	2,000	ST	0,000	0,000
0260	1099536440	DISTANZROHR L= 90	26	3,000	ST	0,000	0,000
0300	0560557002	Unterlegscheibe 8,4x16x1,6 A2 D...	30	6,000	ST	0,000	0,000
0310	0625555302	Sechskantschraube M8x16 A2-70 ...	31	6,000	ST	0,000	0,000
0320	0904980743	Klammer	32	3,000	ST	0,000	0,000
0330	0723810282	Spannstift 4x20 Niro DIN 1481	33	2,000	ST	0,000	0,000
0340	0905570232	Verschleißprofil Variante1 H=20 ...	34	2,000	ST	0,000	0,000
0350	0905607530	Führungsbogen B1=66,5	35	2,000	ST	0,000	0,000
0360	1800747158	GRIFF KPL. A= 270	36	2,000	ST	0,000	0,000
9000	0950133036	Garniturenschild		1,000	ST	0,000	0,000

Zurück Weiter

Figure 20: New version of the drawing

4.1.2 Design department – current and future

This is the current state. While the number of errors decreases, new problems appear. All the data and drawings are made by the designer. After accepting the assignment, the designer has to customise the parameters for the guiding system. The design process is not completely flawless due to the possibility of human errors. Every project is divided into two parts; the first part is the designing part, and the second part is data management. For inexperienced designers, that aren't that long on this project, are errors possible due to the amount of data. All the data has to be inserted by the designer and consulted by more experienced designers, so the schooling time in this project is very time-consuming.

The schooling time for the employees on this project is usually one to two years. Any errors in the design department cause errors in the assembly department. In the future will be the data management automated, to prevent any human errors. It will be possible to generate all the guiding parts through a computer program and all the data will be added into SAP automatically. The time consumption of the schooling time will be shortened dramatically, the transparency will be levelled, and the standardisation will be also improved.

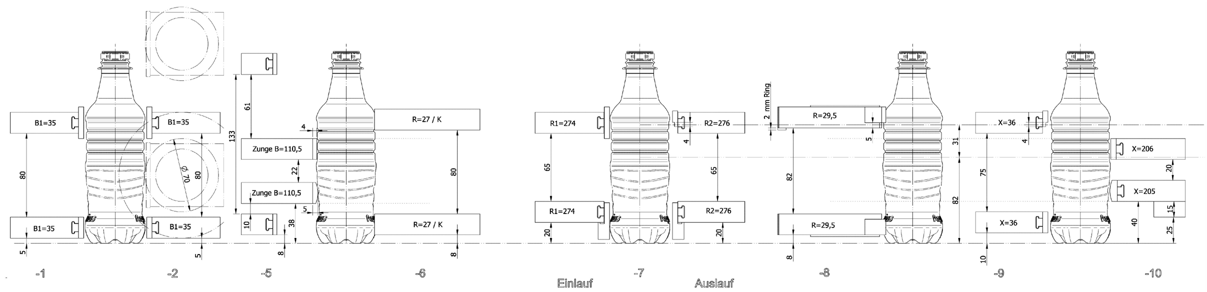


Figure 21: Technical drawing of a cross-section view through the bottles

All these improvements could have a great impact on the reclamation and F3 messages numbers. Here are some numbers for reclamations and F3 messages for the first semester of 2017, to evaluate the profitability of the project (the new ME software). The number of reclamations could be reduced by 40% (50 reclamations overall) as pictured in *Figure22*.

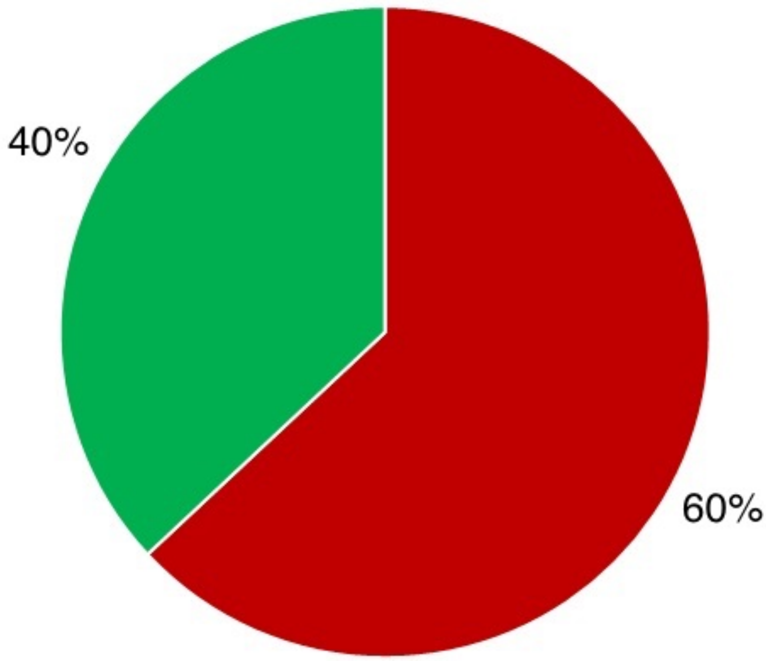


Figure 22: Number of Reclamations in the first semester of 2017 [17]

Further, is the F3 message number more impactfully decreased. As the data pictured in *Figure23*, 90% (120 F3 messages overall) of the messages could be potentially prevented. Here could be the new software even more significant.

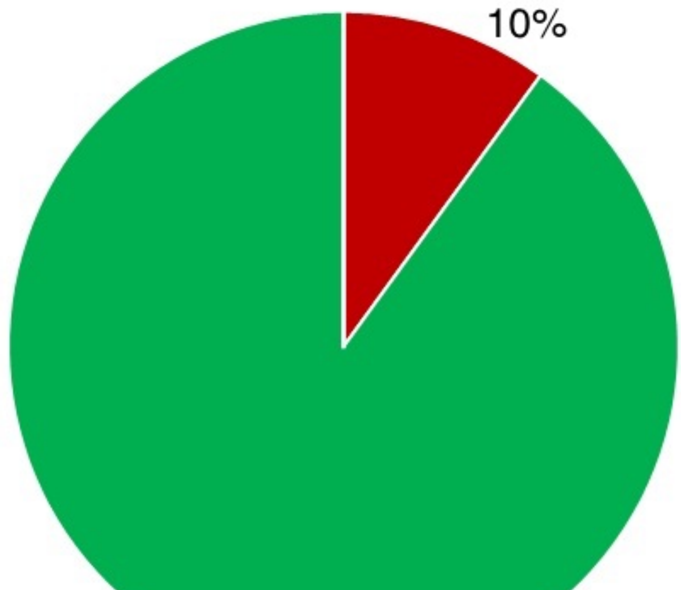


Figure 23: Number of F3 messages in the first semester of 2017 [17]

4.2 The production

Since mentioned in the previous chapter, is the production department next in line, behind the design department. This chapter will introduce all the major production stations for the container guiding system. Overall are all the pieces produced in four separate stations, according to the specific shape and size of the parts:

- Flat-shaped pieces
- Snail gears
- Oversized pieces
- Smaller and more detailed pieces

4.2.1 Flat-shaped pieces

Most parts of the container guiding system are flat and made on this working station. The whole process isn't fully atomised, due to the human-influenced for the finishing part of the work process. Like every production process, also this operation starts with the stock as pictured in *Figure 24*. Because of the specific requirements of the materials, is the room temperature regulated to 20 to 21 degrees Celsius. This plastic material has the best performance at 20 degrees Celsius, so it has to be stocked at least for 2 days in the warehouse. Further is the whole system manageable by one person, due to the high automatization and standardisation. The material dispending is atomised with a vertical carousel. Newly arrived material is stocked outside and added if needed into the vertical carousel stock system. Errors in this section are fairly rare. Fail reports could appear if the operator makes intentional or unintentional mistakes in the takeover of the material and damage the workpiece.

Figure 24: Stock for the flat-shaped material

After the takeover, is the current needed material placed on a specific table. The workpiece has to be accessible by both milling machine operators on two opposite sites. Because of the weight of the material, is the workpiece moved by a rail crane into the CNC milling system. After the automated milling process, is the workpiece not finished yet. The whole piece is not fully cut out, there are 0.5 mm of material left for a fine finish. It has to be finished by other workers on a table band saw and after that, cleaned by hand.

Figure 25: Production station for flat pieces

Problems could appear due to the higher influenced of human resources. There are a lot of steps, that could result in errors. The milling machine operator could enter the incorrect program of the CNC milling machines, due overlooking value changes of the technical drawing. It could result in a reclamation by the quality department.

With a higher error potential is the next step for the manual cleaning of those flat shape pieces as pictured in *Figure 26*. The workers have to cut the desired piece out and clean the edges. Thus, is the possibility of damaging the final product higher than the fully automatized process before. Another factor is the ergonomics of the manual process. Due to the shape and size of the workpiece, the workers have to do their work mostly in a standing position. If they got a fairly larger piece, they have to frequently bend over the table and potentially damage their lower back. Besides the health risk, they could incorrectly clean the edges due to the inconvenient reach all the edges (problematic for shorter workers in height).

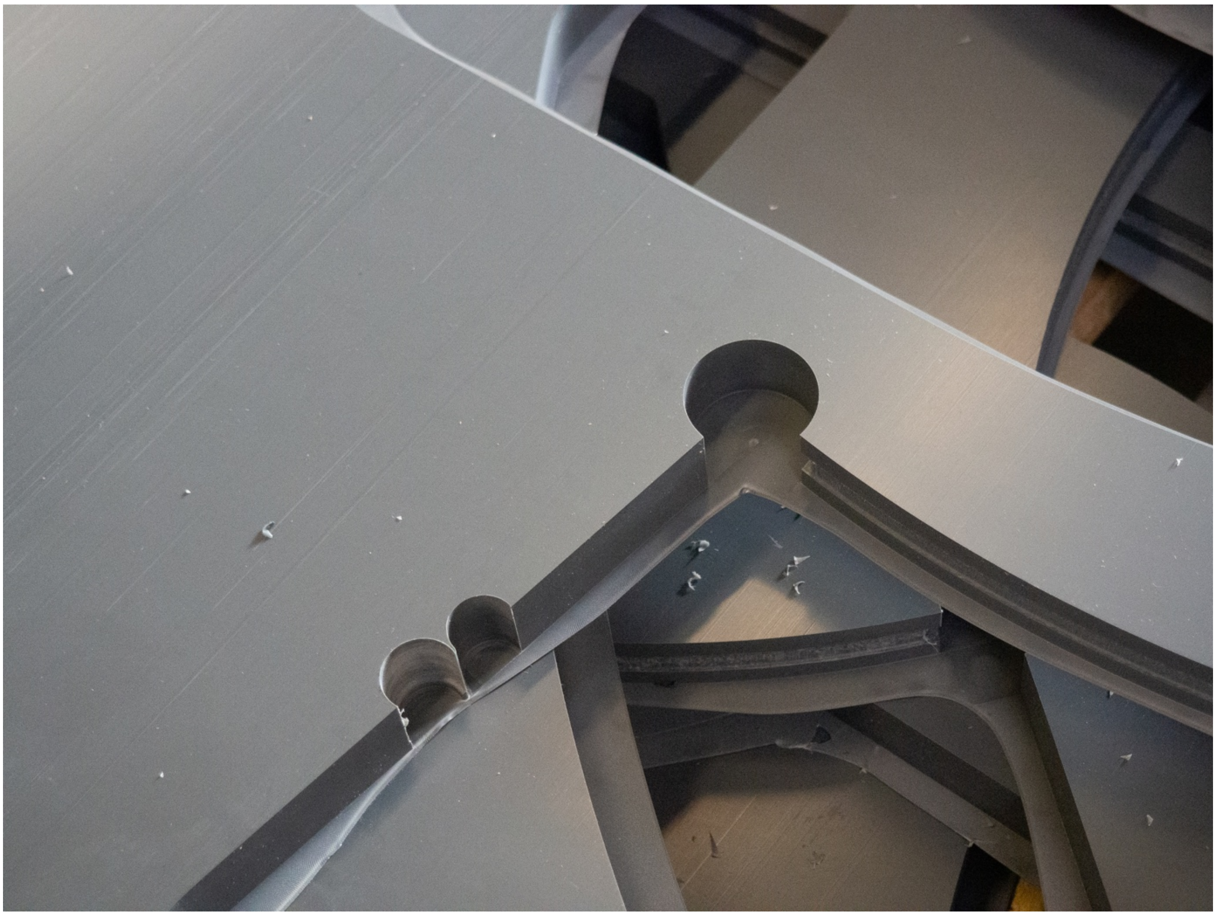


Figure 26: Manual cut out of the flat-shaped pieces

4.2.2 Oversize pieces

This working station is special because of the utilising of special machinery. The majority of the machines are based in the timber industry and specially adjusted for the harder plastic material. In this working place are mainly manual operating machines, like table milling and band saw machines. All the operations are provided by one to two operators per shift. Like in the previous chapter, are human errors existent here as well. But more limited, due simplicity of work and little variety of the workflow.

4.2.3 Smaller and more complex pieces

Automatization and standardisation in this workstation are even more advanced than in the previous operation stations, due to the smaller form factor and complexity of the workpieces. The technological process is mainly about the two 5 axel CNC milling machines by DMU (DMU 105 Monoblock and DMU 60 eVo). Besides of these CNC machines, are the operators provided with a vertical table drill and a machine for tool maintenance.

Figure 27: Smaller and more complexed workpiece

Every single workpiece (like one in *Figure 27*), stands for a single commission. Due to the complexity and size are these CNC machines operated by experienced workers.

The problems or errors are similar as in the working station for the flat-shaped parts. Some values on the technical drawing could be potentially overseen and the working piece could have some errors. One example is pictured in *Figure 28*. In this particular case, did the operator overlooked the one value change highlighted in the technical drawing above. They used an older CNC program and after the F3 message, they had to do the whole commission one more time with the right values. This problem could be prevented by better preparation or even special message of any changes in the drawing, for the optimal transparency between the divisions.

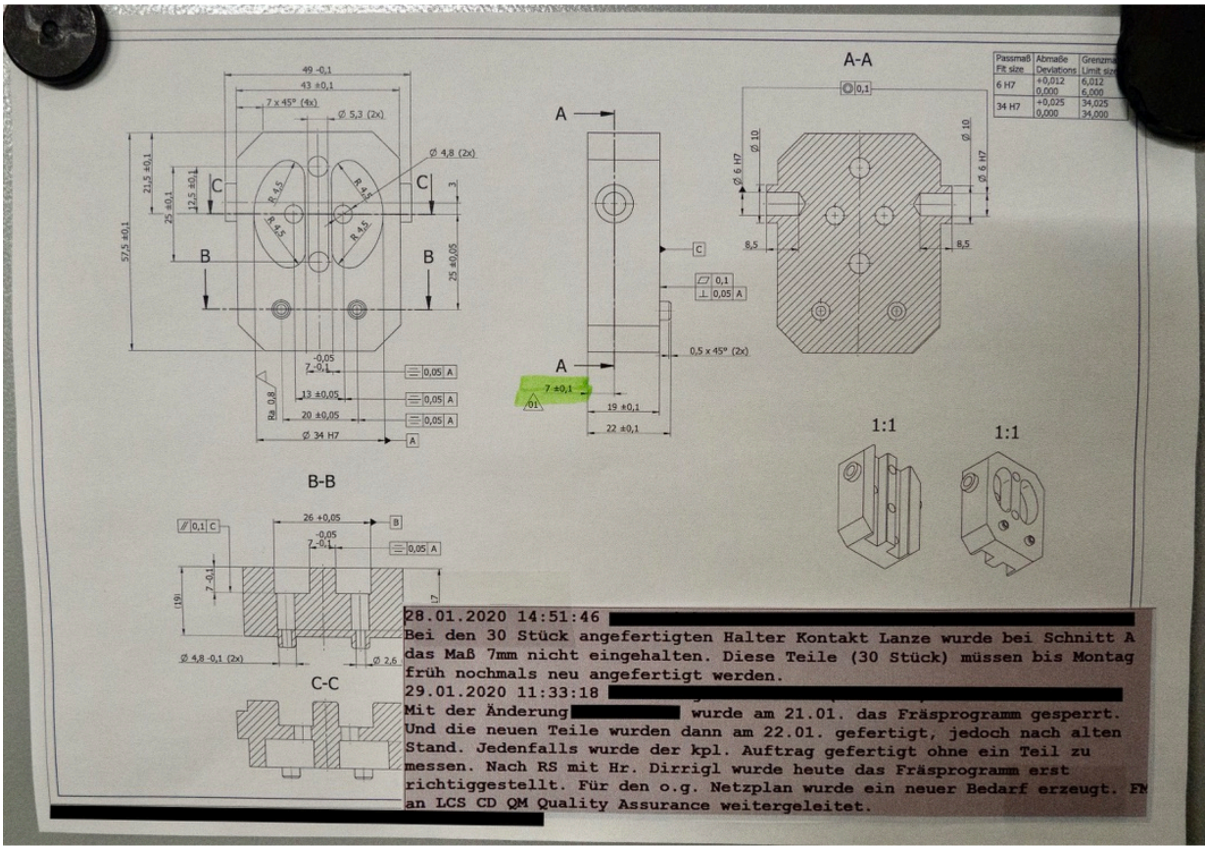


Figure 28: F3 message report by the quality department

4.2.4 Snail gear

Snail gear of different diameter and length are produced on the last working station of this production subchapter. The automatization and standardisation is high as well, due to the usage of a CNC lathe. At this station are usually two workers, one CNC operator and one worker for the finishing process. This process contains drilling holes into the end of the snail gear and installing holders. These holders are important for the final installation of the snail gear into the final label machine system. Problems in the automatized are the same as in the previous stations.

4.3 The assembly

As discussed in the previous chapter, is the assembly division next in line with the technological process of the container guiding system. This division is divided into separate one-man working stations. One worker is responsible for all the guiding parts within the commission. Since mentioned in the theory chapter, is this the assembly ordered into a unit production. The variety of label machines are fairly large, but they differ only in details. All the necessary partial parts are delivered in trolleys as pictured in *Figure 29*. These trolleys could consist of wrong or fewer parts than needed. This results in frequent visit in the warehouse (Kanban boxes).

Figure 29: Trolleys for the assembly

These trolleys are assembled by the warehouse through a Kanban system. Due to the sheer amount of partial parts, are missing parts possible. These missing parts are mostly noticeable during the assembly, and the worker has to go for the missing part up to 2 times in an hour. Incomplete trolleys are more often assembled by inexperienced warehouse workers.

4.3.1 Assembly of one commission

All assembly workers are provided by three major data sources, which are contributed by the mechanical engendering designers.

1) Handling parts overview drawing (rustteilwechselblatt)

This specific drawing gives important information as the positioning of the behelterrusteile and crucial data of the current commission.

2) TAB datasheet (TAB datenblatt) - a drawing for high measurement

Older TAB data sheets could consist of errors due to the sheer amount of data, that has to be added by the designer (as mentioned in the previous chapter). The data on this document is especially important for the correct assembly or even the correct partial part modification. Some partial parts are modified by the current worker according to the actual measures on the datasheet. A specific measure is a container reaching high, as the worker has to drill into an adjusting screw at a specific position.

3) PC to review data, mainly part lists and relevant drawings

Newer commissions have lower flawlessness. Part lists in these commissions are complete and are filled with the proper parts. The Einstelllehre of these commissions are tested by pre-building of the current commission on the testing table (Prüfftisch) pictured in *Figure 30* below. Older commissions with the older part list are more affected by misleading or errors and resulting in an F3 message. Those problems are made in the design department due to the old method of the drawing process. All the data used to be added by the designer (as mentioned in the previous chapter). Wrong parts with a slight difference are hardly noticeable for novice workers and more noticeable for more experienced workers. Therefore, are incorrect parts often assembled and sent to the customers, resulting in a reclamation.

Figure 30: Pre-build container guiding system on the test table

4.3.2 Standardisation

The standardisation is exceptionally high at the assembly work stations, especially the implementation of 5S and ergonomics at the individual working tables pictured in *Figure 31*. Consequently, the most important thing in the assembly are tools given for the workers. A showcase is the organisation and standardisation of necessary tools, following the 5S method. Every tool got its place and should be stored at its position. All the workers are well trained to follow and kept all these rules to optimise their efficiency.

On the other hand, is the standardisation through technology impactful as well. As mentioned at the beginning of this subsection, is every single worker provided with a computer for searching and visualising the part list and 3D renderings if needed. This standardisation minimises the number of errors and accelerates the whole assembly process. The older part list could potentially still keep some flaws and are mostly uncovered by experienced assembly workers and resulting in an F3 message. If not uncovered, it could result in a wrongly assembled part and therefore resulting in a reclamation by the consumer.

Figure 31: Assemble working station

On the contrary, is the ergonomics important as well. As time progresses, companies are more anthropocentrically oriented than mechanistically oriented. That means an all-round adjustable working place for the operating assembly worker. Consequently, to photograph *Figure 32*, are workers provided with a height-adjustable table. It opens the option for working in a standing position or sitting position. Further, it helps to keep the optimal ergonomic posture for a great variety of workers. Besides, are on the tables all tools and additional components in an optimal reaching position. For instance, are KLTs (euro container) mounted on adjusting arms to achieve an ergonomically reaching distant for the workers' unique postures.

These ergonomic standardisations significantly minimise the potential of health issues caused by accumulated strain on a human physique. On the other hand, is the assembly process improved as well.

Figure 32: Ergonomics in the assembly department

4.4 Analysis of the working area in the assembly

As mentioned in the previous chapter, is the assembly the last step for finalising of the container guiding system. This last subchapter of the analysis should provide deeper knowledge into the ergonomic side of the assembly division. In practically a working station, where are all the necessary parts made. This working station consists of a table to assembly on and trolley for the entry material. As mentioned in the previous subchapter, are the provided standardisations on a high level, but some improvement of the ergonomics and working process could be made and should improve the overall ergonomics.

The working station consists of a height-adjustable table with a rigged system. This rigged system is connected with a complex internal system to provide IT connectivity and electricity. As pictured in *Figure 33* does the typical station consist of a variety of accessories that are necessary for the working process. These accessories are differentiated with a blue colour scheme.

1) Drawer – located under the table and contains tools needed in the working process
2) Rubbish bin – is also located under the table
3) Arm rig with KLT containers – is completely adjustable
4) All in one computer desktop – for the revision of important data as the part list or technical drawings
5) The main tool case – it contains the main tolls needed (organised with the 5S system)

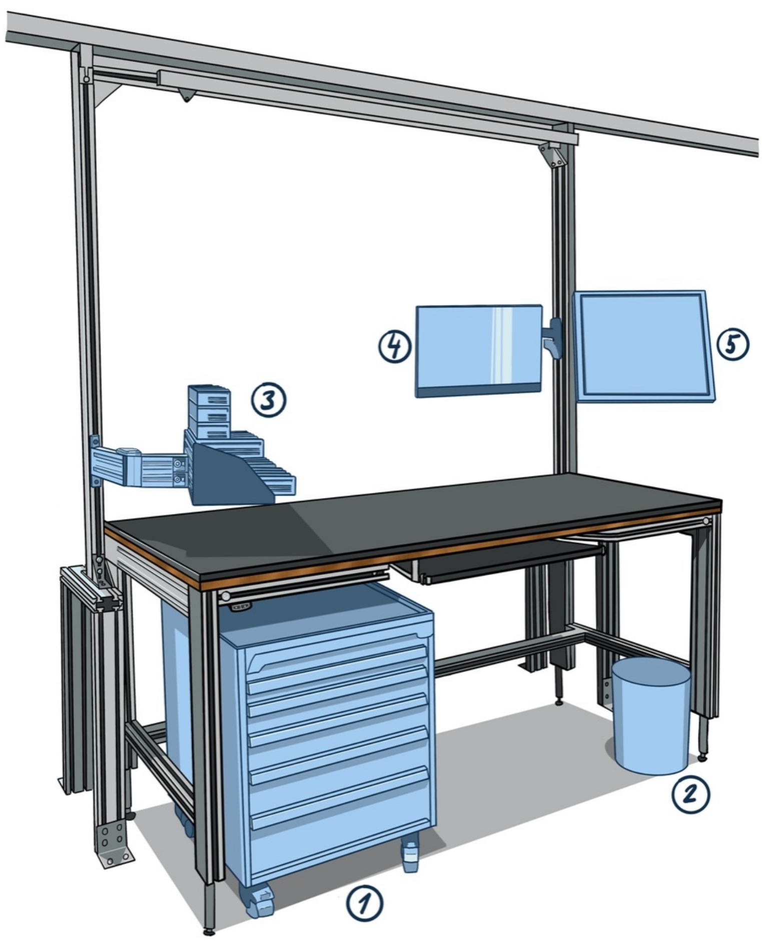


Figure 33: Assembly working station - Illustration

4.4.1 Improvement of the drawer system

The main focus point considering the ergonomics side, are the none adjustable accessories under the table. As for the drawer, are the higher drawers mostly reachable. But lower drawers are more difficult to reach. This considers if the worker is in a sitting position. Due to the matter of the working process, are the workers mostly standing, to have a better grip on the working pieces. Therefore, are the drawers even more difficult to reach. A solution could be a drawer system, that is directly connected under the table. Thus, the drawer would take over the height-adjustable behaviour of the table and would be adjustable as well. The ergonomics results should be visible with the assistant of RULA.

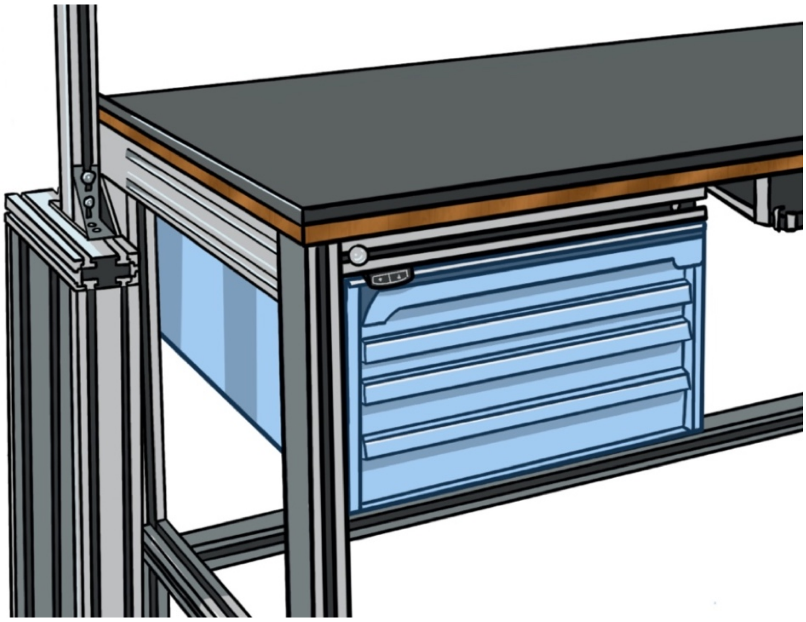


Figure 34: Connected drawer under the table - Illustration

As shown in *Figure 34* is the drawer installed directly under the table. The rigging system of this table should provide the technology for this possibility. Therefore, should the new improved drawer contain rig compatibility. A suggestion of this particular look is pictured in *Figure 35*. Grooves on the sides should help the installing process from the inner side. This drawer system should be practicable also on the opposite side of the table.

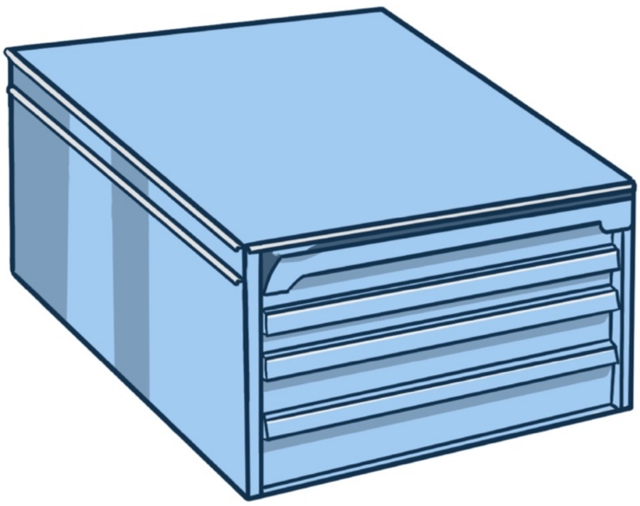


Figure 35: The drawer system - Illustration

Given the above, should be the contents of the drawer categorised. This categorisation system should differentiate all the things needed on the working process and personal level.

1) First category – Most used tools – these tools should be installed into the tool case above the table
2) Second category – Occasionally used tools – these tools should be in the upper drawers
3) Third category –Storage space for heavier tools – these tools consist of drills and its accessories, and it should be located at midrange
4) Forth category – Storage space for personal thigs – the second storage space should be for the personal things of the worker, and it could be lockable. This drawer is on the bottom part of the new drawing system

4.4.2 Improvement of the rubbish bin system

Besides of the drawer, is the location of the rubbish bin not ideal as well. Due its size and position is rubbish clearing more difficult in a standing position. The worker has to bend over for throwing rubbish into the rubbish bin, or even less accurately throwing it at a higher height. The solution could be a simple rubbish bin system, consisting of a pipe as pictured in *Figure 36*. This whole concept is variable. The container is not specified and could be in any size and shape. As pictured below are two different variants of pipes, the first is a corrugated pipe. This type of pipe provides more adjustability due to the material the second pipe is made from a smoother material. This type should decrease the jamming of rubbish in the pipe. The diameters of these pipes should be designed for the matter of the rubbish. The profile could also be squared to maximises the rubbish cleaning efficiency.

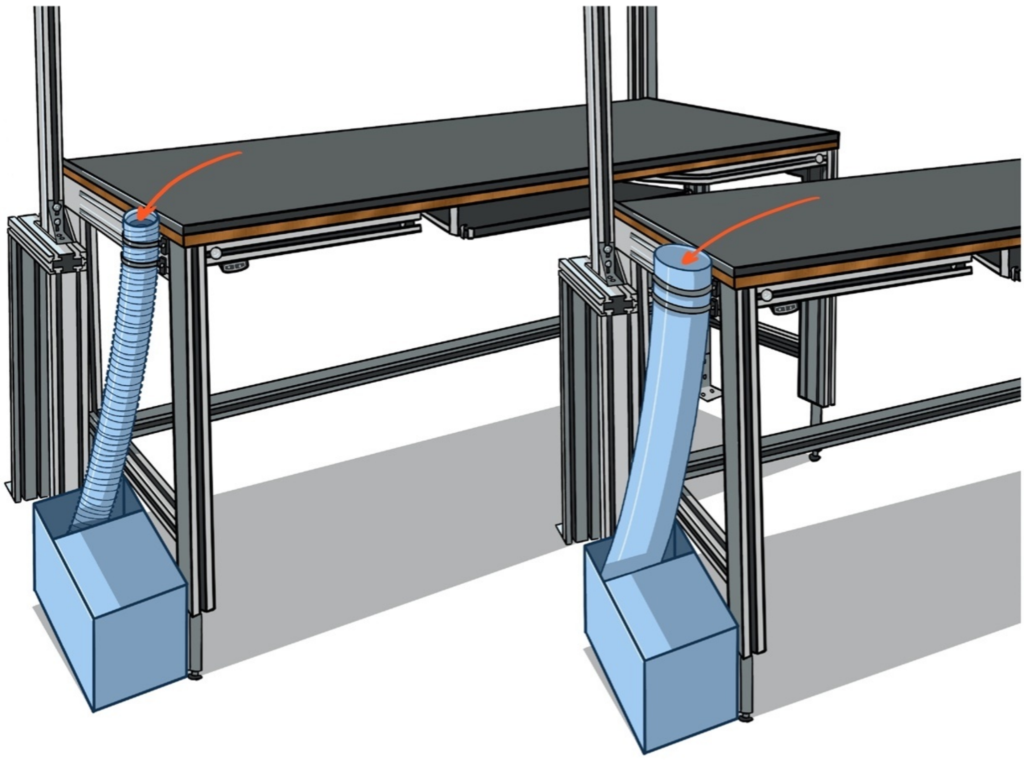


Figure 36: Improved rubbish bin - Illustration

The outlet of the pipes should be installed on the side of the table, for the most optimal reach. Therefore, the worker can throw all the rubbish with a more ergonomic posture. Due to the versatility of the working table, is the outlet installable on all four sides of the table and should suit every worker personal preference. The ergonomics results should be visible also with the assistant of RULA.

4.4.3 Load limits for the trolley

Besides the main working station is a metal trolley for the entry components. The worker has to assemble all the pieces of the container guiding system from these components and put the finished product back into the trolley. Problems could appear due to the weight of the finished parts (all the parts are illustrated in ***Supplement 1***). The ergonomics guidelines for load manipulations are reviewed in the previous chapter. As shown in the illustration below, does the load manipulation limits vary with the height and gender of the particular worker.

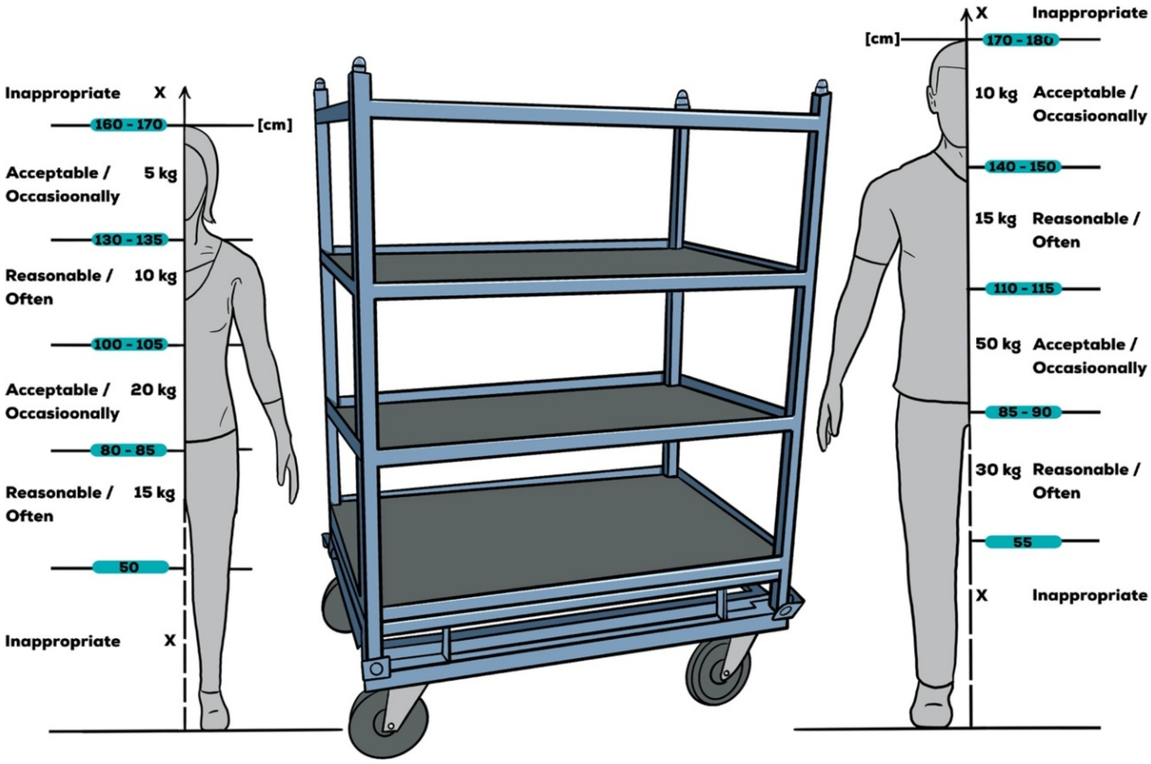


Figure 37: Load limits for the trolley - Illustration

In the following chapter will be this guideline, designed for the parts of the container guiding system. The result will be a recommendation of the most optimal ergonomic position of the assembled parts. As pictured in *Figure 37* should be the heaviest parts in the centre level, less heavy parts in the bottom level and the lighter parts on the top level. The limits above are for an average percentile of the population. For women 160 to 170 centimetres of height and man 170 to 180 centimetres of height.

The improved guideline will be created by data provided with different experiments in an ergonomics analysis software and will be followed by the NIOSH method. One of the most important aspects is the specific weight of the assembled parts of the container guiding system. The exact weights are not listed and categorised, so it had to be calculated with the already provided data, as dimension and type of material. These assembled parts are illustrated in ***Supplement 1*** and all the data and illustrations have been specified within one commission (number *K810-D65 – 12.1.*).

5 Analysis of the current process

As described in the chapter above, the main focus point is a working station in the assembly division. For the conclusion of an ergonomics analysis, are some specific components needed. These components are decisive for the correctness and value of the results.

Working process

The main task is the assembly of all the parts needed for the container guiding system. These parts are listed in ***Supplement 1***. As for the specific assembly process, the worker is obligated to follow the instructions. All the partial parts are stored on a provided trolley and have to be assembled followed by the technical documentation (as part lists and technical drawings). The assembled parts are restored on the trolley.

3D CAD models

These CAD models are needed, as entry data for the ergonomics software (Tecnomatix JACK). A rendering of the workstation is pictured below. The specific measurements are visible in the attached technical drawing (***Supplement 2***).

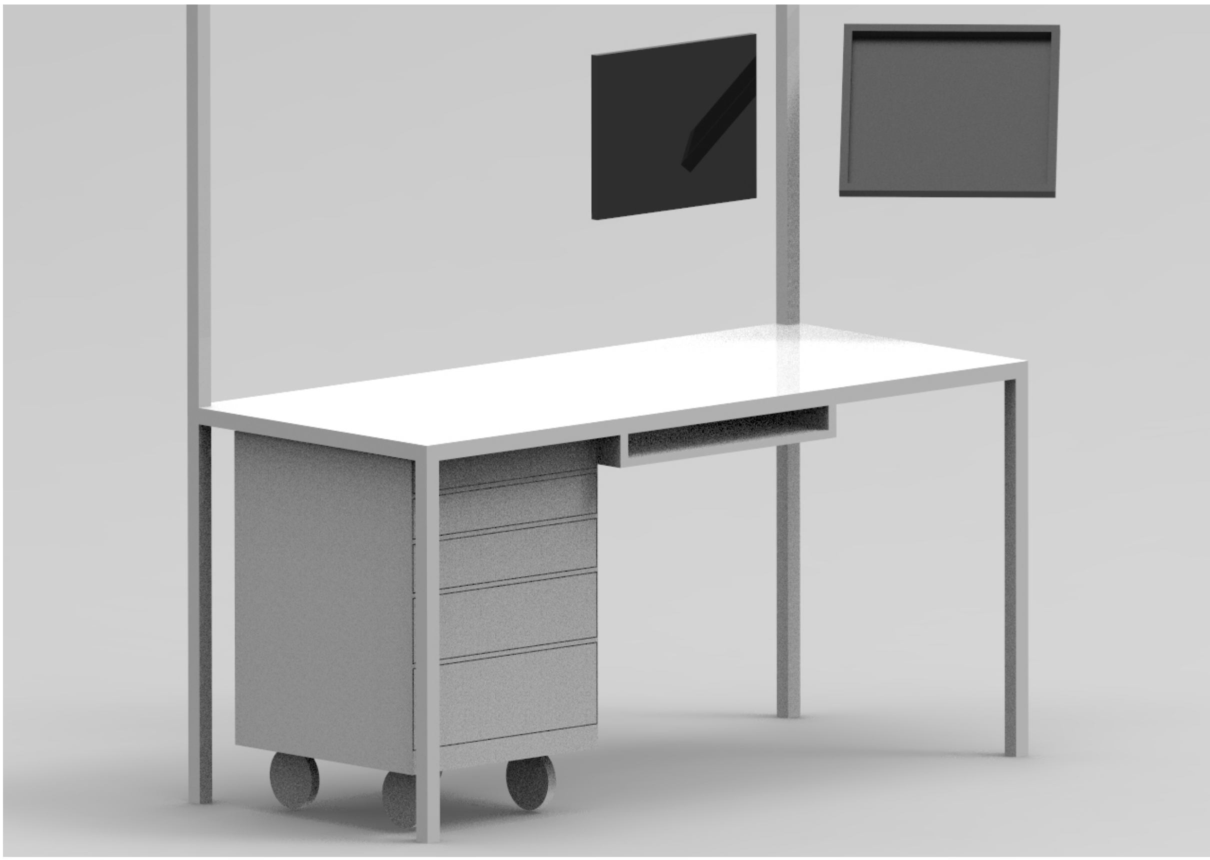


Figure 38: Current working station of the assembly - Rendering

The ergonomics pressure points, and possible improvements are described in the chapter above. The following experiments will decide if these improvements are determinative on the ergonomics side. Therefore, the output will be a modified working station and a specified guideline for the load manipulation of the assembled parts. These experiments will take the lower 5 and higher 95 percentile of body types in the human population.

5.1 Digital model of the working area

These digital models are visualised as screenshots from the ergonomics software Tecnomatix JACK. Following the text above, are theses digital models a result of the previous work. They have been imported from CAD software into this ergonomic software with the help of Mr Bureš. And as mentioned previously are these experiments designed for the lower and higher percentile of the population. The height versatility of the working table unlocks the possibility of optimising the height for the current worker.

Percentile	Table height	Body height	Weight	Gender	Anthropology
5%	96 cm	153,5 cm	52 kg	Woman	German
95%	115 cm	185,5 cm	100 kg	Man	German

Table 5: Entry data for the ergonomics experiments

This current workstation for both percentiles will provide the base ground for the experiments. These experiments will look into three different positions at the assembly table. Two of them are for the drawer and the third position for the rubbish bin (purple). All three positions are valued with the RULA method. For the trolley on the opposite side are three other experiments needed, for the three height levels of the trolley. The experiments at that carriage are valued with the NIOSH method. The results of these experiments will provide enough data for later work.

The current table-level is distinguished with a different colour (brown), due the different body heights is the table level in different positions as well. The first workstation visualisation is pictured in *Figure 39*. The table-level is on the lowest setting at 96 cm parallelly with the ground (left). For the higher 95 percentile of the population, has the table to be adjusted (right). The table-level had to be lifted to 115 cm from the ground, to achieve the most ergonomics height for the 185,5 cm tall subject (pictured below).

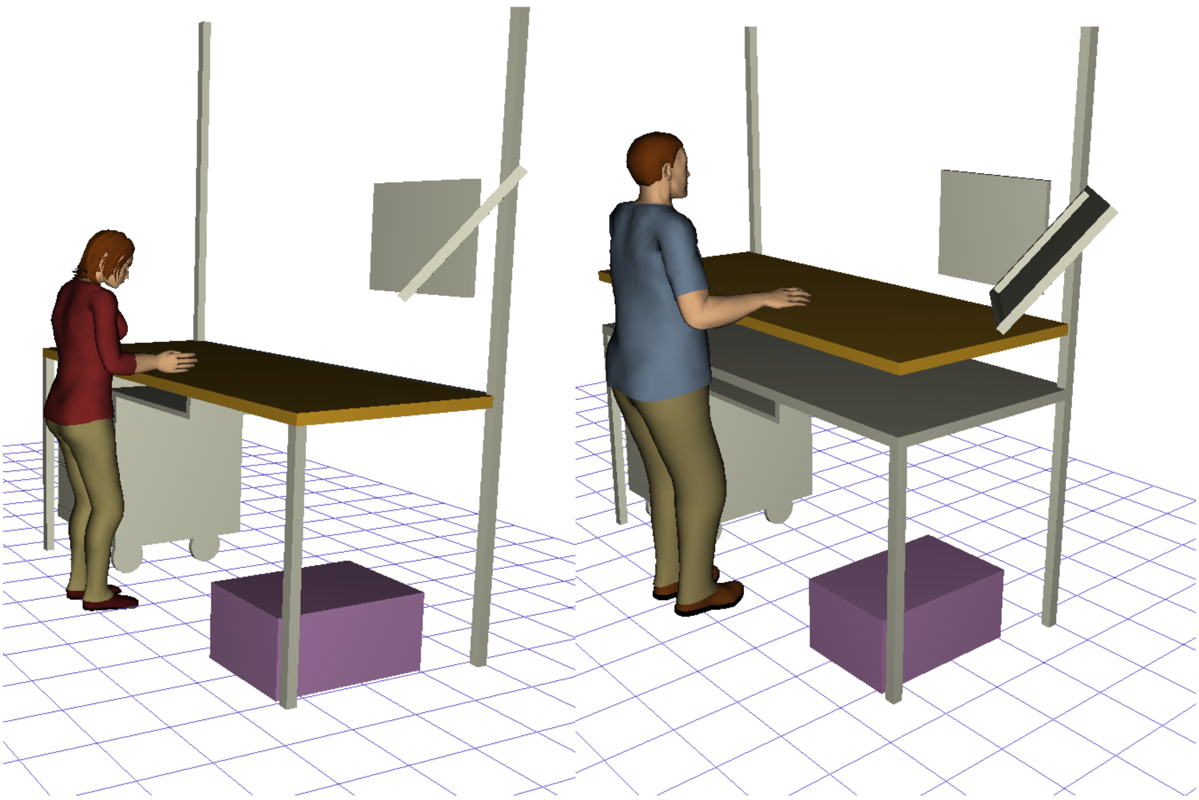


Figure 39: Current workstation for the 5% (left) and the 95% (right) - Screenshot

5.2 RULA analysis of the current state

This RULA analysis values the three main working positions at the table. The first working position is for the bottom part of the drawer.

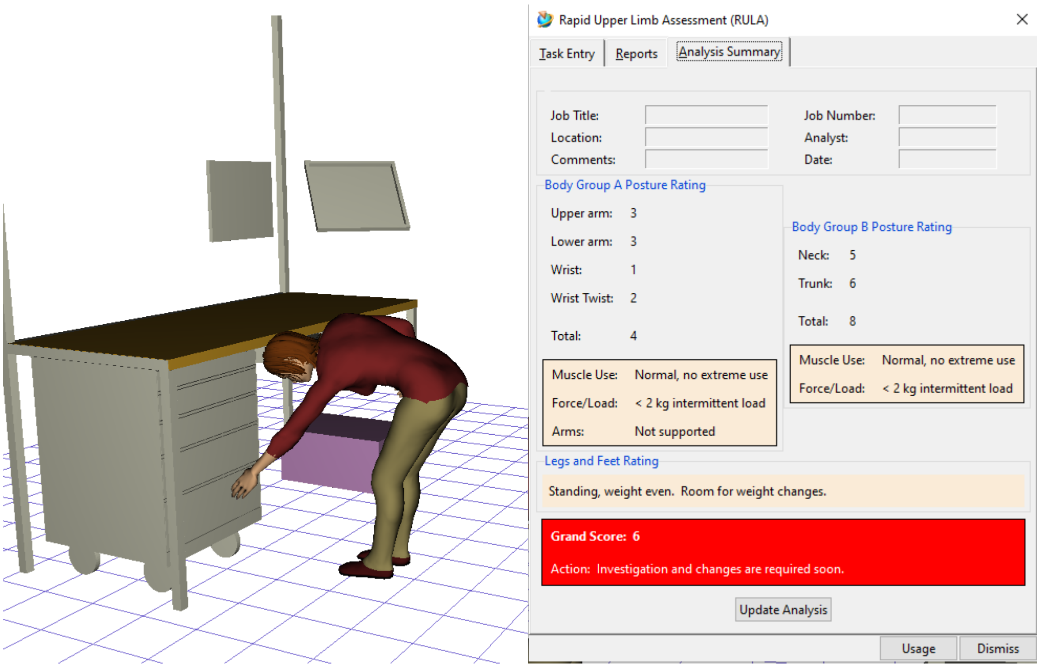


Figure 40: RULA analysis for the lower 5% body - Position 1 - Screenshot

The results of this position got the grand score 6. Following the theoretical review is the person working in a poor posture with a risk of injury from their work posture, and the reasons for this need to be investigated and changed shortly to prevent an injury. The second working position is for the top part of the drawer. This working position has been granted the score 4. The person is working in a posture that could present some risk of injury from their work posture, but practically is the posture acceptable.

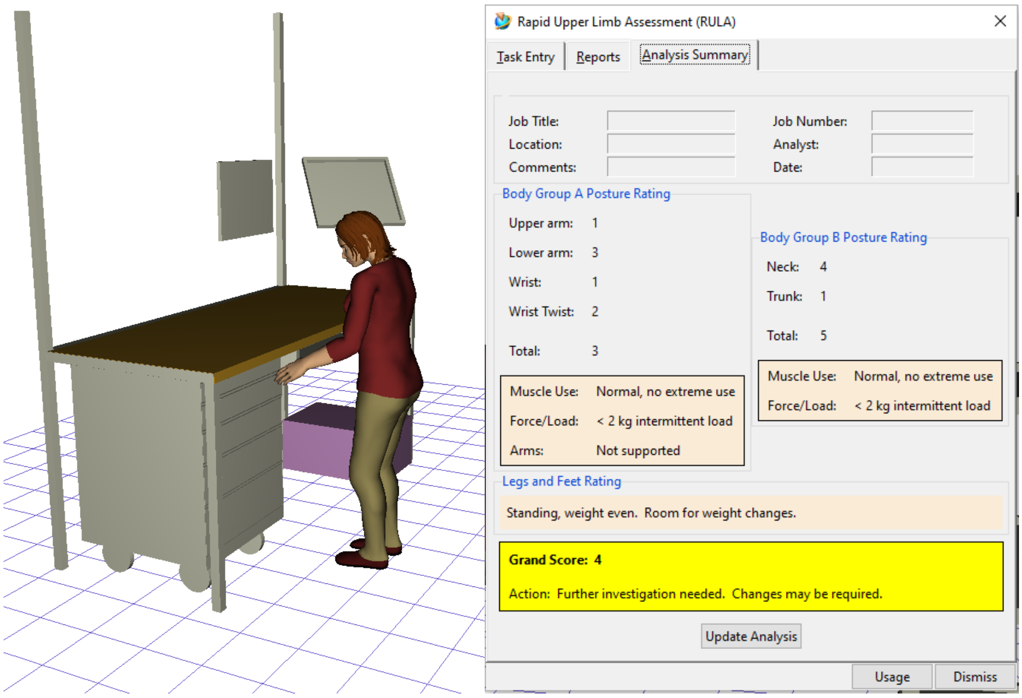


Figure 41: RULA analysis for the lower 5% body - Position 2 – Screenshot

The last experiment at the working table is the position at the rubbish bin. As pictured in *Figure 44* is this working position not ergonomically ideal. The RULA grand score is at 7. The person is working in the worst posture with an immediate risk of injury from their work posture. The reasons for this need to be investigated and changed immediately to prevent an injury.

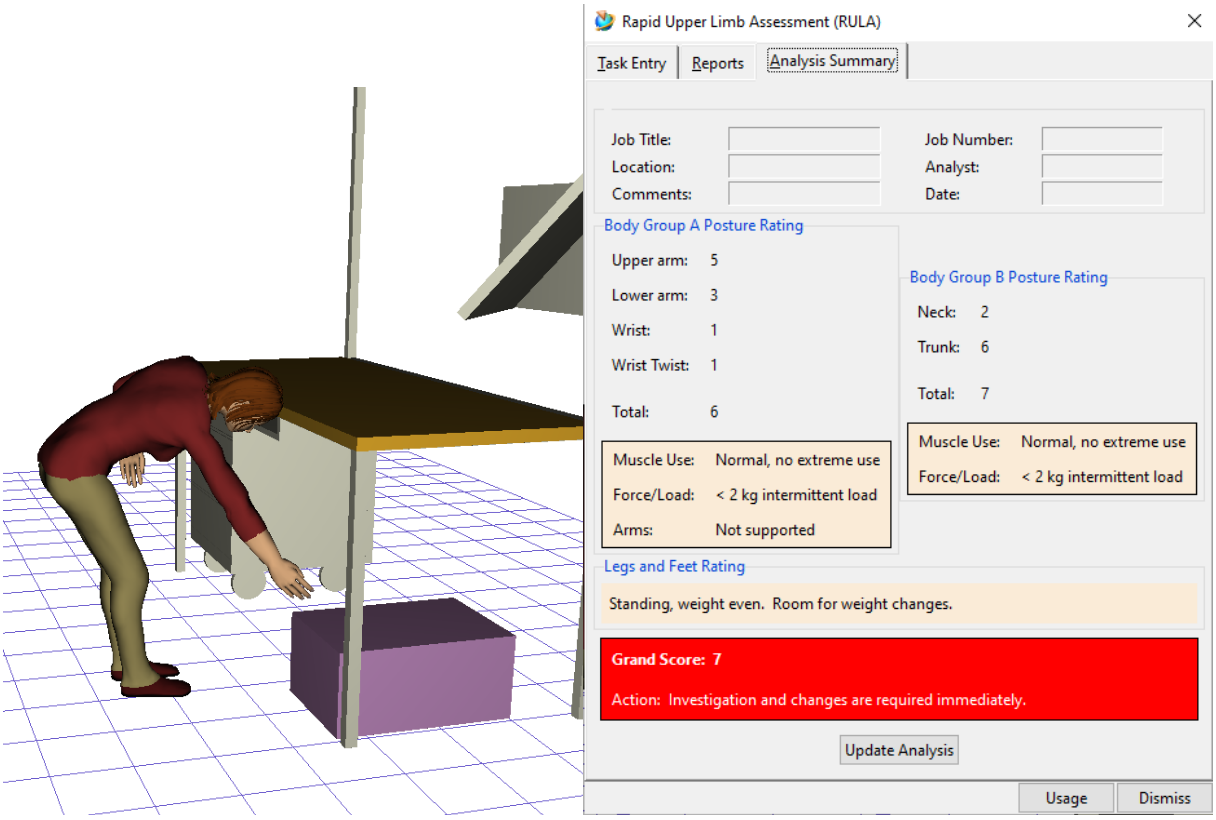


Figure 42: RULA analysis for the lower 5% body - Position 3 – Screenshot

All the RULA experiments at the current workstation are listed in ***Supplement 3***. As a result of these experiments are the postures ergonomically far from ideal. The conclusion of these results is combined into the table below. Redly coloured RULA grand scores need to be improved, to optimise the ergonomics posture of the workers. The improvements of the working station will be 3D CAD designed as well and after that, RULA grand scored. A direct comparison of these results will show the benefits of the improvements suggested in the chapters above.

Position	Place	Gender	Percentile	RULA grand score
1	Bottom drawer	Woman	5%	**6**
2	Top drawer			**4**
3	Rubbish bin			**7**
1	Bottom drawer	Man	95%	**6**
2	Top drawer			**5**
3	Rubbish bin			**6**

Table 6: RULA grand scores of the experiments at the working table

5.3 NIOSH analysis of the current state

The NIOSH analysis will provide enough data for a comprehensive review of the ergonomics side of the load manipulation within the working process. The main focus point is on the trolley. This component is the anchor factor for entry material and finished assembled guiding system. As a result, are recommendations for the load manipulation for all the assembled parts. All the experiments are designed similarly as for the RULA experiment. This analysis will take the lower 5 and the higher 95 percentile of anthropological factors into account. For the right function of the analysis are some entry data needed. These data are listed in the table below.

Average load (kg)	**Maximum Load (kg)**	**Lift rate**	**Work time (hours)**	**Recovery time (hours)**	**Object type**	**Load control**	**Grasping**
6,5725	10,242	0,015	7,5	0,5	Lose	Optimal	Optimal

Table 7: Entry data for the NIOSH experiments of the current workstation

For each extreme percentile are three experiments. These experiments are representing the three levels on the trolley. As mentioned in the theoretical review are two results decisive. The first coefficient is the recommended mass limit (RWL). This limit is a weight limit and should not be passed above. In the first position of the 5 percentile is the RWL result 6,18 kg. The second coefficient is the lift index (LI), which tells if the position is ergonomically functional. This index should be kept below 1, and in the case of the first position is the lift index 1,060. This result is acceptable.

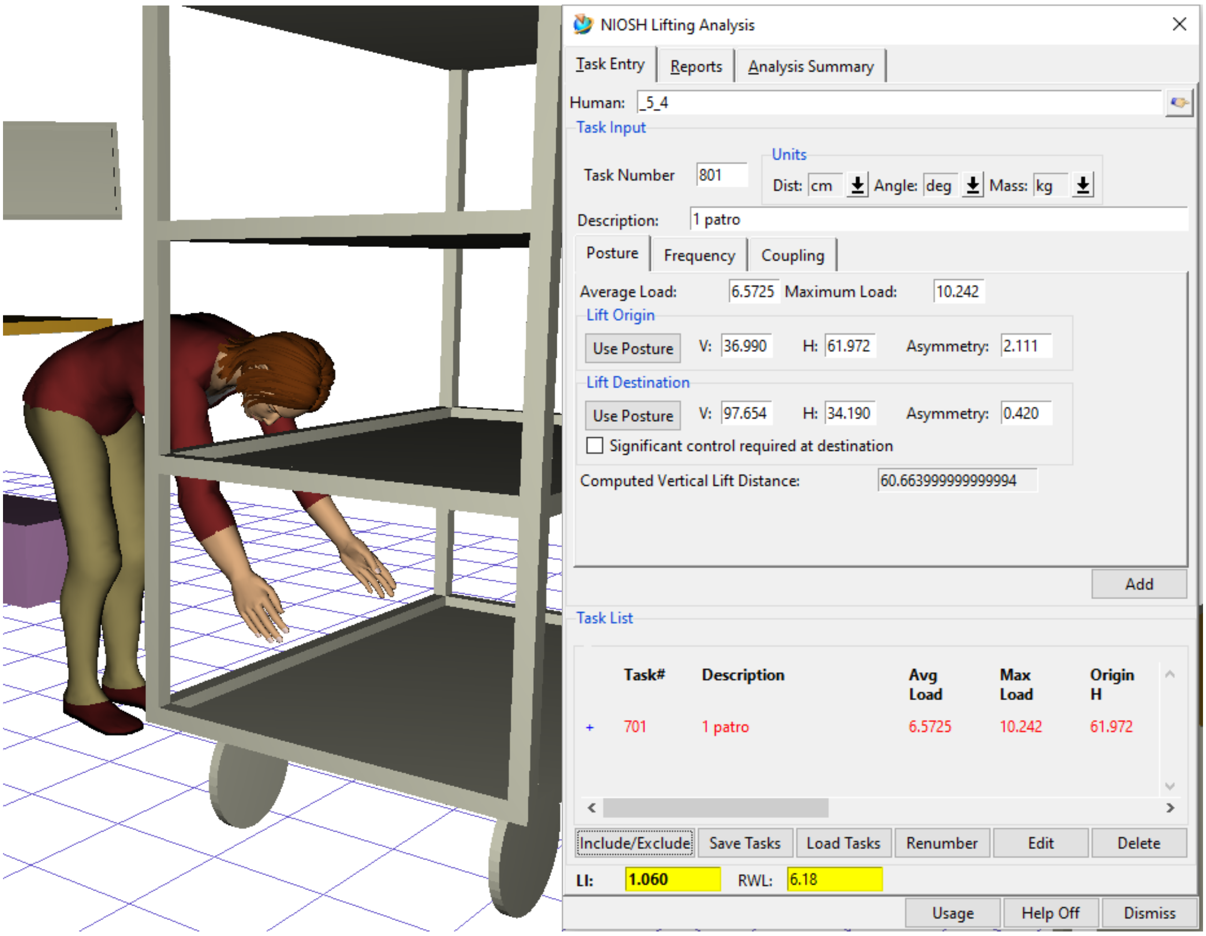


Figure 43: NIOSH analysis for the lower 5% body - Position 1 - Screenshot

The second NIOSH experiment is for the middle level of the trolley. Based on the results is this position more suitable for heavier parts. In this particular case is the lift index 0,870 and as mentioned above value lower than 1 is optimal. The recommended mass limit went to better results as well. The RWL of the second position is valued 7,56 kg. As for the third position are the improvements even more noticeable. The lift index is 0,660 in this case and the recommended mass limit went up to 9,93 kg.

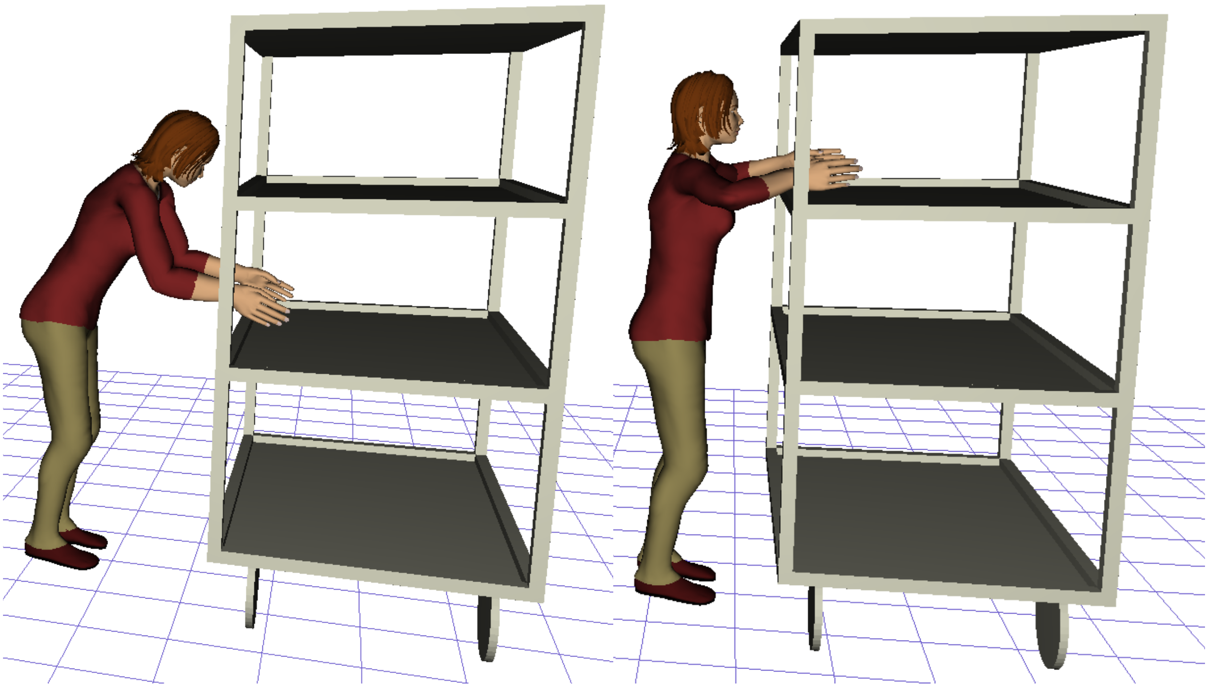


Figure 44: Second position (left) and third position (right) - Screenshot

Similar to the RULA analysis is the NIOSH analysis based on three experiments for both percentile extremes. The results are listed in the table below and direct results are listed in ***Supplement 4***. These results should provide enough data for the new load manipulation guideline for the assembled parts of the container guiding system.

Position	Place	Gender	Percentile	LI	RWL (kg)
1	Bottom	Woman	5%	**1,060**	**6,18**
2	Middle			**0,870**	**7,56**
3	Top			**0,660**	**9,93**
1	Bottom	Man	95%	**1,090**	**6,01**
2	Middle			**0,900**	**7,33**
3	Top			**0,980**	**6,71**

Table 8: NIOSH results of all working positions

The results of the lower 5 percentile are slightly better than for the higher 95 percentile of the population. This fact is due to the size of the trolley. Higher workers have to bend over to reach into levels of the trolley. An anomaly is the result of the third position of the lower 5 percentile. These numbers are given by the fact that the test subject got a completely straight back and this percentile, in reality, is fairly rare. As for the load manipulation is the correct posture crucial for maximising the load and parallelly keeping the most optimal ergonomics standardisations.

6 Suggestion for improvements

This chapter will provide suggestions based on the data of the experiments. These suggestions should improve the overall working process at the working station. As mentioned in the previous chapters, will be the new working station analysed with the same ergonomics experiments. The direct comparison of the current and improved working station will confirm the benefits of these suggestions. A visualisation of the improved working station is pictured below.

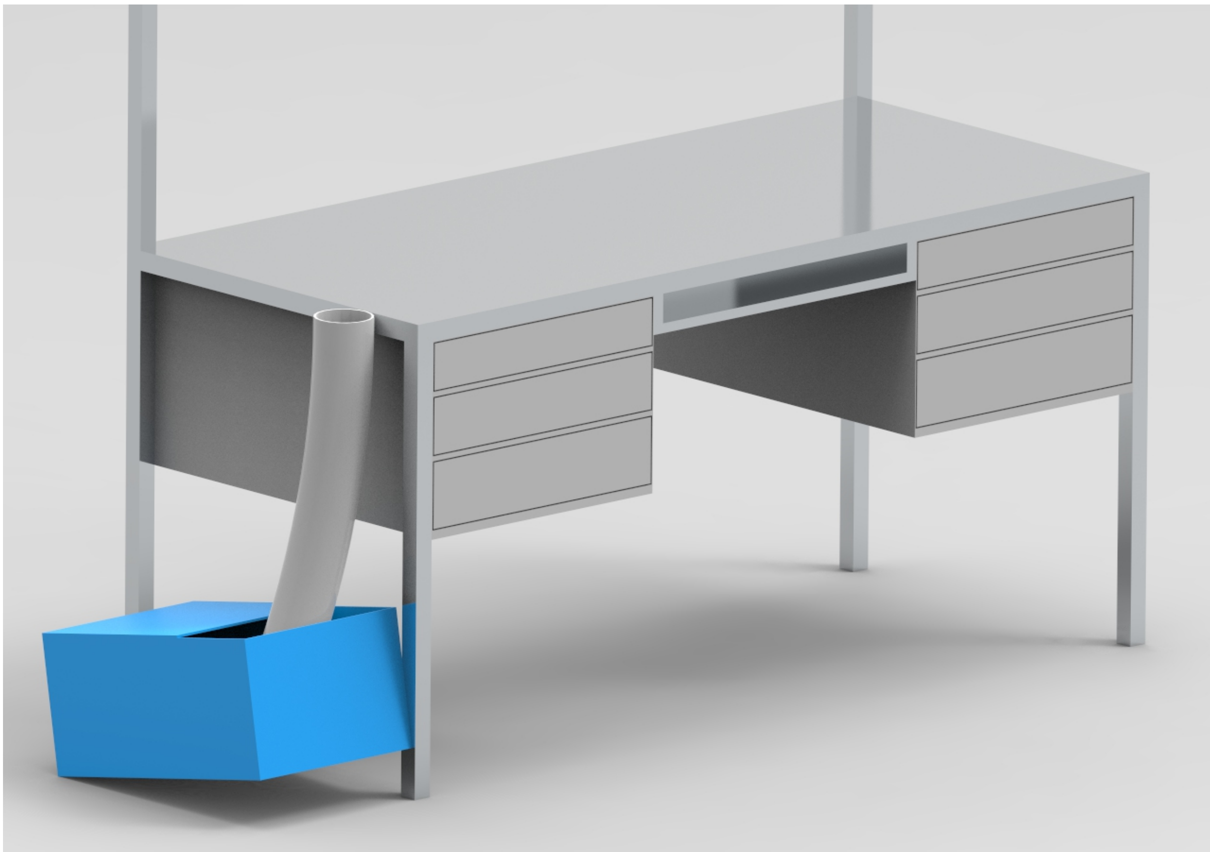


Figure 45: Improved working station of the assembly - Rendering

To correctly illustrate the benefits, is this chapter divided into two subchapters. The first subchapter is focused on the working table. This particular case got two pressure points, and the first one is the drawer. Its position has been improved by the new drawer system. On the other hand, is the position of the rubbish bin. Its philosophy has been improved and an innovative suggestion has been made. The second subchapter will provide load manipulation guidelines for the trolley. This guideline is based on the most optimal load manipulation posture for the assembled parts.

All these suggestions and their benefits will be proved by the RULA and NIOSH ergonomics experiments. These experiments are designed in the same way as the experiment in the previous chapter. For the spectrum coverage, the extreme percentiles of the human population. As for the anthropology, is the German database the most optimal solution. The analysis will look into the lower 5 and the higher 95 percentile. Furthermore, these experiments take the gender into account. The outgoing data will be provided in ***Supplement 5*** for the RULA analysis and ***Supplement 6*** for the NIOSH analysis.

6.1 RULA analysis of the improvements

The RULA analysis values the three main working positions at the table. These working positions are design for the lower and higher percentiles. The first working position is for the bottom part of the drawer. As illustrated below, the farthest drawer is easily reachable and the RULA grant score is 3. This grand score is practically optimal. Better results as grand scores 2 are rare and grand score 1 is mostly impossible.

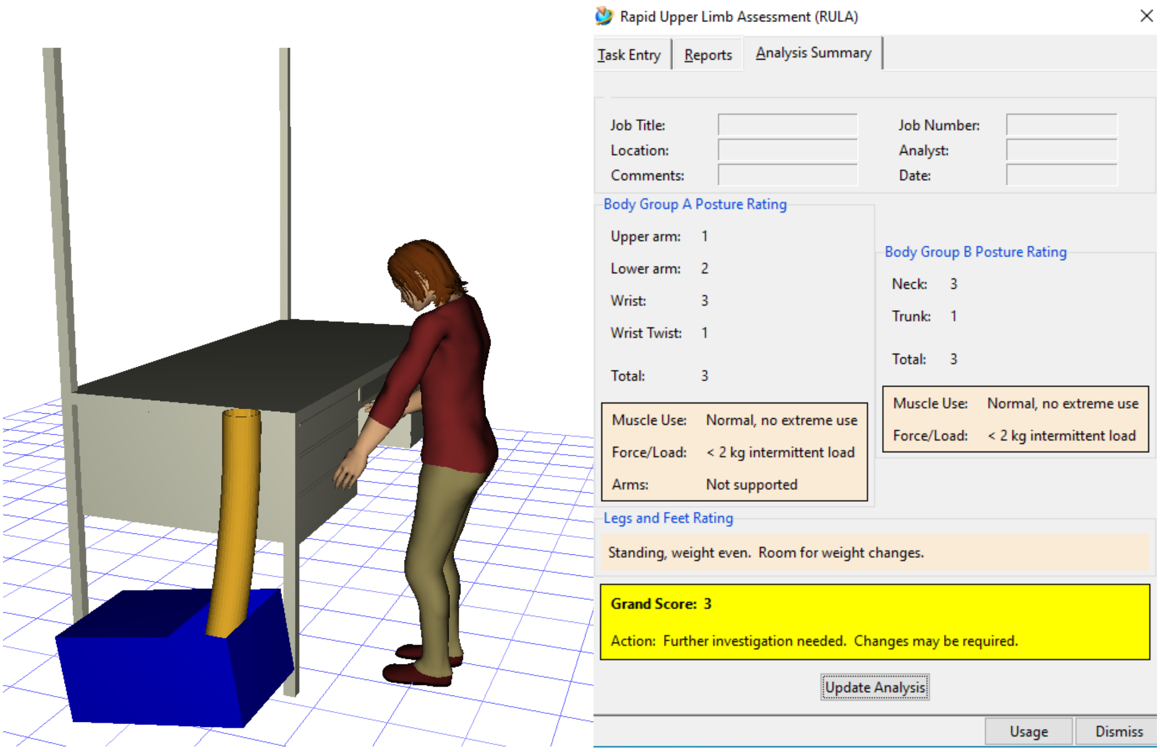


Figure 46: RULA analysis for the lower 5% body – Improved position 1 - Screenshot

The second and third working positions got better RULA grand scores as well. All the data and visualisations are in ***Supplement 5***. As pictured in *Figure 47* is the improvement of the posture very noticeable and an evaluation will be in the following chapter.

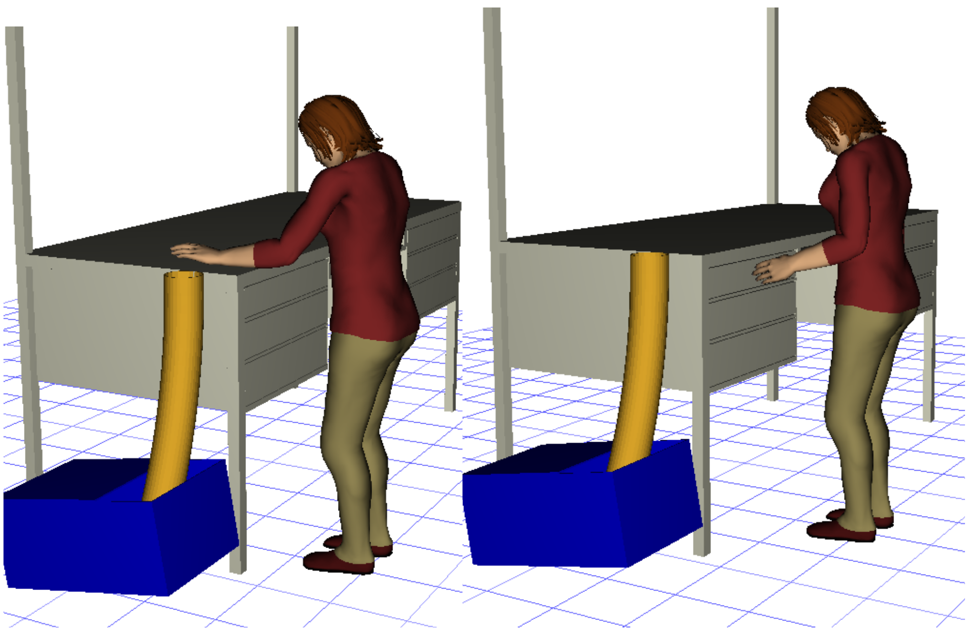


Figure 47: Second and third position at the improved working table - Screenshot

6.2 NIOSH analysis of the improved working postures

If the worker keeps the right working posture, are the ergonomics benefits at the most optimal level. For the load manipulation, the right posture is very important. A comparison of these postures is pictured below. And all the outgoing data is visualised in ***Supplement 6***.

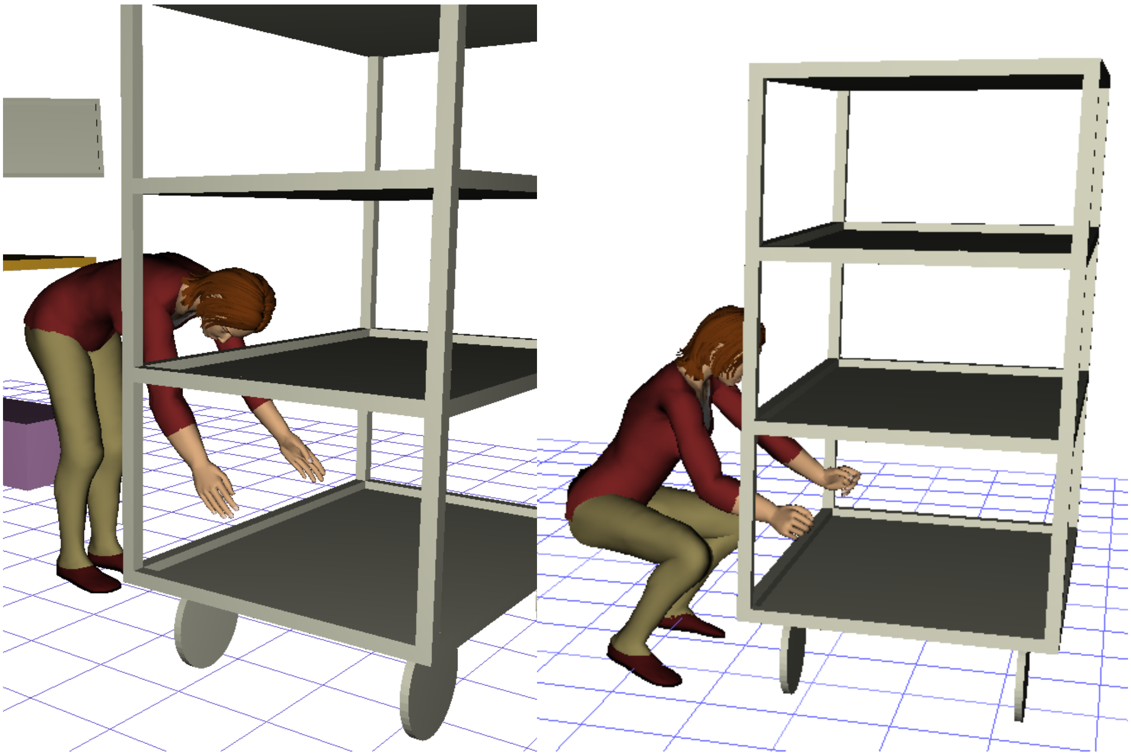


Figure 48: NIOSH analysis for the lower 5% body - Position 1 – Comparison - Screenshot

The result of the more ergonomics posture got significantly better. As visualised in *Figure 49*are the results for the working posture noticeably different. The first position at the bottom level, got better LI (from 1,060 to 0,830) and also RWL (from 6,18 kg to 7,88 kg). These results are for the lower 5 percentile of the anthropological German body type. A comprehensive review of these data will be in the next chapter. In the evaluation is the new guideline for the load manipulation at the trolley included.

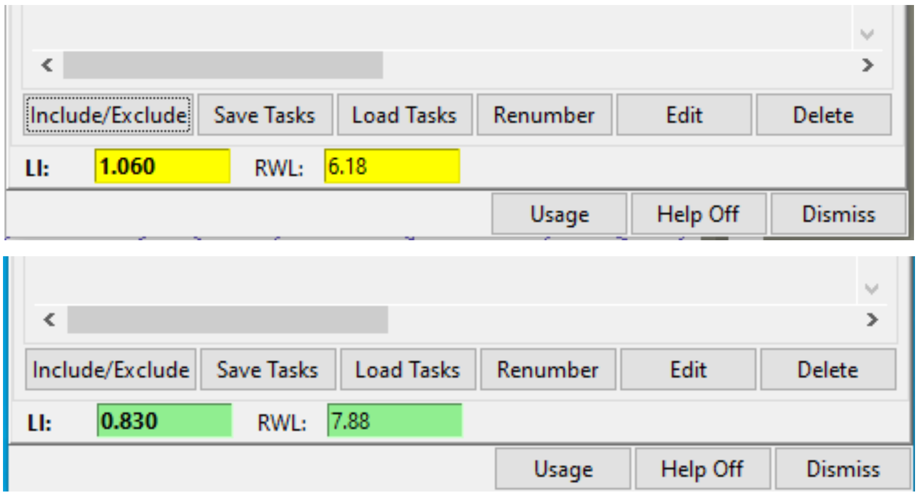


Figure 49: NIOSH analysis of the improved load manipulation posture for the lower 5 percentile - Screenshot

7 Evaluation of the new improvements

The first focus point in this chapter is a comparison of the RULA grand score results, provided by the experiments. These results are visualised in the table below.

Position	Place	Gender	Percentile	RULA grand score at the Current WS	RULA grand score at the Improved WS
1	Bottom drawer	Woman	5%	**6**	**3**
2	Top drawer			**4**	**3**
3	Rubbish bin			**7**	**3**
1	Bottom drawer	Man	95%	**6**	**3**
2	Top drawer			**5**	**3**
3	Rubbish bin			**6**	**2**

Table 9: RULA grand scores of the experiments at the improved working table

Based on these results, the improvements are significant. Therefore, the realisation will improve the ergonomics at the workstation. Some of these improvements are easily practicable and at a lower investing price point. For example, the improved rubbish bin system is easily feasible due to the already provided technology at the current table.

The second focus point are the results, provided by the NIOSH analysis. These results are visualised in *Table 10*. The lift index (LI) and recommended weight limit (RWL) got way better results.

Position	Place	Gender	Percentile	Current LI	Improved LI	Current RWL (kg)	Improved RWL (kg)
1	Bottom	Woman	5%	**1,060**	**0,830**	**6,18**	**7,88**
2	Middle			**0,870**	**0,540**	**7,56**	**12,21**
3	Top			**0,660**	**0,660**	**9,93**	**9,93**
1	Bottom	Man	95%	**1,090**	**0,810**	**6,01**	**8,09**
2	Middle			**0,900**	**0,710**	**7,33**	**9,23**
3	Top			**0,980**	**0,720**	**6,71**	**9,14**

Table 10: NIOSH results - Comparison

Due to the dimensions of the trolley, the guideline is different for the higher 95 percentile, than for the lower 5 percentile. For smaller bodies, the 1650 mm high trolley is more reachable and accessible. This new guideline differentiates the specific weight of the different parts and recommends the right trolley level, given the anthropological percentile and the NIOSH results. Based on the data, the lightest parts should be on the bottom level. The heavier parts on the top level and the heaviest parts on the middle level. Looking into the data provided by the table above is the middle level and the top level for the 95 percentile similar and therefore are parts placement exchangeable. The optimal placement for the assembled pieces is in *Table 11*.

All the data in the table below are new recommendations. Keeping these recommendations in combination with the right load manipulation posture provides the most optimal ergonomics results. This guideline is based on the data above and by following the load manipulation standards should the limits look like this:

<table>
<tr><th>Assembled parts title</th><th>Weight</th><th>Trolley level for 5%</th><th>Trolley level for 95%</th></tr>
<tr><td>Tongue to the Entry star</td><td>2972 g</td><td rowspan="5">Bottom</td><td rowspan="5">Bottom</td></tr>
<tr><td>Locked star wheel</td><td>4146 g</td></tr>
<tr><td>Internal entry guide</td><td>4692 g</td></tr>
<tr><td>Exit guide</td><td>6050 g</td></tr>
<tr><td>External entry guide</td><td>6280 g</td></tr>
<tr><td>Exit tongue</td><td>7222 g</td><td rowspan="3">Top</td><td rowspan="4">Top or middle</td></tr>
<tr><td>Entry star wheel</td><td>7458 g</td></tr>
<tr><td>Exit star wheel</td><td>7988</td></tr>
<tr><td>Guide arch</td><td>8675 g</td><td rowspan="2">Middle</td></tr>
<tr><td>Snail gear</td><td>10242 g</td><td>Middle</td></tr>
</table>

Table 11: New guideline for the load manipulation - Assembly division

As mentioned before, the right manipulation posture is crucial for the ergonomics. Here is base knowledge into the load manipulation. This information is provided by Mr Bureš [15].

- The right posture and symmetrical load on the body
  - Enough space for movement
  - No body rotation under load
  - Gripping and laying load height from 70 to 100 cm
  - Sufficient view
- Loads carried over long distances should be carried on the back, medium distances should be carried on the shoulders and short distances should be carried in the hand
- Lifting loads with a straight back
  - The intervertebral discs are better loaded
  - However, it requires more physiological energy consumption
  - It takes more time than lifting with a round back
- The principle of the vertical plane
  - The distance between the grip of the load in front of the body must be as small as possible, which presupposes the smallest distance between the lines of the human body and the load
- Principle of the horizontal plane
  - Move loads at the same level and optimum height
- A reasonable amount of work
- Reasonable time distribution (alternation of operations)
- Reducing the weight of the load
  - Division of cargo into several parts
  - Reduction of package weight
  - Use of other materials

8 Conclusion

This master’s thesis shows the benefits of the industrial engineering field in a specific case. As mentioned in the introduction, was the first part about the analysis of the current state. The most important part is to show the importance of the transparency within the firm on division level and nationwide. This transparency signifying helps to minimise the reclamation rate and the overall customer experience. These divisions are turning to more automatization for the most optimal result. The analysis is mostly focussed on the design, manufacturing and assembly division. Because of the variety of the products, this thesis is only about the label machine. Specifically, the container guiding system

For this thesis, the analysis of the assembly division is most important, due to the second part of this paper. After the analysis should be a suggestion of the improved working process. These improvements are achieved with the industrial engineering methods described in the theoretical review. The chosen industrial engineering side is ergonomics. Most importantly the upper limp analysis and the load manipulation. A working process analysis has been done and suggestions have been made. The results of these analyses are evaluated, and the results showed significant improvements.

The results of this master’s thesis should provide enough data to improve the overall understanding of the whole engineering process of the container guiding system. Furthermore, to improve the working station in the assembly division. Due to this more ergonomics focused time, should these improvements minimise the cumulative strain on the human body and also minimise the number of working related health injuries.

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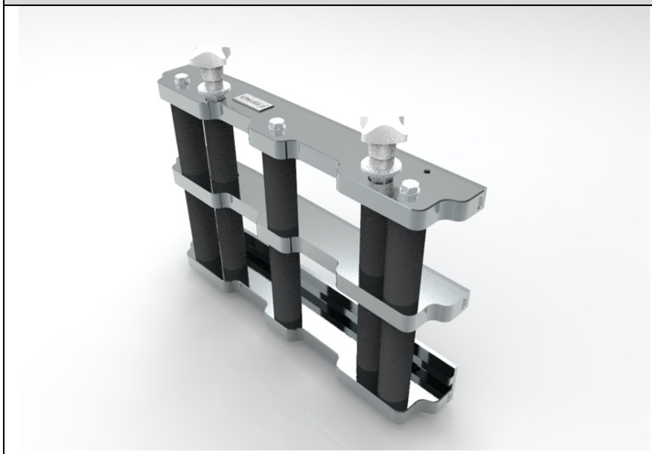
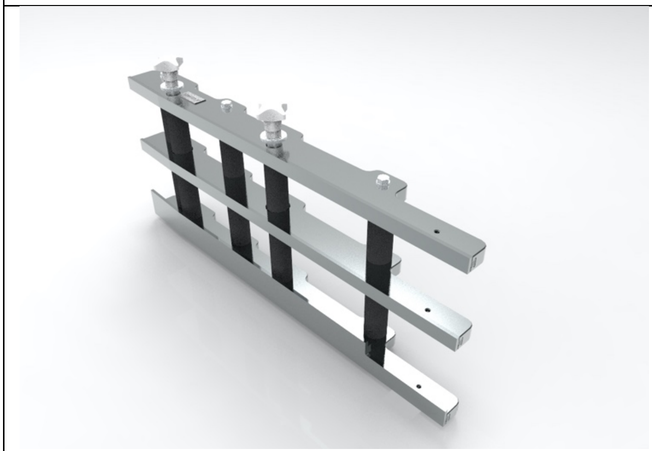
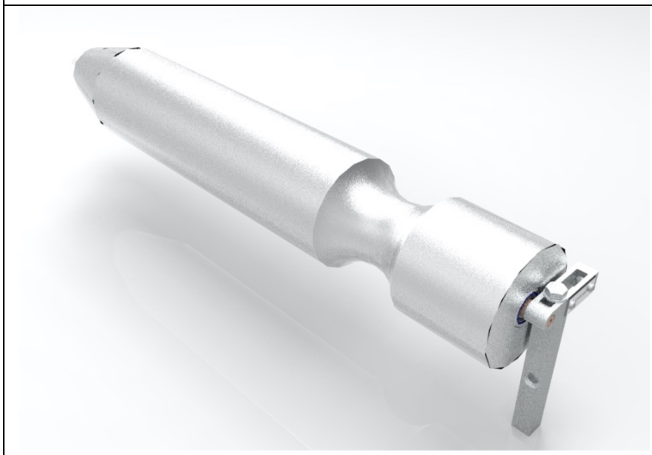
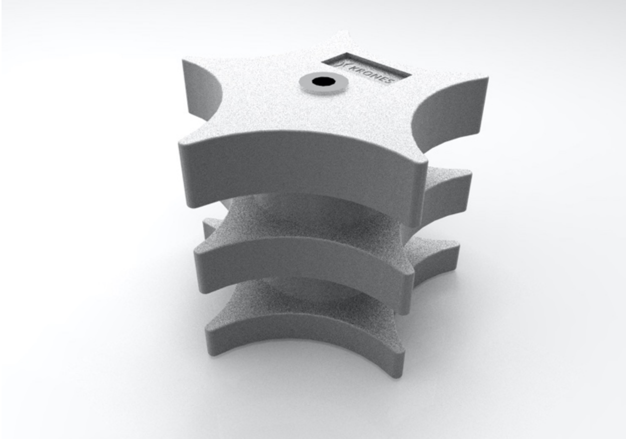
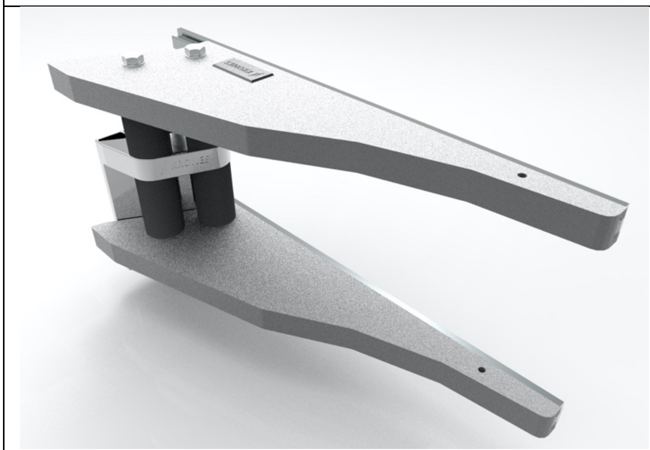
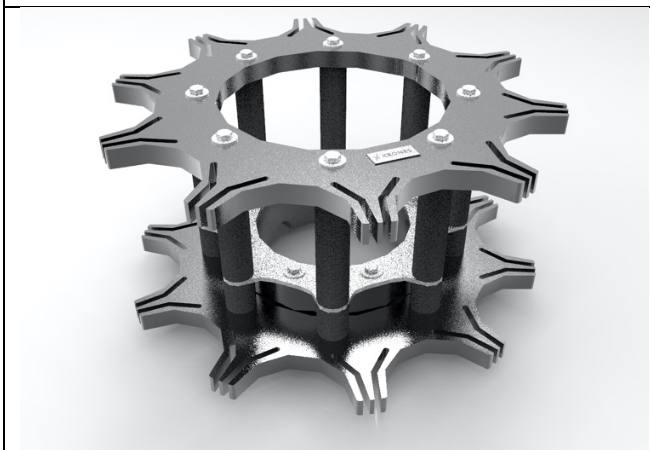
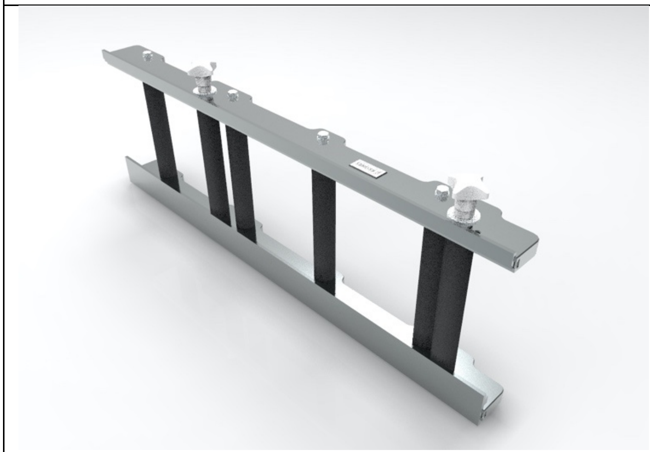
Supplement 1

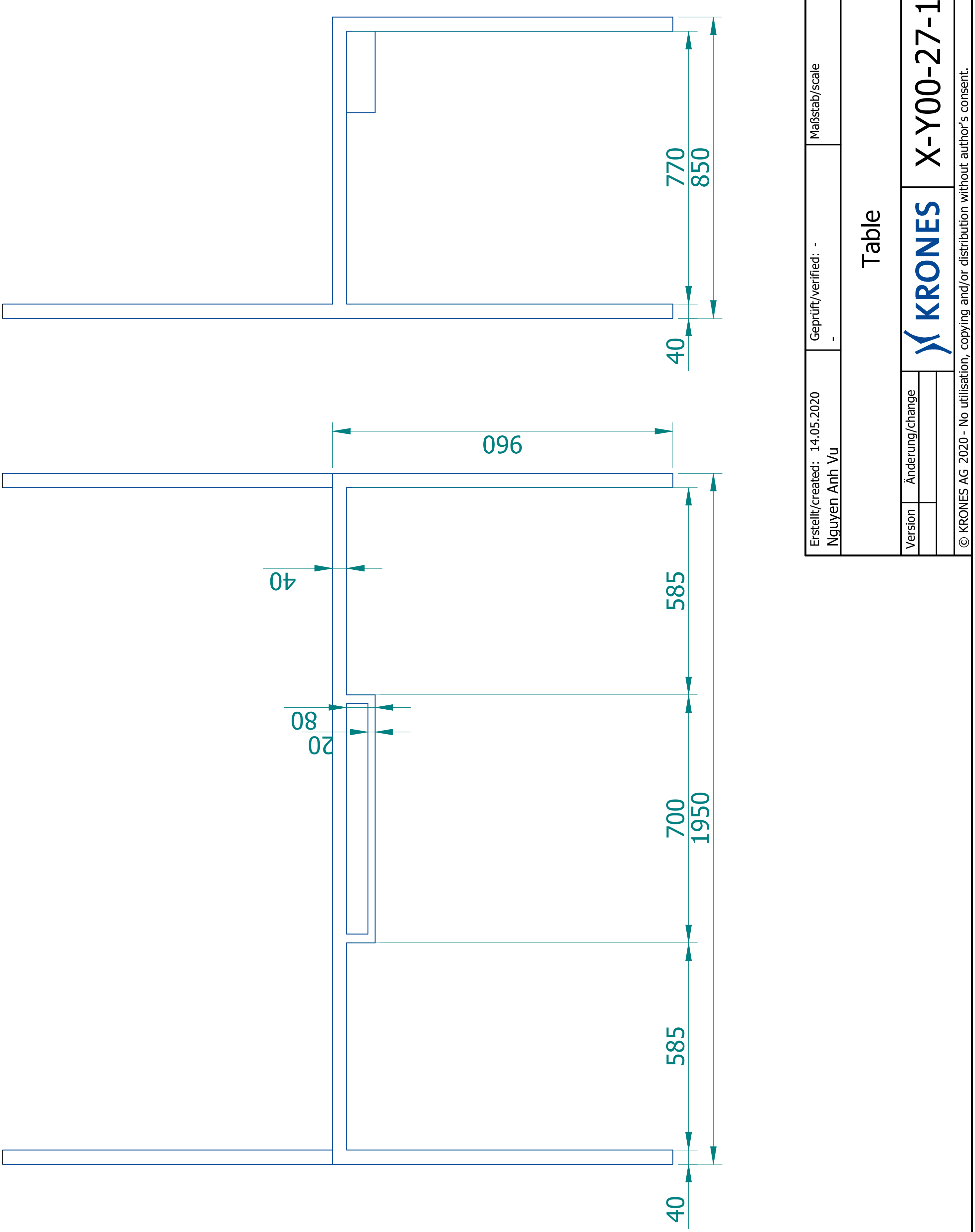
The data and illustrations have been specified within one commission (number *K810-D65 – 12.1.*).

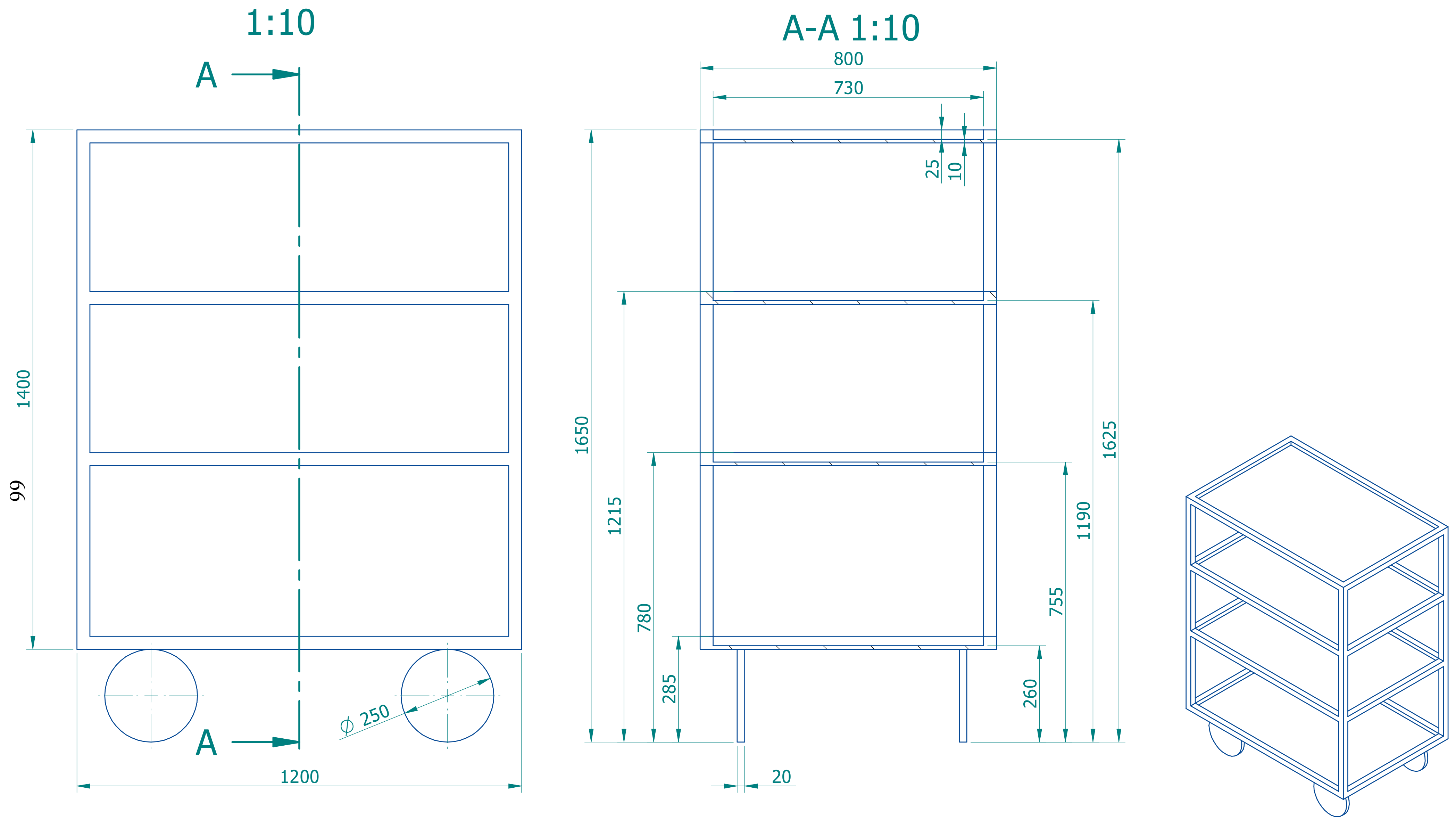
Illustration	Assembled parts title	Weight
	Internal entry guide	4692 g
	External entry guide	6280 g
	Snail gear	10242 g

	Locked star wheel	4146 g
	Tongue to the Entry star	2972 g
	Entry star wheel	7458 g
	Guide arch	8675 g

	Exit star wheel	7988 g
	Exit guide	6050 g
	Exit tongue	7222 g

Supplement 2





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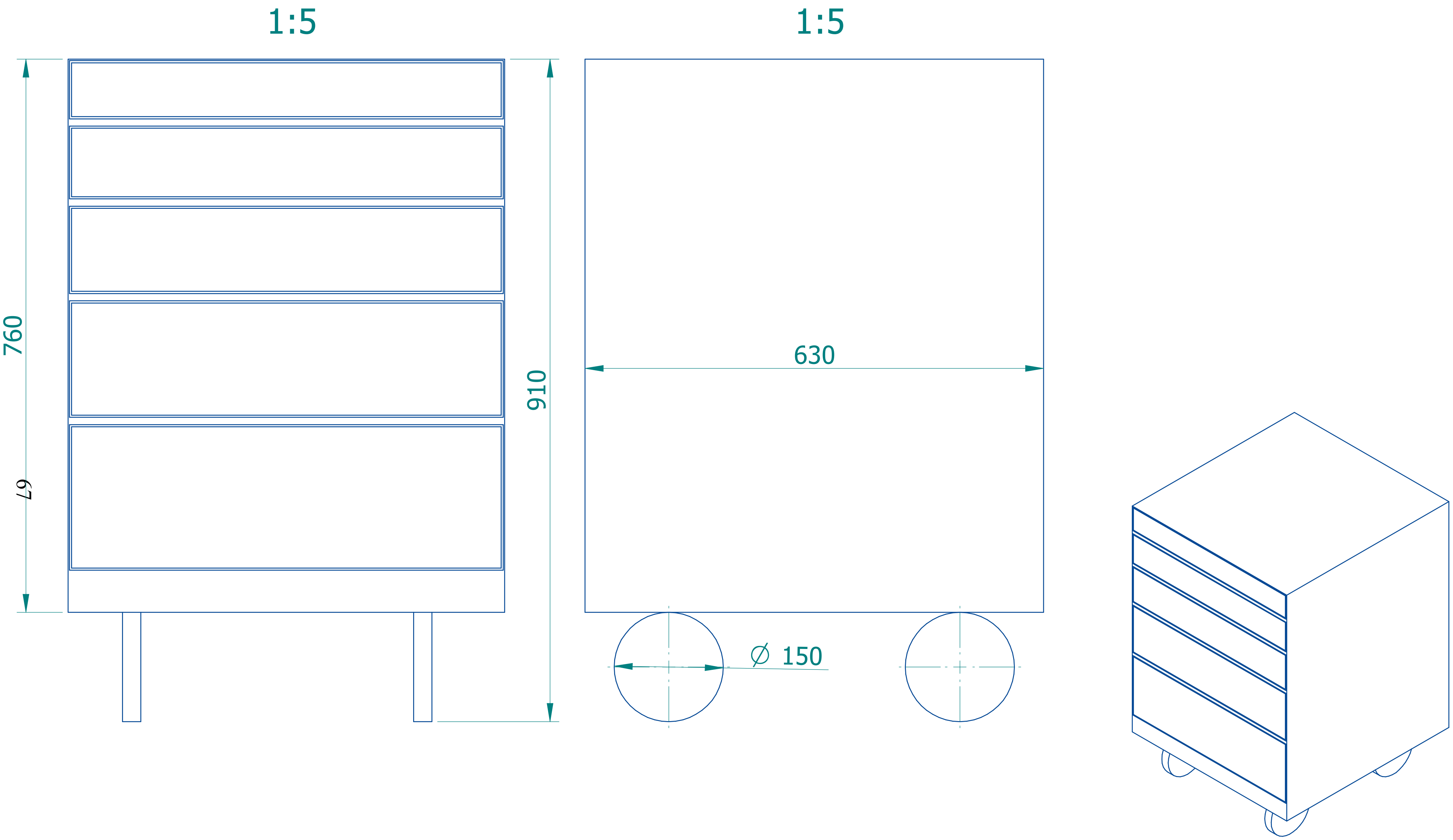

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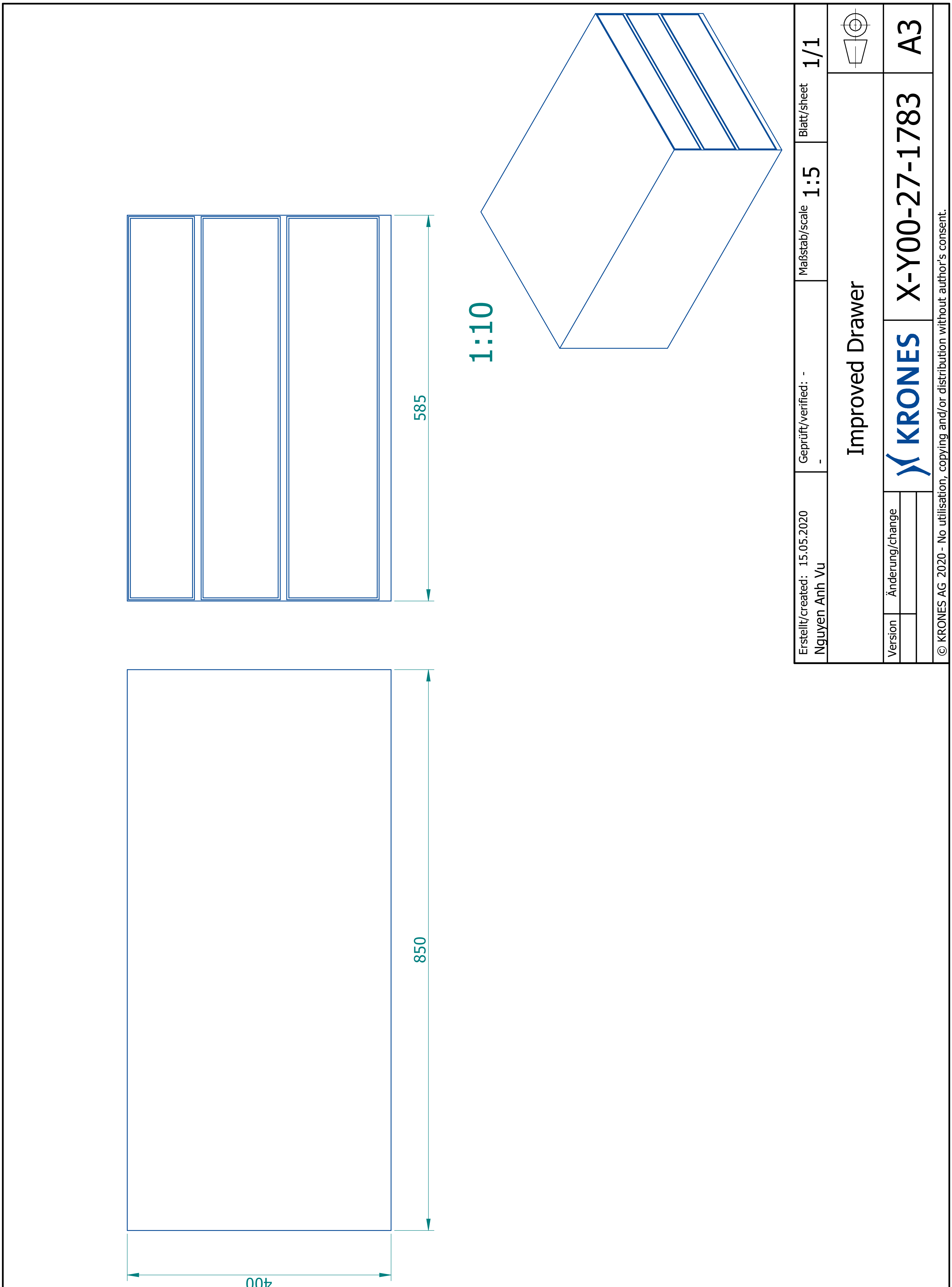
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Improved Drawer
Version
Änderung/change
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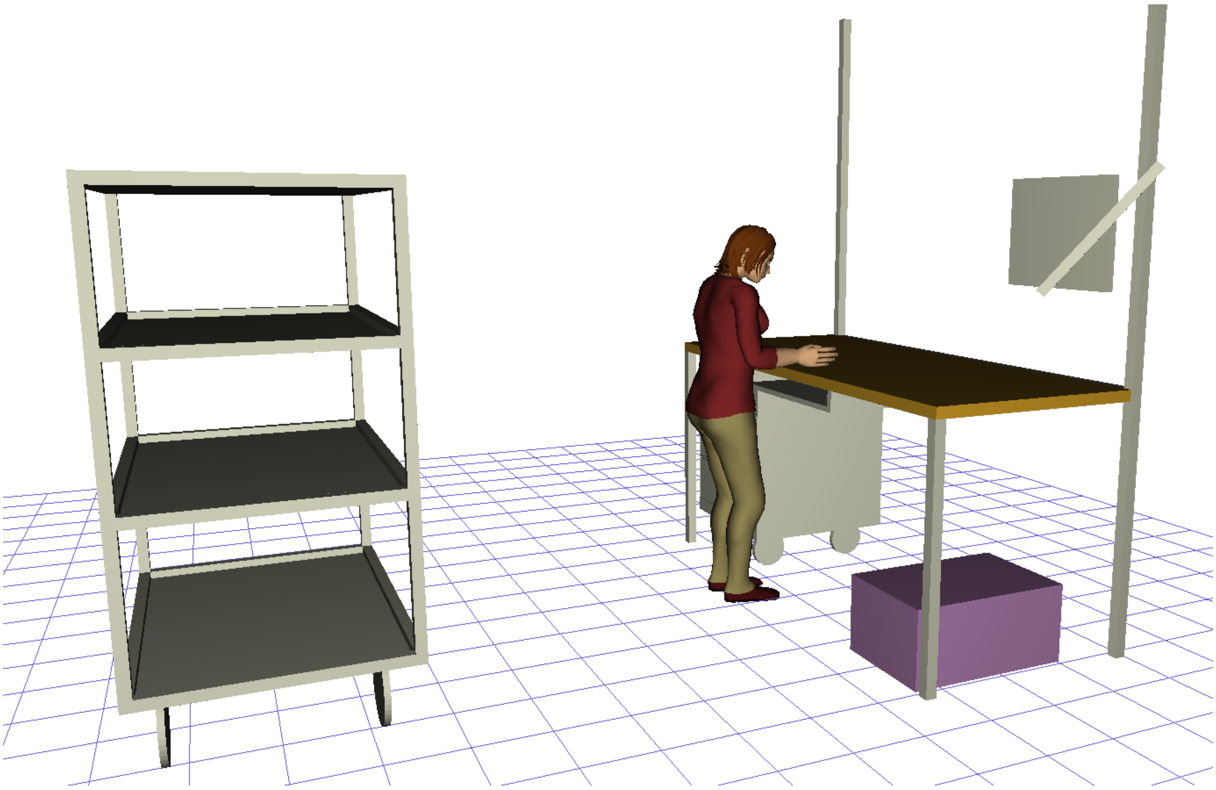
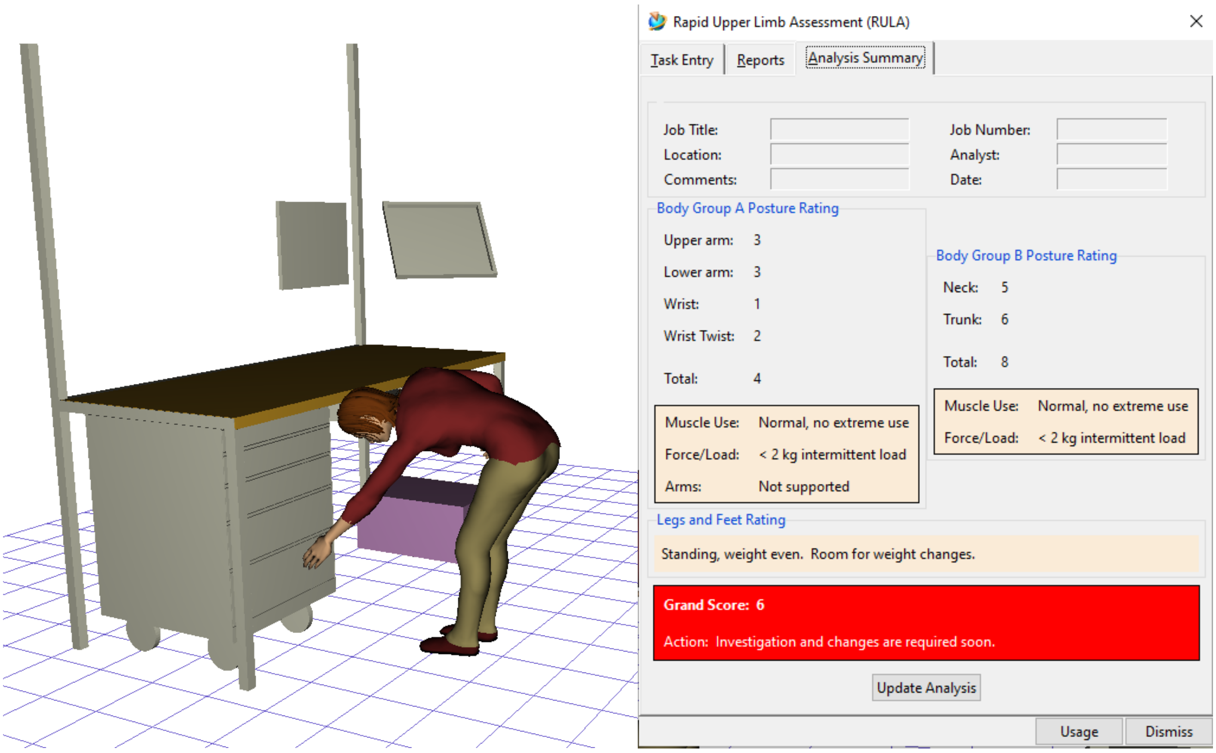
Supplement 3

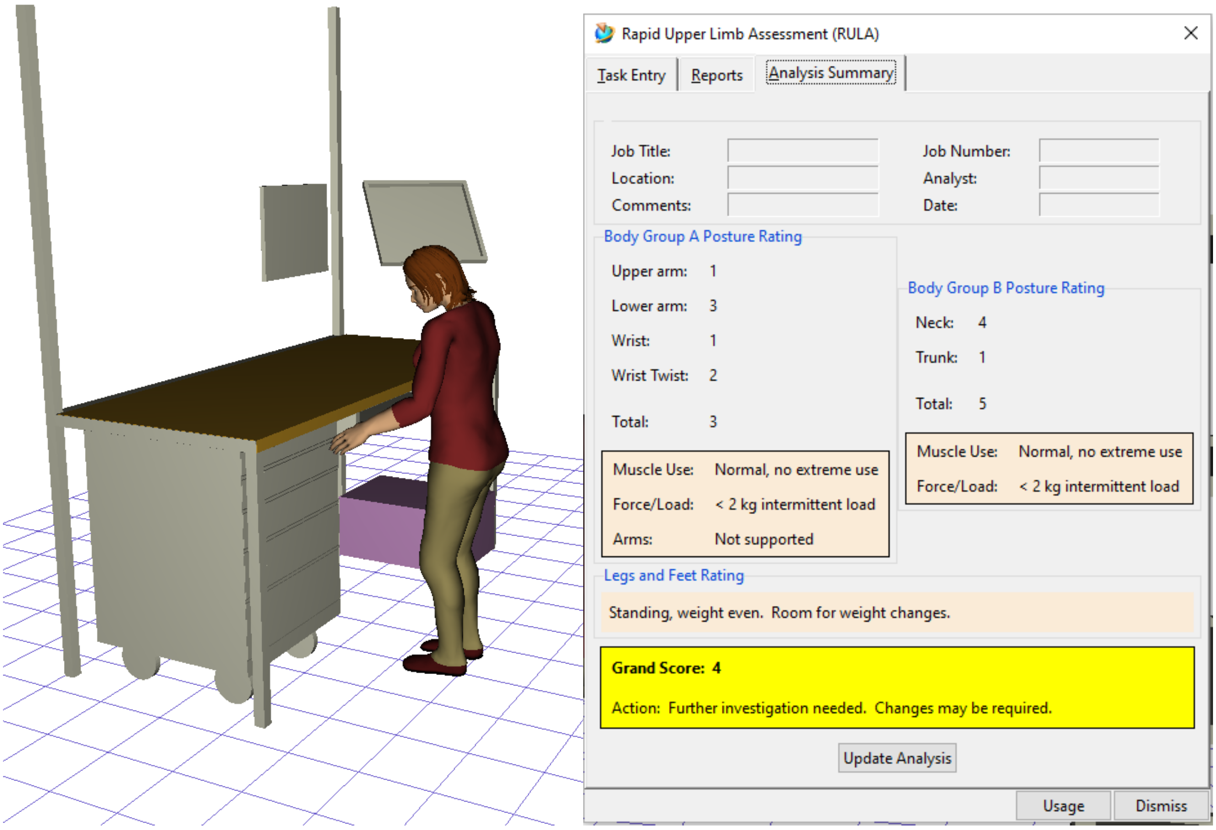
Current workstation experiment for the lower 5% percentile. Visualisation with RULA grand scores.



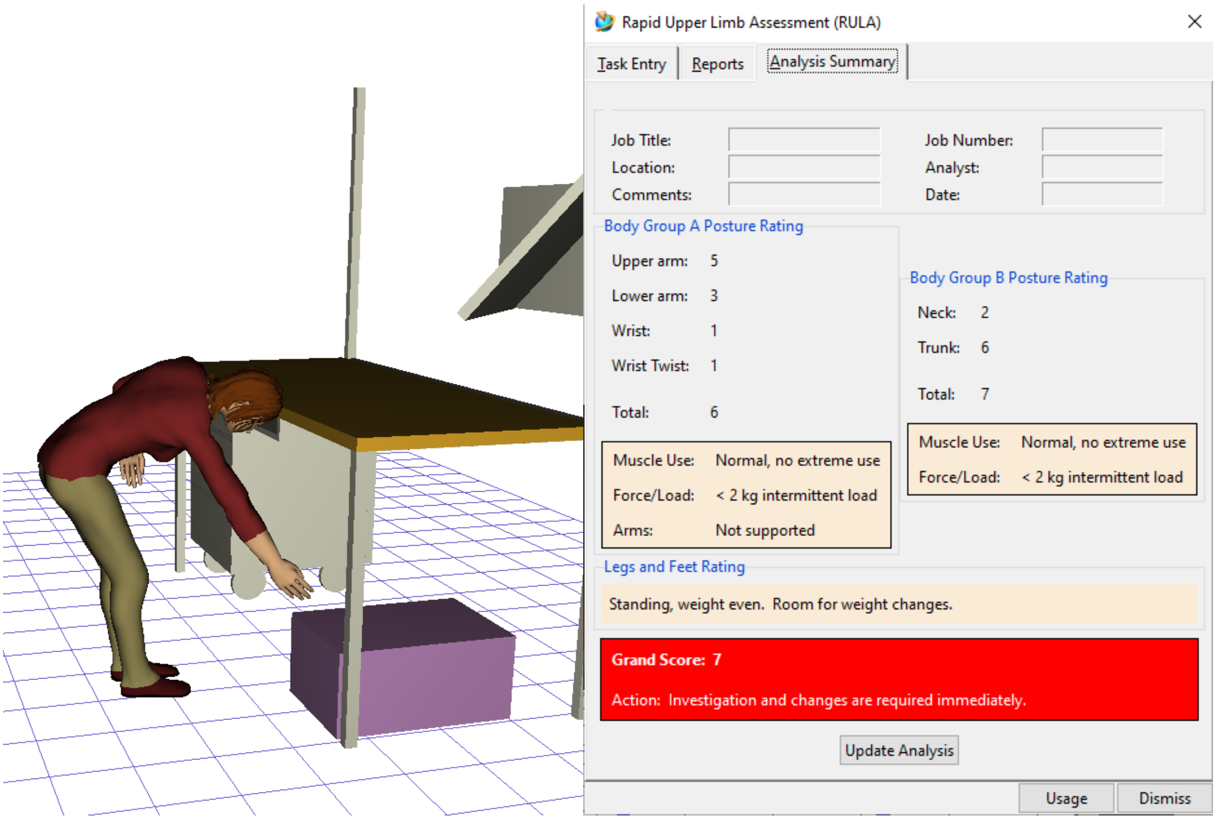
First position – Bottom drawer – RULA grand score 6



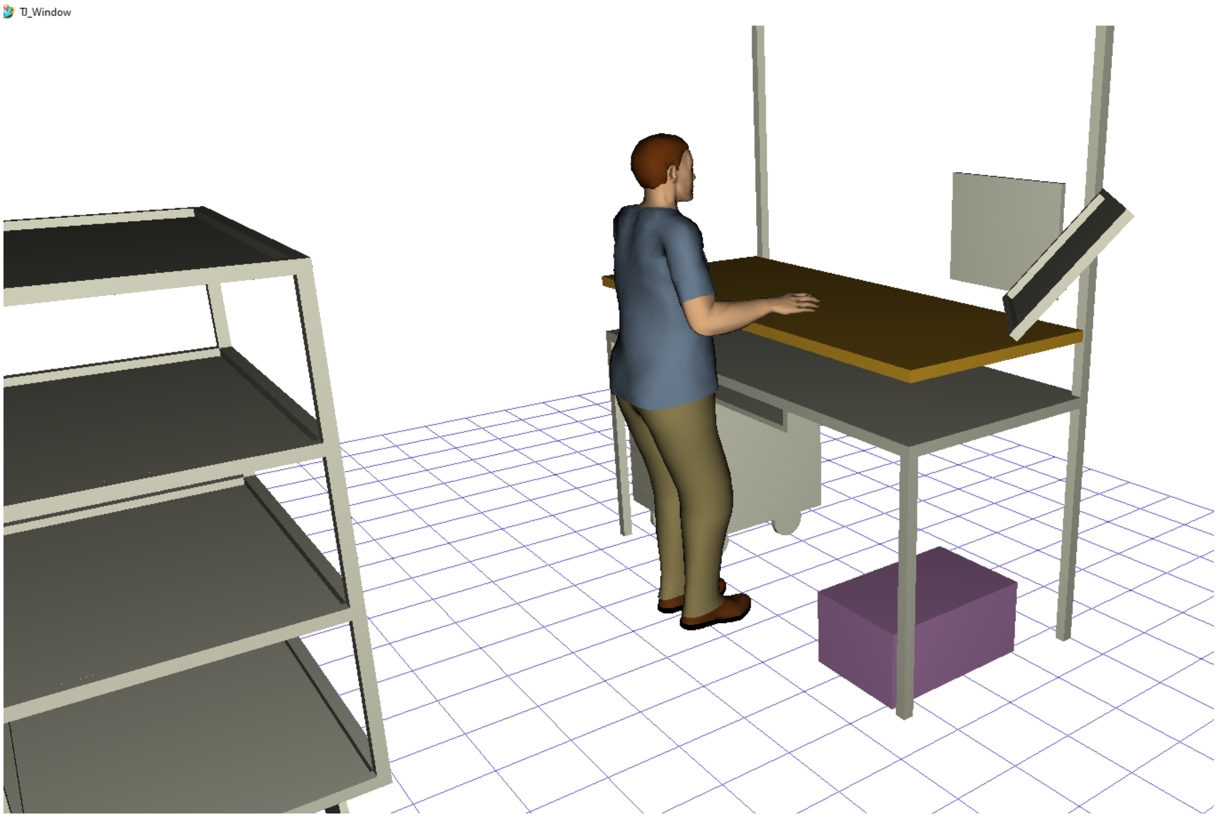
Second position – Top drawer – RULA grand score 4



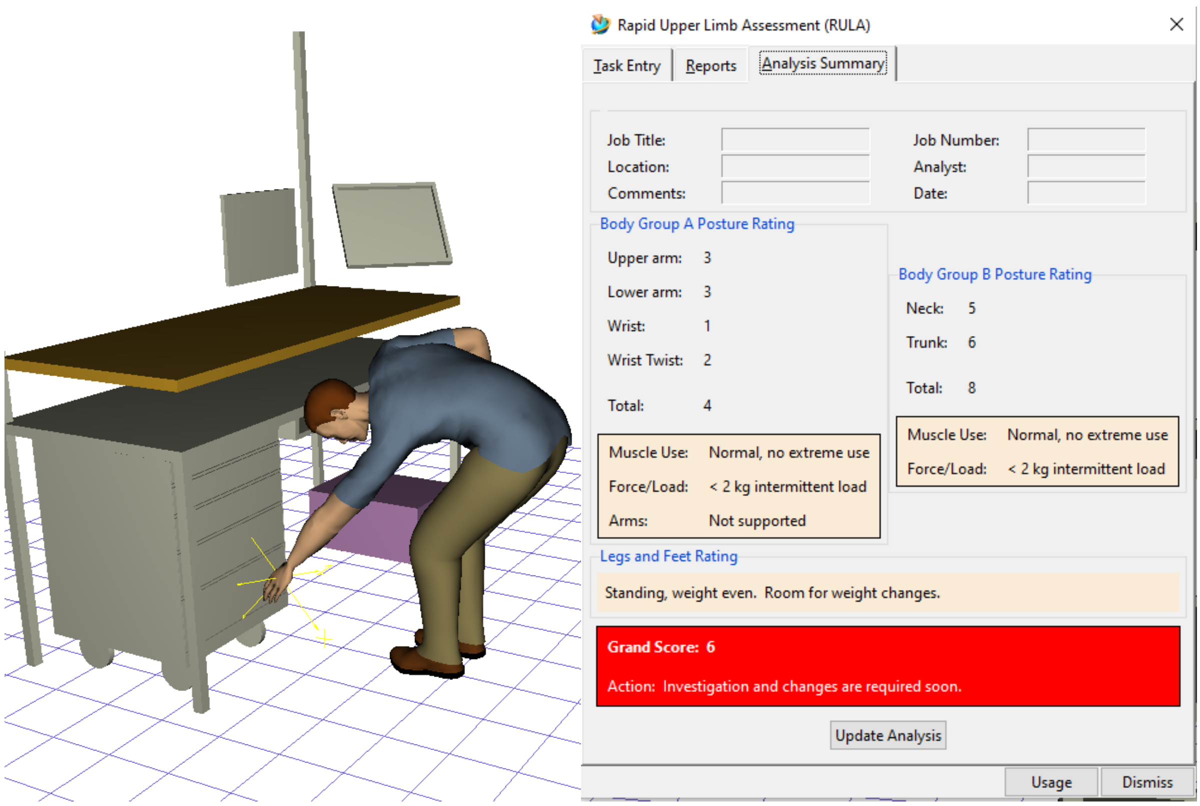
Third position – Rubbish bin – RULA grand score 7



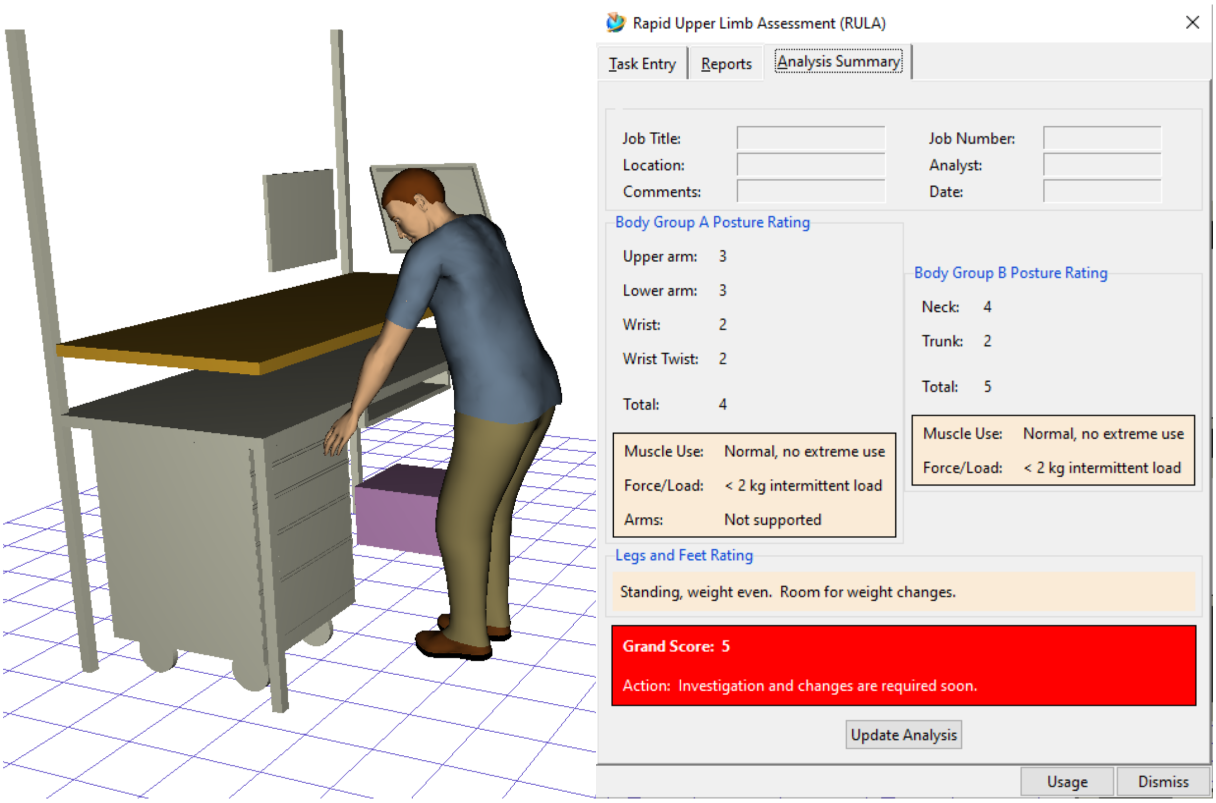
Current workstation experiment for the higher 95 percentile. Visualisation with RULA grand scores.



First position – Bottom drawer – RULA grand score 6



Second position – Top drawer – RULA grand score 5



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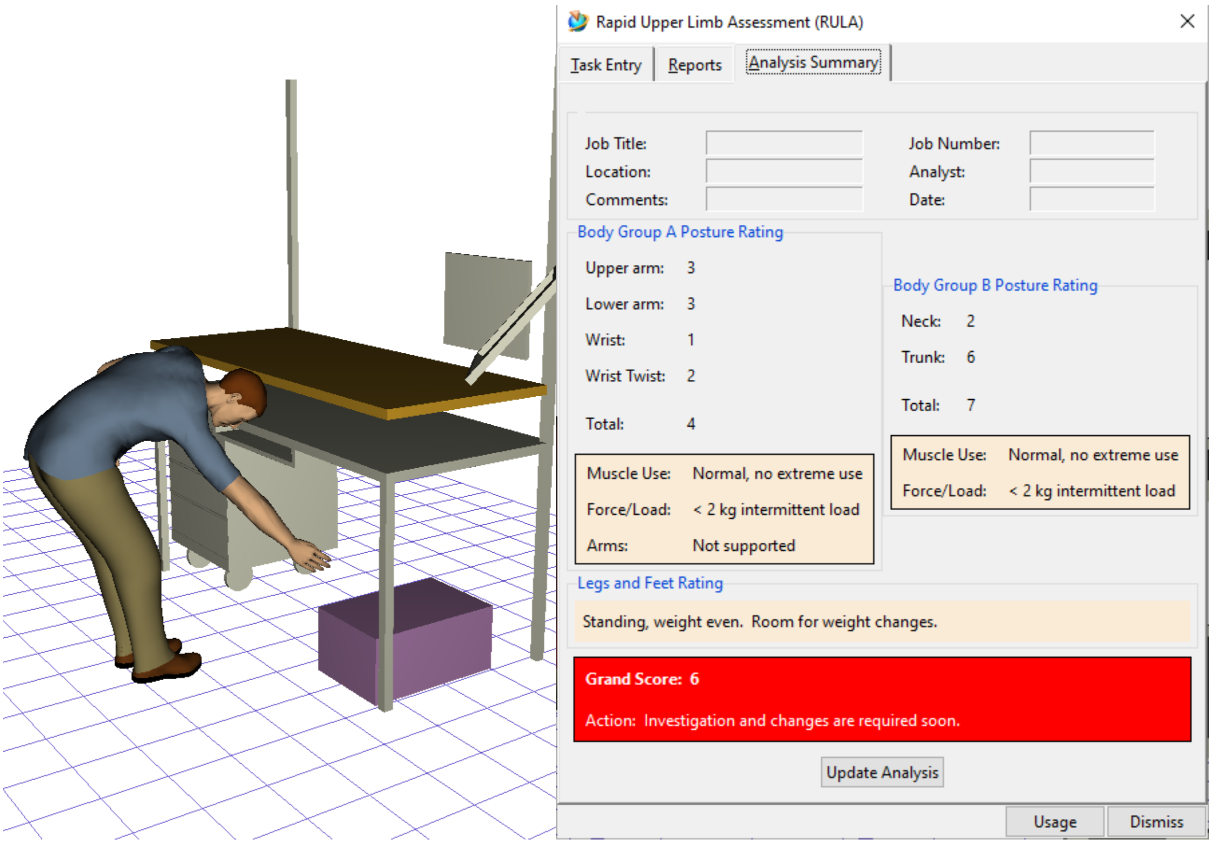
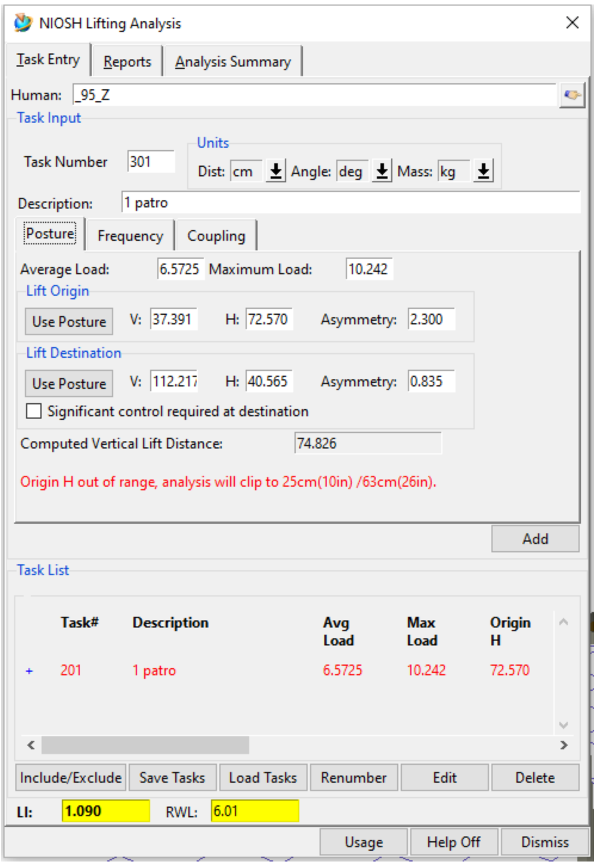
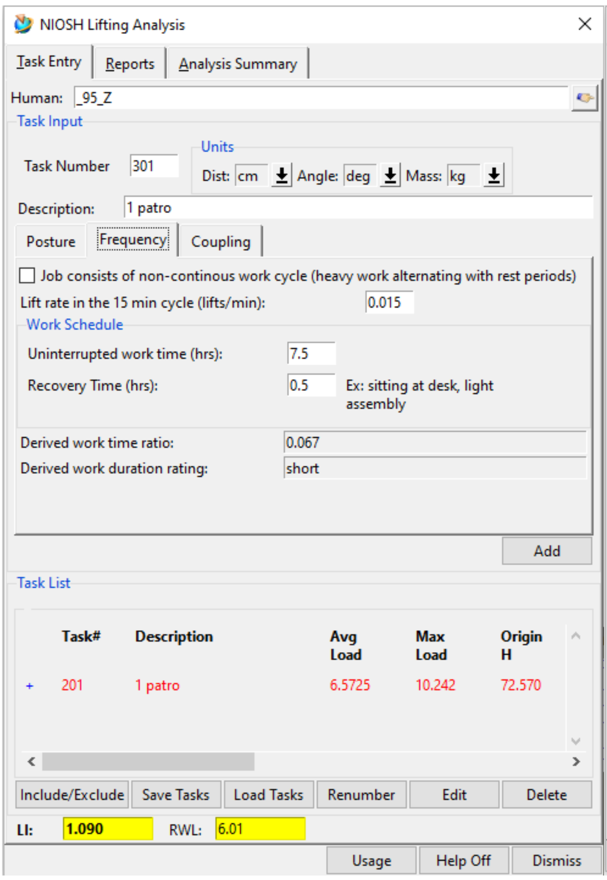
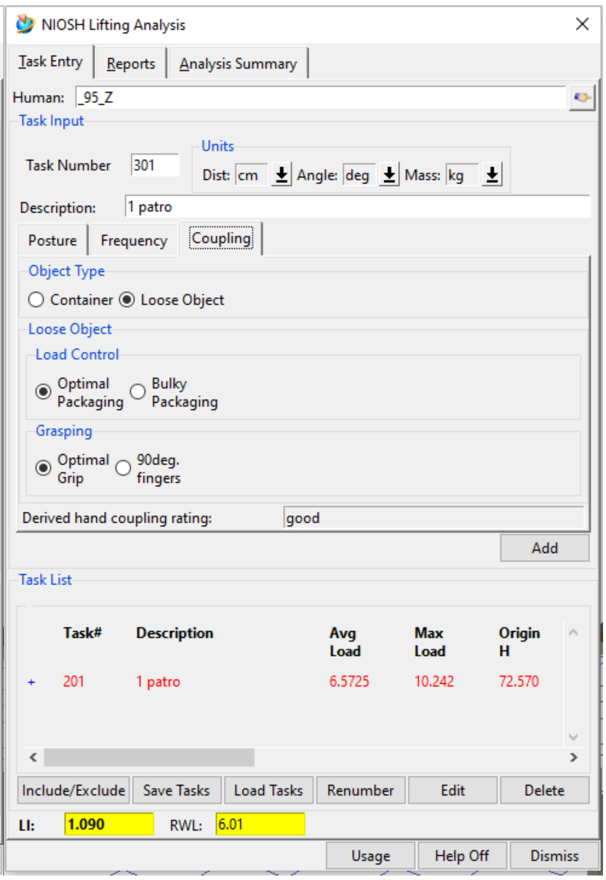


Supplement 4

Entry data of the experiments for the NIOSH analysis.

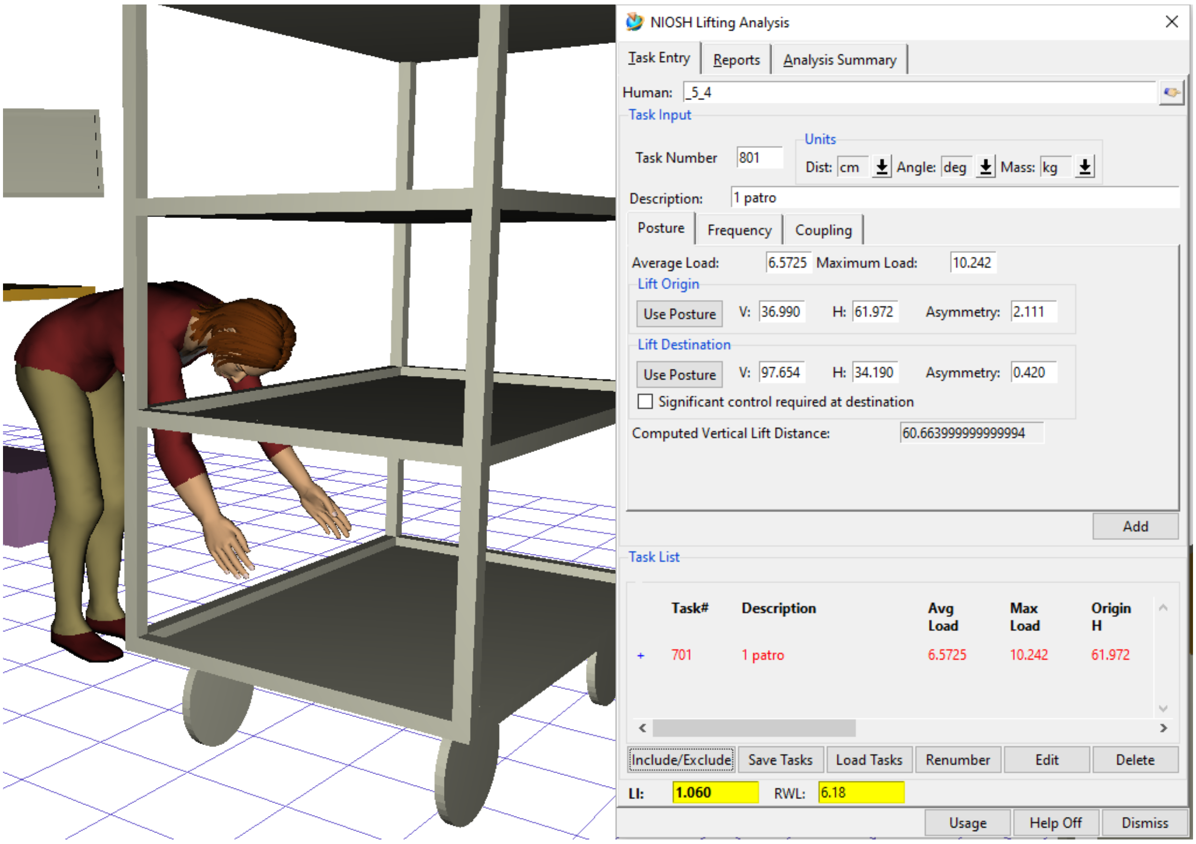




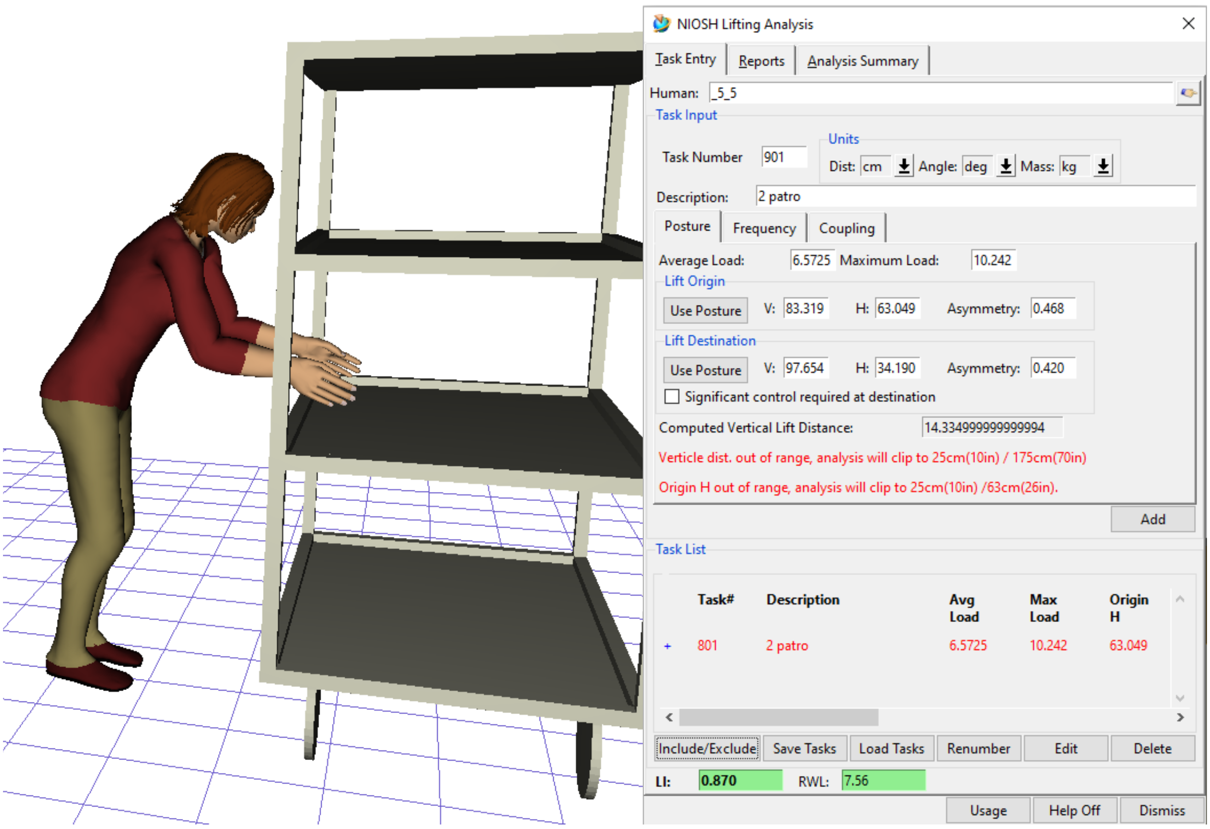


Current workstation experiment for the lower 5 percentile. Visualisation with NIOSH coefficients LI and RWL.

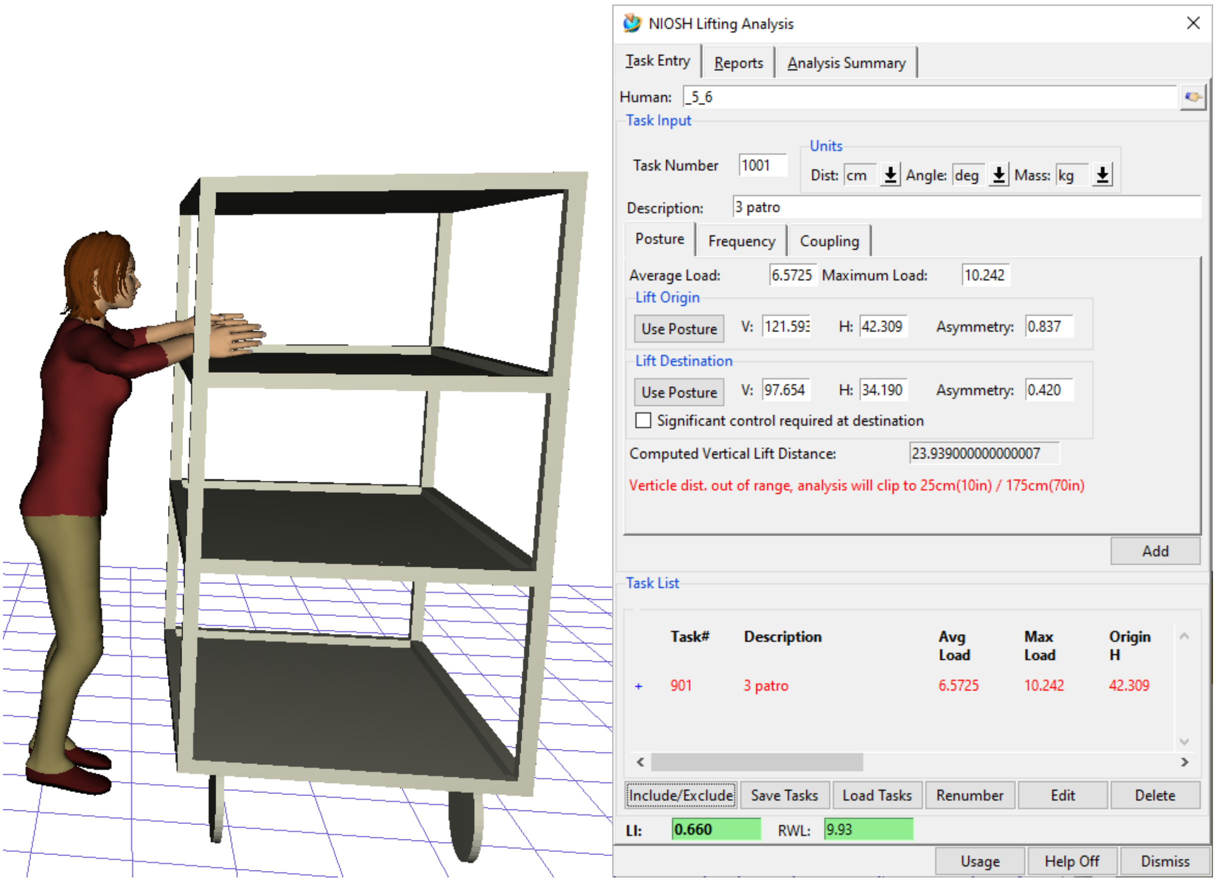
First position – Bottom level of the trolley – LI = 1,060; RWL = 6,18 kg



Second position – Mid level of the trolley – LI = 0,870; RWL = 7,56 kg

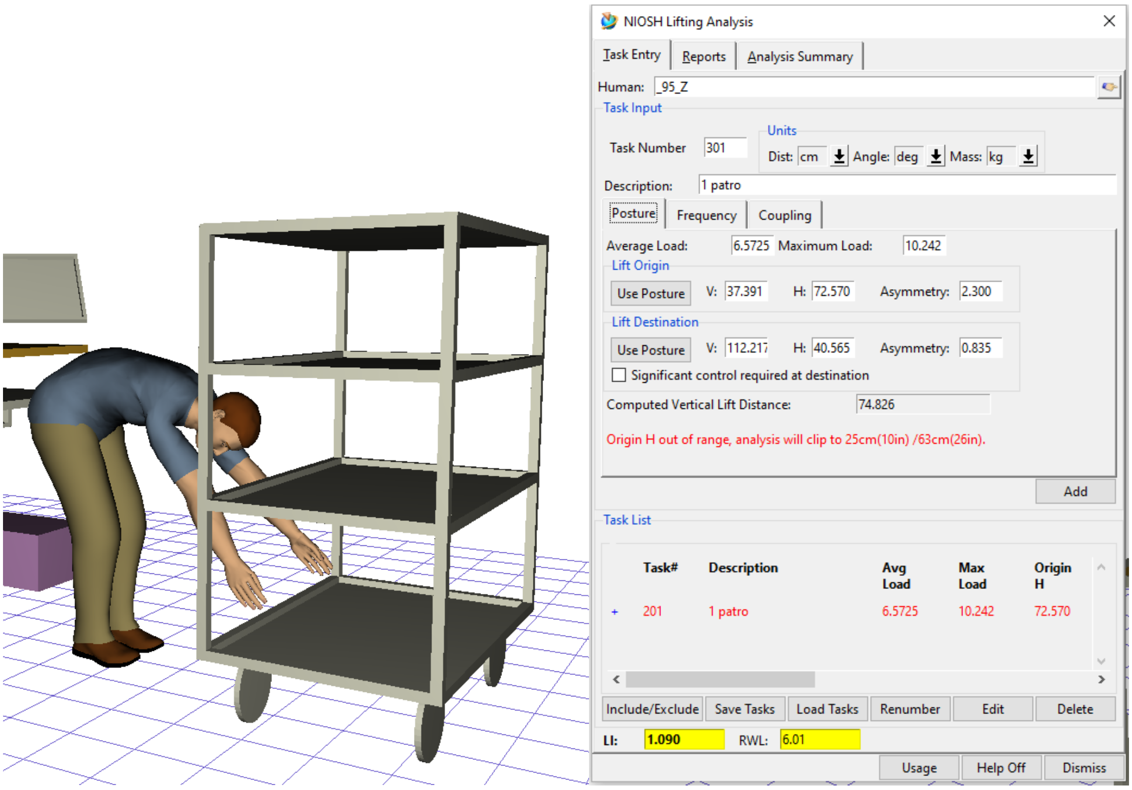


Third position – Top level of the trolley – LI = 0,660; RWL = 9,93 kg

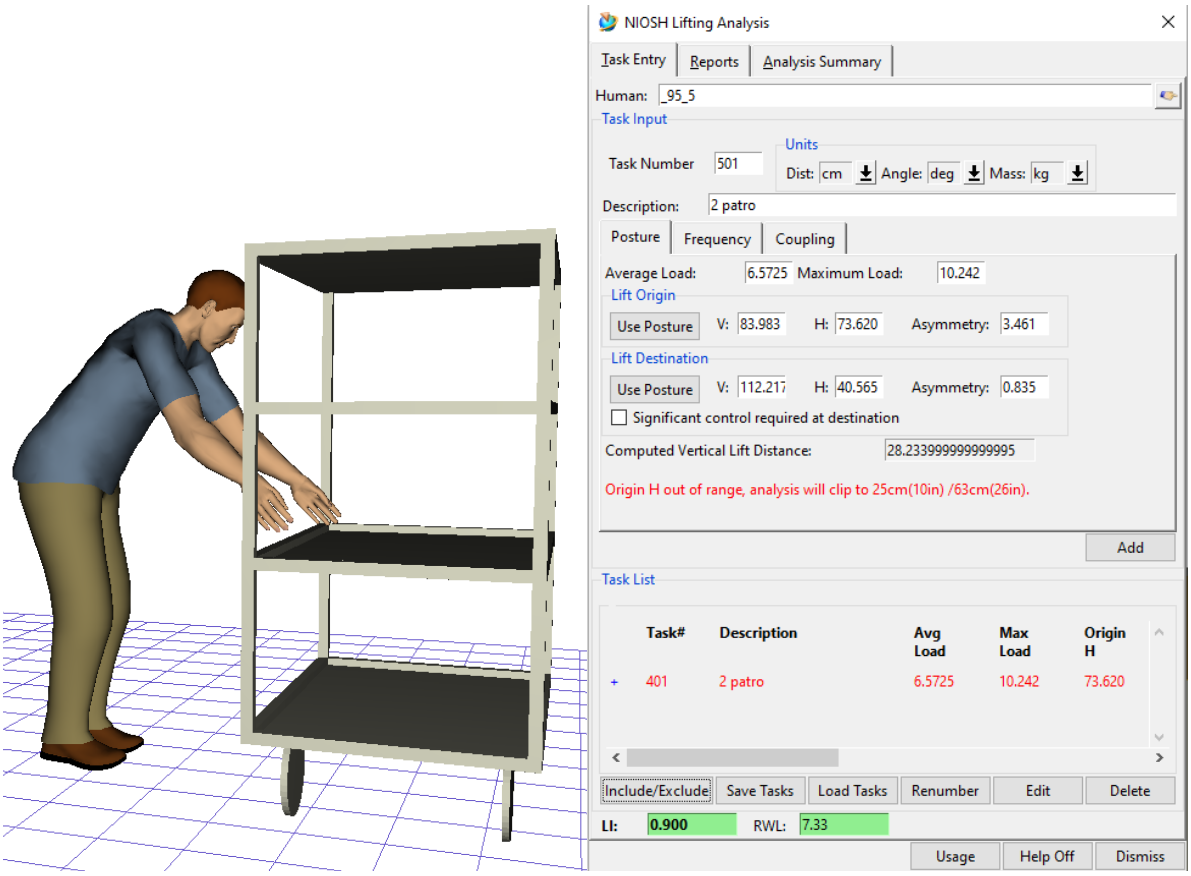


Current workstation experiment for the higher 95 percentile. Visualisation with NIOSH coefficients LI and RWL.

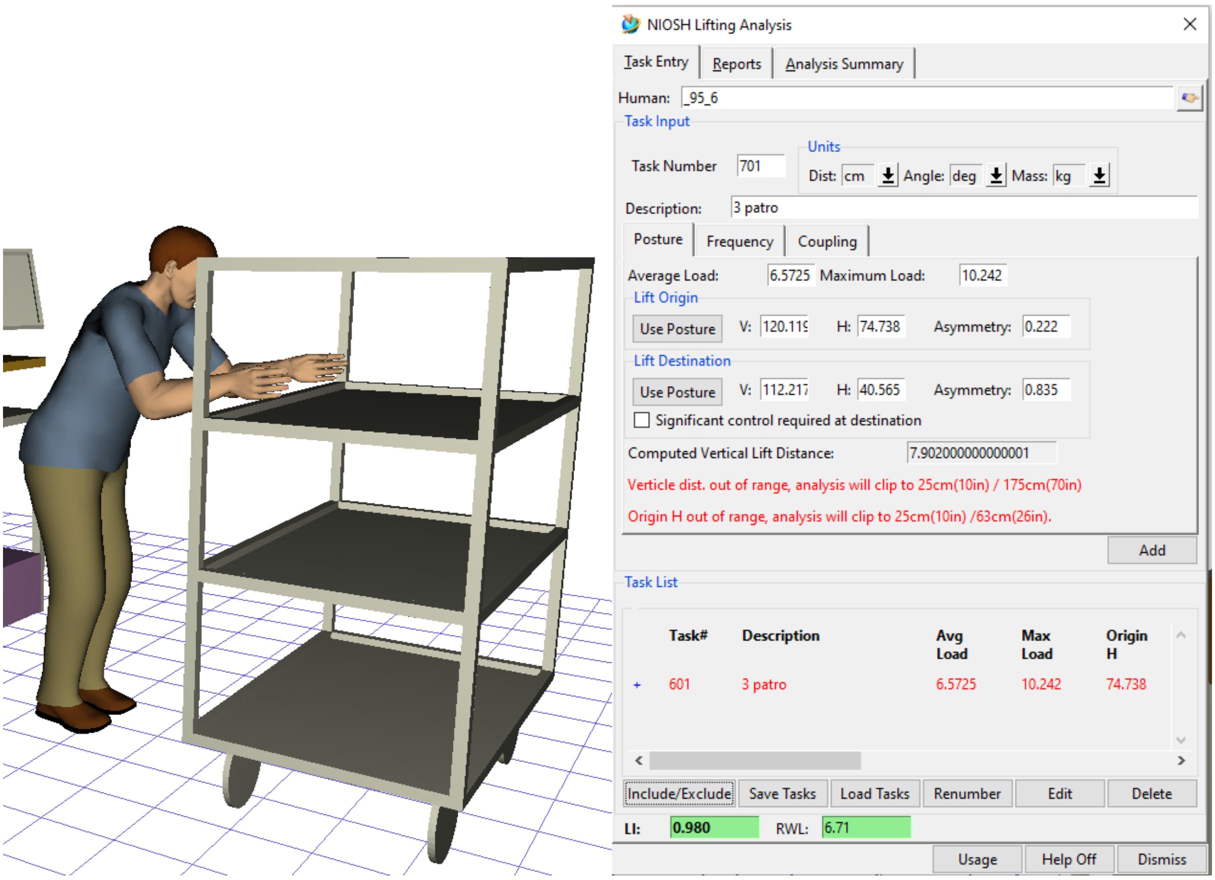
First position – Bottom level of the trolley – LI = 1,090; RWL = 6,01 kg



Second position – Mid level of the trolley – LI = 0,900; RWL = 7,33 kg



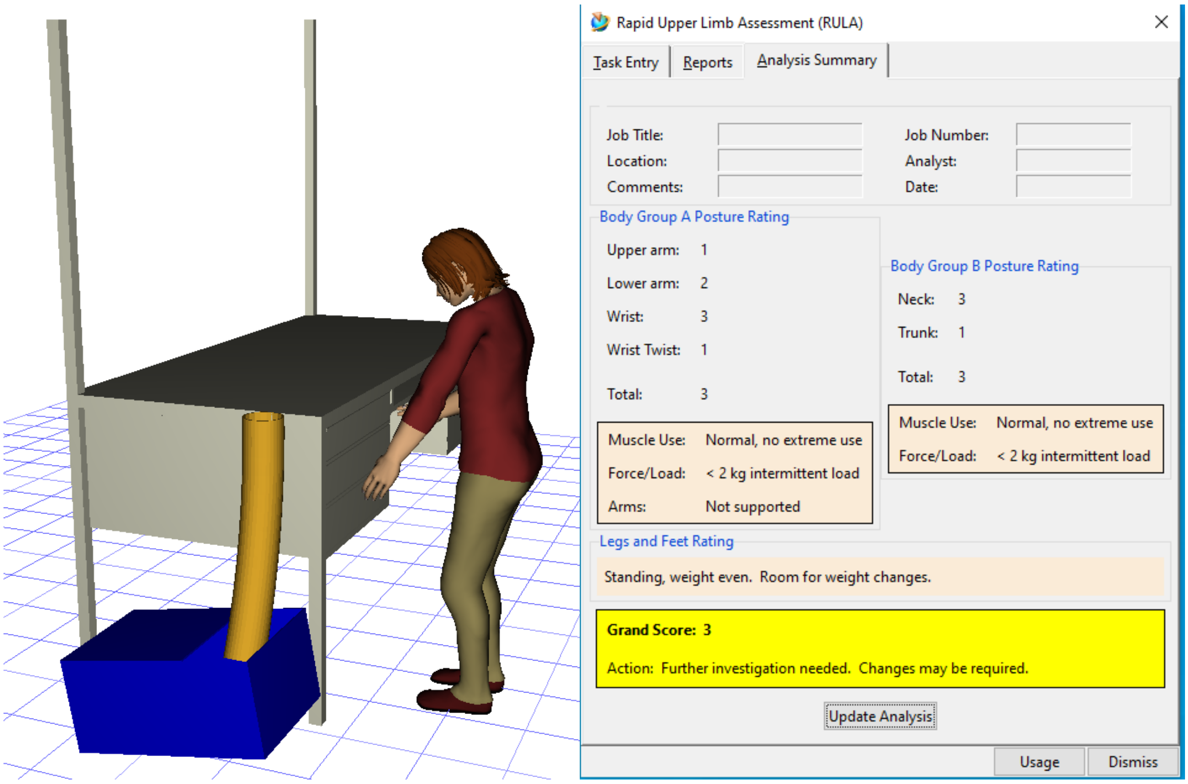
Third position – Top level of the trolley – LI = 0,980; RWL = 6,71 kg



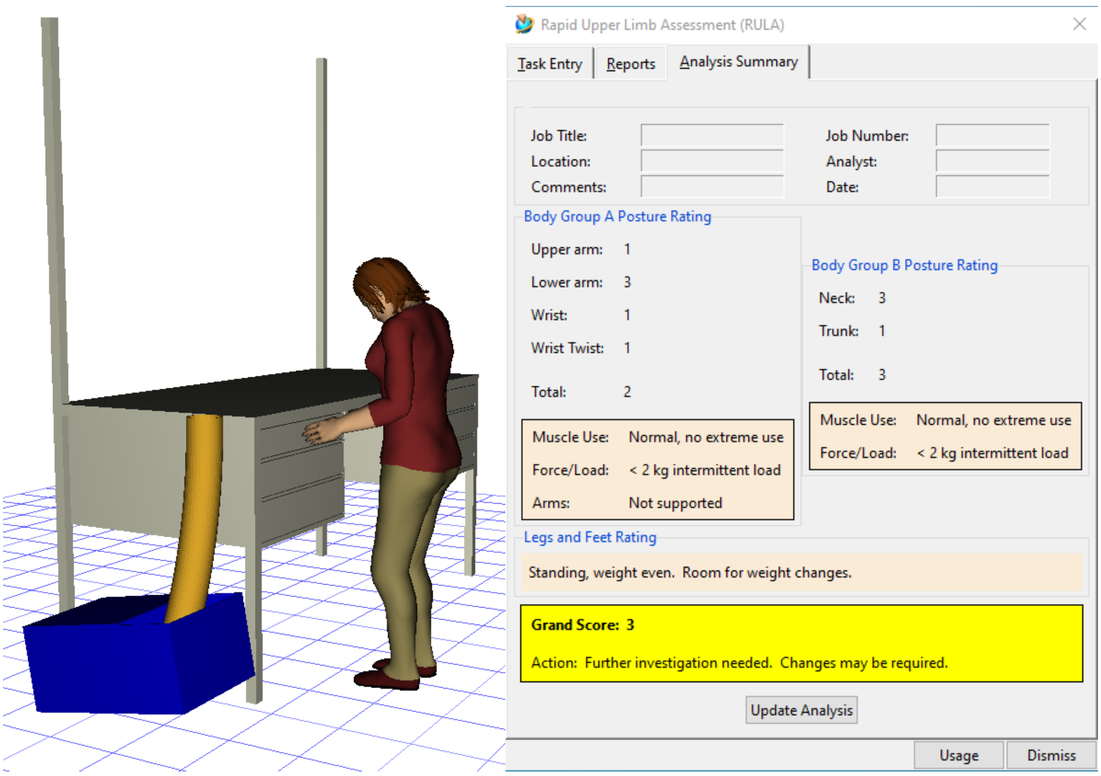
Supplement 5

Improved workstation experiment for the lower 5 percentile. Visualisation with RULA grand scores.

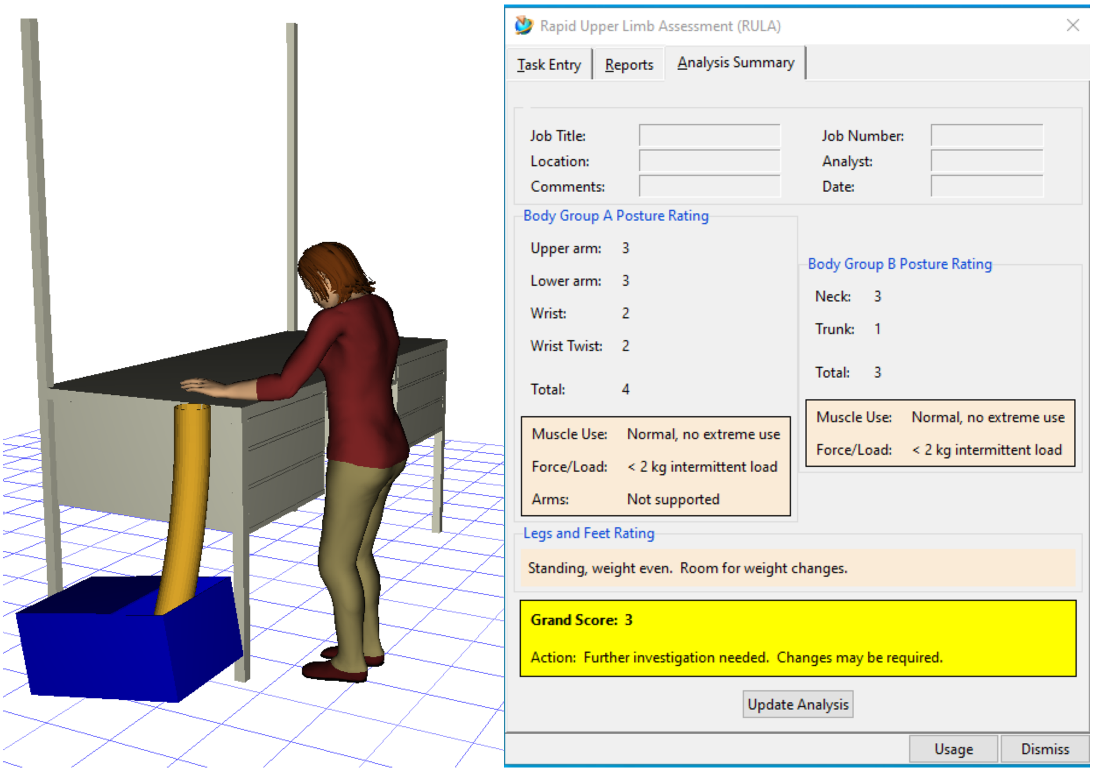
First position – Bottom drawer – RULA grand score 3



Second position – Top drawer – RULA grand score 3

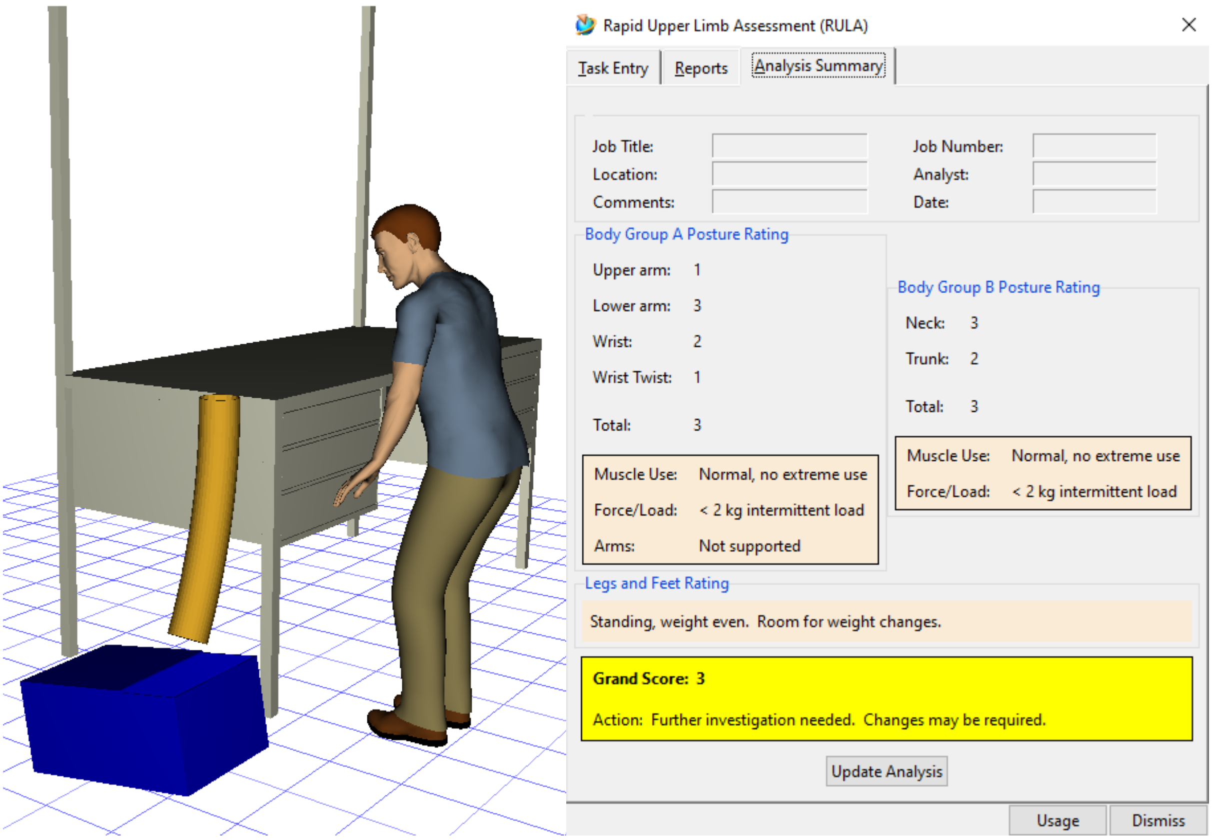


Third position – Rubbish bin – RULA grand score 3

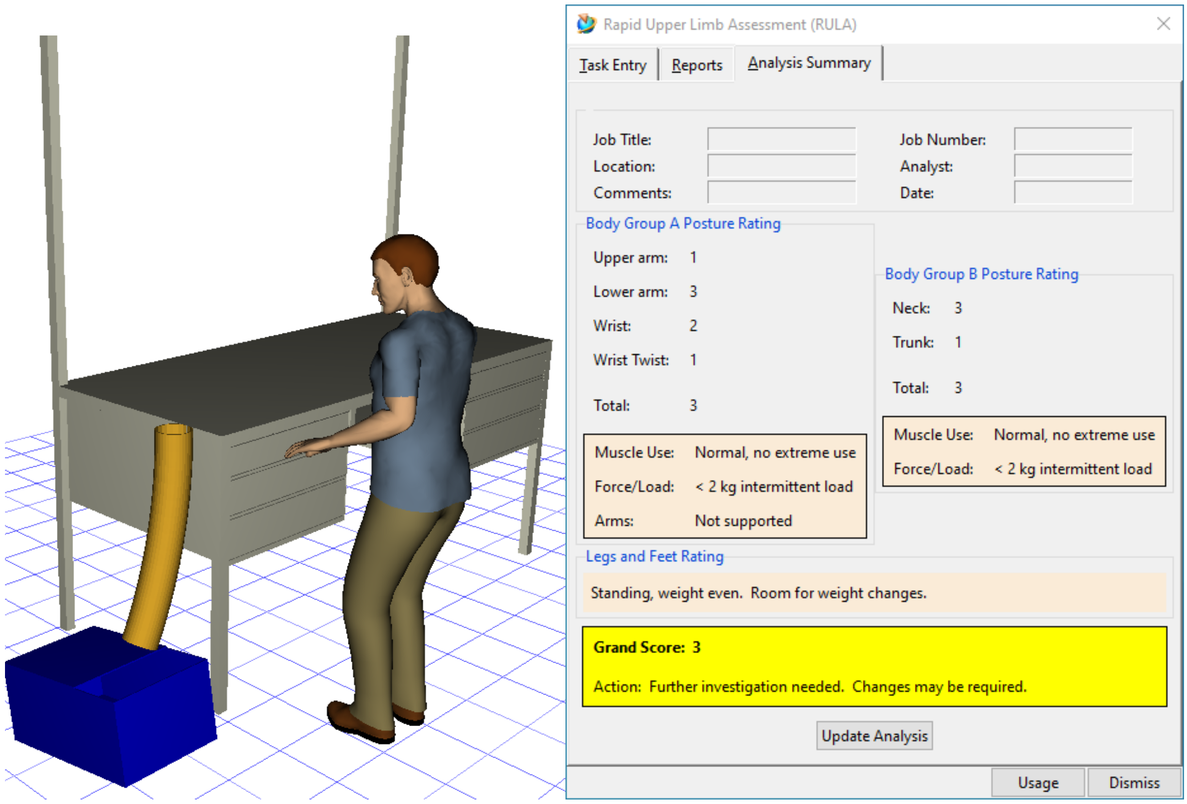


Improved workstation experiment for the higher 95 percentile. Visualisation with RULA grand scores.

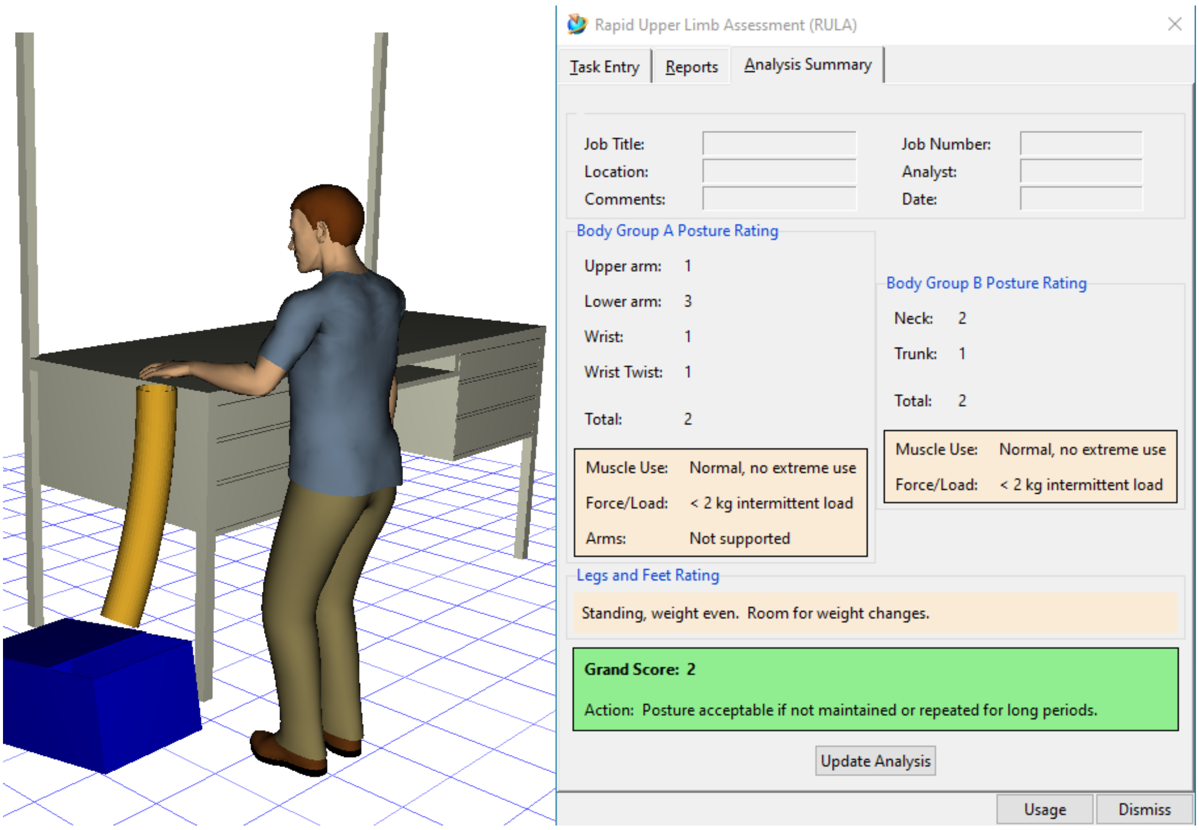
First position – Bottom drawer – RULA grand score 3



Second position – Top drawer – RULA grand score 3



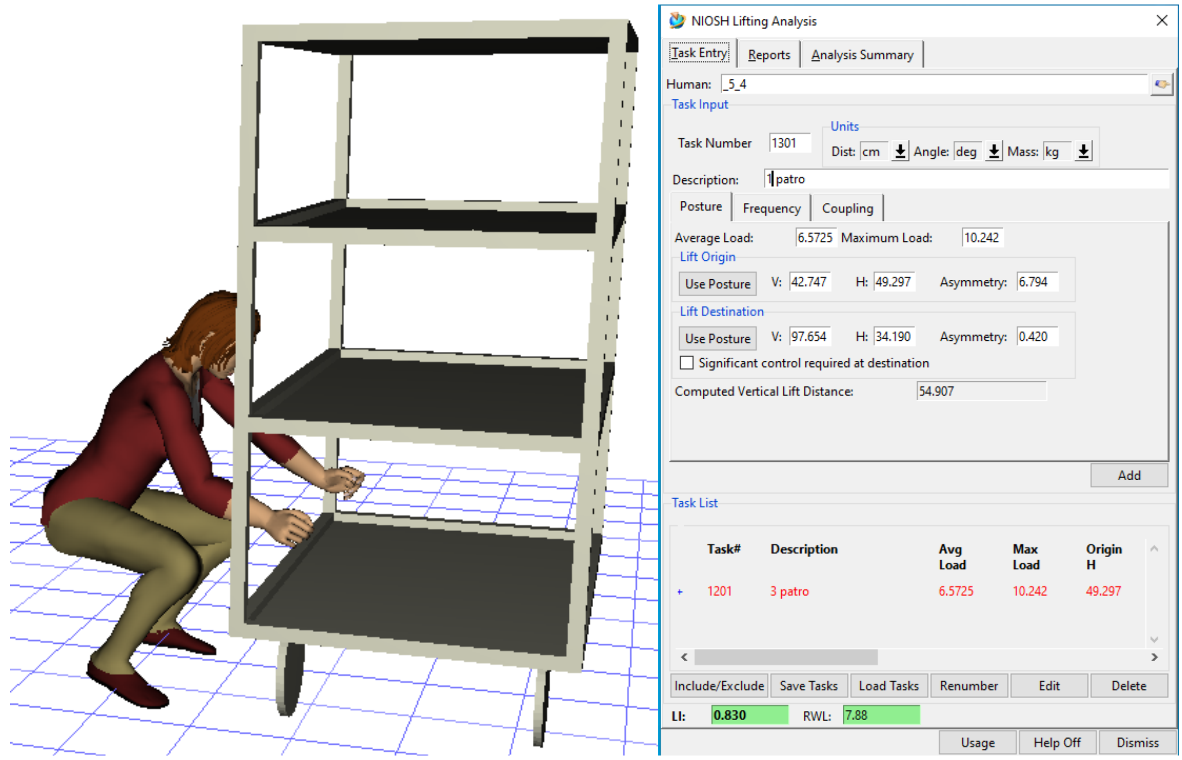
Third position – Rubbish bin – RULA grand score 2



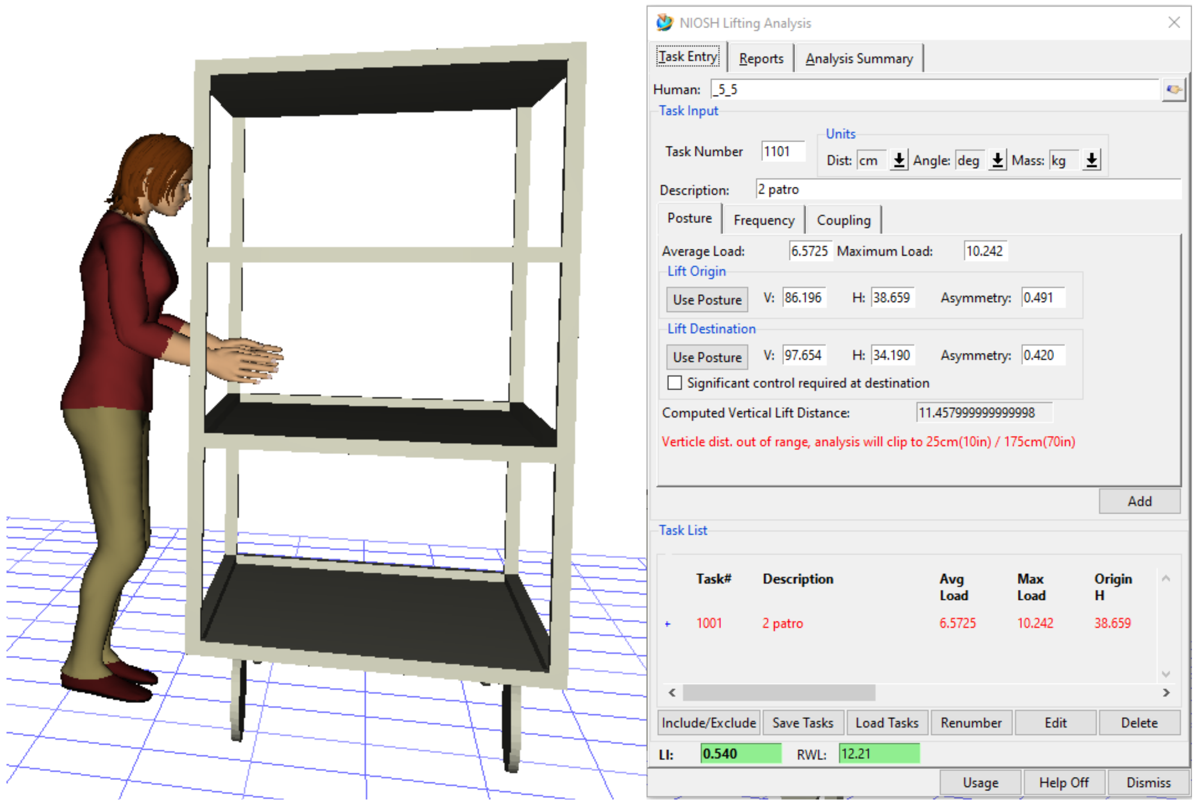
Supplement 6

Improved posture for load manipulation. Experiment for the lower 5 percentile. Visualisation with NIOSH coefficients LI and RWL. The third position is optimal.

First position – Bottom level of the trolley – LI = 0,830; RWL = 7,88 kg

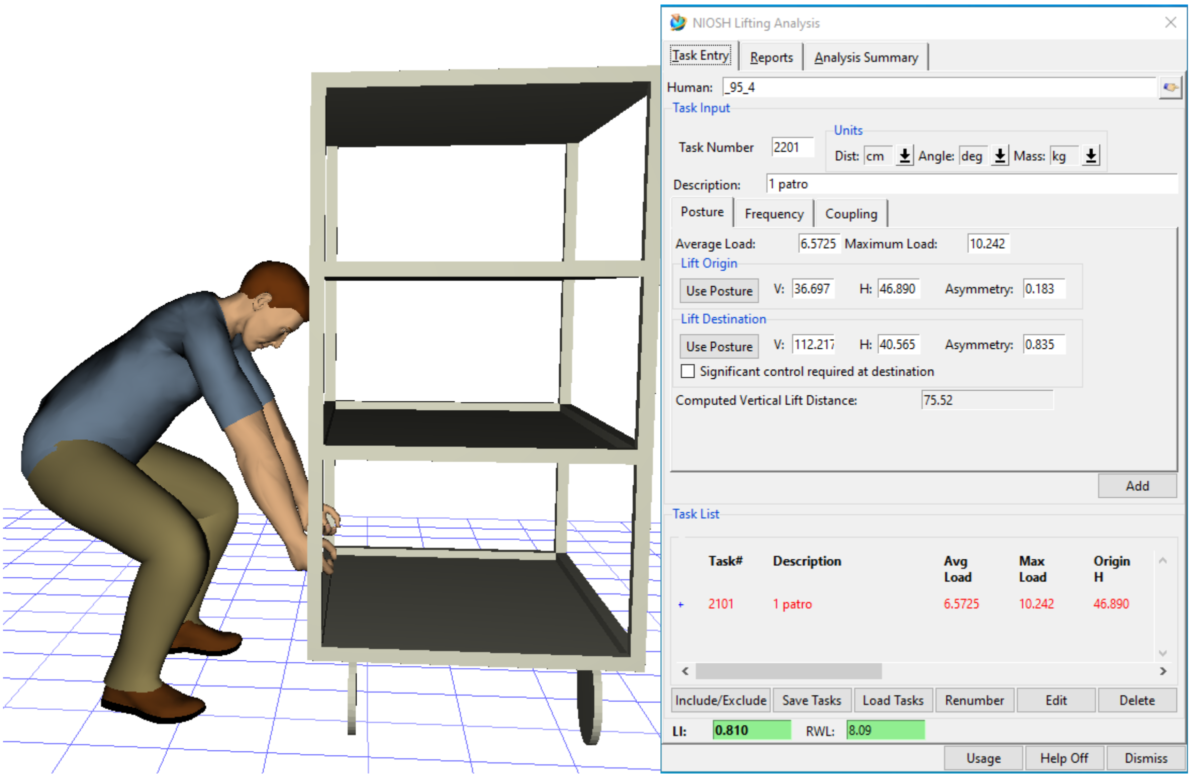


Second position – Mid level of the trolley – LI = 0,540; RWL = 12,21 kg

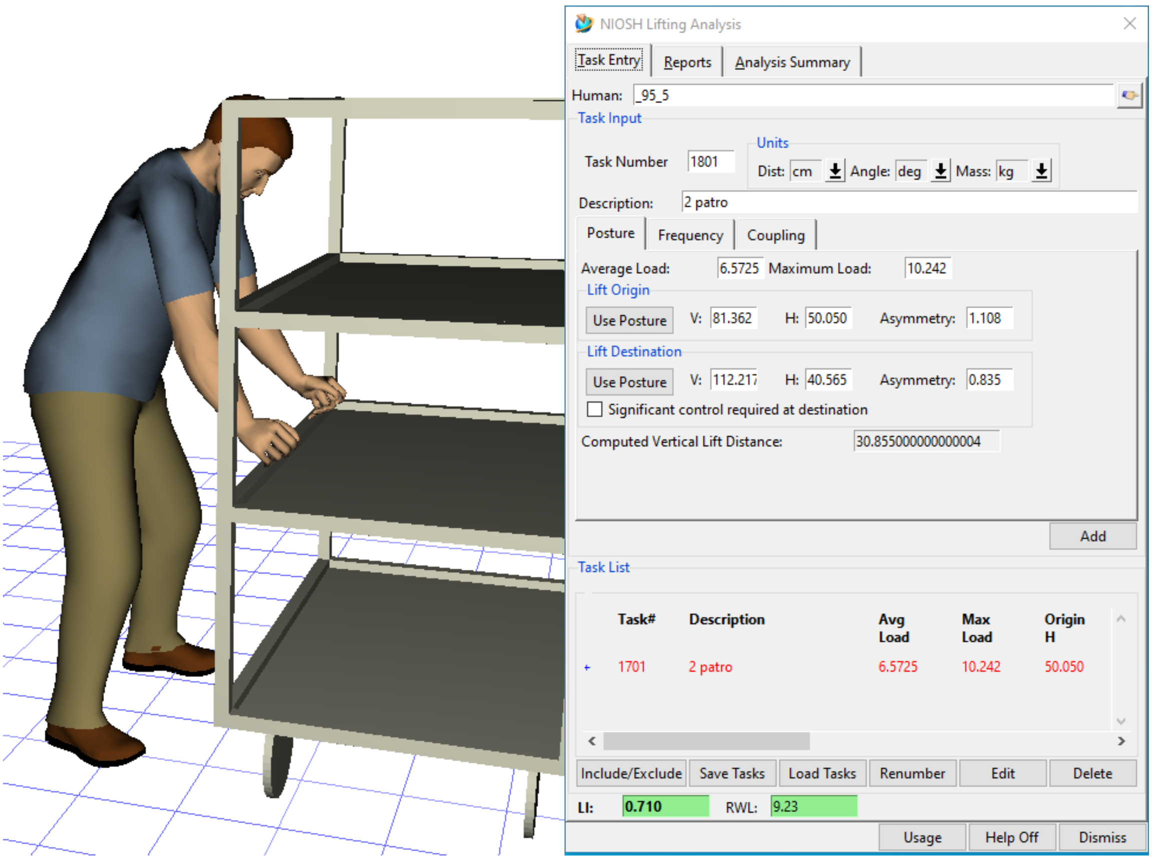


Improved posture for the load manipulation. Experiment for the higher 95 percentile. Visualisation with NIOSH coefficients LI and RWL.

First position – Bottom level of the trolley – LI = 0,810; RWL = 8,09 kg



Second position – Mid level of the trolley – LI = 0,710; RWL = 9,23 kg



Third position – Top level of the trolley – LI = 0,720; RWL = 9,14 kg