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Still Line Customer -Assembly Production Improvement

Production Economy of a Welding Department

Bachelor's Thesis
Mechanical Engineering
2025
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Hämeen ammattikorkeakoulu

Mechanical Engineering | Abstract
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Subject Still Line Customer -Assembly Production Improvement
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The thesis ordered by Bluefors Oy (hereinafter Bluefors) is to provide a new welding facility. The manufacturing process of a Still Line Customer -assembly is evaluated based on production economy. Enabling the future of quantum technology (Bluefors, 2025), Bluefors is the global leader in manufacturing dilution refrigerators that are used in research purposes in academia and notably in research of quantum computing and physics. Dilution refrigerators reach millikelvin temperatures close to absolute zero point and provide conditions mandatory for quantum research.

Parts in regular production and under development are welded. Welding department has been in a small room that has not had anything else besides welding cells in it. Machining, helium leak testing, pickling, and finishing works have been made in different facilities located not in proximity of the welding room. Welded assemblies have not necessarily been ideal for mass production. Engineering drawings for welded assemblies have been adequate for internal use but not ideal to outsource them efficiently defining critical technical features, e.g. tolerances and surface quality to ensure wanted quality level.

Main deliverables from the thesis are comparisons between old and new manufacturing processes of Still Line Customer -assemblies where manufacturing in old facilities and old equipment is compared to manufacturing in new facilities with changes, opportunities, and investments in the process. Cost differences in between manufacturing and outsourcing a DN 100 ISO-K Straight Connector and a DN 100 ISO-K Elbow 90° are compared. Payback times are presented for investments that bring savings. Total investments on the project are presented together with characteristics of the new welding facility and how it better serves manufacturing compared to old facilities.

New welding facility serves Bluefors well in the future in providing welding work conducted in-house. No further need to expand welding facilities is to be expected in the coming years. Outsourcing of standard parts is taken more to use to have welding department better serving research and development activities and to prioritize conducting challenging welding works. Simpler welded assemblies are to be expected to be outsourced more compared to the history where a lot of welding work has been conducted in-house.

Focusing on core knowledge of producing world class dilution refrigerators is where it is beneficial to use human resources in Bluefors and not to use them on producing standard vacuum components. Outsourcing frees resources to more value creating work.

Keywords Economic evaluation, outsourcing, production facility, vacuum component

Pages 38 pages and appendices 7 pages

Koulutus	Konetekniikka, insinööri (AMK)	Tiivistelmä
Tekijä	Sami Korhonen	Vuosi 2025
Työn nimi	Still Line Customer -Assembly Production Improvement	
Ohjaajat	Teppo Syrjäaho (HAMK), Veli-Jukka Kara (HAMK), Ville Hänninen (Bluefors)	

Bluefors Oy:n (jäljempänä Bluefors) tilaama opinnäytetyö on uuden hitsaamon toimittaminen. Still Line Customer -kokoonpanon osien valmistaminen arvioidaan tuotannon taloudellisuudella verrattuna ulkoistamiseen. Kvanttiteknologian tulevaisuuden mahdollistaja (Bluefors, 2025) Bluefors on maailman johtava laimennusjäähdyttimien valmistaja, jonka tuotteita käytetään tutkimustarkoituksiin akateemisessa maailmassa ja erityisesti kvanttilaskennan ja -fysiikan tutkimuksessa. Laimennusjäähdyttimet saavuttavat lämpötilan lähellä absoluuttista nollapistettä ja tarjoavat kvanttitutkimukselle tarvittavat olosuhteet.

Säännöllisessä tuotannossa sekä tutkimus- ja kehitystyössä olevia osia hitsataan. Hitsausosasto on ollut kooltaan pieni huone, jossa ei ole ollut muuta kuin hitsausasemat. Koneistus-, heliumvuototestaus-, peittaus- ja viimeistelytöitä on tehty eri tiloissa, jotka sijaitsevat hitsaushuoneen ulkopuolella. Hitsatut kokoonpanot eivät välttämättä ole olleet ihanteellisia massatuotantoon. Hitsattujen kokoonpanojen tekniset piirustukset ovat olleet riittäviä sisäiseen käyttöön, mutta eivät ihanteellisia kokoonpanojen tehokkaaseen ulkoistamiseen kriittisten teknisten ominaisuuksien, kuten toleranssien ja pinnan laadun, määrittämiseksi halutun laatutason varmistamiseksi.

Opinnäytetyön päätuotokset ovat Still Line Customer -kokoonpanojen vanhojen ja uusien valmistusprosessien vertailut, joissa valmistusta vanhoissa tiloissa ja vanhoissa laitteissa verrataan valmistukseen uusissa tiloissa. Kustannuseroa 1000 mm pitkän Still Line -putken ja 90 asteen mutkan valmistuksen ja ulkoistamisen välillä verrataan. Sijoitusten takaisinmaksuajat esitetään sijoituksissa, joissa sijoitukset nähtiin kannattaviksi takaisinmaksuajan perusteella. Hankkeen kokonaisinvestoinnit on esitetty uuden hitsaamon ominaisuuksien kanssa ja kuinka uusi hitsaamo palvelee paremmin tuotantoa.

Uusi hitsauslaitos palvelee Blueforsia tulevaisuudessa hyvin talonsisäisen hitsaustyön tarjoamisessa. Hitsauslaitoksen laajennustarvetta ei ole odotettavissa seuraavien neljän vuoden aikana. Standardiosien ulkoistamista hyödynnetään aiempaa enemmän, jotta hitsausosasto palvelee paremmin tutkimus- ja kehitystoimintaa ja priorisoi haastavien hitsaustöiden suorittamista. Ulkoistettavia osakokonaisuuksia on odotettavissa enemmän verrattuna historiaan, jossa suuri osa hitsaustyöstä on tehty talon sisällä.

Yksinkertaisten hitsaustöiden ulkoistaminen vapauttaa hitsausosaston resursseja enemmän arvoa tuottaviin töihin. Blueforsin kannattaa keskittyä ydinosaamisalueensa tuotteiden valmistamiseen ja kehittämiseen, joita ei ole yhtä helppoa eikä kannattavaa ulkoistaa.

Avainsanat Kustannustarkastelu, tuotantotila, tyhjiökomponentti, ulkoistaminen

Sivut 38 sivua ja liitteitä 7 sivua

Figures

Tables

Equations

Appendices

List of Terms, Symbols and Abbreviations

Cryohall: A manufacturing facility at Bluefors Oy where dilution refrigerators (DR's) are assembled and tested in their operation to ensure DR works as intended reaching promised eight mK base temperature.

DN 100 ISO-K Flange Weld: A rotatable welded flange used for mounting DN 100 ISO-K vacuum components together.

DR: Dilution Refrigerator. A cryogenic device that by using a mixture of ^3He and ^4He achieves without moving parts in the low-temperature region temperatures as low as two millikelvin.

mK: Millikelvin. One thousandth of a kelvin, 10^{-3}.

Ninety Degree Elbow: Sold under marketing name DN 100 ISO-K Elbow 90°. See Figure 1.

ODH: Oxygen Deficiency Hazard. "Displacement of oxygen in the air by gases released from cryogens such as liquid nitrogen or liquid helium." (Woods et al., 2019, p. 51).

PPE: Personal Protective Equipment.

Still Line Customer -assembly: A custom assembly consisting of various amount of DN 100 ISO-K vacuum components in various lengths depending on customers' needs and facility requirements for a dilution refrigerator. Assembly (Figure 1) formed using Still Line Tubes, Ninety Degree Elbows, and a T-Damper.

Still Line Tube: Sub assembly of Still Line Customer -assembly. Consisting of a 104 mm outer diameter 316L steel tube in various lengths depending on need and two rotatable welded flanges (DN 100 ISO-K Flange Weld) welded to the steel tube. Sold under name DN 100 ISO-K Straight Connector.

TIG: Tungsten Inert Gas (Arc Welding). An arc welding process suitable for stainless and acid-proof steel, aluminium, copper titanium, nickel, and magnesium, as well as these alloys (Vaissi & Huovinen, 2005/2011, p. 136). TIG welding is slower than many other welding techniques. Manually difficult to master, TIG welding offers good welding seam quality and arc penetration is small. Welding technique is used specially in automated pipe welding and in industries such as aviation, aerospace, and sheet metal industries when welding thin materials.

1 Introduction

Bluefors is the industry standard for ultra-low temperature cooling solutions used in quantum technology. Institutions in all habited continents are relying on dilution refrigerators, also known as cryostats, made by Bluefors. Industry leading companies are in close co-operation in creating and developing quantum computers for the future with Bluefors. (Bluefors, 2025)

Demand for dilution refrigerators has been growing in the past years and so does the demand for higher production numbers. Production facilities have been growing gradually in the Pitäjänmäki industrial area the past seven years and in 2026 Bluefors Campus opens its doors when plans to expand go as intended (Siippainen, 2023). To get the most out of the existing facilities methods of working and products made are evaluated and improved continuously to have a competitive product customers choose also in the future.

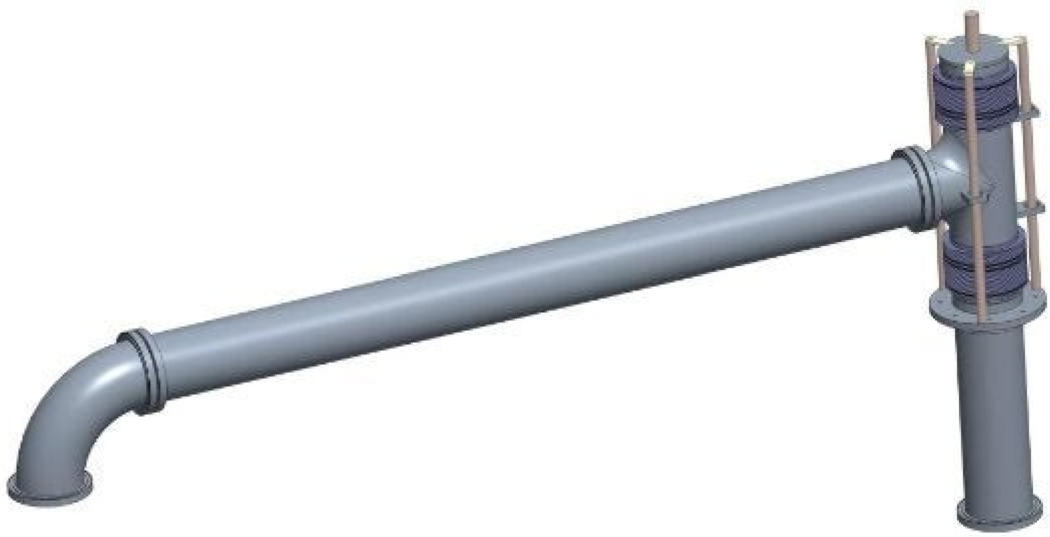
Before Bluefors Campus is constructed, existing facilities are rearranged. To get the best out of facilities project ‘Cryohall capacity increase’ began in 2023. New welding department and its moving to new facilities is a side project to free space for the Cryohall expansion. Projects are made side by side in co-operation scheduling move of welding department together with re-arranging old facilities to have more production bays for testing dilution refrigerators. By moving the welding department, the company gets four new production bays for testing and research. The thesis is made in co-operation with Manufacturing Engineering department of Bluefors, providing mentoring and weekly meetings on progress of the project on the way in planning and implementing the move of the facility.

During the time of the thesis process, I am the project manager for moving welding facility. As well as planning the new facilities for welding activities, improvements for the whole Still Line Customer -assembly production process are made considering improvement opportunities from designing to packing the ready system to the customers. Work is made in co-operation with welders and the department that uses new facilities. Improvements are to support not only Still Line Customer -assemblies but also other welding processes conducted in the welding facility. The findings are reported to further improve manufacturing process of Still Line Customer -assembly and other welding activities when seen feasible. Not all findings are implemented to manufacturing process when in the moment not seen feasible or part of long-term plans and goals of the company in developing production.

Improved and investigated areas on the project are standardizing designing practises for Still Line Customer -assembly considering logistics, storing of raw materials and parts, production methods and technical solutions that influence lead time of the produced assembly and savings coming from lower number of work hours needed. Outsourcing opportunities and comparing this to producing Still Line Customer -assemblies in-house are investigated. Data is collected and produced to support evidence-based decision making to better justify investments and process changes. Calculations provide data on making decisions on whether outsourcing is an opportunity on the side of in-house manufacturing and under which conditions.

Still Line Customer -assembly in its basic form in Figure 1. Due to customer needs modifications to it can drastically influence its length, orientation of different components and custom features. Function of the assembly is to be a channel for helium from gas handling system to the cryostat. The assembly in the figure consist of two DN 100 ISO-K Straight Connectors in two different lengths, a T-Damper in between straight connectors which is not part of thesis works scope, and a DN 100 ISO-K Elbow 90°. Not shown in the figure but part of the assemblies are corrugated hoses in sizes DN6, DN16, DN25, DN32, DN40 and DN50. Corrugated hoses are cut to required length according to Still Line Customer -assembly length and have in their ends welded connecting ports. Number of hoses depends on the configuration of a dilution refrigerator system.

Figure 1. Still Line Customer -Assembly



2 Still Line Customer -Assembly

Welded, unannealed and pickled stainless-steel tube 104.0 x 2.0 EN 1.4404 AISI 316L (Kimet, 2025) is the base material for DN 100 ISO-K Straight Connector. Material 316L is used instead of regular stainless steel 304 due to it being non-magnetic and thus preferred choice in a dilution refrigerator. Inside diameter of steel tube is 100 mm. Steel tubes at the both ends are equipped with rotatable welded flanges, named DN 100 ISO-K Flange Weld, that are jointing surfaces to connect individual Still Line Tubes together using various amounts of double claw clamps, DN 100 ISO-K Double Claw Clamp, Zn plated Steel. In between rotatable welded flanges are sealing centring rings.

Short standard length DN 100 ISO-K Straight Connectors are readily available from many suppliers and on request custom lengths are manufactured. Vacuum leak rate of parts used in Still Line Customer -assembly, and vacuum components in general, is required to be HV <1x10-8 mbar l/s. This means in practise a vacuum component that is helium leak proof and passes quality inspection in a leak test where helium is used as a test gas. Dilution refrigerator uses a mixture of ^{3}He and ^{4}He and thus system needs to be leak free to be functional.

Figure 3 illustrates a DN 100 ISO-K Straight Connectore in length of one meter and its technical characteristics as when bought from most suppliers. Welding operation symbol 142 according to standard SFS-EN ISO 4063:2023 means autogenous gas tungsten arc welding using inert gas (SFS-EN ISO 4063:2023, p. 3). Welding filler material is not used in this welding process as filler material is available in DN 100 ISO-K Flange Weld in its geometry.

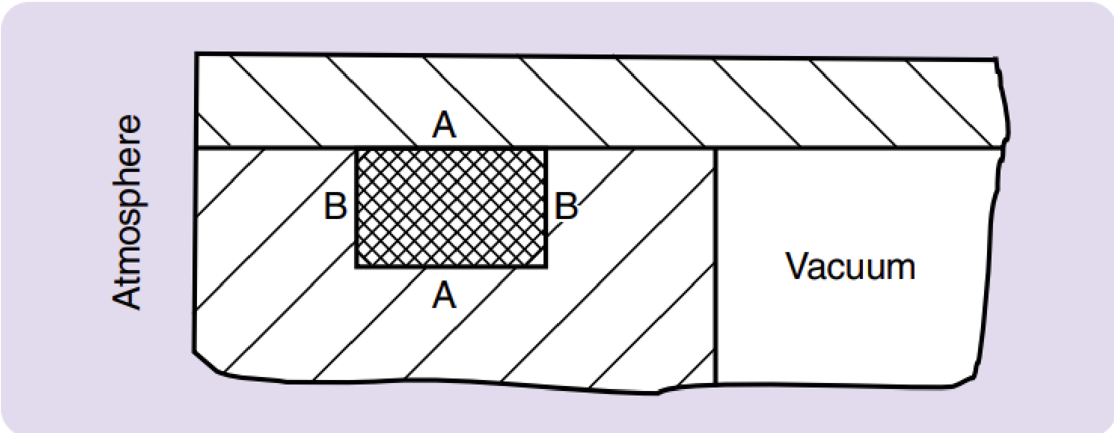
Using a surface roughness meter Ra1.6 is measured from an example outsourced DN 100 ISO-K Straight Connector tube surface being a visual surface. For a good visual quality, this good surface quality value is not mandatory and values up to Ra6.3 provide an esthetical finished surface. According to visual look compared to different machining techniques surface quality has been achieved by plain grinding. Being a vacuum component, surfaces of rotatable welded flanges that seal surfaces where O-rings have a groove are needed to be in good surface quality. Figure 2 shows a table and a visualization of sealing surfaces from *Parker O-Ring Handbook*. Values in between Ra0.4 and Ra1.6 all around vacuum gland provide good sealing surfaces for O-rings to ensure the needed leak rate of HV <1x10-8 mbar l/s. Higher Ra -values up to 6.3 can be used in gland flanks. (Parker Hannifin Corporation, 2021, p. 66). Values are valid in the use of designing vacuum components.

Figure 2. Surface Finish of Vacuum Gland

Surface Finish of Vacuum Gland

	Surface Roughness of Vacuum Gland Load Area t_p > 50%			
	A Contact Area		B Gland Flanks	
	R_a	R_{max}	R_a	R_{max}
Vacuum	0.8	3.2	1.6	6.3
to 10^{-8} Torr	0.4	1.6	1.6	6.3
to 10^{-11} Torr	0.10	0.40	1.6	6.3

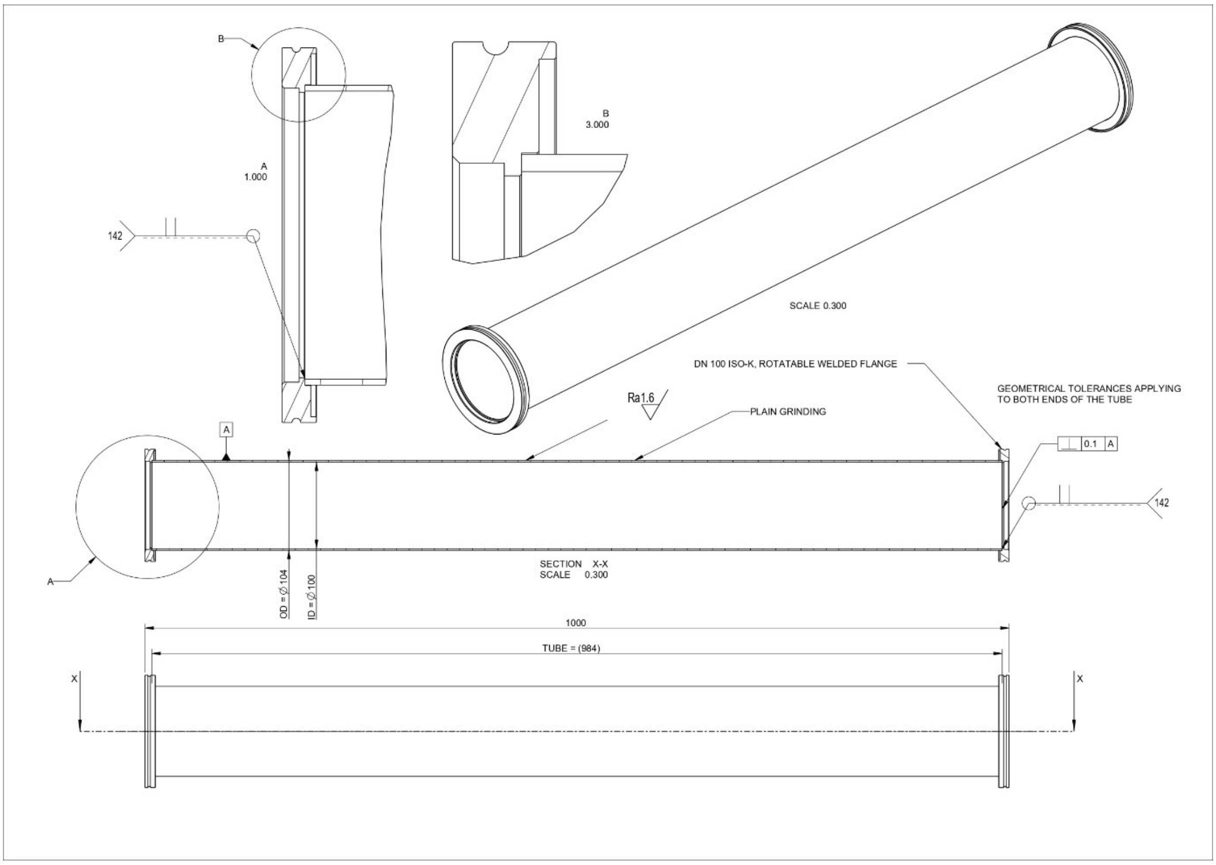
Table 3-20 Surface Finish of Vacuum Gland (See also Figure 3-9)



Plain grinding is not conducted in-house and steel tubes are left with a raw material surface. Visually raw material surface on the steel tube has been seen adequate for the assembly and visually a better surface has not been machined. Suppliers and manufacturers of vacuum components offer DN 100 ISO-K components at least machined (plain-grinded) and sand-blasted on visual surfaces. On request different finishes to tube outer surfaces are available to meet needs for visual quality.

Concentricity requirement is for guiding on cutting with an adequate sawing value steel tube raw material 104.0 x 2.0 EN 1.4404 AISI 316L to ensure ready Still Line Tube is straight enough in use. This and other characteristics given to internal production to guide on manufacturing the products on required quality to have functional components.

Figure 3. DN 100 ISO-K Straight Connector, 316L in Length 1000 mm



Still Line Tube in Figure 3 is available under marketing name DN 100 ISO-K Straight Connector. Material is 304 or 316L depending on requirements and length is commonly in between 200 and 1200 mm. Still Line Customer -assemblies have commonly plenty of custom length tubes depending on the laboratory layout and other requirements.

3 Objective and Purpose

The first goal of the thesis is to create a welding facility that ensures a lean manufacturing process where work safety and logistics are considered. The facility and equipment should provide an environment where Still Line Customer -assemblies can be manufactured better and financially in a more economical way than previously. Differences on old and new manufacturing processes are compared. Welding facility layout is left out from reporting but is discussed internally with the department manufacturing welded assemblies in it to achieve a functional layout that ensures the manufacturing process flow as well as possible from the very beginning. Considered are supply of material inside, storing solutions and their locations inside the facility, welding cell’s locations and needed material resources for welding work, and facility related needs to conduct manufacturing work successfully, i.e. electricity requirements, work safety influencing solutions, and renovation to be made before moving welding department to new facilities.

The second goal is to find ways to manufacture Still Line Customer -assemblies in a more economical way than has been manufactured previously. Methods include manufacturing engineering considering flaws in the design of the product, manufacturing process from start to finish, logistics and storing methods, and investigating automation possibilities for the welding process. Outsourcing opportunities are investigated to get data for price comparison in-between assemblies made in-house and outsourced. Technical design is observed to find solutions that provide value on degreasing manufacturing costs and giving possibility for automation in welding process.

4 Planning, Implementation and Description of Output

An improvement on projects conducted in Bluefors has been taken to use year 2023 in form of a common project model that can be implemented to all projects in the company. Practises in the project model are widely used in industries following best known practises to conduct projects, giving project after project common deliverables ensuring certain level how projects are managed.

Bluefors project model follows similar principles like most common project models used in manufacturing industry to conduct a project from the beginning to an end with same project steps that guarantees every project has certain same deliverables. Deliverables are not dependant on individual Project Manager but on the agreed project model that is used.

4.1 Bluefors Project Model and Moving of Welding Department

The project is conducted using a Bluefors project model. Project sizes are in three categories. These are small, medium, and large projects. Size is determined on the amount of personnel involved that includes all stakeholders who are affected by changes that come from the project and budget amount. The size of the project corresponds to the number of ‘Gates’ where planning, ideas, budget, observations, and from these reporting is done to the steering group and necessary stakeholders to whom it is mandatory to report on the progress and needed actions. The number of gates in a small project is four whereas in a big project there are seven gates. Every gate has certain deliverables that must be met before a steering group meeting is held, gathering steering group members and other stakeholders who need to be informed on results and deliverables. Acceptance to move forward in the project is given by the steering group.

The project for moving welding department is named ‘Weld Large Move.’ Coaching for the project includes Lean manufacturing methods to give tools to analyse current situation and comparing it to the results. These tools are used to analyse how the welding process in-house for Still Line Tubes is improved. Results are relatable to any welding work conducted in the welding department. Project related material and notes are stored in company’s Project Management Office (PMO) for future reference on projects that are related to the new welding department or areas covered in the thesis work.

Steering group consists of Operation and Supply Chain directors and managers. Business side is presented in form of a Business Controller. Steering group accepts and denies projects moving forward. Budget for investments is accepted by the steering group. For this thesis and project ‘Weld Large Move,’ project size is chosen to be small based on a small budget needed for investments and the number of stakeholders being low.

4.2 Cryohall Capacity Increase Project

Moving welding department to new facilities is one of many smaller projects connected to the bigger project ‘Cryohall capacity increase.’ All these projects support future growth and demand to grow the number of assembly bays by thirty in the existing production facilities in Helsinki. By doing changes to existing production facilities, i.e., by moving welding department to new facilities and doing layout changes in between current manufacturing departments, production capacity is increased to better meet the future needs of growing dilution refrigerator market.

Due to rapid growth of Bluefors in the past years, production facilities have been needing regular observation to keep facilities capacity to manufacture on an adequate level. In year 2020 a new Cryohall and facilities for manufacturing departments were completely renovated from old facilities running manufacturing operations at the same time in old facilities. Needs for facilities have changed for manufacturing departments.

5 Implementation and Results of the Study

By moving welding department to new facilities, capacity in the Cryohall is increased giving the space that previously was used for welding operations for testing of dilution refrigerator systems. Old welding area provides space for testing four DRs at the same time. These facilities serve future needs for the next couple of years including other operations that are moved to new facilities for the same reason it was decided to move the welding department. New welding facility is in a different building compared to the old place and is separated from the packing area where ready products are packed. Previously manufacturing Still Line Customer -assemblies and other welding work was conducted in the same building.

From the point of lean manufacturing methods, the process of manufacturing Still Line Customer -assemblies is now conducted in a smarter way combining logistics, handling, cutting, welding, testing, and cleaning of produced assemblies in the same room. Parts are no longer moved between different rooms because machineries and other equipment were not available in proximity. Parts are no longer moved from one manufacturing floor to another between process steps. Placement of equipment for different operations are organized in a better manner decreasing time in between process steps. When welded assemblies fail a leak test, they can be repaired before moving forward in production. Old and new manufacturing processes are presented in Chapters 5.3 and 5.4.

Work safety has been improved by ordering bigger quantities of corrugated hoses in full wooden drums that can be placed with ease to a storing solution designed especially for the purpose. Previously two people were placing DN6 and DN40 corrugated hoses in wooden drums to their place to old storing solution but now one person can perform this task with ease safely. Storing method was not working ideally increasing risk of injuries to personnel handling wooden rolls. New storage solution shown in Figure 4. Old shelf for corrugated hoses ordered in cardboard boxes shown in Appendix 1. In same Appendix also shown old design for storing wooden drums that was working as the basis on improving design for more user-friendly storing solution taking work safety aspects better into consideration.

On the side of improving work safety, ordering more reasonable amounts of corrugated hoses gives significant savings as unit price for hoses drops down drastically. Financial reason behind investment in Chapter 5.3.2 *Shelves for Corrugated Hoses*. Procurement department is informed on the opportunity to have savings by ordering minimum order amount of a one full wooden drum of corrugated hoses, in all sizes, used in manufacturing Still Line Customer -assemblies and in other welded assemblies.

Figure 4. Shelves for Corrugated Hoses

5.1 Welding Facility

New welding facility has adequate amount of space for future needs. All materials have functional storage space nearby workstations. Increasing welding cell amount from two to three provides required amount of welding stations serving in-house manufacturing needs for many years.

Work shifts and working time being not part of the project but influencing manufacturing capabilities and future possibilities of in-house manufacturing, worth mentioning is change in work time model in Bluefors. Previously work has been made in one morning shift and using over time to fill acute need of extra work. As a result from change negotiations, three work shifts are possible in production. Evening work is taken to use where manufacturing facilities and number of workers cannot be increased in the demand of increasing production. Potential three working shifts make it possible to better use existing facilities. As of February

2025, possibility to use more than one working shift has not been taken to daily use in the welding facility. Occasional second shift has been used when seen necessary.

5.2 Work Safety

Manufacturing steps of Still Line Tubes involve common work safety hazards like injuries to eyes due to metal chips or burns caused by welding arch. Handling of cut steel tubes presents a risk of cutting fingers to burrs. Pickling process involves chemicals that cause skin irritation and risk of eye injury is present.

New welding facility has personal protective equipment (PPE) readily available in its own shelf that is being regularly filled by the supplier of these consumables. New supply is brought weekly to keep all safety equipment available for use always when needed. The company provides for everyone PPE but if, for some reason these are missing, temporary single-use safety equipment is always readily available to avoid situations where an individual potentially would be neglecting required safety measures when conducting working duties.

Work safety is too easily taken for granted. Progress has been happening over the past decades but one does not need to go long back in the history to find examples when work safety was not on the same level where it is nowadays, often due to lack of better knowledge. Work safety in industrial work like in welding has seen vast improvement over the decades. As risks of welding work on human health are well known risks can be mitigated well. PPE to avoid breathing welding fumes ensures even demanding welding work can be conducted with an adequate respirator. In the manufacturing facility environment local exhaust ventilation ensures good fume control together with a welding mask. These and other best practises are followed in the new welding facility for best work safety for welders and people working near welding site. Ways to lower number of accidents and work-related sick leaves can be reduced by providing PPE fit for purpose.

Respirators and local exhaust ventilation systems are used in controlling welding fumes. On top of this work health care makes regular checks where lung health of welders is followed to find signs of exposure to excessive amount of zinc and other harmful substances. This is done so it can be confirmed current safety measures are appropriate. Lightning of the room has been improved. In Appendix 1 are shown the change that provides better overall visibility for conducting all work processes compared to old lighting solutions.

5.2.1 Work Safety and Wellbeing Contributing to Productivity

In preventing accidents at work and reducing sick leaves work safety has a key role. A company that takes care of working conditions will see the benefits of good work safety. In thesis work *Hitsauksen tuottavuuden tehostaminen (Enhancing the Productivity of Welding)* (Koski, 2012) are presented benefits and disadvantages of following work safety measures. Among benefits are named:

- Reduced number of work-related sicknesses
- Reduced work accidents
- Improved work well-being keeping workers in the company
- Positive effect on company's reputation
- Recruiting is easier when the company has a good reputation
- Increased quality and productivity
- Lower insurance fees.

Disadvantages of unsuccessful work safety are:

- Reduced productivity
- Interruptions in production
- Compensations for damages
- Increased sick leaves
- Higher insurance fees
- Reputational damage to the company
- Decreased employee well-being and motivation. (Koski, 2012, pp. 36–37)

Koski (2012, pp. 36-37) presents a wide list of reasons why it is in the interest of every company to take care of safety aspects at work. Observing productivity of welding work, not only looking at numbers and calculating times used in process steps, showcases such costs that are not necessarily calculated directly to the cost of manufacturing. If a worker is injured while conducting welding work in his work shift this can be counted as a cost when welding station is not used actively. When the worker is on a sick leave a longer period the company is in a situation where it potentially needs a new welder. Salary to the employee on a sick leave is continued to be paid at the same time.

Work safety takes active measures and being passive on risk mitigation can be expensive. These expenses are adding up to poorer competitiveness compared to other companies. Taking care of work wellbeing helps on building up higher productivity.

Global competition is tight and loosing advantage by adding up expenses unnecessarily by neglecting work safety matters is not in the interest of any company who wants to be offering competitive products and services.

5.2.2 Cold Hazard Mitigation

"The most obvious hazard typically associated with cryogenics is extreme cold. People can be injured by this cold either by direct exposure to low temperature liquids or vapours or by contact with other materials that have themselves been cooled down by exposure to cryogenic fluids" (Woods et al., 2019, p. 16).

Handling liquid nitrogen introduces different kinds of safety measures. Work induction is needed for new personnel who has not been handling and working with liquid nitrogen. Liquid nitrogen being –196 degrees Celsius is a major threat when not handled with care. Cotton gloves must not be used when handling liquid nitrogen as this blocks liquid nitrogen from evaporating or leaking to the floor and increases skin exposure time radically. Insulated gloves that are easily removable and appropriate for cryogenics are to be used. Loose shoes where liquid nitrogen can be accidentally poured are not to be used. Scenario where liquid nitrogen gets to the shoe and a person is not fast enough removing shoes and socks will be in major risk of severe nitrogen burn to feet and toes. Severe frostbites and amputations are a threat when exposure to liquid nitrogen lasts too long. Liquid nitrogen exposure to eyes causes severe damage to vision and blindness. This threat must be mitigated by wearing safety glasses and on top of these a face shield that covers the whole face. Safety glasses alone are not sufficiently protecting a person who handles liquid nitrogen. Specialized PPE is required when handling liquid nitrogen. (Woods et al., 2019, pp. 6, 15–18)

5.2.3 Oxygen Deficiency Hazards

Manufacturing of Still Line Customer -tubes involves many such liquids and gases that introduce a risk of oxygen deficiency in the room where these are present. Oxygen Deficiency Hazards (ODH) in nature are dangerous as they cannot be visually detected, smelled, or necessarily heard. Risk mitigation is necessary to avoid hazardous situations to personnel who works with gases imposing ODH.

"Oxygen constitutes 21% of normal air by volume. Oxygen is, of course, necessary for human life and an oxygen deficiency hazard is generally defined as any situation in which oxygen 19.5% or less by volume at a barometric pressure of 1 bar." (Woods et al., 2019, p. 52). In the welding department used substances that impose potential ODH are inert gases used in welding, i.e. argon and nitrogen. Helium and liquid nitrogen used in leak detecting for quality controlling purposes impose same hazards.

Risk mitigation on ODH in the welding department is handled by keeping amounts of these substances low, locked in place properly so they cannot fall, and using regulators in gas bottles limiting oxygen displacing gasses replacing oxygen in the welding department area. Oxygen displacing gases, i.e. inert gases nitrogen, argon, and helium, have own locked storage outside department building. Only the necessary number of gas bottles needed in the production area are stored inside in their dedicated locations and new ones are brought in when replacement is needed. Used gas bottles are stored in the same locked storage where full bottles are stored.

The biggest risk of ODH in the new welding department is introduced when liquid nitrogen is used in testing of parts that are wanted to be exposed to cold temperatures before helium leak test. One traditional sized twenty-five litres cryogenic storage dewar, commonly used in storing lesser amounts of cryogens, poured on the floor in a small laboratory room introduces a hazardous situation. As pictures from the facility in the Appendix 1 show, the new welding facility is large and volume of air in the room requires a bigger amount of liquid nitrogen than a classical sized dewar has when it is full. Displacement of oxygen does not happen in dangerous levels with tiny amounts of liquid nitrogen stored in the new welding facility. Changes made on the amount of liquid nitrogen stored in a room where work is conducted, or a room layout changed that make working area smaller in volume, are reasons to evaluate the situation whether risks of ODH are mitigated accordingly.

Best practises of working with cryogenics are followed in the new welding department to ensure safe working environment. These practises are repeated from previous working facilities and in that sense new risks company wise are not introduced in the new welding department. Oxygen level sensors give an alarm signal visually and audibly in cases where oxygen level drops from normal 21%. In this case personnel still have time to exit the building before potentially losing consciousness. These sensors are used in high-risk areas like small rooms where cryogens are handled and imposing a risk of ODH. Evaluation for need to have an oxygen level sensor is followed by the company’s responsible instance for work safety related matters.

5.2.4 Noise Hazard Mitigation

Personal hearing protectors provide the main protection from loud noises when noise producing work, i.e. cutting and grinding of metal, is conducted. A powerful air compressor that is a major source of loud noise operates in its own room to reduce extra noise in the area where personnel work to lower overall exposure to noise.

Air pistol silencers limit noise produced by air pistols used to clean and dry parts. These silencers together with air pressure regulators limit sharp noise from use of compressed air in cleaning of holes, threads, and other hard to reach areas in parts where use of compressed air is seen beneficial and justified.

5.2.5 Fire Hazard Mitigation

The floor of the facility is made of non-burning material. No changes in the facility on floor material are needed as facility was serving previously for welding and hot work. Instead of coating bare floor with epoxy, plastic or other common floor materials, priming is only needed. Sparks from welding are least harmful when floor is primed with a material suitable for areas where fire work is conducted.

Gas bottles are stored outside and only needed minimum number of bottles are stored indoors in proximity of the working spaces where they are used as stated in Chapter 5.2.3 on mitigating oxygen deficiency hazards. Regular fire alarm system gives a warning signal to all people working in the facilities.

5.3 Investments

Investments for new welding facility can be categorized to two separate groups: Those that are mandatory to perform everyday activities and those that are justified based on the savings they create. Mandatory investments were needed as many resources are shared in use with other production departments in old facilities. Table 1 lists all material investments that were needed for the new welding facility. Total euro amount totalling little under fifty thousand euros. Acceptance for investments is given in a steering group meeting. Renovation costs needed for the new manufacturing department are not part of project investments showcased in this chapter and are outside the project scope.

Table 1. Project Investments

Purchase Order	Product	Price, VAT 0% (€)
PO34013	Helium leak detector	24 300.00
IPO00034	Shelves for corrugated steel hoses	6 380.00
PO34982	Long material shelf	5 410.00
PO34733	Hand tools, patch two	2 388.16
PO34740	Tool carousel	2 073.97
PO34163	Washing table	1 982.00
PO34058	Long material cart and welding curtains	1 635.00
PO34563	Hand tools, patch one	1 188.93
PO34466	Belt sander	883.06
PO34524	Electrode grinder	839.50
PO34579	Regulator for a gas bottle	427.20
PO34049	Welding table legs	244.00
PO34140	Chemical locker	209.00
PO34597	Table wheels	102.60
Total		**48 063.42**

Improvements to storage and logistics solutions contribute to ease of handling and moving Still Line Customer -assemblies and raw materials from which assemblies are made. For handling 6.0 m long raw material for Still Line Tubes a cart designed for handling long tubes is procured. Shelves to store pipes and corrugated hoses are designed for the purpose by Salpomec Oy according to maximum dimensions set by the new welding facility.

In logistics a concept of cut in size packing material fitting to a Euro pallet is created to provide a quick solution in protecting Still Line Tubes in internal logistics before packing. Further improvement to the design can be made according to feedback on the first design. Further development is outside of project scope of the thesis.

Investments that are justified based on savings have a reasonable payback time. Payback time has been calculated with a calculation tool provided by Bluefors. Values added to the calculator are investment cost, depreciation, and annual saving the investment brings. Discount rate 8.4% is given by Bluefors Finance department. Payback time calculation shown in Figure 5 in Chapter 5.3.2 *Shelves for Corrugated Hoses*. Calculation made in April 2023.

Raw material shelves providing optimal storage space are suitable to be designed as the company designing and installing these has been for years delivering storage solutions for Bluefors in the warehouse but also for production departments for special needs. A shelf for long raw material is seen mandatory to be purchased to store stainless-steel tube 104.0 x 2.0

EN 1.4404 AISI 316L, used in Still Line Tubes. All straight raw material used in the welding department is stored on the same shelf. Taken into consideration is maximum allowed height of 2.5 meters due to short ceiling height. Fitting to the facility and best positioning compared to the door from where material is being supplied was discussed in a meeting where departments opinion was heard on all related subjects of the new welding department. Design work and installation on-site performed by Salpomec Oy.

A shelf for corrugated hoses is found to be the best storing solution for wooden barrels for practicality. In Chapter 5.3.1 *Shelves for Corrugated Hoses* are shown results from ordering full wooden barrels of corrugated hoses. Results indicate that raising minimum order size to one full wooden barrel is financially justified. Payback time for a storing solution is ideal when considering lowered unit price and a need to have a functional storing solution for corrugated hoses.

Bluefors' Procurement department is informed on the opportunity to order next purchase orders with adjusted minimum order amounts being full wooden barrels of all corrugated hose sizes used for Still Line Customer -assemblies.

5.3.1 Shelves for Corrugated Hoses

Corrugated hoses part of a Still Line Customer -assembly have been ordered in six varied sizes: 6, 16, 25, 32, 40, and 50 mm in diameter. Six- and forty-millimetres corrugated hoses have been ordered since 2018 in wooden barrels. High usage of raw material has been justifying bigger order amounts of one full wooden barrel for these two corrugated hose sizes.

When a concept of a shelf providing a storage solution for wooden barrels back in 2018 was created production numbers were lower compared to year 2023. The storage solution six- and forty-millimetres corrugated hoses had previously, shown in Appendix 1, was not justified for other hose sizes due to low annual consumption. Coming to year 2023, situation has changed and ordering other hose sizes in small patches has become less economical choice compared to purchasing full wooden barrels of raw material. Annual consumption of corrugated hoses is shown in Table 2.

Table 2. Annual Consumption of Corrugated Hoses

Corrugated Hose Size (mm)	Full Wooden Barrel (m)	Annual consumption (m)	How Long One Wooden Barrel Lasts (Years)
DN16	1100	100	11
DN25	465	200	2.33
DN32	250	250	2.77
DN50	135	100	1.35

Consumption of corrugated hoses in sizes DN25, DN32, and DN50 are big enough to justify purchasing full wooden barrels. DN16 hose is justified to be ordered as unit price is significantly lower. In five years, purchasing a full wooden drum has paid back itself. Biggest factor that justifies change in minimum order amount is the change in unit price and short amount of time the wooden barrel of raw material will be financially profitable to procure in current production numbers. Leaving this hose size out from the designed storing solution would introduce an inconvenience in storing raw material.

Change in unit price is showcased in Table 3. New unit prices from a quote from the same supplier who supplies materials in smaller lengths delivered in cardboard boxes. Price reduction is calculated with Equation 1.

Equation 1. Price Reduction

$$Price\ Reduction = \frac{Old\ Unit\ Price - New\ Unit\ Price}{Old\ Unit\ Price} * 100$$

Table 3. Unit Prices of Corrugated Hoses

Corrugated Hose Size (mm)	Old Unit Price (€/m)	New Unit Price (€/m)	Price Reduction (%)
DN16	22.36	12.70	43
DN25	29.35	18.40	37
DN32	39.50	33.80	14
DN50	47.32	38.70	18

Payback time for the shelving solution is estimated to be 1.7 years. Annual save by ordering full wooden drums is 4531.00 € and is increased year by year 15% to consider increase in production numbers and expenses in raw materials. Investment cost for the shelves is 6 38000 € and depreciations in 2023 a thousand euros. A calculation is shown in Figure 5.

Figure 5. Payback Time for Corrugated Hose Shelves

Investment name: **Shelves for Corrugated Hoses**

Undiscounted payback time **1,7** years — #REF! = payback cannot be calculated

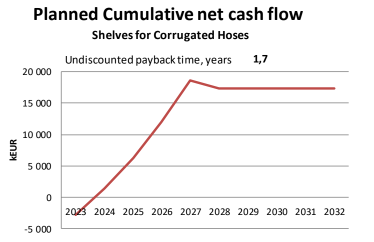
Discounted payback time **1,7** years — Insert discount rate here: 8,4 %

Currency: **kEUR**

Business scenario **without** the investment										
Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Net Sales										
COGS incl production overheads and depreciations	4 531	5 210	5 992	6 890	7 923					
SGA - Sales, General & Administration overhead costs										
Other income(+) and expenses(-)										
EBIT	-4 531	-5 210	-5 992	-6 890	-7 923	0	0	0	0	0
EBIT-% of NS	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Business scenario **with the** investment										
Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Net Sales, total										
COGS incl production overheads and depreciations	1 000	1 000	1 100	1 200	1 250	1 300				
SGA - Sales, General & Administration overhead costs										
Other income(+) and expenses(-)										
EBIT	-1 000	-1 000	-1 100	-1 200	-1 250	-1 300	0	0	0	0
EBIT-% of NS	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Investment costs											
Depreciation years		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
10	Investment costs, heavy machinery >180kEUR										
8	Investment costs, other machinery <180kEUR	6 380									
3	Investment costs, IT equipment										
20	Investment costs, buildings										
	Investment costs, land and other with no depreciations										



5.3.2 Orbital Welding

Orbital welding is a welding method originally developed to take away operator error in Tungsten Inert Gas (TIG) welding. Technique is allowing to produce a uniform weld around tubes and pipes. Developed in 1960 in the aerospace industry, TIG welding is widely used in automated pipe welding and sheet metal in aviation and aerospace industries to produce excellent quality welding seam. (TWI Global, n.d.)

DN 100 ISO-K Straight Connectors and 90 Degree Elbows are pipes that can be manufactured by using orbital welding technique where welding tool is rotated 360° around the workpiece. Ready solutions from welding equipment manufacturer Axxair Group cost in total around fifty-two thousand euros in June 2023, price in VAT 0%. Welding cell number one is capable of welding curve-to-tube and tube-to-tube joints, priced around twenty-four thousand euros. Cell number two for curve-to-flange joints and tube-to-flange priced around twenty-eight thousand euros. Delivery times are 4-6 weeks from order. Suitability of orbital welding for Still Line Tubes is good. Welding cells are made fit-for-purpose repeating the welding process with a steady quality. Notable to mention is cells are specific for Still Line Tubes and are not capable of other welding processes than welding Still Line Tubes.

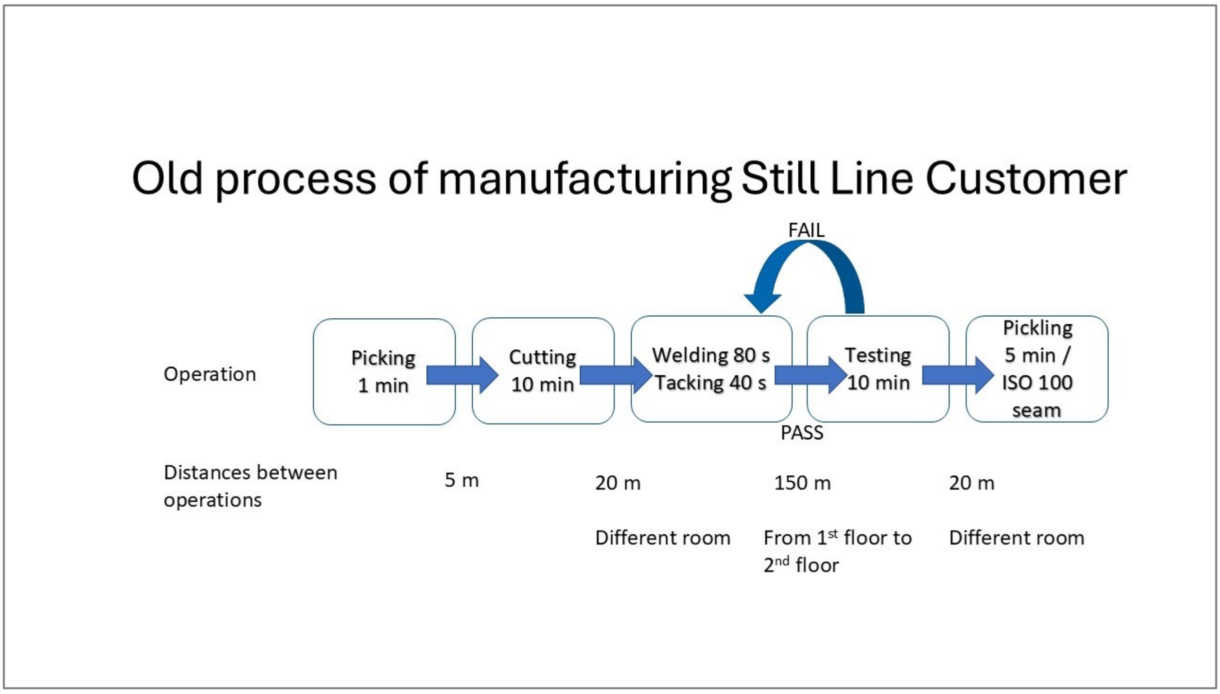
Orbital welding cells are not procured in 2023. The decision to purchase orbital welding equipment is made when seen as an attractive opportunity to improve in-house manufacturing capabilities and the budget is reserved for investment.

5.4 Old Manufacturing Process of Still Line Tubes

Manufacturing of a Still Line Tube is consists of eight process steps: Picking raw material, cutting steel tube to length, cleaning surfaces to be welded from cutting fluid, tacking rotatable welded flange from four places to the tube, welding rotatable welded flange and steel tube all around together, helium leak testing, pickling, and cleaning. In Figures 5 and 6 process steps are shown with less steps. Time used in cleaning after cutting is calculated to cutting and tacking of parts is calculated in the same process step with welding. Pickling and final cleaning are together in the last process step. Manufacturing process is shortened in ERP routings to four steps for reasonable and reliable data collecting under names: Cutting, Welding, Leak Testing, and Finishing. It is not reasonable to separate manufacturing process to too small process steps for ease of work and collecting decent quality data of time used on different process steps. Setting times are calculated to process steps.

Figure 6 shows the old manufacturing process and moving Still Line Tubes to the location where the next process step is conducted. Distances and different floors marked between process steps. Setting times are included in their respected work phases and are not separated. Failure in the leak test brings parts that leak helium back to the welding process step for re-welding.

Figure 6. Old Manufacturing Process

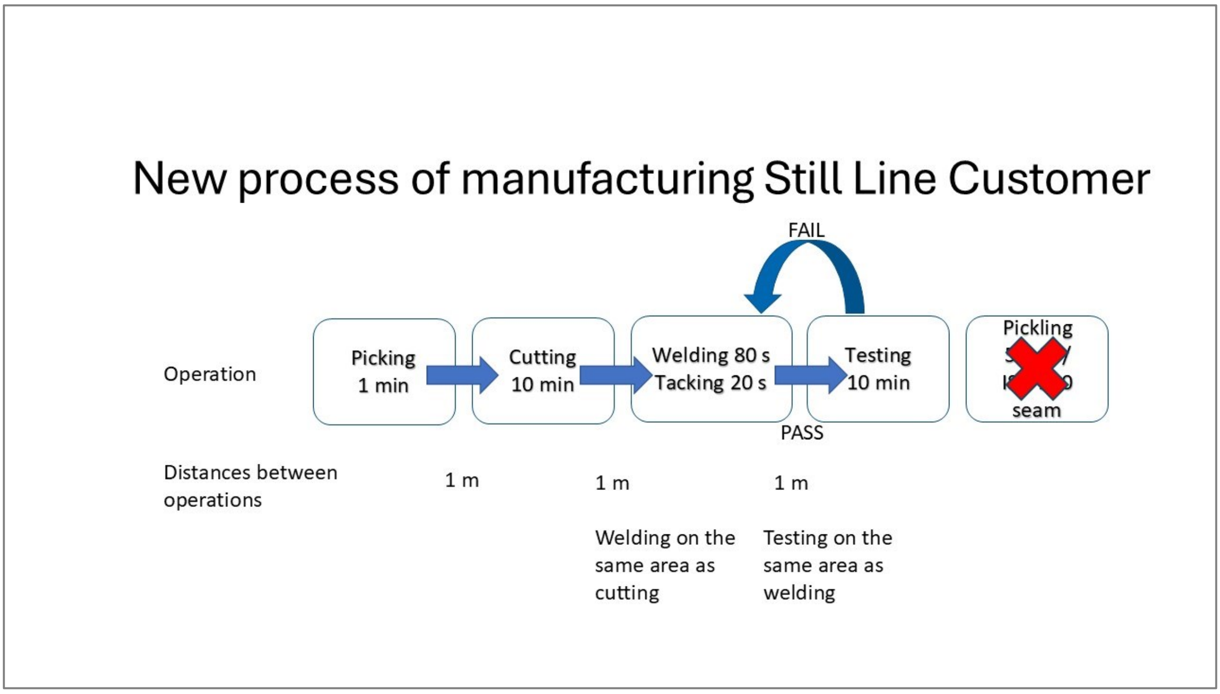


5.5 New Manufacturing Process of Still Line Tubes

New manufacturing process in the new facilities is conducted in the same room. Raw material is supplied directly to the welding facility by subcontractors or from the Bluefors warehouse. Steel tubes and corrugated hoses have their respected shelf locations serving manufacturing: Steel tube is lifted from the shelf straight to the cutting machine minimizing time in handling 6.0 m long steel tube. Figure 7 shows the new manufacturing process. From the cutting area tubes are delivered to welding stations where they are welded to rotatable flanges. From the welding stations Still Line Tubes are moved in carts designed for this task to helium leak testing station. After successful testing, parts are moved to washing station where tempering colours from visual surfaces are removed by pickling.

With a new potential rotatable welded flange design, pickling process is significantly reduced or in the best scenario completely non-mandatory for visual surfaces. Tempering colours are very minor with improved design as a collar feature is hiding them. Effect of design change influencing tempering colours shown in Appendix 1. Adjusting welding parameters to optimal state can make pickling process not mandatory. Decision on whether pickling process is wanted to be completely removed is not decided based on this finding but is delivering information to decision making process when process change is seen acceptable.

Figure 7. New Manufacturing Process



5.6 Improvements in the New Manufacturing Process

The welding process is improved by having different steps of manufacturing process inside the same room. Time is not lost moving Still Line Tubes in between three rooms and in between two levels to move them to the next manufacturing phase. Going back one process step due to a quality issue, e.g. not passing helium leak test, is not introducing major loss of time in overall work of producing a Still Line Customer -assembly.

Handling of items in the ERP system takes less time compared to previous as Still Line Tubes which do not pass helium leak test under its requirements are not needed to be moved manually in the ERP system back and forth to have accurate storage location information. No need to manually move parts in the ERP system the same amount as in old manufacturing process and involvement from personnel is decreased.

New manufacturing process of one Still Line Tube from picking of raw material to moving finished Still Line Customer -assembly to packing area takes 22 minutes and 40 seconds compared to old manufacturing process that takes 33 minutes. The new process saves around ten minutes of manufacturing time when focusing on process steps and not on distances between operations. When process time is wanted to be reduced, rotatable welded flange is needed to be revised to allow centring welded parts together for tacking and that the geometry of parts better hides tempering colours on visual surfaces. Welding shielding gas does not protect outer surfaces from tempering colours the same way compared to inside surfaces.

5.7 Logistics

Due to production facilities and logistic functions are located not in the same facility, moving of parts is not in the ideal state where everything is in line streamlining the whole production from receiving of materials to final packing to the customer. Downside of moving welding department to the new facilities to different address compared to packing area where Still Line Customer -assemblies are packed for shipping, is need for logistics in between two facilities. Planning manufacturing according to days when logistics is arranged transporting parts from welding department to the packing area, due to numerous factors like availability of human resources and materials, can cause a day or two delay if manufacturing work cannot be completed as planned. Extra transportation can be arranged and is taken to active use acknowledging need for it exists to not cause a day or two delay in packing a complete system. Delay of Still Line Customer -assembly causes a bottleneck in packing where packing area can get overfilled with unready systems. Delay in shipping the whole dilution refrigerator system to the customer is a potential risk.

Expenses from internal logistics of Still Line Customer -assemblies are considered in overhead costs as stated in Chapter 5.10.2 *Cost of Manufacturing Still Line Tubes In-House* and thus are not calculated as separate expense due to the nature of expense where many other items also have a role in creating expenses in logistics. To be acknowledged is that in ideal situation logistics requiring vans or trucks in between facilities would not be needed if welding facility was in the same facility together with other manufacturing functions. An advantage of one big manufacturing facility where all functions are under the same roof.

A standard Euro pallet with a collar is not capable of housing Still Line Tubes longer than 1150 mm in straight length. A picture in Appendix 1 showcases an issue raised in internal logistics whenever long Still Line Tubes are designed and manufactured. In final packing of the ready system Still Line Tube is acceptable to be 1200 mm without causing logistical difficulties. When Still Line Tube is longer than 1150 mm it might not fit properly on the pallet and potential of damage to its outer surface is higher in transportation of the part. More on length limitation of a Still Line Tube in Chapter 5.8 *Design Work on Still Line Customer -Assemblies*.

5.8 Design Work of Still Line Customer -Assemblies

To get the best out of outsourcing DN 100 ISO-K vacuum components, in ideal situation standard lengths of Still Line Tubes are to be used in designing suitable layout for the sold dilution refrigerator system. This is possible partly and practical experience indicates that around 30% of Still Line Tubes can be standard in length when following good design practises. Standard lengths can be in size 200, 400, 600, 800, 1000 or 1100 mm in length. A decision to limit length variations is not necessary but a work instruction that gives certain lengths is advised to be used to collect data on most suitable lengths in practise.

Suppliers can produce DN 100 ISO-K Straight Connectors in various lengths but from design guideline point of view no longer than 1100 mm is wanted to be used in layout design to consider limitations in wooden boxes used in packing the complete system and handling of a single tube. Too long a tube is hard to handle and poses a work safety risk from manufacturing all the way to assembling Still Line Customer -assembly at the customers facility. Eleven hundred millimetres long tube is ideal in internal logistics as a standard Euro pallet can take parts in that length when using pallet collars. Longer tubes do not necessarily fit firmly on a pallet as shown in Appendix 1 where Still Line Tubes are stored on a Euro pallet.

Designer can with his design solutions influence quality, usability, and competitiveness of the welded assembly (Hasari & Salonen, 2006, p. 189). Value can be found from offering to the customers technical solutions where number of custom parts, i.e. Still Line Tubes in random lengths, is low. Suppliers have readily available certain lengths and procuring a custom length will be more expensive when outsourcing is used. Manufacturing methods do not necessarily support random lengths but rather mass production of same articles. A difference in a well-designed and a poorly designed welded assembly is in Bluefors' case not necessarily a matter of loosing sales because of design work of Still Line Customer - assembly. In some cases, customization is a reason a customer has chosen Bluefors. Using standard parts can bring the positive sides of mass production in form of lower unit price in the future. Time is saved when DR systems are sold to the end customer with a standard layout and modifications to the Still Line Customer are kept small if any are made. Having design practises is promoting a culture in the workplace where design work has form of rules and guidelines to create technical solutions in a smart way.

5.9 Technical Design of Still Line Customer -Assemblies

Welded rotatable flanges (DN 100 ISO-K Flange Weld) have a mating surface where a steel tube is mated for a welding process. Clearance in between diameters is more than ideal causing that in tacking a welded flange and a tube together, a welder hand adjusts these two parts together before he tacks them together. Concentricity between parts is not guaranteed to be ideal and a welder is using extra time to mate parts together for tacking. Self-guiding of mated parts by having adequate clearances in diameters has not been used.

Steel tube that is 104 mm in outer diameter is requiring a welded rotatable flange with inner diameter of 104.30 mm. 0.3 mm clearance between dimensions provides a self-guiding mating of parts. Steel tube is not fully round, especially at the ends of a 90 Degree Elbow. This affects what is the minimum inner dimension for the welded rotatable flange mating surface to ensure fitment of parts together every single time when parts are being ordered based on the used standards. The rotatable welded flange that follows ISO 2768-mK standard being a loose tolerance class is acceptable for functionality. A stricter tolerance potentially increases manufacturing costs and is not needed.

Ninety-degree elbows follow dimensions and tolerances set in a standard SFS-EN 10253-4:2021, *Butt-welding pipe fittings*. Based on this the rotatable welded flange needs to have a nominal value of 104.30 mm and ISO 2768-mK in general tolerances has been found adequate based on these two standards taking into consideration critical dimensions, i.e. tolerances on diameters, out of roundness, wall thickness tolerances, tolerances on specific dimensions, and tolerances on the form of fittings ensuring a proper fitment. To determine proper fitment, tolerances on diameter and out of roundness guide to choose needed nominal value of 104.30 mm for the welded rotatable flange mating surface around the steel tube. This clearance in between mating surfaces provides most importantly for current process of manufacturing Still Line Tubes a suitable fitting for manual welding, but also for semi-automated orbital welding a proper fitment, when this production automation improvement is taken to use. (SFS-EN ISO 10253-4:2021, pp. 23–26)

A problem report in PLM (Product Lifecycle Management) system has been made on design of a DN 100 ISO-K Flange Weld. In the problem report is highlighted a flaw in design of the part which does not support self-centring of welded parts when mated together for tacking. Examples of outsourced similar parts show that companies manufacturing vacuum parts have designed their parts in this manner making orbital welding possible for this product family. In Appendix 1 is displayed a self-guiding design that hides tempering colours compared to the solution used in in-house production.

5.10 Cost of Still Line Tubes

In-house and outsourced manufactured Still Line Tubes are in technical characteristics the same except in-house manufactured Still Line Tubes are not finished on outer surfaces. Plain grinding is an often-used finishing method. From other characteristics both in-house and outsourced Still Line Tubes are like each other’s and combability to mount to each other’s is present as is common with standard components.

From visual quality point of view outsourced Still Line Tubes offer an attractive way to improve overall visual quality of the system sold to the end customer. Still Line Customer -assembly is not the first detail one sees when working with a dilution refrigerator system, but a straightforward way to improve Still Line Customer -assemblies visual quality, without investing to a plain grinding machine, is by purchasing components from suppliers.

Finishing outer surface of Still Line Tubes as of March 2023 by plain grinding is not conducted in the current in-house manufacturing process and the surface is left with surface quality of a raw material. Time used for grinding work has its own price in form of machine cost. It becomes even more expensive if this work is conducted on a lathe being of high quality and has a higher machine cost price. Conducting grinding work for Still Line Tubes in-house is expected to cost same as other labour expenses displayed in Table 4 when wanted to estimate how much more would cost to produce same visual finish on outer surfaces as outsourced tubes have. Manufacturing cost is in this scenario in total 159.60 €.

Grinding work for other components has been conducted in-house using in many manufactured parts and assemblies a manual middle-sized precision lathe. This is not an ideal situation as a manual lathe, at least of excellent quality, should not be a number one option to carry larger size production grinding work. Lathe bed and ways are easily damaged by grinding abrasive, tool holder is potentially needed to be removed, a grinding attachment is needed to be equipped to the cross slide with adequate fasteners, and work safety is not necessarily always on the same level as with a machine made for grinding work. A lathe should be used only occasionally on single work pieces when another machine is not available. (Maaranen, 2012, pp. 235–237). Lathes are delicate instruments that can be prematurely misused to such a state they are not any more accurate in their results. Abrasive material mixed to oil in the leads grinds them to a state where a lathe cannot be used anymore on precision work. In worst scenario manufacturers are not providing replacement parts to repair damaged machines. From experience cleaning and maintenance of a lathe used regularly on grinding work needs to be rigorous. If not, lathes expected service years can be cut in half thus increasing machine cost of the lathe that is not treated as should be. (de Carle, 1952/1980, pp. 7–10, 14, 17–18)

5.10.1 Cost of Outsourcing Still Line Tubes

DN 100 ISO-K Straight Connectors are readily available from local suppliers of these standard products. Suppliers can deliver these in various lengths based on needs. Manufacturing of Still Line Customer -assemblies is possible to be outsourced fully. This means manufacturing phases welding, helium leak testing, finishing, and cleaning can be outsourced to the supplier of the parts.

In 2025 an offer from a vacuum component supplier for a 1000 mm DN 100 ISO-K Straight Connector gives a unit price of 227.00 €, VAT 0%. DN 100 ISO-K Elbow 90° costs from suppliers around 220.00 €, VAT 0%. Prices do not take into consideration potential quantity discount for a long-term customer who purchases same vacuum components in larger quantities.

5.10.2 Cost of Manufacturing Still Line Tubes In-House

Direct work is estimated to be in industrial manufacturing work in March 2023 fifty, machine cost twenty-five, and overhead cost ten euros. Values provided by Bluefors Finance in total 85.00 €/h. Overhead costs include equipment maintenance, depreciations, factory rent, utilities, supervision, and administrative costs. Overhead costs in Finland can be estimated from 1.30 to 1.50 depending on the number of benefits offered to the employee. Factor does not consider work related PPE. To not leave any expenses out from calculations, it is advisable to use factor 1.4 or 1.5 to take into consideration all expenses. (Accountor, 2022). Values are to be confirmed annually in manufacturing cost calculations.

Factors not considered in cost of manufacturing in-house are cost of subpar quality and logistics. Cost of subpar quality is not being followed in ERP system for DN 100 ISO-K Straight Connectors or similar welded assemblies which would be comparable. Experience shows cost of subpar quality is close to zero based on amount of Still Line Tubes failing helium leak test thus needing re-welding and leak testing or discarding of materials.

Expenses usually not calculated to welding costs are raw materials, cutting sheet metal, making chamfers, pre-heating, heat treatment after welding, quality control, repair works, or any other work conducted after a welding process. These expenses are calculated to overall expenses of the ready product. (Lukkari, 2022, p. 4) All equations presented in this chapter by the same author. To ensure correctness of welding cost calculations, information from Chapter 19.7 from book *Koneenpiirustus 1 & 2* (Pere, 1981/2016, pp. 54–58) is used to cross-check information with other references used, mentioned in Chapter 5.9.3. *Welding Costs*.

Even when quality control and repair works are not calculated to welding costs, they are causing expenses in form of helium leak testing and repairing potentially leaking Still Line Tubes by re-welding them. Welding seam is regarded as a weak point in a welded pipe. Over decades of improvement in production methods, quality of welding seams has improved, and subpar quality is hard to come by in modern manufacturing and welding methods where welding process is well controlled. (Woxén et al., 1947, p.129). Quality issues are possible even in well controlled welding processes in extreme examples where a welding seam must not leak helium through it and sets that way a strict requirement for a welded seam and material in general. Welding process for Still Line Tubes is not automated and thus quality of welded seams can vary more than in a fully automated orbital welding process.

Leak rate of a vacuum component must be in tolerance HV <1x10-8 mbar l/s (Allectra GmbH, 2024). Helium leaks in dilution refrigerator systems are wanted to be avoided. This strict baseline from the functionality requirement of the machine introduces a need to test and ensure all vacuum components are helium leak free.

Helium He N46 50 L 200 bar DIN 10 RPV, sold by Woikoski Oy for around 2300.00 € per fifty litres bottle introduces an expense in helium leak testing not only in form of labour costs but also in consumption of helium gas. Depending on a component tested with helium cost of using this material resource can be significant. Leak testing a DN 100 ISO-K Straight Connector or a 90 Degree Elbow, on the other hand, is not a complicated process and usage of helium is limited to the least amount of helium a gas bottle regulator can limit flow. Not a lot of helium is needed to be used as an area to be tested is small and flow of helium can be easily directed to the welded seam. As helium is used a lot in Bluefors' manufacturing in helium leak testing different assemblies and components in bigger amounts, expense of used helium in one Still Line Tube is not a major cost factor and can be seen included in labour cost 21.25 € in Table 4, article 'Helium Leak Testing'. This even when used helium N46 costs around 2300.00 € per fifty litres in January 2025 compared to, e.g., argon bought in a fifty litres bottle for a price of around 400.00 €. Calculating use of argon in welding is more reasonable to do as welding process takes considerable amount of time and gas flow is 8 l/min and thus is a major cost factor in welding related costs. In other calculations conducted outside of these cost evaluation's, role of helium consumption in leak testing must be evaluated case by case how big of an expense factor it is.

Steel tube raw material used in Still Line Tubes is welded, unannealed and pickled stainless-steel tube 104.0 x 2.0 EN 1.4404 AISI 316L (Kimet, 2025). Welding seam in raw material is rarely if never a source of a leak in helium leak testing. More likely but not often leak is present in welding seam area in between steel tube and a rotatable welded flange that is made by rotating work pieces in a rotating table.

Cost of manufacturing a single DN 100 ISO-K Straight Connector in year 2023 shown in Table 4. Welding costs totalling around 1.50 € are specific to manufacturing a single straight connector including expenses from labour, machine costs, shielding gas, and energy costs.

Table 4. Cost of Manufacturing a 1000 mm Still Line Tube

DN 100 ISO-K Straight Connector 1000 mm					
Materials	**Article**	**Time (h)**	**Quantity**	**Unit**	**Total Amount (€)**
	DN 100 ISO-K Flange Weld		2	pcs	13.40
	104 mm SS Tube		1.0	m	38.50
Cost of Labor	**Labor Type**				
	Cutting Tube	0.25	21.25	€	21.25
	Welding	0.25	21.25		21.25
	Helium Leak Testing	0.25	21.25	€	21.25
	Pickling and Cleaning	0.25	21.25	€	21.25
Cost of Welding			1.49176	€	1.49176
				Total Cost	**138.39**

5.10.3 Welding Costs

Overall welding costs in Still Line Customer -assembly consist of four components:

- Labor costs
- Machine costs
- Welding shielding gas consumption
- Energy costs.

The biggest cost factor in welding is labour and it is present in all process steps in manufacturing Still Line Tubes or any other assemblies. Following that are welding filler material, shielding gas, machine costs, and energy in this order. Welding filler material in these calculations is not a source of costs as filling material is already available in the welded flange design. (Pere, 2016, Chapter 19, p. 58)

Welding additives and welding slag expenses (K_L) are zero. TIG welding used in welding process does not require slag and geometry of welded parts provides needed material taking away the need for welding additive. Parts welded together do not need pre-heating carbon equivalent value (CEV) being for stainless steel 316L under 0.45 and thus do not introduce extra energy expenses (Valtanen, 2022, p. 986). Amount of carbon in 316L does not exceed 0.03.

One Still Line Tube has 0.628318 m of welding work based on geometry of parts and values calculated from them. By multiplying results from equations with this value cost of individual welding factors for producing one Still Line Tube are calculated. Equations 2–7 present calculations to get different welding cost factors. Below equations are DN 100 ISO-K Straight

Connector specific euros per meter values are calculated based on the previously mentioned value of ≈ 0.63 m.

Calculating welding costs requires different parameters that are needed to be known, calculated from available knowledge, or estimated. Consideration is needed on estimating adequate values. Quantity of welding material (*M*) is needed to be estimated from geometry of the rotatable welded flange to get results close to reality as in welding work under observation, welding filler metal is not used but instead design provides filler metal. Listed are parameters needed for calculations:

- Quantity of welding material, $M\ (kg/m) = A * L * \rho$, where A = 0.00003 m^2 is welds cross-sectional area, L = 0.314159 m is length of the weld and ρ = 7 850 kg/m^3 is density of welding filler metal, steel in this calculation (Lukkari, 2022, p. 5)

- Weld metal production, $T\ (kg/h)$ is gotten by using a small value from a chart “Hitsiaineen kulutusarvoja” (Welding filler metal consumption values) from *Tekniikan taulukkokirja* (Valtanen, 2022, p. 996). Value of 1.0 kg/h is chosen as welding process in conducted to a feature where filling is not required, and design of the welded part provides welding filler metal

- Burning time ratio, $e\ (\%)$ is estimated to be for a human being 20% while a robot is capable of 65% (Oy Machine Tool Co, 2024)

- Hourly price of labour (H_T) consists of direct work 50.00 €/h, overhead cost 10.00 €/h, and machine cost for a TIG welding machine, K_K = 0.16 €. In total, hourly price of labour in manual TIG welding according to 2023 March parameters provided by Bluefors are 60.16 €/h

- Calculating shielding gas costs requires parameters flow of gas (V) and purchasing price of used gas (H_S). Gas flow used in welding process is 8 l/min and purchasing price of argon, Argon Ar 50 L 200 bar DIN 10 RPV, in January 2025 from Woikoski Oy approximately 400.00 €, i.e., 40.00 €/m^3

- Calculating energy costs (K_E) requires energy consumption (E) and price of energy (H_E). As a guideline, energy consumption is 3.0 kWh/1 kg of welding material. Price of energy is estimated to be 0.04 €/kWh.

Equation 2. Labour Costs

$$K_T = \frac{M}{T} * \frac{100}{e} * H_T\ (€/m) = 2.22536\, €/m$$

$$0.628318\, m * 2.22536\ €/m = 1.39823\ €$$

Calculating labour cost (K_T) requires parameters

- *M* = 0.00739814 kg/m, quantity of welding material
- *T* = 1.0 kg/m, weld metal production
- *e* = 20%, burning time ratio
- H_T = 60.16 €, hourly price of labour
- *L* = 0.628318 m, weld length in one Still Line Tube with two ISO 100 welded flanges.

Length of the welded seam is not used to calculate labour costs (K_T) directly. It is needed to calculate quantity of welding material (*M*). Parameters *M*, *T*, *e*, and *L* are also used to calculate other welding expenses in other equations.

Equation 3. Machine Costs

$$K_K = \frac{M}{T} * \frac{100}{e} * H_{KT}\ (€/m) = 0.005919\, €/m$$

$$0.628318\, m * 0.005919\ €/m = 0.003719\ €$$

Equation 4. Shielding Gas

$$K_S = \frac{M}{T} * V\ x\ H_S * 0.06\ (€/m) = 0.142044\, €/m$$

$$0.628318\, m * 0.142044\ €/m = 0.089249\ €$$

Equation 5. Energy Costs

$$K_E = M * E * H_E\ (€/m) = 0.000888\, €/m$$

$$0.628318\, m * 0.000888\ €/m = 0.000558\ €$$

Equation 6. Cost of Welding

$$Overall\ Costs = K_T + K_K + K_S + K_E = 1.49176\ €$$

Needed is to know hourly rate of the welding machine. Hourly rate is calculated with an Equation 7. Hourly rate *(H_{KT})* is used in Equation 3 to calculate machine costs. Hourly rate of the TIG welding machine is low. This is due to not utilizing the full potential of the machine meaning welding machine is not used in two or three shifts. This keeps annual operating time of the machine much lower than what is the annual theoretical maximum. Purchasing price of a welding machine is not considerably high that lowers hourly rate. In March 2023 hourly rate for an average manufacturing machine, i.e. lathes and milling machines, is higher estimated to be 25.00 €.

Equation 7. Hourly Rate of the Welding Machine

$$H_{KT} = \left(H_H * \left(\frac{1}{T_p} + \frac{p}{2 * 100}\right) + Y\right) * \frac{1}{T_K} (€/m) = 0.16\ €/h$$

- H_{KT} = 5000.00 €, purchasing price of a TIG welding machine
- T_p = 10 yrs, removal time (years)
- p = 0%, interest rate on capital
- Y = 300.00 €, annual maintenance costs
- T_K = 5000 h, annual operating time of a TIG welding machine.

5.10.4 Price Difference Between In-House Manufacturing and Outsourcing

Manufacturing in-house DN 100 ISO-K Straight Connector in length of a 1000 mm costs 138.39 € based on calculations in Chapter 5.10.2 *Cost of Manufacturing Still Line Tubes In-House*. Price from a supplier for the same item in 2023 is 227.00 €, VAT 0%. Price difference in between manufacturing in-house and outsourcing is estimated to be 88.61 € based on calculations and available data from material and part suppliers and cost estimation parameters for work in industrial manufacturing in March 2023 provided by Bluefors.

Parameters from Table 4 can be used to calculate manufacturing costs of a DN 100 ISO-K Elbow 90°. Only change needed to the calculation is to change straight steel tube to a ninety-degree elbow. Price of one ninety-degree elbow is 18.35 €. This means manufacturing one DN 100 ISO-K Elbow 90° in-house costs 118.20 €. From suppliers this vacuum component costs around 220.00 € year 2023. A little more challenging welding work, that can be made in-house with a proper welding jig easily, gives this component a little more premium price compared to straight connectors when purchased from suppliers.

In a scenario where plain grinding on the surface of a DN 100 ISO-K Straight Connector is made in-house, a new estimated price for a 1000 mm Straight Connector is 159.64 €. Plain grinding work cost is estimated to be the same as other labour types (See Table 4) 21.25 €. In this scenario where visual quality is wanted to be improved price difference to a straight connector from a supplier would be 67.36 €. Machine investment and a facility for grinding work are needed when wanted to conduct plain grinding in-house in a proper way. These are not considered in the price of manufacturing Still Line Tubes with an improved visual quality.

Factors like cost of subpar quality in manufacturing, i.e. Still Line Tubes that do not pass helium leak test, are not available due to lack of long-term data like first pass yield in helium leak testing of Still Line Tubes. Cost of subpar quality thus can be only roughly estimated, as proven numbers are not available. Based on authors and production workers experience euro amount of subpar quality per one DN 100 ISO-K Straight Connector in length of a 1000 mm is very small, close to zero, and does not have major influence in price comparison. Tested parts pass helium leak test on a good percentage and so introduce from the point of cost of subpar quality a very tiny percentage of costs to the overall manufacturing costs.

6 Conclusion

New welding facility was taken to use in September 2023 according to plan. The new facility had in the moment of opening minimum requirements needed to conduct welding work. Some ordered products from the investment list had later delivery than planned due to the holyday season.

Work safety practises used in other activities in Bluefors production work were implemented to the new welding department the same way as experience on working with cryogenics has shown to be a safe way of working in such environment where cryogenics pose threats. Work safety is improved by providing shelves for corrugated hoses that make handling of wooden barrels convenient and safe. Raw material is easy to take from wooden barrels to welding cells and cut in length.

Logistics of Still Line Customer -assemblies and other welded assemblies require vans and trucks to move materials between two facilities. This is a negative compared to an ideal situation where manufacturing would be conducted under one roof. Manufacturing process conducted in the same room from picking material to final testing is making manufacturing process lean compared to the old process. Time is not used on moving parts in between different rooms and levels. When time used on moving parts is left out, process time is reduced from around 33 minutes to around 23 minutes. This requires the design of a rotatable welded flange is revised better serving mating parts together for tacking and welding. A new design for the part reduces if not eliminates need for pickling on visual surfaces where welding has caused unwanted tempering colours.

Automating DN 100 ISO-K components welding process by investing to orbital welding cells is not done as it is not seen in the moment complimenting long term plans of Bluefors where outsourcing such standard components brings more value and flexibility than growing own manufacturing capabilities. Calculations on production economy of these vacuum components in this thesis are supporting this strategic decision. As business of dilution refrigerators has been in the history growing rapidly and changes are expected to happen also in the future, investing a considerable sum of money to automating welding can be found out to be not that good of an investment. A potential scenario is this equipment would not be needed when outsourcing takes place more on standard components. Delivery time of welding cells is not long and when needed cells can be purchased fast.

Designing practises have been adjusted to create Still Line Customer -assemblies so that more standard length Still Line Tubes are used. Customer requirements are wanted to be fulfilled influencing on creating odd size Still Line Tubes. This is a competitive decision to offer custom designs when requested to meet customers’ needs and wishes. Custom designs are sometimes influencing on winning customers when special needs from customers’ side are needed to be filled. Longer than a 1100 mm Still Line Tube in straight length are avoided to be designed as this influences negatively internal logistics. Unnecessarily long tubes are a work safety hazard from manufacturing to assembling Still Line Customer -assembly on-site at the customers end.

Possibility to best utilize advantages of outsourcing start from the designing table where a product is designed. When possible, design-related flaws should be considered in the design work to consider possibility of outsourcing. A too long Still Line Tube is an example part where a designed product influences packing and logistics negatively when a design guideline is not followed. The importance of surface quality on a vacuum component’s sealing surface is a practical example what needs to be considered in designing functional vacuum components.

Outsourcing Still Line Tubes offers an attractive opportunity where pricing is competitive, and visual quality of ready products are improved. Well established manufacturing practices from manufacturers of vacuum components where automation in welding is already in place, offers stable welding quality compared to more manually conducted in-house welding where a rotatable table is the level of automation currently. Quality is expected to stay long term on a higher level compared to manually conducted welding work in-house due to successful automation. When conducting plain grinding in-house prices of compared DN 100 ISO-K Straight Connectors are not far from each other. Good is to consider that manufacturing Still Line Tubes in-house is more affordable as plain grinding is left out from cost factors. This is to be noted in comparison. Economical point of view is seen as a great positive side of manufacturing Still Line Tubes in-house in current production numbers. Flexibility to produce in short lead time Still Line Customer -assembly parts is another positive aspect

Pricing on outsourced vacuum components can be kept on a competitive level as there are many suppliers on the market and dependency on one supplier is not a risk. Quantity discount of minus 20–30%, when achieved in negotiations, makes the price difference between in-house manufacturing and outsourced components close to each other. In comparison made in between 1000 mm Straight Connectors, a Still Line Tube made in-house plain grinded on outside surfaces is estimated to cost 159.60 € when considered plain grinding process step that is not currently done. An outsourced 1000 mm Straight Connector costs 227.00 € and when considering potential quantity discount of, e.g. minus 20%, price of the Straight Connector can be potentially 181.60 €. The price is only 22.00 € more compared to an in-house manufactured Straight Connector.

One can name this difference as the cost of convenience: No need to hire more people to conduct repetitive welding work, no potential drops in quality level when a new person starts hand welding of Still Line Tubes, less components in internal logistics to be handled, less time and helium used on helium leak testing components, and no need to make big investment to two orbital welding cells to manufacture Still Line Tubes more efficiently and reliably, to name a few. The price of convenience in outsourcing Still Line Tubes is not remarkably high. Considerable is that by outsourcing one is getting, from aesthetics point of view, parts that are better suited to the overall quality image dilution refrigerators manufactured by Bluefors give.

The moment when overall presentation of Still Line Customer -assemblies is to be improved, by plain grinding outer surfaces, outsourcing is a more attractive solution than purchasing a new machine for grinding work and to have a person doing this work on the machine. Labor cost of plain grinding makes manufacturing cost of a single Still Line Tube close to a well negotiated purchase price of the same component from a supplier of vacuum components. These suppliers have invested in good orbital welding machineries so that companies buying their products do not need to make that investment but can continue to focus on producing solutions from these components.

Delivery times of outsourced vacuum components are likely to be stable in the long term. As there are many suppliers of vacuum components, in a scenario where one supplier has issues delivering components, supply of materials does not become an issue as many other suppliers can supply needed components on the required quality and most likely without major quality issues putting production of dilution refrigerators on halt.

As there is a price difference in favour of manufacturing Still Line Tubes in-house with the current visual quality requirements, producing them from financial point of view is an economical option so long as visual quality level is kept the same as it previously has been. In a scenario of increased production numbers situation is to be followed to evaluate how beneficial it is to outsource more standard vacuum components. Welding small number of vacuum components in-house by a small number of welders using basic manual welding methods is beneficial for a small company. Especially when customer needs are often requiring custom length Still Line Tubes to facilitate the entire system in the laboratory in a favourable way for the customer, the need for custom parts does not disappear.

When approaching mass production numbers, it needs to be estimated for how long a company wants to grow a welding department and how many welders are wanted to conduct manual welding operations. Manual welding has its limits in higher production volumes and thus automation and investments to machinery are required to keep productions economic status competitive compared to outsourcing possibilities. This is especially notable when manufacturing vacuum components is not the core business of a company. Prizing is competitive for standard vacuum components when purchased in high enough numbers. It has long been a common standard for big businesses to outsource products that are not the main product a company sells to its customers.

Findings from production economy of the welding department are supporting on evaluating manufacturing costs of in-house manufactured welded assemblies. Information can be used in price comparisons of assemblies to find attractive outsourcing opportunities specially when own manufacturing is not wanted to be increased. Different price factors in welding are presented and shown are their significance on creating overall expenses. One needs to be cautious on what factors have a significant role and what do not have from a price perspective to get a good estimation how much costs to manufacture welded assemblies.

Information on work safety supports on evaluating and improving work safety of any manufacturing department where special practises of working with cryogenics are needed to be followed for best work safety. Common more well-known safety aspects of work and how to improve these with practical solutions are presented. Mitigating possible new risks when bigger or smaller changes in manufacturing are made needs special attention.

Evaluating risks and mitigating them is a continuous process and this work is never ready. Due to human factors and involvement in work new findings can be made when observing manufacturing processes from different perspectives and by different people. One perspective does not necessarily give the best outcome in evaluation of work safety. Monetary value for well addressed work safety can be hard to give but it has significance on the overall success in producing economically competitive products. Were these products made in own manufacturing or by other companies, in the ideal situation expenses from failed work safety on top of manufacturing costs are close to zero. Otherwise, the ready product cannot reach the ideal price point, let it be outsourced or not.

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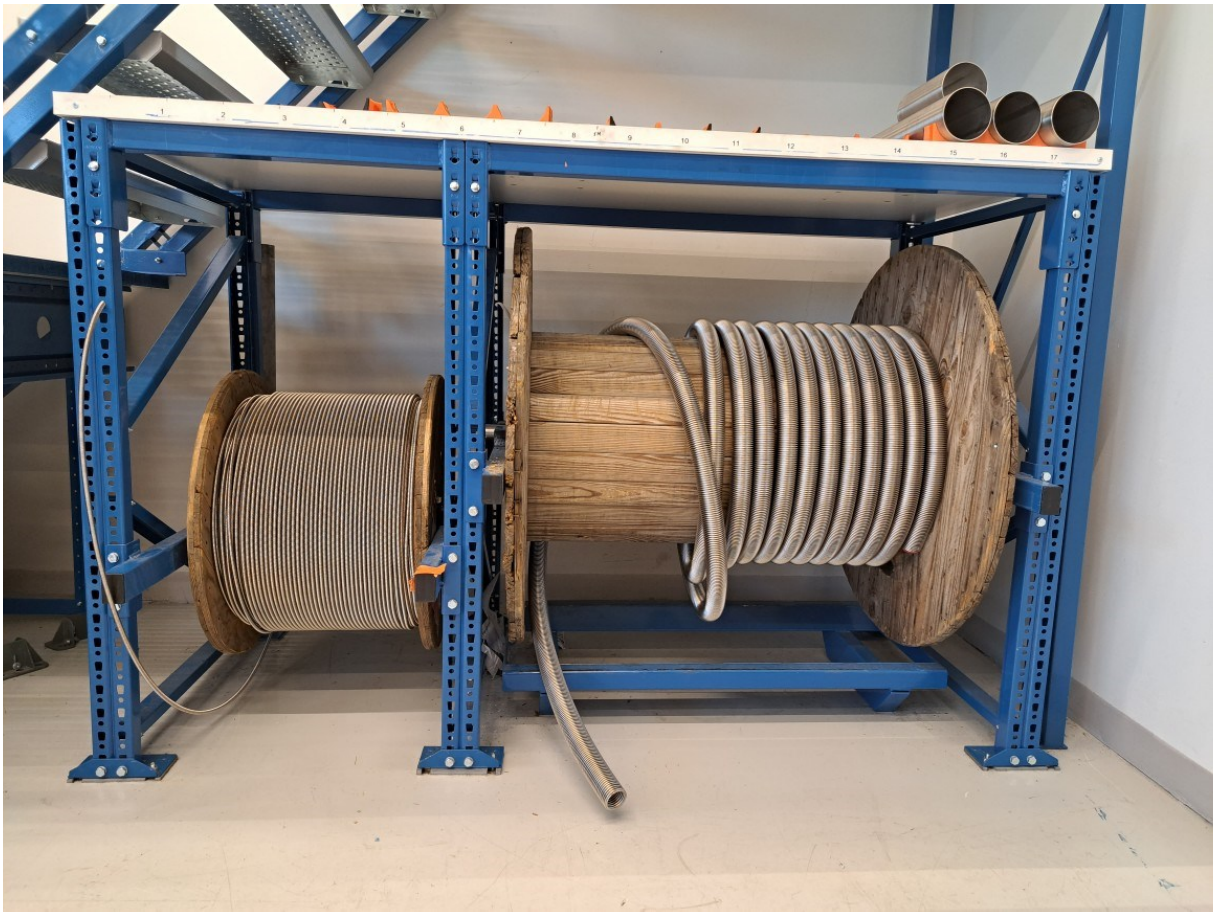
Appendix 1. Pictures from the Project

Old storing solution for corrugated hoses delivered in cardboard boxes.

Old storing solution for DN6 and DN40 corrugated hoses ordered in full wooden drums.



Rotatable welded flange without a collar not covering tempering colours before pickling.

Rotatable welded flange with a self-guiding collar covering tempering colours before pickling.

A Still Line Tube too long (over 1150 mm) to fit inside a standard Euro pallet with collars.

New welding facility without a floor coating and old lighting solutions in place.

New welding facility floor with a firesafe coating and improved lightning solutions installed.