Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Study of Loss Identification and Elimination in Food Manufacturing Company "X"

Master's Final Degree Project

Inga Kiverytė
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Assoc. prof. Rūta Rimašauskienė
Supervisor

Kaunas, 2022

Kaunas University of Technology
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Industrial Engineering and Management (6211EX018)

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Task of the Master's final degree project

Given to the student – Inga Kiverytė

1. Title of the project

Study of Loss Identification and Elimination in Food Manufacturing Company “X”

(In English)

Nuostolių identifikavimo ir eliminavimo studija maisto pramonės įmonėje “X”

(In Lithuanian)

2. Hypothesis

Autonomous maintenance is effective for loss identification and elimination.

3. Aim and tasks of the project

Aim: Identify loss analysis and elimination tools by using autonomous maintenance in food manufacturing company “X”.

Tasks:

1. To review Lean and Six Sigma implementation and loss identification practices in the food manufacturing industry.
2. To conduct loss analysis in food manufacturing company “X”.
3. To implement tools of autonomous maintenance in model line according to the framework of company “X”.
4. Assess the influence of autonomous maintenance tools on the efficiency of the model line.

4. Initial data of the project

Not applicable.

5. Main requirements and conditions

Use Lean and autonomous maintenance tools according to the framework of company “X”. Implement loss identification and elimination process and tools at the line level.

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Supervisor	Rūta Rimašauskienė		2022.02.28
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Kiverytė Inga. Study of Loss Identification and Elimination in Food Manufacturing Company “X”. Master's Final Degree Project, supervisor Assoc. prof. Rūta Rimašauskienė; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study field and area (study field group): Production and Manufacturing Engineering (E10), Engineering Sciences (E).

Keywords: Lean, total productive maintenance, autonomous maintenance, loss, food industry.

Kaunas, 2022. 64 p.

Summary

The main aim of this research project is to analyse the influence of systematic autonomous maintenance implementation on efficiency losses in the food manufacturing environment. Analysis of existing literature was performed and disclosed that utilization of Lean methods in the food industry is still low, mostly due to industry specifics, such as inflexible layouts, unpredictable demand, food safety requirements, and product perishability. Also, a lack of practical research papers was identified. Therefore, the study presents the implementation of autonomous maintenance steps 1 and 2 according to the framework of food manufacturing company „X“ in the model line, and the results of it are presented in terms of general efficiency losses. Initial line-level loss analysis was performed according to general types of efficiency losses and a system to collect data on equipment level losses was established. The tools of 2 initial steps of autonomous maintenance were implemented: small group activities, 5S, sources of contamination and hard to reach places elimination, equipment defects handling system, autonomous cleaning and inspection, as well as skill matrix, one-point lessons, daily management system and continuous improvement tools: Kaizen and root cause analysis. The results demonstrate the high capability to eliminate line losses related to breakdowns and operational losses through small group activities and problem-solving techniques, for instance, root cause analysis. Systematic implementation of autonomous maintenance steps 1 and 2 increased the general efficiency of the model line by 2.4%, which results in 128 hours of production time or 18 048 EUR yearly labour cost savings. In addition, cost avoidance due to reduced duration is 11 280 EUR per year as the number of changeovers on the line increased by 20%. As well as the high potential of labour cost savings by elimination of sources of contamination and hard to reach places which are estimated at 1251 labour hours per year, or 11 759 EUR.

Kiverytė Inga. Nuostolių identifikavimo ir eliminavimo studija maisto pramonės įmonėje “X”. Magistro baigiamasis projektas, vadovė doc. Rūta Rimašauskienė; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: Lean, visuotinė gamybos priežiūra (TPM), autonominė priežiūra, nuostoliai, maisto pramonė.

Kaunas, 2022. 64 p.

Santrauka

Pagrindinis šios studijos tikslas – nustatyti sisteminės autonominės priežiūros diegimo įtaką efektyvumo nuostoliams maisto pramonėje. Atlikta literatūros analizė atskleidė, jog Lean įrankių panaudojimo lygis maisto pramonėje yra žemas, daugiausiai dėl pramonės specifikos: nelankstaus gamybos patalpų išplanavimo, neprognozuojamos paklausos, maisto saugos reikalavimų ir greitai gendančių produktų. Taip pat pastebėtas tyrimų, nagrinėjančių praktinį Lean įrankių pritaikymą maisto pramonėje, trūkumas. Ši studija pristato 1 ir 2 autonominės priežiūros diegimo etapus maisto pramonės įmonėje „X“. Diegimo rezultatai vertinami iš efektyvumo nuostolių perspektyvos. Rezultatai pateikia pmaisto pramonės įmonės „X“ modelio linijoje rezultatus, vertinant iš nuostolių perspektyvos. Pradinė linijos nuostolių analizė buvo atlikta naudojant bendrinius efektyvumo nuostolių tipus ir tokiu būdu identifikuoti didžiausi linijos nuostoliai. Modelio linijoje buvo įdiegti autonominės priežiūros 1 ir 2 žingsnių įrankiai: mažų grupelių veiklos (SGA), 5S, taršos šaltinių ir sunkiai pasiekiamų vietų šalinimas, įrangos defektų registravimo ir šalinimo sistema, autonominis įrenginių valymas ir tikrinimas, taip pat įgūdžių matrica, vieno lapo pamokos, kasdienio veiklos valdymo sistema ir nuolatinio tobulinimo įrankiai: Kaizen, šakninės priežasties analizė. Rezultatai atskleidžia didelį potencialą eliminuoti linijos nuostolius, susijusius su gedimais ir veiklos praradimais taikant mažų grupelių veiklas ir problemų sprendimo įrankius, tokius kaip šakninės priežasties analizė. Sisteminis 1 ir 2 autonominės priežiūros žingsnių diegimas padidino bendrą linijos efektyvumą 2,4%, kas sudaro 128 valandas gamybos laiko arba 18 048 EUR metinį sutaupymą darbo sąnaudoms. Taip pat, sumažėjusi gaminio keitimo trukmė leido išvengti papildomų 11 280 EUR išlaidų darbo sąnaudoms per metus dėl 20% išaugusio gaminio keitimų kiekio. Taršos šaltinių ir sunkiai pasiekiamų vietų identifikavimas ir eliminavimas suteikia potencialą sutaupyti dar 1251 darbo valandą, arba 11 759 EUR.

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Introduction

The food industry is one of the most important sectors which consists of a different range of supply chains: from local to worldwide. Despite the level of a supply chain, participants of the food industry face challenges caused by short shelf life of products, changeable demand that is hard to forecast, long mandatory changeover and cleaning times in production, and high variation in materials while pressure and competition in the market increases. Therefore, the necessity to identify and eliminate losses of different forms should be an important part of each company's strategy.

Costs of products increase due to losses and might affect competitiveness of the producer. Approximately 25 - 30% of food is lost in the supply chain [1, 2]. It is evaluated that approximately 1.3 billion tons of wasted food were lost in 2021, causing a monetary loss of 1 trillion USD. Approximately 1/3 of all losses in food supply chain are created in food harvesting and production [3].

Another important aspect related to loss elimination nowadays is sustainability. As attention to climate change increases and countries pursue to become CO2 neutral, the consciousness of society also increases, and sustainability becomes a part of competitive advantage in most industries. Euro monitoring announced sustainability as a global consumer trend for 2022. Analysis reveals, that percent of consumers, believing that they can affect climate change by their actions and choices increased since 2015, and in 2021 it exceeded 55% [4]. This creates pressure for companies to improve their environmental performance.

Even though Lean and Six Sigma methodologies are commonly consented to be effective in waste elimination and improvement of environmental performance, application of these systems in the food industry is still uncommon. Companies tend to focus more on food safety and regulatory obligations [5, 6] rather than on improvement initiatives. It is evident that there is a lack of research on Lean and Six Sigma application in food manufacturing, only 1,4% of articles linked to Six Sigma and 3,1% of articles analysing Lean were related to the food industry according to quantitative research performed in 2017 [7]. Other authors also affirm the scarcity of literature in the area [5, 8].

Study of autonomous maintenance in the context of loss reduction in food production address this lack of practical research in several aspects. Firstly, authors, for example, L.Costa and S.Raval, articles of whom analyse Lean maturity through literature reviews recognize a lack of practical implementation guidelines and best practices [5, 8]. Secondly, by providing a different perspective of Lean implementation and loss reduction. Most of the articles on Lean application in the food industry are based on supply chain analysis [5, 7] by providing tools implemented, results, barriers, and success factors, but are not presenting details, or guidelines for practical implementation [5]. Thirdly, autonomous maintenance is part of Total Productive Maintenance, which despite its confirmed contribution to loss elimination in production [9, 10], and, also having a high influence on sustainability [11], is still rarely used in the food industry [5]. Therefore, research support limited existing information about the implementation of the tool in food production. Also, the study will support efforts to evaluate the potential of loss elimination at the line level.

The aim of the thesis is to identify loss analysis and elimination tools by using autonomous maintenance in food manufacturing company "X".

The tasks are:

1. To review Lean and Six Sigma implementation and loss identification practices in the food manufacturing industry.

2. To conduct loss analysis in food manufacturing company “X”.

3. To implement tools of autonomous maintenance in the model line according to the framework of company “X”.

4. Assess the influence of autonomous maintenance tools on the efficiency of the model line.

1. Lean implementation in the food industry

Lean and Six Sigma methodologies are widely applied for improvement of effectiveness, as well as combined Lean Six Sigma strategy [8, 9]. Term Lean refers to the Toyota production system which was developed in Japan after the second world war to enhance the effectiveness of production. The main aim of the system is to eliminate waste in a process through the application of Lean tools. Elimination of wasteful activities and optimisation of labour, space usage and other resources is one of the main Lean principles [12, 13]. Also, Lean introduces customer focus, as it seeks to produce exactly what the customer needs [5] and all activities, which do not directly change product are described as process waste.

Lean is a holistic approach, which refers not only to the methods of waste reduction but also to crucial cultural changes. It is often described as a philosophy and overall management system [14, 15], which involves not only technical implementation of the tools but also managerial and human-related aspects. R.A.Dominguez, et.al. [12] present the main principles of lean, which are: waste elimination through continuous improvement activities and respect for people. Social aspects are crucial as employee engagement and positive attitude related to changes is one of the most important success factors for Lean implementation [16], while only technical application of the tools brings limited benefits.

Six Sigma was created at Motorola, the title of the methodology refers to the main aim, which is the reduction of variation, as the Sigma letter is used to mark variability [5]. The title of Six Sigma means a defects level of 3.4 per million opportunities [5]. Six Sigma is a method based on structured problem solving using define – measure – analyse – improve – control (DMAIC) [13] improvement cycle simultaneously with statistical tools, such as statistical process control (SPC), measurement system analysis (MSA) and others. The combination of these two strategies to the Lean Six Sigma method conjuncts benefits of both systems [8, 13]. Lean supplements Six Sigma methodology by providing methods of value stream mapping for identification and prioritization of wasteful activities before moving to problem-solving and application of Six Sigma. Whilst Six Sigma provides tools and a structured problem-solving framework (DMAIC) to reduce process variation and waste. Lean, Six Sigma and Lean Six Sigma methodologies are widely used for waste, variation reduction and enhancement of overall efficiency.

1.1. Specifics of the food industry

Even though representatives of the food industry are interested in various opportunities for continuous improvement [5], there is still a gap in the literature, related to Lean, Six Sigma or Lean Six Sigma application in the food industry [5, 8]. While existing articles are mostly academic, authors emphasize the lack of practical literature [8]. There are obvious differences in Lean implementation levels, when comparing different sectors, which is also confirmed by the fact, that there is no information about the continuity of Lean programs and sustained results in the food manufacturing sector. The food industry is at one of the lowest levels regarding utilization of Lean tools [8, 17], which is possibly related to specifics of the food industry.

There are several specific attributes of the food processing industry, which not only distinguish it from other sectors, but also might become a barrier to Lean implementation. First, the demand for food products is highly uncertain and variable, therefore it is complicated to create reliable forecasts [5, 6]. Analysis performed by I.Vlachos confirms great variability in forecasts, the author presents the results where actual demand, compared to initial forecasts differs by 200% [18]. Even though the demand is highly variable, the food industry has short delivery times, which is related to product perishability, as well as pressure from retailers, which typically have high power in the supply chain [5].

Another group of industry attributes is related to internal production environment and processes which create barriers to the implementation of Lean practices. One of the most important aspects is quality assurance and hygiene requirements [5, 12]. In the context of the food industry quality most often refers to food safety rafter than defects of the product itself [17], which conveys that food processing companies tend to focus on food safety and legal requirements compliance more than on the improvement of the process [5]. Because of these requirements, companies face mandatory cleaning and increased changeover time and other activities required for quality assurance. Another feature important to be noted is inflexible layout of a factory. Most food manufacturing companies are continuous process manufacturers, materials are supplied, and equipment is connected to pipe systems. Thus, changing arrangement of a shopfloor would require capital investment and additional space on a shop floor [6].

High variability in production processes is also discussed in the literature. High variability in recipes is reported by M. Dora et.al. [6]. A part of this irregularity could be explained by machine variability, but the most important factor in food production is variability in materials properties [6, 14]. Variability in materials, especially in the materials of natural origin is hard to control, because these might be affected by humidity, temperature, and other factors during their growth and/or processing [6].

All the food industry attributes noted above, could become a barrier to Lean implementation, some authors state, that in the food manufacturing environment Lean has a low impact [14], while others highlight the need for adoption and potential of Lean practices.

1.2. Application of Lean tools in the food industry

Food industry-specific requirements lead to non-value-added activities and increase production costs; therefore, it is not surprising, that the main stimulus for companies to start Lean deployment is cost-related [5, 17]. First, reduction of variation in production process which can generate a huge amount of rework or sanitary waste and reduce overall process efficiency, which is stated as one of the main motivators for Lean. Variation might be related to weight and size variation, which is also important as companies are balancing between overweight of the products, because it is a direct loss for the company and legal requirements for allowed minimum weights of the products. Another motive for Lean initiatives is overall process efficiency, losses of which increase costs through increased energy and labour costs, as well as unearned incomes due to lower quantity of produced finished goods.

Several research presents positive impact of Lean on the overall performance of food manufacturing companies [5, 17]. Costa, et.al [5], present that benefits achieved in the food industry by implementing Lean most frequently are cost-related, which coincides with business expectations. The most significant gains are reported in productivity, cost, and inventory level improvements [5], which are influenced by improvements in other, lower-level key performance indicators. For example, R. A. Dominguez, et.al.[12], presents multiple case study, where one of the companies analysed managed to achieve a 25% increase in equipment uptime and reduce defect level by 5% within 1 year. The findings of other authors also represent improvements in operational performance that results in cost reduction, 83% reduction of quality defects (from 1.2% to 0.27%) and overall costs of low quality were reduced by 46% [19].

In general, Lean is a methodology, the main aim of which is waste reduction and increase of value for the customer by optimising resource usage [12, 20]. There are 3 general types of waste: Mura – unevenness which leads to other waste types, Muri – overloading and Muda – wasteful activities, which are directly related to costs [12]. There are identified 7 main types of Muda type waste, which include defects, overproduction, waiting, transportation, inventory, motion, and excess processing (Fig. 1). Nowadays, 8 wastes are used: underutilised capability of employees is enclosed with the 7 conventional wastes.

Fig. 1. 7 Lean wastes [14]

Even though terminology used in traditional business companies and Lean philosophy is different, waste is directly linked to various types of losses and makes an impact on performance in various areas: cost, quality, flexibility, and environmental performance [10, 11, 20].

Defects are directly related to cost and quality as production of these consumes materials, labour time, and energy resources. It is strongly tied to environmental performance as well, especially, when defects cannot be returned to process and fixed, in this case, not only resources are used but also materials will be wasted. The further in the process defect is found, the higher costs are.

Overproduction – is related to high levels of finished goods inventory, and inappropriate use of machines and labour. A high level of finished goods inventory brings risks of hidden defects and increases the need for transportation. In the case of the food industry – the risk that outdated products will be provided to the market, as products are perishable.

Waiting – in production, it is related to all types of downtime: breakdowns, minor stops, cleaning, as well as unbalanced production line, when part of the operation is waiting for inputs from upstream operation, this aspect is strongly related to the implementation of lean principle related to creation of the flow, which was discussed before.

Transportation – according to the Lean philosophy, any additional action that does not change product for the first time is non-value added, and this type of loss is a great representation of that. Excessive transportation requires additional human resources as well as equipment, it is usually a signal of overproduction, high inventory levels and inefficient plant or line layout. In addition to this, in the case of the food industry, it increases risks of product or materials defects occurrence, as well as the risk of mixing allergens.

Inventory requires space, therefore, costs for additional storage space increase the period of conversion from purchasing materials to selling finished goods. In the case of the food industry, excess inventory along with unpredictable demand creates an additional threat of expiration of materials and write-offs.

Motion is additional movements of employees mostly due to inefficient workplace organisation. This type of waste reduces employees' work satisfaction, and increases the need for human resources, as part of their actions are pure waste. Also, motion might increase losses at line level, for example, time to repair breakdowns.

Excess processing creates additional costs because operations that are not required by the customer are performed. In this way, additional costs of labour, material, equipment amortization and energy appear.

The necessity of Lean and Lean Six Sigma adaptation for the food industry is evident and waste types identified in Lean methodology are applicable to the industry for the purpose of loss reduction. Even though, Lean is referred to as a methodology and a systematic approach is emphasized, most of the case studies demonstrate a piecemeal approach, when companies select only specific tools for implementation, case studies are related to specific problem solving and demonstrating project approach, rather than systematic Lean implementation [13, 21–26].

A significant number of research articles are focused on a whole supply chain, rather than specific production lines. Companies that implement a piecemeal approach, when only a few selected tools are applied, might gain benefits in reduction of losses without changing established work methods in the organization [18], though, fragmented application of individual tools is criticized because it does not bring a company full benefit that Lean system is capable of [6, 18]. Not only selection of the tools is important, but some of the methods are also required to be implemented in parallel to achieve the best result, thus a piecemeal approach, when one tool is implemented with no other supporting tools. Lean should be implemented by using sequential order of tools, thus reducing waste constantly and consistently, enabling the adoption of principles and cultural changes that bring sustainable results and continuous improvement culture. Therefore, a systematic approach to the selection and adaptation of tools is of critical importance and requires substantial expertise on the subject [18], even though is not widely analysed in the literature [1, 5].

One of a few investigations that attempt to define the sequence of lean tools implementation, even though does not provide a list and sequence of specific tools proposes the following 5 main lean principles (Fig. **2**), by emphasizing the importance of their implementation in succession, as outcomes of one step are input for the next step [14]. Firstly, a company should define, what is valuable from the customer's perspective and only then map the value stream. Improvements identified during value stream mapping should eliminate waste and lead to the creation of flow. After this step pull system can be established. I. Vlachos, et.al., suggest Lean implementation in 3 stages: first, the preparation that covers gaining management commitment for Lean implementation, as well as data collection related to demand variations and initiation of Lean improvements, as the company presented in this case study encountered several failures, the second stage was the definition of the current state, the main barriers for implementation and countermeasures were defined. The third stage is based on lessons learned from previous steps when the implementation of Lean starts based on 5 main lean principles [18].

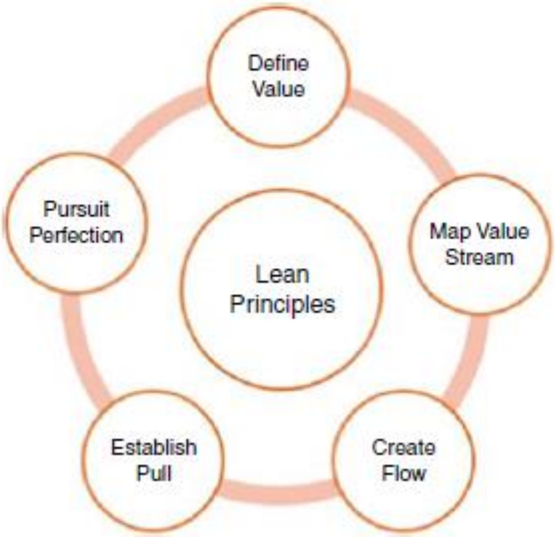

Fig. 2. 5 Lean principles [14]

Because of food industry specifics, it is apparent, that one of the main aims of companies that strives for Lean implementation is the reduction of variance and cost, which leads to productivity improvement and higher competitiveness [5]. Tools, which are most used in different sectors gained their success mostly due to versatility and significant results compared to low investments. Most often used tools in the food industry are [5]: value stream mapping, as well as process maps, Ishikawa diagrams, problem-solving through define – measure – analyse – improve cycle (DMAIC) and Pareto chart.

Value stream mapping (VSM) – is one of the most popular Lean techniques to visualise process flow (both, material, and information), amount and place of inventory accumulation, and identify waste types and locations of its occurrence in the process [13, 20], bottlenecks, other process deficiencies through process parameters including cycle time, defect rate, downtime and other. One of the important features of VSM is a measurement of value-added (VA) and non-value added (NVA) time in the process (Fig. 3). and improvement opportunities. The use of VSM consists of two parts: documentation of the current process (creating current state map), where waste is identified and visualisation of process state after improvements (creation of future state map).

Even though, VSM is one of the most frequently used methods, some studies show, that there are more effective tools to increase the overall performance of the organisation, for example, JIT production and automation [27]. Also, data contradicts common presumption, and states that VSM has a negative effect on organizational performance. I. Belekoukias presented an analysis [27], that indicates no or negative effects of VSM on several parameters of organizational performance, namely, quality, cost, and flexibility. Even though this discrepancy requires further investigation, there are several possible reasons for this negative correlation that was found. First, VSM is usually one of the first Lean tools which are used in the company, it might be accomplished improperly, for example, if outdated or incorrect data was used, or a VSM event was held during the presence of special conditions, when data differs significantly from an ordinary situation, which reveals the importance of expertise [5, 6].

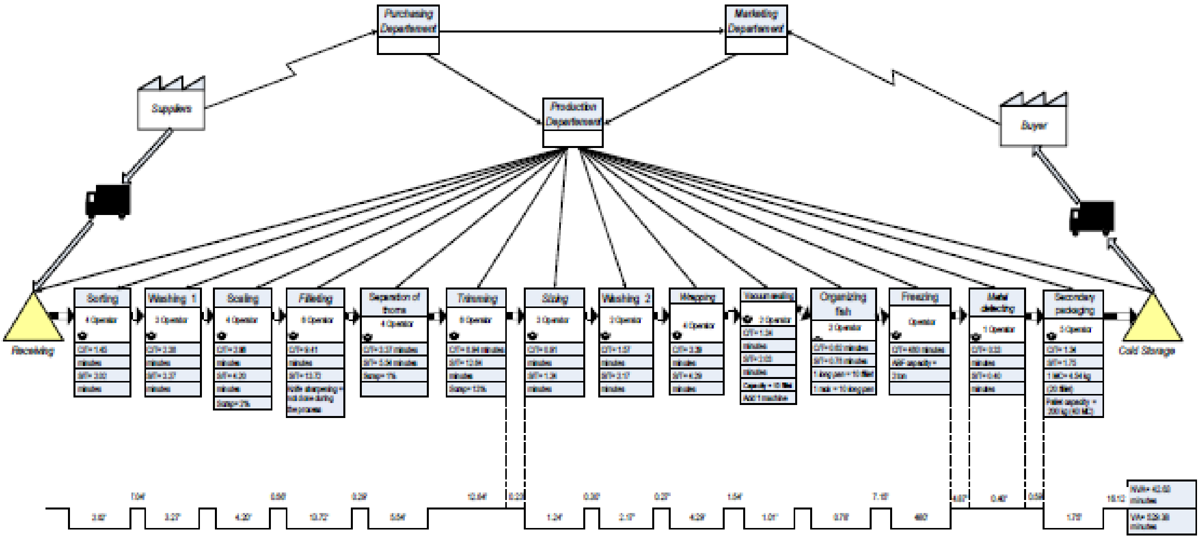

Fig. 3. Typical VSM current state example [24]

Process mapping is also well known as a process flow chart. It is a visualization of sequential process steps, therefore, some authors classify it as a type of VSM [27]. In addition, process map covers not only the main process stream, but also process branches when different decisions are made, therefore reveals loops of rework, excess processing steps and other process wastes, also, it includes inputs and outputs of specific steps, related documentation. This tool is most often used for the definition of a process current state, to identify non-value-added steps and identify process improvement possibilities. Also, it is used for process standardization, as procedures are described using the form of a flow chart.

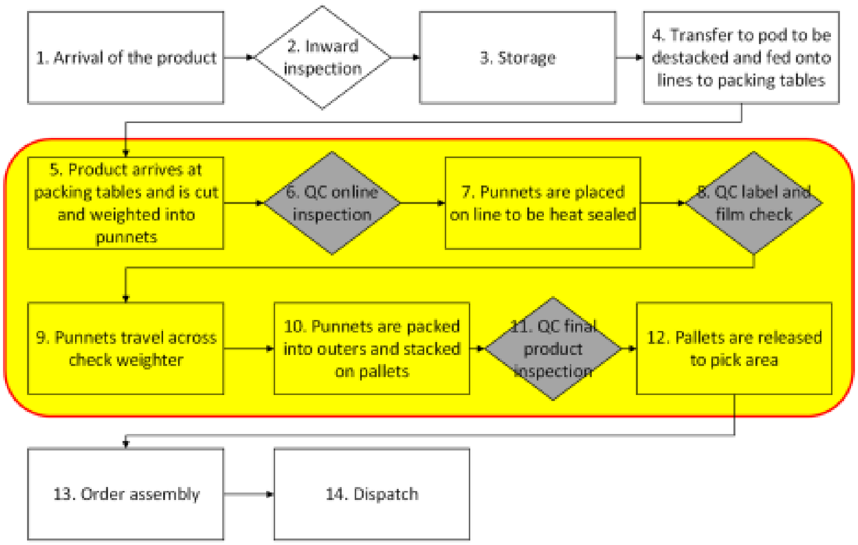

Fig. 4. Process flow chart [28]

Ishikawa (fishbone) diagram is also recognized as a cause-and-effect diagram. The tool is most often used during problem-solving / root cause analysis activities to identify potential causes of the problem

[28]. Standard 6M (machine, method, measurement, material, man, mother nature) categories are used to classify potential causes for manufacturing problems [13]. There are several authors, which, instead of the 6M model, which is commonly used in a manufacturing environment, suggest using a simplified version of 5M [13, 24], or most frequently 4M [22]: machine, man, material, and method. G.Garcia et.al., in a case study of waste reduction, adopted the traditional 6M model for a particular problem and next to manufacturing-specific categories included management, which is more related to business processes [28]. The other example of flexibility is related to TPM implementation when units of equipment were used as a category in the fishbone diagram (Fig. 5). These cases show flexibility and wide applicability of the tool.

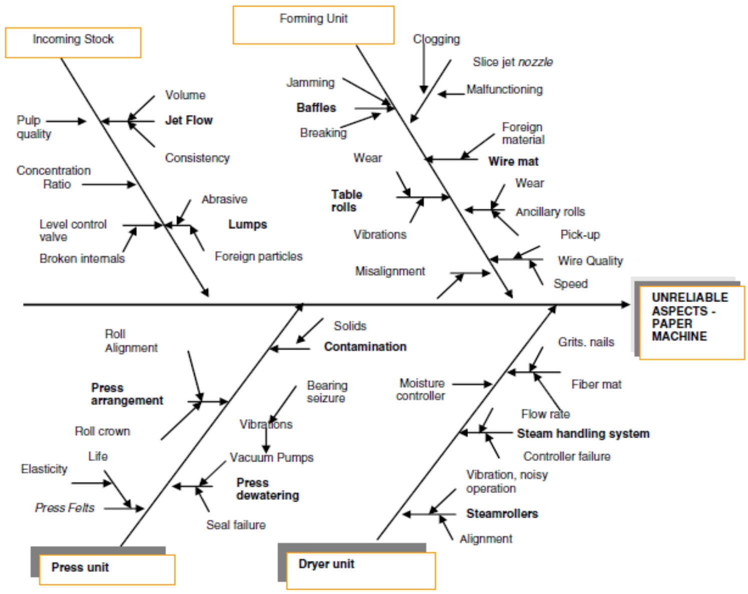

Fig. 5. Fishbone example [29]

5S – method for workplace organization consists of 5 steps: sort, set in order, shine, standardize, and sustain. This visual management tool supports the reduction of defects, both, equipment, and products, waiting for equipment to be repaired, motion by searching for specific tools or information, excess inventory, as storage places are organized for the best utilization and limited space is assigned for specific materials or products. 5S is of special importance in the food industry, as it supports food safety standards and diminishes the risk of product contamination. Sometimes 5S system is supplemented by safety and is represented as 6S, which for the food industry is recommended as a first, therefore most important „S “. The method aims to create a visual workplace and standardize it. It is a universal tool and is considered relevant to the requirements of the food industry, such as quality and cleanliness standards, and general food safety requirements [12].

Define- measure – analyse – improve - control (DMAIC) cycle is an improvement/problem-solving cycle, which is usually associated with Six Sigma methodology and used together with other Lean Six Sigma tools, such as fishbone, 5why, standard work, control charts, and others to eliminate various types of waste [13].

Pareto chart aims to distinguish categories which have the highest influence, according to a well-known 80/20 principle. Most often used with other tools in problem-solving activities and requires detailed data collection to provide results from different perspectives.

The fact, that only several basic Lean tools are used more frequently affirms a low level of Lean in the food industry and fragmented implementation with project approach when Lean tools are used only in problem-solving projects, even though, other well-known Lean tools might be perfectly applicable and increase benefits attained.

One of the rarely used tools is control charts. It is a statistical tool, associated with Six Sigma and used to identify abnormalities in the process. Statistical process control is sometimes described as non-applicable for the food industry, too complex and progressive tool and is one of the least utilized methods in the industry [17]. This is related to high variation in the processes that are not always possible to control, and a lack of knowledge of how variation can be controlled.

Another tool, that could be beneficial in food manufacturing, but is rarely used is a single minute exchange of dies (SMED). SMED is considered an advanced Lean tool, which requires high competence of the employees [20]. It could be valuable for food manufacturing companies with batch production to shorten changeovers, and changeovers after products containing allergens, which requires a long time not only for materials change, machine set-up and cleaning, but also for disinfection of all equipment. Applying the same SMED methodology in the context of the food industry could be applied not only for changeovers but also for mandatory sanitary cleaning.

The authors also suggest that structured root cause analysis tools, e.g. A3 are applicable in the food industry. Even though elements, like Ishikawa diagram and DMAIC cycle, are widely used, there is a lack of a systematic and structured approach [5].

One more Lean tool, Just-in-Time (JIT) production might seem applicable, due to short expiration times of materials and products, but in the food industry, it faces challenges due to unpredictable demand [5]. Some authors state that inventory reduction is one of the greatest benefits for food sector enterprises [5], while others oppose that companies are not able to organize their activities in this way and meet short lead times, which are required in the market [6]. Therefore, the application of this specific tool highly depends on each company's specifics and level of integration in the supply chain.

Researchers find the implementation of several specific tools problematic, for example, research by Dora et.al. [6] analysed 4 case studies of Lean application in the food industry, 2 companies, that were identified as successful examples of Lean implementation, did not manage to implement, and sustain Kanban system in a long term. One of the main reasons is the low reliability of demand forecasts as well as relationships within supply chain and expected supply times: as a downstream supply chain members expect JIT supply, a company, which reduces inventory and implements a pull system with its suppliers faces a high risk of product shortage in the market.

TPM is also one of the most frequently used Lean methods in various manufacturing industries, defined as an effective tool for breakdowns reduction and equipment OEE improvement [20]. Though, there is a lack of information about its utilisation in food manufacturing. TPM, depending on the implementation framework, consists of many other tools, such as, preventative maintenance, SMED, abnormalities handling, autonomous maintenance, and tools for employees' development, such as one-point lessons (OPL), and skill matrix, cleaning and inspection, abnormalities handling and others. The whole system and full model are not well described, and different variations can be found in the literature, however, the core tools can be found in different concepts.

Skill matrix is a tool of high importance, especially in the context of TPM and autonomous maintenance, but it, or similar tools like training needs matrix is rarely discussed in the literature. There are several case studies, which found root causes related to human resources, for example, operators' responsiveness to abnormalities in the process [22]. As Lean philosophy is not to blame people, but rather to pay attention to processes. This directs to training and development of the line employees, as well as improvements in manufacturing processes. Skill matrix is important in several aspects, it uncovers areas where individuals need additional training (theoretical or practical) [20], but also represents, how flexible line is in terms of work organisation, which appeared of critical importance during recent years when due to COVID-19 any employee could get isolated at any time. Skill matrix enables cross-training and substitution in case of illness, holiday, or leaving the company thus, continuity of operations.

One-point lessons (OPL) are widely applied in the food industry in the context of TPM implementation or work standardization. OPL is short, visual instruction on how to perform some specific operation, action or even step. The main idea behind this is to simplify instructions, to make these easy to understand for everyone and enable every employee to create them. This tool is used for knowledge sharing, communication about changes that were implemented and definition of standard methods and how tasks must be performed correctly.

1.3. Application of total productive maintenance

Total productive maintenance (TPM) is one of the main Lean strategies for waste elimination in manufacturing [9, 27], which is oriented to increase equipment availability and production efficiency by constant observation, checks and maintenance of the equipment [20]. Equipment availability and performance are the main objects of TPM, which could be supported by the analysis of J.D.Morales Mendez, et.al., in a specific case study uncovered that 59% of unplanned stops makes an effect on equipment availability while 41% on efficiency [30]. The main aim is to minimize equipment breakdowns, all types of unplanned stops, time of operations at reduced speed and defected products. These three measures: availability, quality and performance defined one of the main KPIs related to TPM – overall equipment efficiency (OEE), which is the main measure of TPM effectiveness [9, 31].

The six big losses, that are commonly tied to equipment, namely: breakdowns, changeovers and adjustments, minor stops, working time at reduced speed and production start-up losses due to defected first products and further in the process [32] are directly related to OEE measurement [29]. Fig. 6 represents this relation, where breakdowns and changeovers are directly affecting equipment availability, while speed losses and minor stops reduce performance, quality losses are related to reduced yield at production start-ups and defected products. OEE of 85% is generally considered and acknowledged by the Association of Manufacturing Excellence (AME) as a world-class achievement [33].

TPM several different KPIs are used, of which, most often used are MTBF – measurement of the average time between equipment stoppages, MTTR – mean time to repair and OEE – overall equipment efficiency [34].

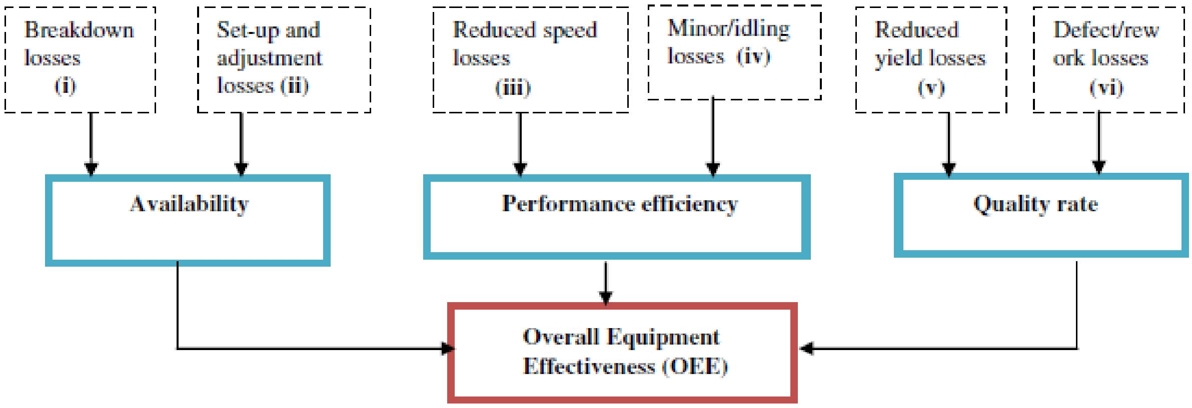

Fig. 6. Links of 6 big losses and OEE [29]

TPM is a method of critical importance for every manufacturing company as it is evaluated that costs of corrective maintenance are 3-4 times higher than preventive maintenance [35]. Different authors estimate maintenance costs take 25 – 30% [32] or even 15 – 40% [31] of all manufacturing costs and thus make a significant impact on a company's profitability. In addition to cost reduction, TPM provides several other benefits for the company, for example, production effectiveness, higher quality, and schedule adherence, also improved safety and employee engagement [36]. TPM effect on loss reduction is observed from different perspectives. First, improved uptime, quality, and performance of the equipment, in addition to this, TPM reduces the usage of materials including raw and auxiliary materials, required for machine operations, such as oil [11].

Despite the popularity of TPM in different industries and its tremendous potential for cost reduction, practical application in the food industry is very low, as presented in the research of Costa, e.al., [5], frequency is below 4%. This might be related to a lack of literature, which is also admitted [37]. Therefore, analysis of TPM implementation methods and results is based on research in various industries.

There are different implementation models and sets of tools used under TPM, even though, it always consists of Lean methods that are applicable to the maintenance field [15]. Azin, et.al., present 5S, OEE, JIT and learning management system (LMS) as commonly used tools [10]. Another approach defines TPM as a system consisting of OEE monitoring and improvement efforts through the implementation of changeover time reduction (SMED), 5S, both, autonomous and planned maintenance, quality maintenance, equipment checks before production start-up as well as a safe and hygienic environment [27].

Autonomous Maintenance (AM) is key method for TPM implementation [15, 31, 38]. Qualified operators through daily checks and minor maintenance tasks maintain technical condition of their equipment and thus productivity improvement can be achieved [10, 36]. TPM is implemented over small group activities, part of which AM is. This concept develops and empowers line employees to eradicate losses and initiate improvements to improve production effectiveness [36].

Implementation of autonomous maintenance requires high engagement of line operators and development of their sense of ownership. Their competencies must be developed, and tools introduced gradually [36]. Operators should be able to perform simple maintenance tasks, for example, inspection and lubrication, and handle minor breakdowns, while more complex tasks require support of technical personnel. Also, one of the core skills for operators is the identification of equipment abnormalities and defects, as their identification and escalation might prevent future losses [36, 39].

For successful autonomous maintenance collaboration and support of other pillars are necessary. Firstly, the pillar of education and training should help to assess operators' technical skill level and together with the preventive maintenance pillar prepare an appropriate training program. Preventive maintenance is also responsible for the preparation of specific tools, for example, cleaning and inspection standards, and equipment abnormalities handling. Meanwhile, continuous improvement is responsible for building problem-solving capability [15, 30].

A.Azizi et.al. [32] provide a more specific and sequential description of AM implementation (Fig. 7). According to it, firstly, initial cleaning and inspection should be performed to identify sources of contamination and hard to reach places also, to collect information about equipment defects. After this initial event, SOC and HTR elimination and simplification must be accomplished to set proper cleaning, inspection, and lubrication standards. After operators are trained, they should start performing these standard tasks of autonomous maintenance to suggest possible improvements of the process.

Fig. 7. Flow chart for AM implementation [30]

Implementation of AM by using this model and integration of statistical process control (SPC) led to a decrease of defected products by 8.49%, from 14.6% to 6.12%. Also, breakdowns duration was reduced more than twice, from 2502 to 1161 minutes. Both, quality, and breakdown time improvements result in OEE growth of 6.49% [32].

S.Vardhan et.al., present one of a few TPM implementation case studies in the food industry [19]. Even though the scope of the research is limited to the implementation of only quality maintenance, it presents impressive results on how defects might be reduced through TPM and AM activities. First, the article presents pre-defined tools for implementation, 4M (man, machine, method, and material) analysis for incoming materials, association of quality defects and equipment conditions, and preparation of the master plan, which includes initial and periodical employee training. During implementation, a process flow chart was created and analysed, and points for quality checks were identified. Problems, that occurred, for example, variation in product thickness, and uneven spread of condiment, were solved by using Kaizen methodology. Results represent reduction of thickness variation by 3 times, while uniformity of spreading increased by 5%. In addition, leakages of packages were reduced by 78%, from 1.2% to 0.27%. During the period of the 4-year strategy of incremental improvements reduced defects in production by 83% and costs related to quality by 46%.

TPM and AM benefits in other than food industries are described by using more perspectives. For example, research in automotive presents reaching a 10% increase in production capacity together with an 8% to 18% improvement of OEE [15, 30]. While a case study in paper manufacturing SME presents rework was reduced from an initial 22% to 10%, the percentage of maintenance costs compared to operational costs reduced from 30% to 10% and the defect rate from 24.82% declined to only 5% [29]. In lead frame manufacturing OEE improvement of 20% was observed [38]. High achievement in different industries validates AM and TPM versatility and applicability.

In addition to cost and effectiveness improvement, intangible benefits are also acquired through TPM and AM implementation [31]. These benefits include improved cross-functional collaboration between production, technical, quality, and other departments as cooperation is necessary to fulfil the concept of AM and achieve the best results. Also, mutual trust between employees and management, higher employee engagement, a sense of ownership and work satisfaction when employees are continuously developed and empowered to make decisions and solve problems.

Even though the benefits of TPM are clearly defined and its implementation uncovers the great potential for loss recovery, companies must be ready for increased costs for restoration of equipment technical condition and employee training [36], or, in some cases, effectiveness losses as new activities, requiring line downtime starts, e.g., autonomous maintenance. A case study, presented by G.Amorim et.al. represents an increase in maintenance costs by more than 4 times at the start of TPM implementation. This significant increase was related to a lack of preventive maintenance, as before the start of TPM there was only 15% of planned yearly maintenance was conducted and the initial technical condition of equipment had to be restored [34].

TPM implementation is a long-term strategy for equipment availability and efficiency improvement. I. Madanhire states that it takes up to 3 years to develop a mature TPM system and reach full benefits from it [36], which coincides with findings of another study, when OEE increased by 30% (from 55% to 85%) was reached in 2 and a half year (increase by 30%) [34]. Other authors, that emphasize system sustainment claim, that it could be reached within a period of 3 to 5 years [40].

2. Methodology of autonomous maintenance implementation and loss analysis

Research is based on the case of company „X“, where autonomous maintenance is implemented in model line as part of the overall integrated Lean Six Sigma program. Autonomous maintenance implementation is separated into 7 steps, and an additional step 0, which is dedicated to preparation. In this research, the implementation of steps 1 and 2 will be analysed and the results presented.

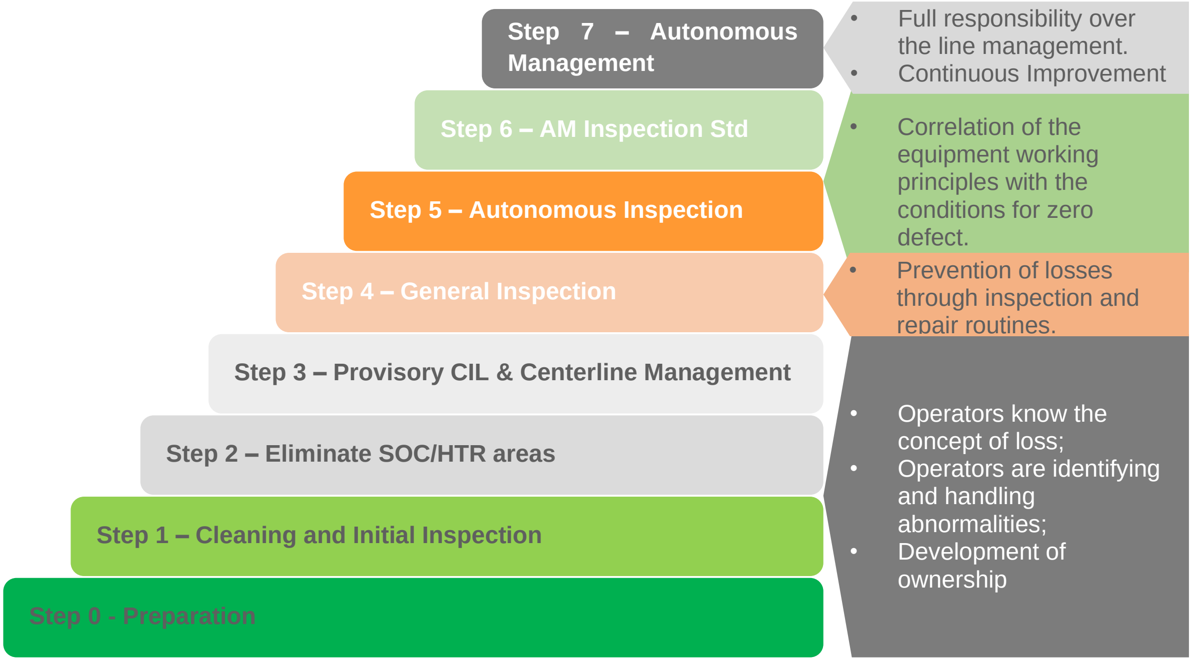

Fig. 8. Steps of autonomous maintenance implementation

First, loss analysis will be performed to identify the greatest losses and possibilities to eliminate these by implementing autonomous maintenance. As a currently used system of data collection and loss analysis is not sufficient to identify specific losses, a new data collection system has been developed to capture and prioritize losses in the scope of autonomous maintenance in the model line. The inefficiency of the old system is that it allows stratification only according to the line and generic loss types, such as, rework, sanitary waste, operational losses, and others, which provides only line level information with no details of specific loss types and identification of equipment, where these losses occur, while activities of AM cover production line, area, or equipment. Therefore, more detailed information is necessary to direct the efforts of SGA teams and other activities.

AM implementation covers the deployment of specific tools, which are pre-defined in the program of Integrated Lean Six Sigma as basic tools to be implemented in AM steps 0-2.

The first 2 steps, according to the framework of company „X“ covers the implementation of tools defined below:

- 5S – standards of each workplace and whole line layout must be created and sustained.
- Kaizen – improvement suggestion system implementation.
- OPL – one-point lessons as a tool for knowledge sharing should be used, OPLs can be created by line employees, technical employees, or others.

- SOC/HTR – all sources of contamination and hard to reach places must be identified and elimination/simplification must be started. It eliminates non-value-added time for various activities, such as maintenance, sanitary cleaning, changeover and autonomous cleaning, inspection, and lubrication.

- CIL – initially, daily / weekly / monthly cleaning and inspection must be performed by line operators. Lubrication is incorporated later, after specific competencies of operators are developed. The tool ensures periodical inspection of equipment and early identification of equipment defects; therefore, breakdowns might be prevented.

- Abnormalities handling (TAG) system – all equipment defects/abnormalities must be identified and eliminated as they could lead to breakdown or safety incidents. Defects are categorized according to their complexity: the ones, that operators can solve themselves and those, where support from the technical department is necessary. Also, safety TAGs are separated, as defects which cause safety risks must be solved within 24 hours.

- Data collection to equipment and failure mode level – the system must be created, and data collection started. It is an important milestone, as data of the system enables identification of the greatest losses in the line and start of elimination through SGA activities.

- Root cause analysis – problem-solving, and loss elimination tool, which should be used in the model line by its employees.

- Daily management system (DMS) – DMS system must be implemented at all levels: from DMS1 (shift handover) to DMS4 (plant level) to ensure information flow, effective escalation of the problems and communication.

- Skill matrix – all required skills must be identified, and employees evaluated according to defined criteria. Identified skills are related not only to technical skills, but also, to safety, Lean Six Sigma tools and other. In case, the required level is not reached, individual development plans are created to reach it.

- SGA – employees must be empowered to initiate and participate in different improvement activities, as well as maintain condition of equipment that they operate by completion of CILs, TAGs registration and resolution, also, suggestion of kaizens, etc.

Autonomous maintenance implementation requires support and collaboration of all the pillars of Lean Six Sigma as they are owners of tools. 5S, SOC and HTR elimination and small group activities are implemented by the pillar of AM. Supporting systems, related to other pillars must be implemented, for example, root cause analysis (RCA) and kaizen from focused important, one-point lessons (OPL) and skill matrixes from education and training, lockout – tagout, quick risk assessment for non-ordinary tasks from HSE pillar.

Even though some of these tools are not directly created or implemented by the pillar of autonomous maintenance, they must be deployed in the line and become part of team ‘s daily work, therefore they are considered AM tools. In the implementation of AM steps 0-2 strong support and involvement of other pillars are necessary, e.g., pillar of preventative maintenance for equipment defects management and CIL creation and implementation, education and training pillar is responsible for OPLs and skill matrix implementation, safety systems implementation -HSE pillar, also focused improvement pillar must provide a system of data collection and build capability for loss identification and elimination through root cause analysis.

In the evaluation of AM effectiveness in loss elimination, GE / OEE change will be evaluated as well as the effect of SGA improvements on the performance of specific equipment or product GE.

3. Model line in company „X“ and loss analysis

3.1. Model line of the company „X“

Company „X“ is a large manufacturing plant of chocolate confectionery, which has 400 employees, located in Lithuania. It is part of the corporation, which owns plants worldwide and is one of the leaders in the market of chocolate and snacks. Part of the business's strategy is the implementation of an integrated Lean Six Sigma program, which includes TPM and autonomous maintenance. According to the framework of the company, tools are initially implemented, and standards are created on the selected model line and then transferred to other lines.

The most complex line in the plant was selected as a model line. This line produces 38 different part numbers of 16 product families, from 6 to 8 tons per shift (8 hours) depending on product type. The top 5 product families create 71% of total line production volume, while the rest 11 families are low volume and create only 29% of volume (Fig. 9). The total amount of production in 2021 exceeded 4700 tons.

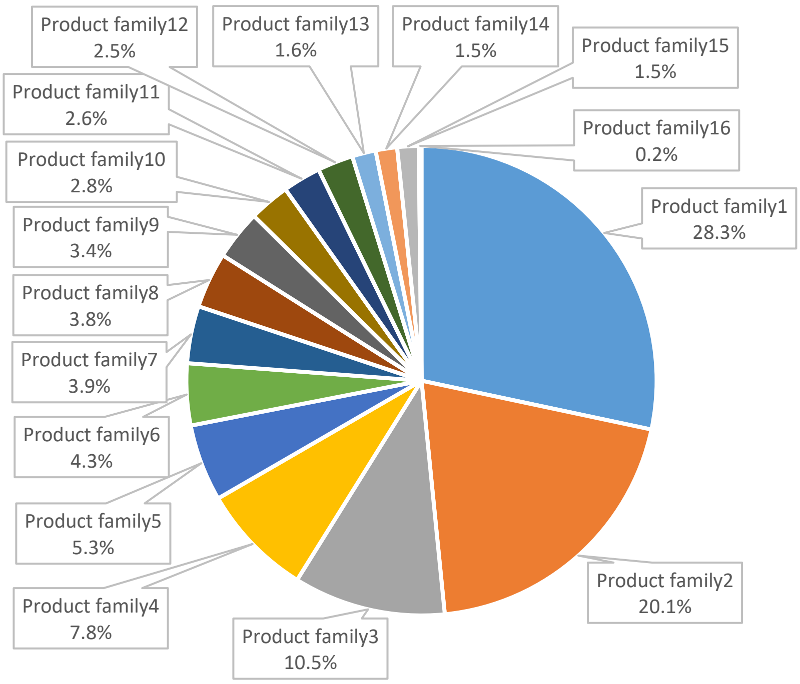

Fig. 9. Production volumes by product family

Products vary from simple, one-layer products to multiple layer products, products with a variety of food accessories applied before and/ or after enrobing, also, part of the products are enrobed in two types of chocolate. It is important to note that some of the products contain allergens, e.g., nuts.
Production process is based on the sheet and cut technology (Fig. 10), where prepared mass or its components are mixed and supplied by pipe system to tank, from there mass goes to the rollers, where a sheet is formed. After cooling, sheet is cut longitudinally, and through a separation table transported into transversal cutting. In this way corps of chocolate bars are formed. The formed body is enrobed and cooled, positioned and packed into single packages and carton boxes. Also, several operations are not incorporated into the line of continuous flow, e.g., caramel, syrup, protein preparation, several specific mass mixing operations, and chocolate tempering. These machines work offline, and supply produced semi-products to the line during production of specific products, main processes, that are

common for all products are part of continuous flow are mass preparation, forming, cutting, enrobing, cooling, and packing. The most common options of process flow are presented in Appendix 1. The line contains 83 equipment units, occupies an area of 600 m^2 in the factory and on average, has 15 employees per shift.

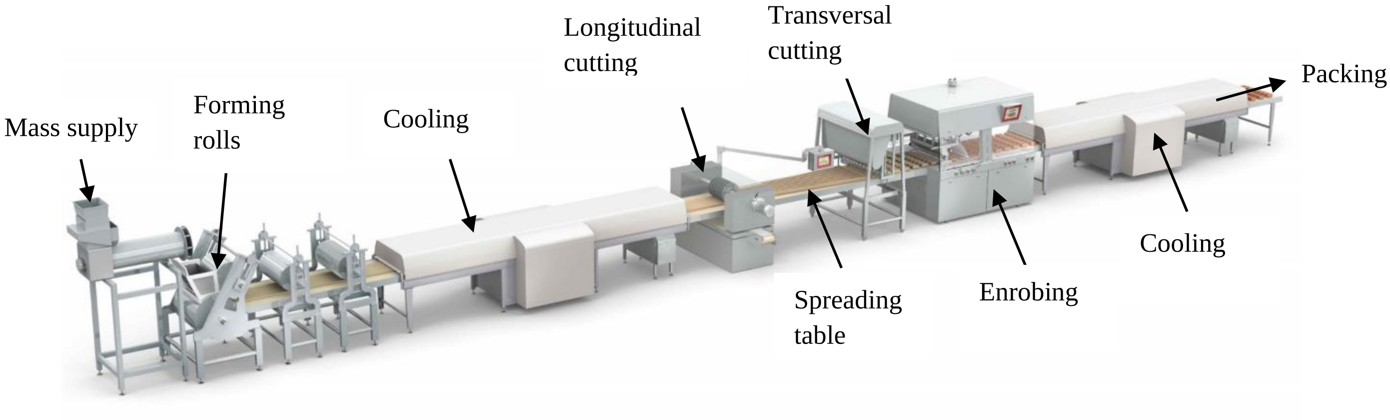

Fig. 10. Principle of cut and sheet technological process [41]

The main challenges related to line losses elimination are related to assortment and number of products produced in the line: there are 38 items of 16 product families (Fig. 9), and therefore many changeover variants and their diversity increase the resources needed to observe, analyse and improve each variant, while it is difficult to determine most frequent types, as it fully depends on demand in the market. Also, a variety of products requires different equipment, such as spreading tables, cutting knives, forming accessories, chocolate tanks, separate tempering, and enrobing machines for different chocolate types and others, therefore lack of space brings questions related to effective line layout: equipment, raw, packing materials and rework, sanitary waste storage. The other challenge is old equipment and deficiencies of its design and technical possibilities, for example, mechanical adjustments based on gear systems or automatic collection of data. Most of the machines on the line are 20-year-old or older and only accessories necessary to implement new products are produced and adapted to current equipment design and working principles. Primary attention of preventative maintenance is focused on overhauls of main moving and wearing mechanical systems to avoid major breakdowns. Outdated design brings risks related to ergonomics, safety, also compatibility with hygienic design requirements, which, increases the risks of product contamination and increases the time of cleaning activities. One more challenge is very high integration of operators into the process. Even though the line has a relatively high number of employees, they are operating several machines during the same time, for example, forming operator is responsible for protein, cacao-fat preparation, syrup making as well as ingredients supply systems and forming rolls. This high integration limits possibilities to involve employees in activities, such as training, brainstorming and problem-solving.

3.2. Line level loss analysis

Analysis of line losses is focused on losses of general efficiency (GE), which could be described as a ratio between the ideal output ratio during all used time and actual output:

$$\text{GE} = \frac{actual\ output, kg}{time\ used,\ \ h * theoretical\ output,\ \ kg\ per\ h} \tag{1}$$

Any deviation from theoretical output should be identified and assigned to a specific loss type. Differently from OEE, GE covers both, planned and unplanned stops, excluding only public holidays, periods of no demand and force majeure. Identified types of GE losses are (Fig. 11):

- Planned stops:
  - Planned maintenance – time for planned repair.
  - Planned autonomous maintenance – line stop for equipment inspection and lubrication or maintenance, performed by line employees.
  - Sanitation – planned time for mandatory sanitary cleaning.
  - Changeover – time of line setup for different product type, calculated duration from last good product to first good product of a new type.
  - Planned stops – time of planned stops for training, lunch, meetings, etc.
  - Consumables replacement – time of changing raw or packing materials when the line is stopped for this purpose.
  - Production starts and stops – time dedicated to activities, that are necessary to start or stop production (equipment cooling, heating, etc.). is not applicable when the line works in the pattern of 4 shifts.
- Unplanned stops:
  - Labour management losses – unplanned stops due to poor employee management, e.g., employees are waiting for instructions, unqualified employees, lack of employees.
  - Material shortage – stops due to shortage of raw or packing materials required to start or continue production (might be caused by delays in delivery or planning mistakes).
  - Minor stops – unplanned stops with a duration shorter than 10 minutes.
  - Breakdowns – unplanned stops, when change or repair of equipment parts is necessary.
  - Operational losses – unplanned stops with a duration of more than 10 minutes, when no repair is required.
  - Line delays – stops due to disruption in steam, water, compressed air etc. supply, due to failure of internal systems of the factory.
  - Speed losses – equipment works slower than it was projected.
  - Quality losses – all defects in production, that were not processed into a finished product, non-product output.

In the initial state, loss tracking was implemented only at the line level, and focused on the measurement of line general efficiency (GE). Data collected at the line level covers these areas: date, shift, product type, amount of production completed, and general efficiency losses (time losses). Tracking of quality losses was limited to the total quantity of rework and sanitary waste during the shift and, also overweight of the products, which, even though it is not included in GE calculations, is an important metric for the company, as product overweight directly generates monetary losses for the company. Therefore, analysis and improvement could have been made only based on general loss type and product type, but not specified to the equipment and failure mode.

As it was mentioned before, there are differences between GE and OEE. GE is reduced by any loss, planned or unplanned, while OEE is affected by only unplanned losses (Fig. 11). The difference between production time and operating time is unplanned losses and the difference between OEE and

GE is the percentage of planned losses. Therefore, by analysing data, it is important to understand the links between key performance indicators (KPIs ‘) and loss types.

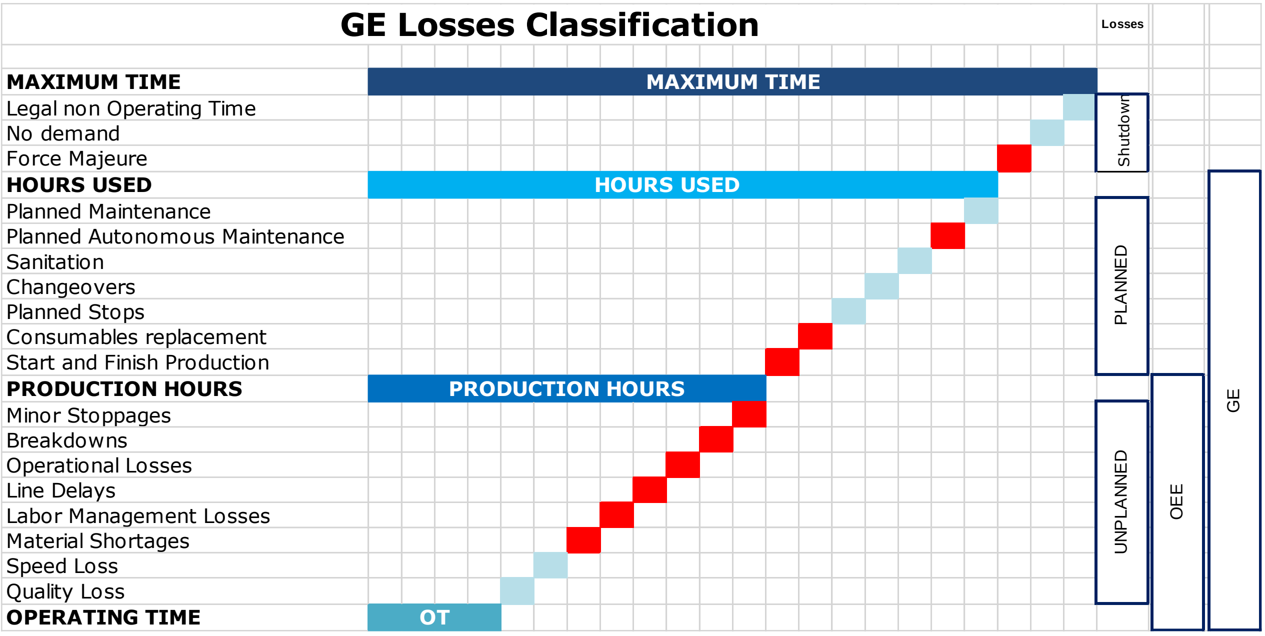

Fig. 11. Line level GE losses

GE of the model line for the year 2021 was 72,6%. Quarterly data of GE for the year 2021 represents, GE variation from 69,3% in quarter 2 to 75,4% in quarter 1 (Fig. 12). Fluctuation could be explained by many factors, which affects line performance, such as product mix during the period, number, and duration of changeovers, planned allergenic cleaning, maintenance, etc. Also, there is a visible decline in GE in quarter 2. This decline can be explained by planned maintenance, which was performed in quarter 2, during this period line had downtime of 9 workdays, which are also included in GE calculation as a reducing factor. s, therefore, GE in the period is lower.

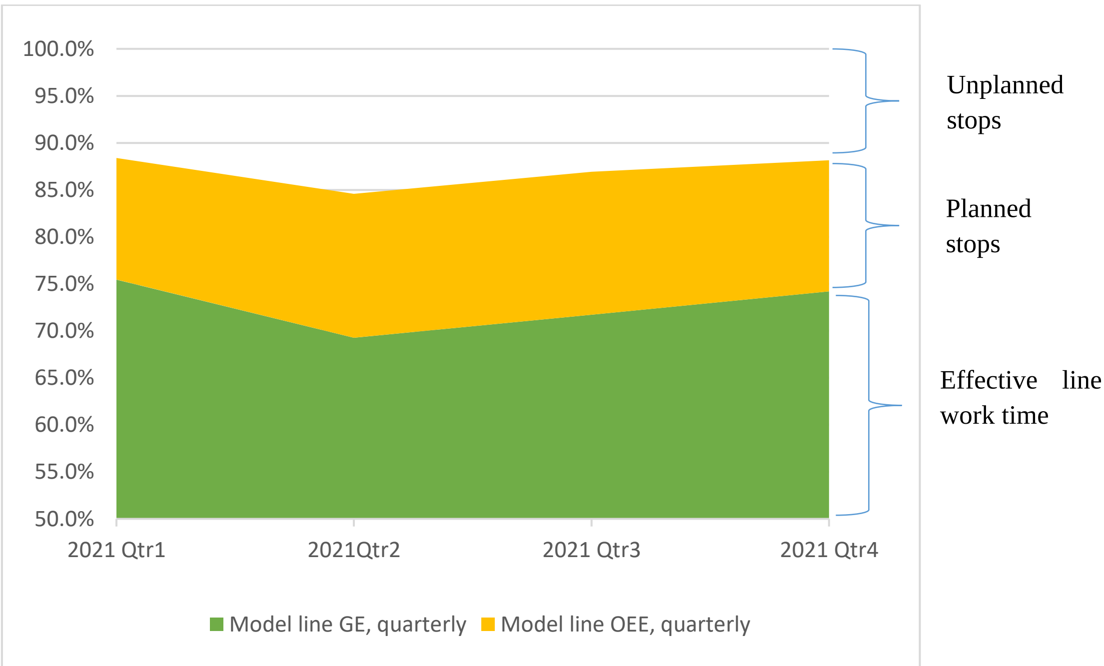

Fig. 12. Model line efficiency, 2021

Line level losses are tracked daily and reported every month. It is observed that the main loss of the line is a changeover, in 2021 it took more than 634 h, or more than 79 shifts, also important to note is the frequency of changeovers on the line. In 2021 there were 290 changeovers in the line, which means, that approximately 1 changeover was made per day, with an average duration of approximately 2 hours. Changeover is followed by operational losses, which is an unplanned stop during production, sanitation, and breakdowns. By using Pareto principle, it was identified, that 80% of line losses are composed of 4 types of losses, both, planned and unplanned: planned losses of changeovers and sanitation, unplanned operational losses, and breakdowns.

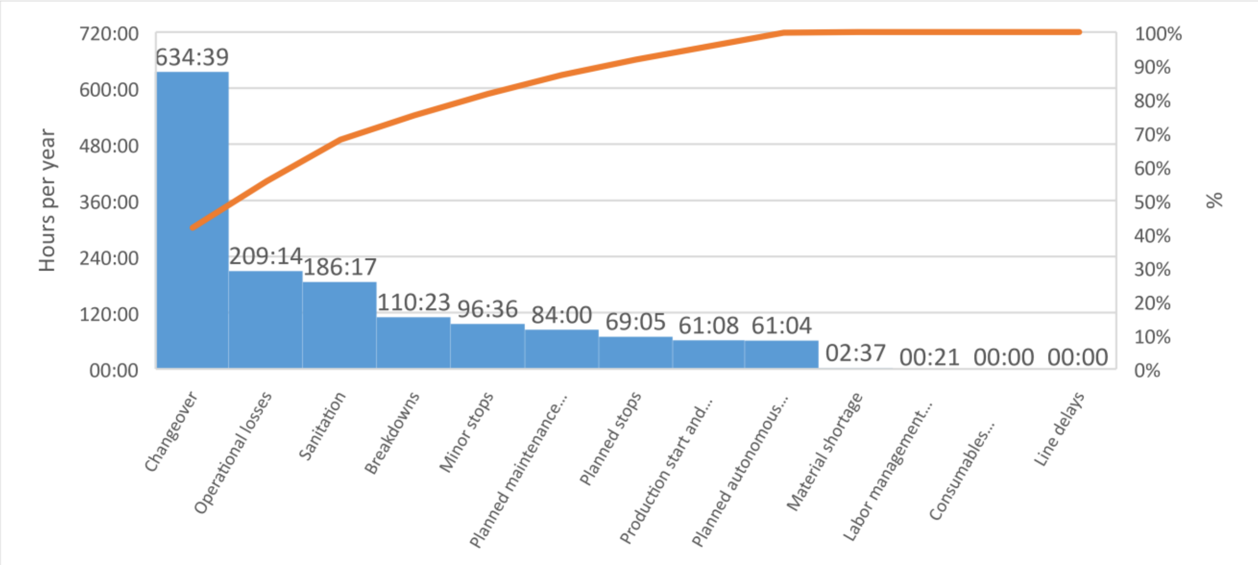

Fig. 13. Model line efficiency losses in 2021

It was observed that the 4 greatest line losses theoretically could be associated with product type, therefore, Pareto charts of these losses were created. Analysis shows that product groups 1, 2, 3 and 7 are the biggest contributors to each of these losses.

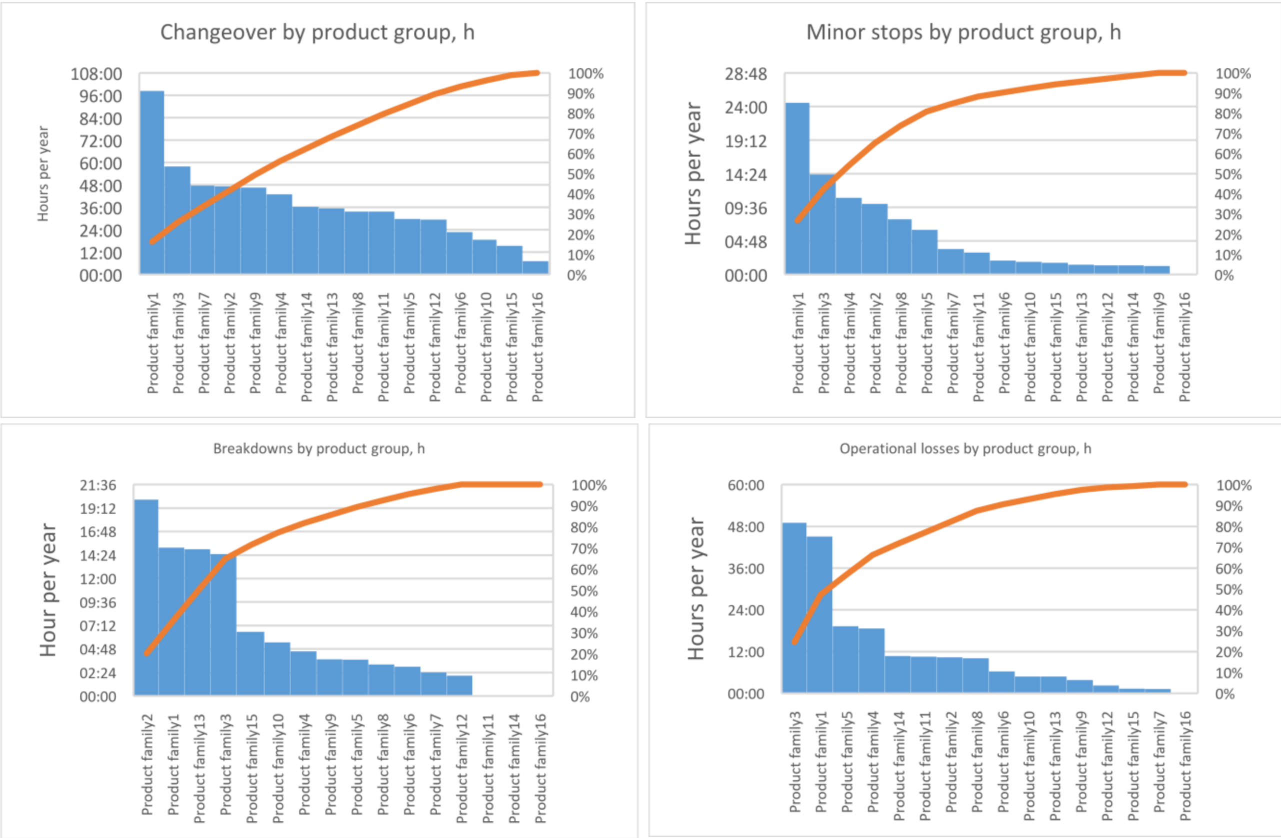

Fig. 14. Greatest losses analysis by product type

There are 5 types of quality losses at the line level, one of them is sheet scraps, which is technological scrap, necessary in cut and sheet technology. It cannot be fully eliminated, only optimized. Fig. 15 shows, that sheet scraps are the greatest loss among non-product output categories. Followed by rework, generated in the process, and packing areas.

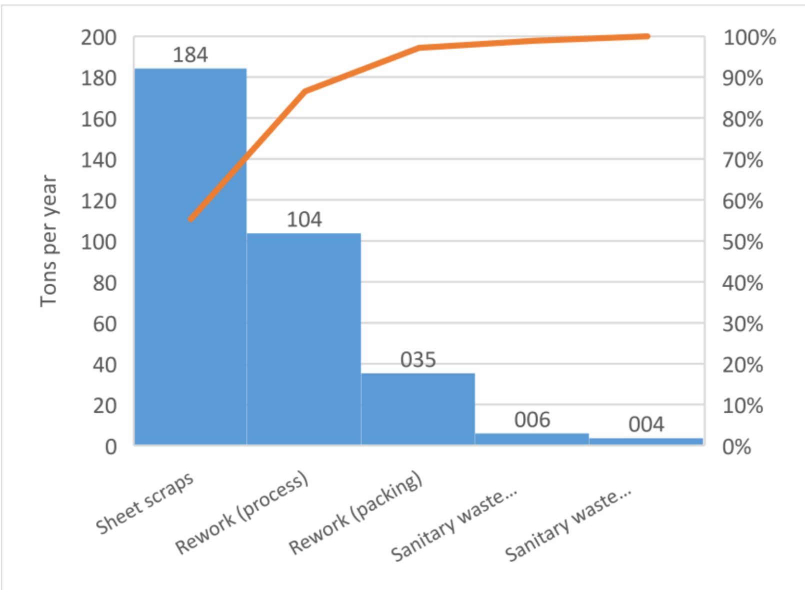

Fig. 15. Losses of non – product output, 2021

Fig. 16 represents the distribution of non-product output losses between product families. It is observed, that even though the loss amount per ton is comparably low, product group 1 generates the highest quantities of these losses. A similar situation is with products 2, 3 and 4, therefore it could be concluded that despite low losses per ton, the total amount of loss is generated due to high production volumes. The opposite situation regarding product group 13, which has the highest losses per ton in all three categories and is one of the greatest contributors to process and packing rework.

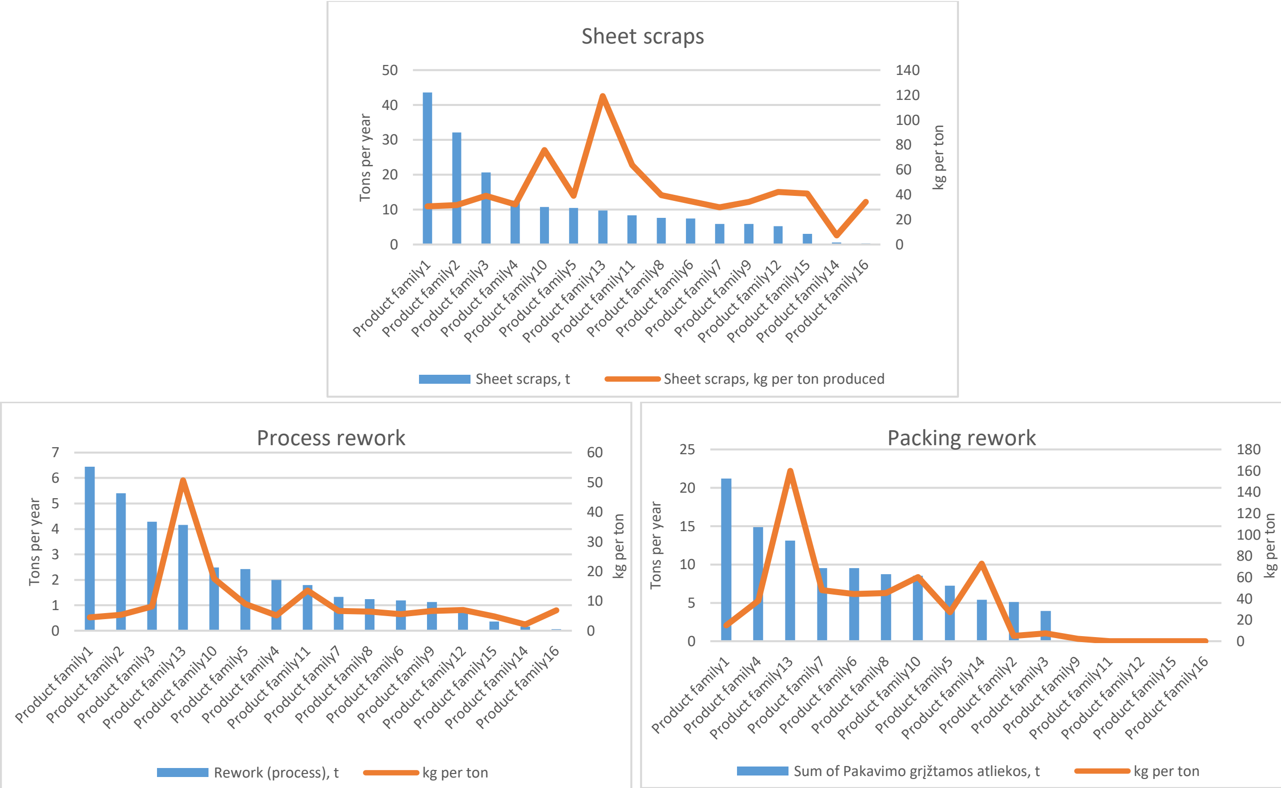

Fig. 16. Non - product output losses by product group

Even though line losses are tracked on every shift, and general situation might be captured by using it, it does not provide enough details for specific insights and does not drive improvement actions.

3.3. Implementation of equipment level data collection

As line-level loss measurement was admitted as not enough efficient, a data collection system for capturing losses on equipment and failure type level was developed and currently tested on the process side of the line. Development of the system is part of autonomous maintenance implementation, main aim of the system is to enable employees to recognize losses, report and eliminate or escalate.

As the company does not own any data collection software, it was created by using MS Excel software, Pivot functions and Visual Basic for Applications (VBA). The most important requirements for the system were convenient data entry and output that visualise the biggest losses during a specific period. Therefore, visualisation was created not only per period, but also trends, how amount of these losses changed through the time. Another part of loss visualisation is daily charts, where employees can observe losses of a specific day (which could be incorporated into the DMS system).

Collected data was categorized as GE and material losses. Analysis reveals the equipment, which generates most of the losses in line, and the biggest loss types in the line, therefore appropriate actions might be taken.

The initial step of the system creation was to map all the most frequent losses of each piece of equipment and then computerized system created. Loss mapping was performed by the SGA team created from members of the focused improvement pillar and line employees. 62 loss types for 29 equipment units on the process parts were identified (instead of 15 general loss types at line level) and transferred to the data collection system. As planned stops are common for all the line, these were left at the initial data entrance window, while the rest of the losses, are entered after selecting loss type: GE or material (non-product output) loss. After selecting zone and equipment, the dependent drop-down list provides a list of identified equipment losses, employees select the right loss and enter the quantity in time or kilograms.

After data processing, production employees, engineers, and line manager can see the biggest material and GE losses and filter these by selected period, equipment, loss type, etc. The system enables data analysis on various aspects. Also, there are trend charts, which allow monitoring of loss changes during longer periods. For production employees daily monitoring and reporting to daily management system (DMS) meetings, there are created daily charts, which also provide the possibility to filter by date, loss type and equipment.

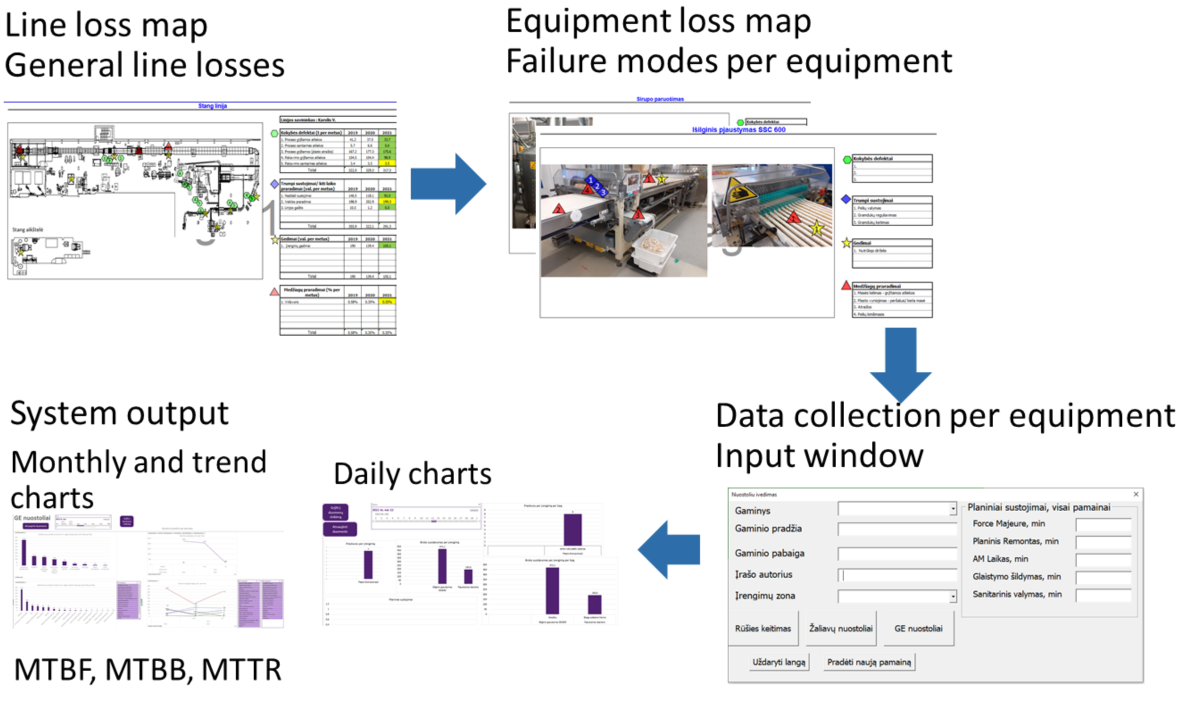

Fig. 17. Data collection system creation process

Even though the system is still in the test phase, data on the line is already collected and data from February shows, that it provides detailed data and sufficient dimensions for loss identification and eradication. E.g., in February highest non-product output losses were generated in longitudinal cutting (Fig. 18), further analysis shows the types of waste in this operation during the period: the greatest losses were sheet scraps and uncut sheet rework. Also, there is a possibility to analyse the amount of each specific loss type by product type. Furthermore, loss trends during different periods can be monitored.

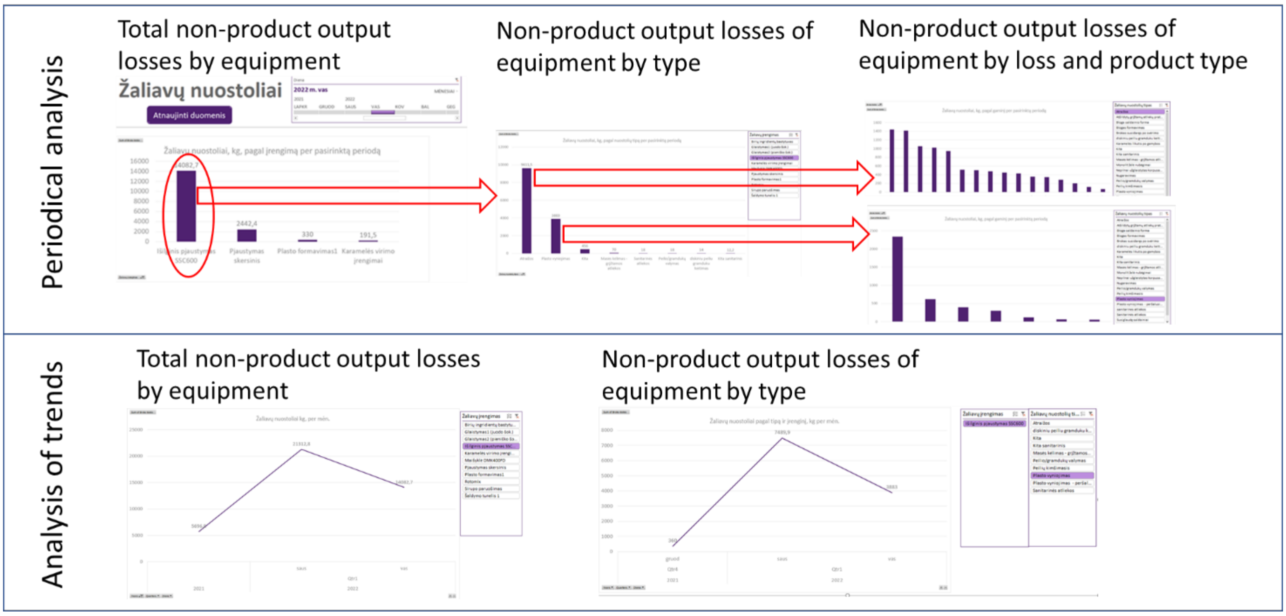

Fig. 18. Loss analysis on equipment level

The other part of important loss indicators is related to unplanned stops are line MTBF, MTBF by equipment, MTTR of the line and MTBB are calculated by using input data. MTBF by equipment allows identification of the priority equipment with the lowest MTBF and further improvement actions might be taken.

Table 1. Equipment failure measurements

Year	Month	MTBB - line	MTTR - line	MTBF - line	Syrup making	Aerotemper MSV1500	Mixer Collette IMH200	Mixer Collette IMH300	Longitudinal cutting SSC600	Transversal cutting
2021	11	79:04	0:45	15:48	24:00	0:00	35:19	0:00	81:19	81:19
2021	12	25:10	1:02	11:11	166:24	21:03	132:11	73:47	63:51	63:58
2022	1	162:27	1:46	21:39	481:30	54:35	167:10	149:25	73:43	73:59
2022	2	103:31	1:32	14:47	268:17	21:50	149:55	21:50	47:29	47:36

As TPM and autonomous maintenance are widely acknowledged as the main techniques to increase equipment efficiency and eliminate losses related to minor stops and breakdowns it was implemented in the model line.

4. Implementation of autonomous maintenance

Autonomous maintenance is an important concept in TPM and overall Lean methodology. It requires a high level of engagement from all levels of employees. Also, employee development must be set as a priority to implement it successfully. Therefore, it is implemented in sequential steps, to ensure step by step development and improvement, starting with fundamentals and continuing to more advanced tools.

4.1. Initial cleaning and inspection

At the beginning of AM implementation on the line, an opening event was held in line. The aim of this event is not only to train employees, but also to stimulate engagement and excitement for the Lean Six Sigma journey. One of the main Lean principles – Gemba was implemented to increase and affirm commitment of the management team. During this event, the line team worked together with management and performed initial cleaning, employees were trained and practically applied basic tools, for example, TAG, OPL, meaning and importance of HTR and SOC and these points were mapped.

The joint team worked in 7 different areas and results were presented in terms of Lean Six Sigma tools use. During this event 339 TAGs were found and registered, 110 kaizen ideas were raised, 70 OPLs were created for knowledge transfer, 15 root cause analyses were completed in addition to that, 138 quick risk assessments were completed to evaluate possible risks and ways to eliminate or reduce risks, LOTO procedures were carried out by 100%, safety maps for 21 equipment were created.

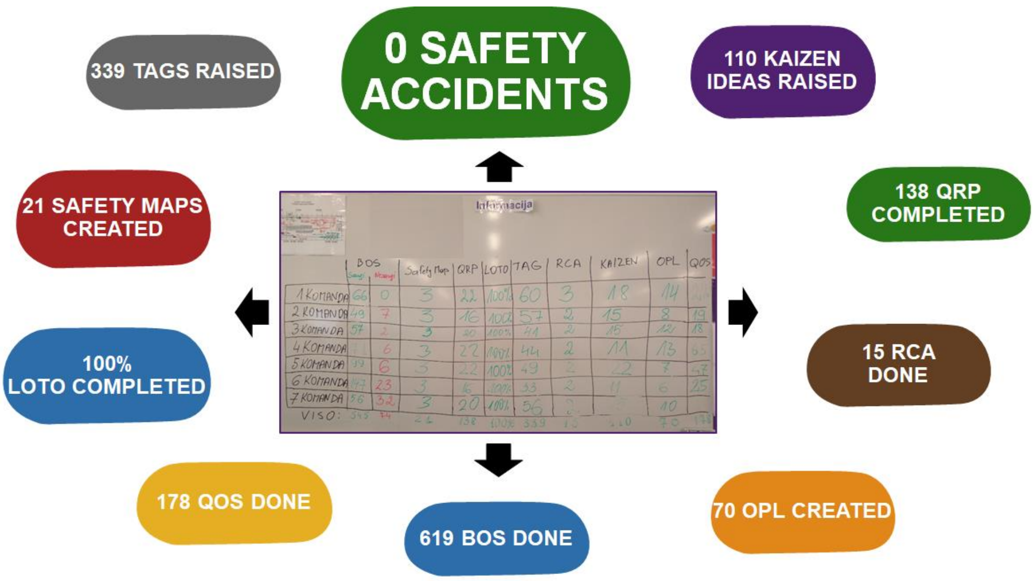

Fig. 19. Results of the opening event

As this event was at the very beginning of Lean Six Sigma implementation in the plant, it was a valuable experience not only for line employees, but also for managers and specialists. After taking part in one of the most common production activities – cleaning, they were able to perceive production problems, working conditions and specifics, as well as the importance and effect of the tools, implementation of which they will be lead and support as members of autonomous maintenance pillar.

4.2. Structure of small group activities

Small group activities (SGA) are a well-acknowledged method used in autonomous maintenance, which engages production employees in ongoing change/improvement activities and enhances teamwork, as production employees work and look for possible problem solutions together with specialists from functional departments or members of other Lean Six Sigma pillars.

SGA members could be classified into 2 different categories. Firstly, core team: fixed team members from the line, based on production area. The other part of SGA is formed depending on the needs. It might be Lean Six Sigma process owner, subject matter expert on technology/equipment or others. Therefore, for solving issues related to sources of contamination in addition to line SGA, there could be included SOC process owner, root cause analysis, and equipment experts. While working together, a team is sharing knowledge and insights from different perspectives which is important to finding the optimum solution.

In the model line, there are 3 SGA groups identified: forming, mixing and caramel making; cutting and enrobing; packing, which owns their area and performs not only periodical and repetitive tasks, like CIL, but also participates in implementation of the tools, for example, 5S, also attempts to reduce losses by using different Lean Six Sigma tools. The expectation is that SGA teams will fully own their work area in terms of AM tools implementation and loss reduction.

4.3. 5S implementation

5s is one of the most often used Lean tools for workplace organization and visualization, which is considered a basis for further implementation of Lean tools. It was also one of the first tools that were implemented in the model line by following 5S steps (sort, set in order, shine, standardize, and sustain).

Workplaces were arranged, all unnecessary items removed, and a place for each item was assigned by using adhesive tape and stickers for identification of places and items in closets and shelves, other places where it does not increase risks of food safety. E.g., commonly used stickers might be damaged during cleaning and detached parts might get into product, especially if it is used to mark tools or equipment which contact product or if marked places are above the product. It increases the risk of food contamination, consumer dissatisfaction and the number of complaints. The main challenge in the food industry related to 5S marking is the need for solutions which would withhold contact with grease and cleaning with aggressive chemicals and would not increase the risk of food contamination while allowing flexibility and development of the initial standard.

Also, shadow boards were introduced (Fig. 20) for cleaning tools, with colour coding for the tools that are dedicated to clean areas, which have contact with products (e.g., transportation belts, forming rolls and others) and those, that do not have contact with product (floors, pallets, technical surfaces of equipment). Separation of contacting tools is an important method to avoid any type of product contamination.

A similar and widely known principle was used for mechanical tools storage in a carriage. Drawers' organizers with cut-outs of the tool forms were used. It created poka-yoke effect, when a standard way of storing tools is ensured, with no possibility to place tools in another location and another drawer, as each of them is dedicated to different tools with different cut-outs.

Fig. 20. 5S shadow board for contacting (white) and not contacting tools

In addition to arrangement of separate workplaces, a standard line layout was created, and areas for storage of equipment parts, also, raw and packing materials, chemicals, rework, and sanitary waste were identified and marked. Marking standard includes colour coding, where different colours correspond to the type of material/equipment stored there. Standard layout created and posted in line.

All marks in the line were done according to a standard which was created at the beginning of implementation: different colours, marking types, fonts and sizes were defined according to the current need of the line. 5 colours for floor marking were selected: red – for marking fire safety stations and electrical panels, where it is prohibited to store items, also, the same colour marking is used for sanitary waste storage. White marks are used for equipment and additional supplies marking. Yellow marks the distance from the walls, where it is not allowed to store and warning signs. Green colour floor marking is used for raw and packing materials, semi-products, finished products and rework. Blue colour indicates production and other sorted waste.

To sustain agreed standards, there was implemented a system of compliance checks (Fig. 21). The first level is self-control – employees review and evaluate conformance during every shift change (3 times a day). Each employee reviews and evaluates areas of his responsibility and evaluates conformance. To simplify evaluation, visual check sheets were prepared for each area and 3 levels of evaluation were used: 10 if all items are in defined places, no unnecessary items, everything is clean and conforms to the standard, and 5 when high number of nonconformities found, for example, items are not in the right places, or surface was not cleaned after work, 0 in case of many non-conformities. Weekly data of each area is summarized and reviewed at the DMS2 meeting (line level) to identify problematic areas and act according to the results. In addition to self-control, monthly audits by 5S owners at the plant level and line leader are accomplished. The audit covers not only conformance of 5S standard but also, system check, as an example, is evaluation completed every shift, are corrective actions from previous audits accomplished. Thus, it could be concluded, that line employees control daily standard compliance and monthly audits are more focused on the overall system.

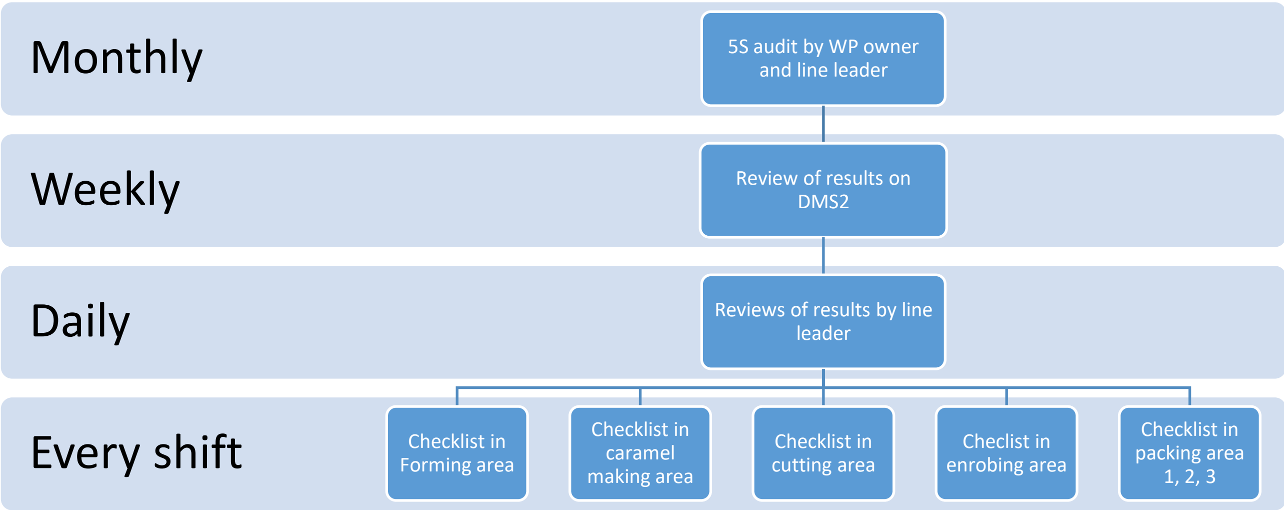

Fig. 21. Scheme of 5S System

The benefits of 5S implementation are obvious, even though, most of them are intangible. Maintaining and developing standards increases employee engagement and ownership of the workplace environment, which is critical during AM implementation. After standards are created, employees and technical operators can easily find the tools they need and avoid unnecessary movements while searching. Employees share their experience, when technical operator was looking for the tools for 20 minutes during a breakdown, therefore 5S supports results of line efficiency by providing an orderly, clean, and visual workplace.

4.4. Sources of contamination and hard to reach places elimination

Elimination and simplification of sources of contamination and hard to reach places is one of the most important activities dedicated to waste elimination in production at the beginning of AM implementation. The company has set the goal to eliminate 80% of SOC and HTR and simplify the rest before the start of the next AM steps and use of more advanced tools.

SOC and HTR places were identified during the initial line cleaning event, where not only line employees, but also management and specialists were participating. Even though, 41 places were mapped, currently, when tools like CIL are introduced, newly identified places are also added to the list.

Currently, the list of SOC and HTR consists of 53 places, all of them have been evaluated according to several criteria to define priorities for elimination and evaluate reasonable investment payoff for each place. Each place was evaluated quantitatively, by measuring time, number of employees and the frequency of cleaning / reaching it, in addition to that, data about the amount of scrap related to specific SOC or HTR is collected. The total amount of loss identified is over 75 000 minutes or 1251 labour hours. All this information was converted into monetary losses. Another step is evaluation of these places based on non-monetary losses: safety, quality risks, minor stops and operational losses caused by each place. Priorities were defined by a combination of these evaluations.

Table 2. SOC and HTR listing and quantification form

Identification				*Quantification Before*					*Analysis & Resolution*	
Equipment	Equipment ABC Classification	Abnormalities description	Category: SOC / HTR /POA	QB Annual Time (min.)	QB Cost of Man-Hours lost in a year	QB Kg Scrap in a year	QB Cost of Scrap in a year	QB Total Cost in a year	Method of Analysis	Selected solution E - eliminate C - combine R - rearrange S - simplify
1st forming roll	C	Automatic valve of forming head	SOC	1560	USD 265.20	52	USD 82.16	USD 416.83	RCA	
1st forming roll	C	End of the transporter segment, band	HTR	260	USD 88.40	0	USD 0.00	USD 106.08	others)	S
Protein cooling system	C	Pipies, pump	HTR	4680	USD 795.60	0	USD 0.00	USD 954.72	Direct Action	E
2nd forming roll	C	Mass residue behind motor cover	HTR	5200	USD 884.00	65	USD 102.70	USD 1,184.04	Direct Action	
2nd forming roll	C	Frame construction	HTR	650	USD 110.50	65	USD 102.70	USD 255.84	Direct Action	S

There are several examples, of when SOC and HTR places were eliminated and simplified by creating value for both, loss reduction and employee involvement. First, simplification of HTR at caramel making as during the years, dosing and materials supply system was changed several times, but old supply pipes were not eliminated. Because of unused pipes, it was difficult to clean caramel boiling area, and the risk that contaminants will start to accumulate in unreachable places was foreseen. After elimination, even though the currently used pipeline was not moved, there was a lot more space for employees to get into the area and made cleaning a lot more ergonomic. Another example of HTR was the simplification of shafts of the cooling tunnel (14 shafts in cooling tunnel no.3) which due to continual contact with the transportation belt and are covered by residues of chocolate mass and need to be cleaned. As shafts are heavyweight and technical operator is not always available to help other employees, most employees tend not to take the shafts out for cleaning but get behind the tunnel and perform cleaning in an unergonomic and unsafe manner. Because of equipment working principles, there was no solution found related to changes in equipment construction, therefore implemented a solution which allows reducing contacting surface – distancers were mounted on shafts (Fig. 22), which reduced contamination of shafts and need for cleaning. Before, yearly time spent on cleaning shafts was evaluated as 1560 minutes, which would cost approximately 339 EUR per year. It was measured that cleaning time per year was reduced to approximately 470 minutes, or by 70%.

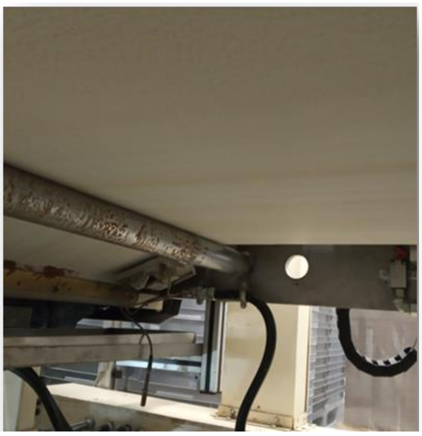

Fig. 22. Cooling tunnel shafts (left), solution for SOC (right)

Currently, 25 of SOC and HTR places (47%) are eliminated or simplified, which reduces cleaning time by 37%, which is equal to approximately 577 minutes per year. The percentage of eliminated and simplified places is higher than the percentage of time saved because at least 2 major SOC places require capital investment, which must be planned and included in the budget during the planning process, therefore their elimination is postponed due to financial reasons. For example, an overhaul of all-round sprinkling equipment, currently its intake and spreading areas, transportation conveyors are open (Fig. 23) and dust are contaminating an area of more than 50 m^2, which must be cleaned after every use of the machine when popcorn rice are used in production, moreover, due to dust, the floor at the line become slippery though increasing risk of safety incidents. Elimination of this SOC requires investment not only into mechanical parts, but also additional ventilation and ATEX filters, due to explosion risk which will appear if the spreader will be closed, and concentration of dust will be high in a small space. Calculated approximate costs are: 5000 EUR for mechanical parts, additional costs for installation of ATEX filter starts from 25 000 EUR. Therefore, the main obstacle to the elimination of SOC and HTR of this kind is financial: formal yearly budget planning and approval process.

Fig. 23. Example of all round sprinkling equipment open construction [42]

According to calculations, elimination of some major SOC or HTR financial payoff is questionable, as yearly costs of cleaning are approximately 2000 EUR, while costs of equipment changes exceed 50 000 EUR, but the company objective is still to eliminate 80% of SOC to reduce wasteful activities, reduce the need for employees to make manual work and therefore gain resources for further implementation and use of Lean Six Sigma tools. Also, SOC and HTR are directly related to safety/ ergonomics, food safety and hygienic design requirements. Elimination or simplification of these places reduce variety of risks, such as, product contamination, and possibly, even recalls from the market, as well as safety risks. A high number of identified places and costs of elimination and simplification is a great indicator of equipment compatibility to current standards and requirements, this is also affirmed by the example of sprinkling equipment, which was produced in 1997 and is now 25 years old. During this period requirements for equipment safety, employee ergonomics, and food safety requirements have been changing, therefore, today overhaul of the equipment becomes a business necessity, even though the payoff period is very high. There are 2 possible solutions to eliminate this SOC: purchase new equipment, costs of which are over 500 000 EUR or overhaul equipment for approximate costs of 50 000 EUR. Evaluating the company's strategy and costs, it is obvious, that the most acceptable decision for the company is to invest in an overhaul.

4.5. Cleaning, inspection, and lubrication

Cleaning, inspection, and lubrication are one of the most important activities of AM to ensure prevention and reduce the number of breakdowns. Only cleaning and inspection are introduced in the initial steps, further development of CILs must introduce lubrication. To do this, skills of operators must be built. Implementation of these tools was strongly supported by the pillar of preventative maintenance, which categorized equipment by criticality and for most critical equipment (24 machines) cleaning and inspection standards were implemented first. Also, PM not only analysed the registry of equipment breakdowns to identify places, which must be checked periodically, but also collected information from line technical operators about the most frequent issues, and small defects that appear during equipment work. All points of cleaning and inspections were reviewed, and frequency was defined as daily, weekly, or monthly CIL. Also, all checkpoints were categorized according to availability – is it possible to clean and check this point while equipment is working.

CIL standard (Fig. 24) was prepared according to best practice, including visual information (photos) of the places, that must be inspected or cleaned, and a description of what exactly must be accomplished. In addition to that, the registration number of OPL where employees can find detailed information about the task is identified (all OPLs related to CIL of specific equipment are kept together with CIL documentation and are easily accessible for employees). Each CIL document provides safety information: which LOTO procedure must be used to lock equipment before checking, and, personal protection equipment that must be used is identified at each checkpoint.

During CIL implementation, all operators were trained on how to use forms, how to perform CIL in specific workplaces and identify nonconformities. All defects that were identified must be registered as TAGs to prevent further deterioration and breakdown of the equipment. 9 to 12 TAGs per month are identified by performing CILs. Defects, such as cracked surfaces of transportation belts, leakages of materials, water from cooling or heating systems, and compressed air leakages are common examples of most often identified defects.

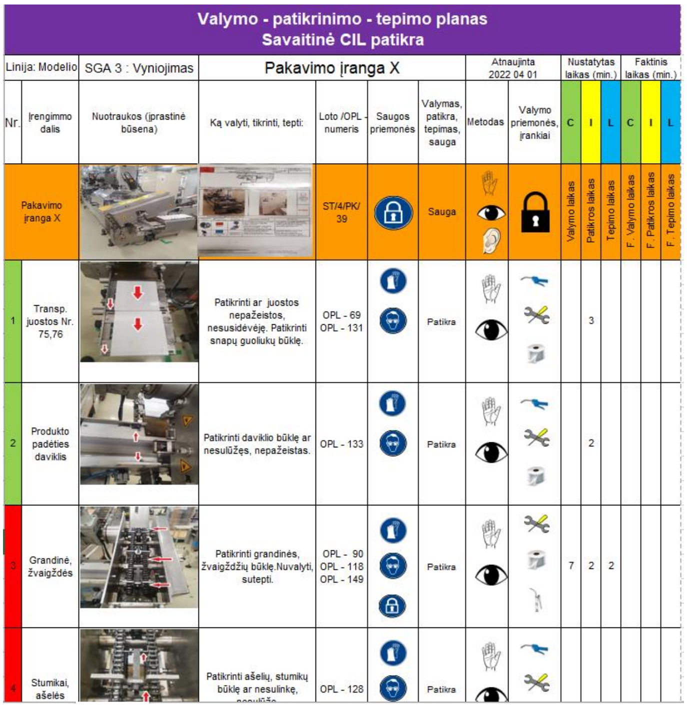

Fig. 24. CIL example of packing equipment

Table 3. CIL completion checklist

Pamainos ir CIL atlikimo dienoraštis kovo men. 2022 metų

PROCESAS

		Kasdienins /Keičiant rūšį /Baigius gamyba																													Savaitinis				Men.	Iškelti TAG'ai
Mašina/įrengimas	Atsakingas už CIL atlikymą	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	10	11	12	13	P3	Numeris
Sirupo tarpinė talpa	Formuotoja	Nera																															Nera					
Sirupo virimo katilas	Formuotoja	Nera																															Nera					
Baltymų ruošimo talpa	Formuotoja	Nera																															Nera					
Baltymų tarpinė talpa	Formuotoja																																Nera					
Rotomiksas	Virtuvės operatorius																																Nera					
Kontimiksas	Formuotoja/Brokų dėliotoja	Nera																															Nera					
DMK maišyklė	Masės maišytoja																																Nera					
Formavimas 1	Formuotoja																																Nera					
Formavimas 2	Formuotoja																																Nera					
Šaldymo tunelis 1	Formuotoja/Virtuvės operatorius																																					
Karameles, agaro virimas	Karamelės virėjas																																				Nera	
Maišyklė Collette Nr1 IMH200	Masės maišytoja																																				Nera	
Maišyklė Collette Nr2 IMH300	Masės maišytoja																																				Nera	
Pjaustymas išilginis(Diskiniai)	Virtuvės operatorius																																Nera					
Pjaustymas skersinis (giljotina)	Virtuvės operatorius	Nera																																				
Juodo šok. Glaz	Glaistytoja																																Nera					
Juodo šok. temperavimas	Virtuvės operatorius	Nera																															Nera					
Pieniško glaisto glaz	Glaistytoja																																Nera					
Pieniško šok. temperavimas	Virtuvės operatorius	Nera																															Nera					
Šaldymo tunelis 3	Glaistytoja/Operatorius																																					

Pamainos ir CIL atlikimo dienoraštis yra skirtas tam , kad sekti visų CIL'u atlikimo procesą .
Svarbu kad kiekvienas darbuotojas ,kuris yra atsakingas už savo procesą , po atlikto CIL ,darbo dienos eigoje , pasižymėtų dienoraščio langelyje savo pamainos grafiko numerį .
Patikrinus ir neradus defekto užrašykite savo pamainos grafiko numerį I ; II; III ; IV . Jeigu nereikia atlikti patikros ar įrenginys tą dieną nedirba dėti brūkšnį " - " .
Radus defektą keliame Tag'ą ir įrašome Tag numerį į laukelį.
Svarbu : Prašau visus atliekančius CIL'us rašytis CIL atlikimo laikus tam skirtame langelyje

In the CIL process, the most challenging part is to keep consistency and focus on performing daily/ weekly/ monthly checks, as defects are rarely found, and benefit is not visible for employees to keep their motivation. Consequently, CIL completion is tracked through the checklist, developed specifically for this purpose (**Table 3**). It represents the schedule of CIL for each piece of equipment: grey cell defines, that there is no CIL planned, and white cell – that CIL should be accomplished. If CIL is planned for the day, the cell must be filled by putting in the number of the shift, that performed it and a sign of „+ " if CIL was performed or „-" if the equipment does not work and therefore CIL is not completed. This agreement is highly important for accurate calculation of the CIL completion rate. Also, if there were defects identified during CIL, the number of TAG must be noted on the checklist. The checklist is reviewed by CIL process owner periodically, also used to measure monthly CIL completion rate. The goal of the completion rate is to have over 80% of CILs completed each month. In the first 2 months of 2022, the completion rate was between 70% and 75 % and in March it reached 85%.

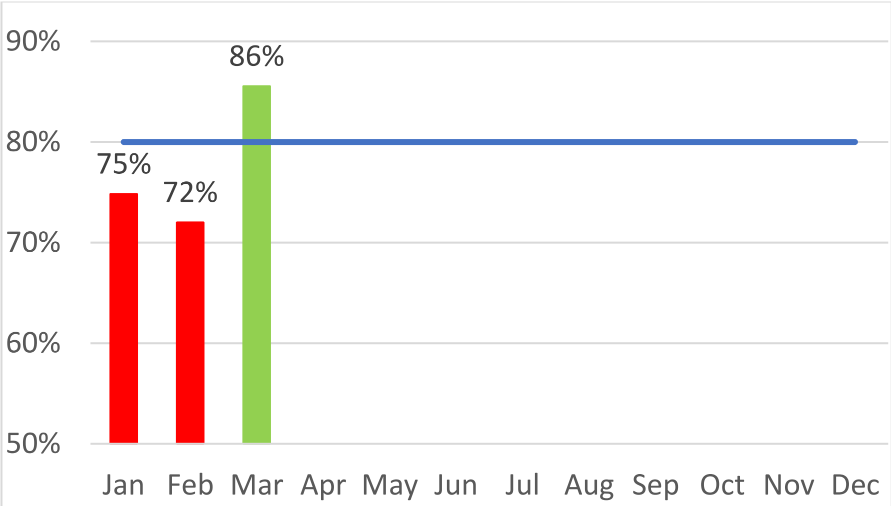

Fig. 25. CIL completion rate, 2022

4.6. Equipment defects management

Abnormalities identification, registering and elimination process was implemented to identify minor defects and fix them to avoid breakdowns. TAGs are raised by all line employees when the defect is identified during regular production or by performing CIL. There are 3 types of TAGs:

- Safety-related TAGs (yellow) –safety TAGs are a priority for line and technical teams and must be solved within the period of 1 day. If it is not possible to solve in such a short period,
- AM (blue) – defects that can be eliminated by line operators. Line employees eliminate defects independently during production.
- PM (red) – complex TAGs, which line team is not able to solve and support from technical department is required.

Identified TAG is registered by using a form of the category and left in a TAG board (Fig. 26), which is prepared according to SGA structure – 1 TAG board per SGA area, where TAGs from all workplaces of this group must be registered and stored. During shift handover, at the DMS1 meeting operators discuss TAGs, which during the last 24 hours were identified in the area of their responsibility. Operators of the morning shift are responsible to bring information about recent TAGs and handover information about safety and PM TAGs to technical specialist of the line. All line employees are trained on the usage of the TAG system, filling out the forms. 191 abnormalities were identified during the first quarter of 2022, which is 64 TAGs per month. 176 of them were solved during the same period, the ratio of solved TAGs versus raised is 92%. On average, 50% of TAGs are solved by the line team, which demonstrates high technical competence of line operators and increases speed of defects elimination.

Fig. 26. TAG card (left) and TAG board (left)

4.7. Skill matrix

As competencies of autonomous maintenance team are key for successful implementation of Am, skill matrix on the line was introduced as a core tool for operators' development not only on functional knowledge of the workplace, but also for development of skills and abilities to use tools required current and upcoming steps of AM.

The initial step to creating a skill matrix was identification of necessary skills per position: for process, packing, forming, caramel making operators, and shift leaders. After identification of specific skills, descriptions and guidelines for evaluation were prepared to ensure clarity and transparency of the evaluation. Each skill can be evaluated from 0 to 4, with a gradual increase of expertise (0 – no knowledge, cannot execute the task, 4 – is an expert and provides suggestions for improvement). Each level from 1 to 4 has a description of what exactly an employee should be able to do to be evaluated in each level. When required levels for each position were identified.

After setting clear expectations for each position, practical evaluation of each employee starts: first, employees accomplish self-evaluation according to provided descriptions of each skill, and the direct manager also evaluates each employee separately. Then calibration process starts evaluations of manager and employee are reviewed during individual conversations, skills, evaluations of which differ are discussed and the final evaluation is agreed upon. If an employee does not reach the required level of knowledge in a specific area, an individual development plan is created to close the most critical non-conformities during the period of the next 6 months. Periodical reviews and updates of skill matrix in the model line are scheduled every 6 months.

After evaluation of all line employees, a simplified version of the matrix is published in the line, on the DMS2 computer and it is accessible to all line employees. This skill matrix represents groups of skills: safety systems, Lean Six Sigma tools, also. 3 main skills functional in each workplace are displayed: the ability to exploit equipment during regular production, perform CIL, cleaning, and changeover. In each workplace, for example, caramel making, forming, and enrobing these 3 areas of knowledge are displayed (Table 4).

Table 4. Skill matrix of the model line

ĮGŪDŽIŲ LYGIO VERTINIMAS

1 - Pagrindinės žinios, dirba su pagalba

2 - Dirba savarankiškai

3 - Savarankiškas problemų sprendimas savo funkcijų ribose

4 - Žino ir teikia pasiūlymus veiklos gerinimui, moko kitus

			Pagrindiniai saugos įgūdžiai		Pagrindiniai kokybės įgūdžiai		Pagrindiniai IL6S įgūdžiai		Funkcinės žinios: Sirupo virimas ir formavimas						Funkcinės žinios: Karamelės virimas						Funkcinės žinios: Maišymas						Funkcinės žinios: Pjaustymas ir glaistymas						Funkcinės žinios: Įrenginių priežiūra, remontas; Formavimas/Pjaustymas						Funkcinės žinios: Vyniojimas ir pakavimas						Funkcinės žinios: Vyniojimo ir pakavimo operatorius						Funkcinės žinios: Apskaita, Darbo organizavimas, Darbas su žmonėmis					
		Įgūdžių grupė	HSE1		QM1		IL1		OP1		CI1		SN1		OP2		CO2		CI2		OP3		CO3		CI3		OP4		CO4		CI4		OP5		CO5		CI5		OP6		CO6		CI6		OP7		CO7		CI7		OP8		CO8		CI8	
			Laikosi HSE politikos, naudoja įrankius LOTO, QRP, BOS, GPĮ/Near miss, Saugos žemėlapiai		Laikosi kokybės politikos, GGV reikalavimų, Geba įvertinti, aptikti ir imtis veiksmų išvengti rizikos kokybei		Turi įvadines IL6S žinias, naudoja įrankius TAG, OPL, Kaizen, RCA, DMS, 5S		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, Atlieka įrenginių sutepimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Geba naudoti, eksploatuoti, paleisti įrenginius, atlikti priskirtas funkcijas		Atlieka valymą ir inspektavimą, Atlieka įrenginių sutepimą, CIL		Atlieka sanitarinį valymą pagal linijos valymo planą, Atlieka rūšies keitimą		Apskaitos vedimas, SAP, Office MC įrankiai		Darbo organizavimas		Darbas su žmonėmis, lyderystė	
Pareigos/ Darbo vieta linijoje	Vardas Pavardė	Įvertinimas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas	Esamas	Reikalaujamas
Visos linijos įvertinimas		90,1%																																																					
Pamainos vyresnysis		111%	4	4	4	4	4	4	3	0	4	4	4	4	3	0	3	4	3	4	3	0	3	4	4	4	3	0	3	4	4	4	3	0	3	4	3	4	4	4	4	4	4	4	0	0	3	4	3	2	4	4	4	4	4	4
Pamainos vyresnysis		76%	4	4	4	4	4	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	4	4	4	4	4	4	0	0	3	4	3	2	4	4	4	4	4	4
Pamainos vyresnysis		91%	4	4	4	4	4	4	0	0	4	4	1	4	0	0	4	4	1	4	0	0	4	4	1	4	0	0	4	4	1	4	0	0	4	4	3	4	4	4	4	4	4	4	4	0	4	4	4	2	4	4	4	4	4	4
Pamainos vyresnysis		104%	4	4	4	4	3	4	3	0	3	4	4	4	3	0	3	4	4	4	3	0	3	4	4	4	3	0	3	4	4	4	3	0	3	4	3	4	4	4	3	4	3	4	0	0	3	4	2	2	4	4	3	4	3	4
Apskaitininkas		106%	4	4	4	4	3	4	3	0	3	4	4	4	3	0	3	4	4	4	4	0	3	4	4	4	3	0	3	4	4	4	3	0	3	4	3	4	4	4	3	4	3	4	0	0	3	4	2	2	4	4	4	4	3	4
Apskaitininkas		80%	4	4	4	4	2	4	0	0	3	4	3	4	0	0	3	4	3	4	0	0	3	4	3	4	0	0	3	4	3	4	0	0	3	4	3	4	4	4	3	4	3	4	0	0	3	4	2	2	4	4	4	4	3	4
Apskaitininkas		70%	4	4	4	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	4	4	4	4	4	4	0	0	3	4	2	2	4	4	3	4	3	4
Apskaitininkas		71%	4	4	4	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	0	0	2	4	2	4	4	4	4	4	4	4	0	0	3	4	2	2	4	4	4	4	3	4
Operatorius/Procesas		106%	3	3	4	3	3	4	3	3	4	3	3	3	3	3	4	3	3	3	3	3	4	3	3	3	3	3	4	3	3	3	4	4	4	4	4	4	3	3	3	3	3	3	0	0	3	3	0	0	0	0	0	0	0	0
Operatorius/Procesas		93%	3	3	3	3	2	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	4	3	4	3	3	3	3	3	3	0	0	3	3	0	0	0	0	0	0	0	0
Operatorius/Procesas		87%	3	3	3	3	3	4	3	3	3	3	2	3	3	3	3	3	2	2	3	3	3	3	2	3	3	3	3	3	3	3	4	4	4	4	4	4	1	3	1	3	1	3	0	0	3	3	0	0	0	0	0	0	0	0
Karamelės virimas		104%	3	3	4	3	3	3	3	2	3	2	3	2	4	3	3	3	4	3	4	3	3	3	4	3	2	2	2	2	2	2	2	2	2	2	2	2	1	3	1	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0
Karamelės virimas		96%	3	3	3	3	2	3	1	2	2	2	1	2	4	3	4	3	4	3	3	3	3	3	3	3	1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Karamelės virimas		85%	3	3	3	3	2	3	1	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	2	1	2	2	2	1	2	3	3	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Karamelės virimas		83%	3	3	2	3	2	3	1	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	1	2	1	2	2	2	1	2	3	3	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0

4.8. One point lesson

OPLs were introduced as a tool for knowledge sharing, and also as part of change management and standardization of operations after problem-solving activities. Important to note, that differently from work instructions, OPL can be created by any employee in the company: line operators, and employees of different departments for communicating practical knowledge concisely and clearly. Also, OPLs can be used to close gaps in current instructions or to inform all the employees about changes implemented.

OPLs can be created by hand or by using a computer at the workplace or on a DMS2 computer. New OPLs are approved by the line team and line leader during DMS2. After approval, on a special matrix, it is noted, that employees need to know the information. After reading newly approved documents, employees mark them on the same matrix. When all employees read new OPL, it is stored at the workplace together with all other equipment documentation.

OPL is an important tool, its use varies from easier methods to clean parts, avoidance of syrup leakages when the engine stops, to balancing the right percentage of dry materials in jelly making and regulation of sensors in packing machines. Even though these are small changes and not measured, but obvious is that each OPL reduced or prevented a certain type of loss: cleaning, changeover time, material losses (including sanitary waste and rework) and minor stops.

OPL on roto mix parts cleaning is a great example of how employees' knowledge and creativity can be utilized (Fig. 27). The operator of forming area found a new easier and safer way to clean parts. After production parts are soaked into water with caustic soda, which is circulating in a closed pipe system, but the line could not fill it into additional tanks, that are not part of the pipe system. Therefore, employees brought it from the other line on a different floor, it was brought to the line using buckets. Caustic soda is a strong chemical that can cause burns of the skin, this method was not safe. In addition to that, it is most effective when hot, caustic soda in the pipe system is hot, but while being filled into a bucket brought to another floor it was cooling therefore less effective. Line employee invented a method (a combination of manual and automatic valves positions) to fill caustic soda directly to the offline tank at the workplace, where parts will be soaked. Not only safety risks due to transportation were eliminated, but also the effectiveness of soaking increased and manual cleaning of parts was made easier.

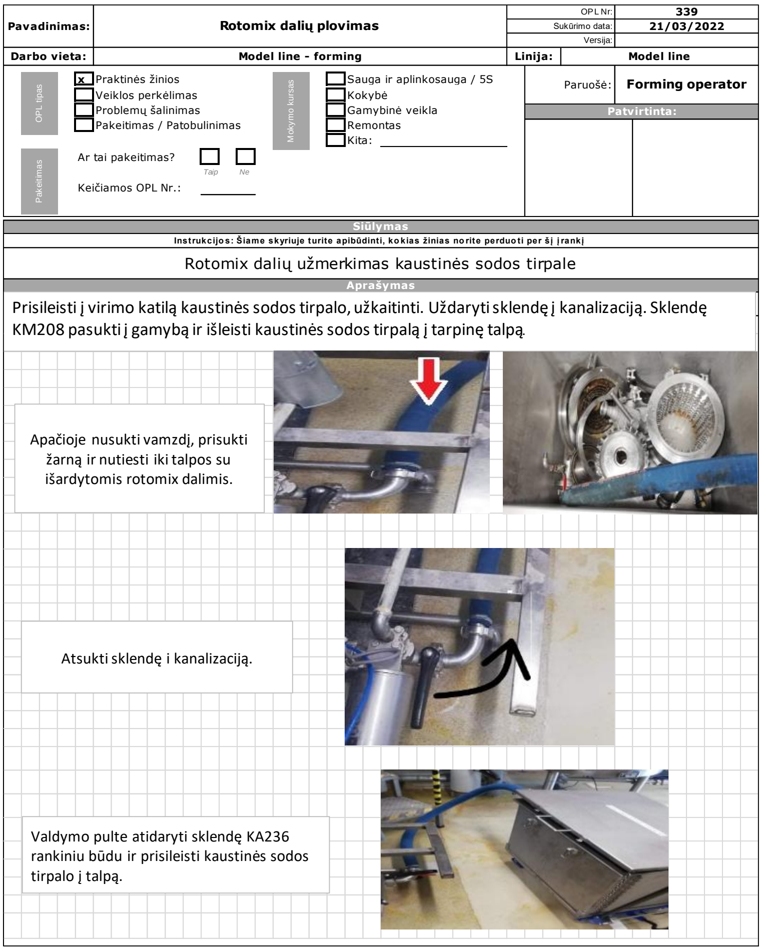

Fig. 27. OPL example from model line forming area

4.9. Daily management system

Daily management system (DMS) according to the organizational structure of the company consists of 3 levels: DMS1 – shift handover between operators, DMS2 – line-level daily meeting where results of the last twenty-four hours are discussed and plan for the next day is created and DMS3 – plant level review of lines results. Even though DMS2 is deployed in all lines, DMS1 is still implemented only on the model line.

DMS1 concept was created as shift handover, information about main details that are important for the next shift to successfully continue production was pulled from employees, this way engaged them and reduced resistance to the new tool. This information was combined with the company's expectations to have all DMS levels implemented according to PDCA principle. Even though a compromise was needed here, DMS1 is simple, practical, and convenient for line employees. It covers safety and quality parts, where any incident or near miss should be discussed, as well as position-specific parameters, unplanned stops, CIL completion and TAGs. All these areas are required only to be marked in red (if there were issues) or green (no issues). If some of the parameters are red, the problem must be described, and actions taken/ required must be noted. Information from DMS1 must be brought to daily DMS2, which is held at line level each day.

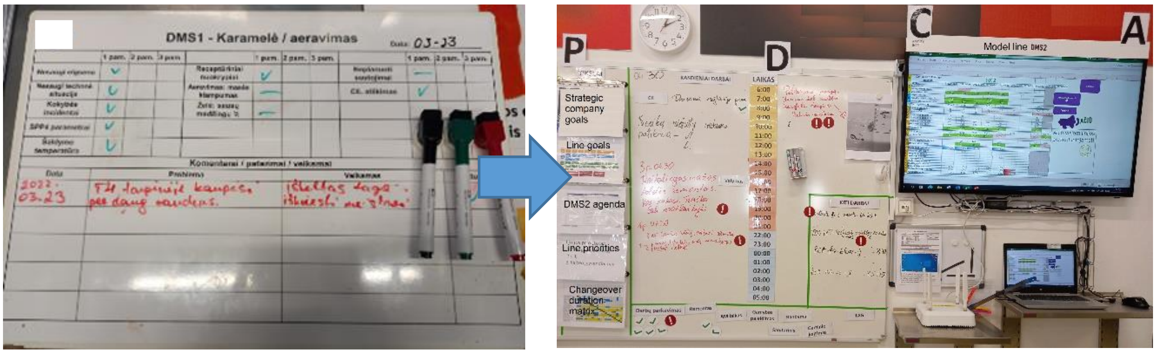

Fig. 28. DMS1 (left) and DMS2 (right) at model line

DMS2 is a daily meeting where line leaders and operators from process and packing areas participate. Additional participants from other departments are quality, continuous improvement engineers and line technician. As DMS2 covers the results of the line are reviewed in a more formalized manner and actual KPIs, daily activity plans, and escalations are covered in it by following PDCA cycle. On the daily planning part, there are line goals of effectiveness, material, and quality losses published, as well as standards of changeover duration and current line priorities. 'Do' part – covers daily activities plan with preliminary timings, check and act are placed on the computer. On the 'check' part, it is convenient that all KPIs are calculated and updated automatically by retrieving data from daily reports. Also, the escalation system is accessible on a computer, supporting the 'act' part of the cycle.

4.10. Kaizen

Improvement suggestion system existed in the company before Lean Six Sigma implementation, during implementation system was updated to Kaizen suggestion system. It is implemented not only in the model line, but in all company. Suggestions could be submitted by any employee.

Kaizen process has several steps: filling in the form, approval, implementation, and rewards. This system, created within the company is solid, as it includes a strong change management part, as all kaizens are approved on 2 levels:

- DMS2, where it is evaluated by line leaders, together with all participants of the meeting
- By the owner of the area for which it would make effect: safety, quality, cost, or morale.

Also, important to note that employees are encouraged to implement their own and volunteer to execute colleagues 'suggestions. The reward system is based on points, which are assigned by area owners according to defined criteria (the greater benefit of kaizen, the more points). Also, if the author implements it by himself, points double, or if someone volunteers to implement kaizen of a colleague, he gets the same number of points, as the author does.

Kaizens in the company vary from small incremental improvements, for example, improvement of 5S standards, to suggestions, making high influence not only on production efficiency, but also on other aspects of company activities, for example, environmental performance. One of the examples would be to define places, where transportation belts could be cleaned while it is moving. Before that, during cleaning equipment was locked by using LOTO and to clean the whole belt employees had to go to the control box, unlock the equipment, move the belt, lock it again and go back to the equipment to continue cleaning. The change was aligned and approved by the health and safety manager, places, where moving parts are unreachable and appropriate speed of belt movement identified and assigned as places for cleaning. This change reduced the time of changeover by approximately 15 minutes and applies to changeovers between products of different product groups, also sanitary and allergenic cleaning. Kaizen was replicated on other lines in this production plant.

One of the examples of how kaizen suggestion improved energy usage and thus environmental performance was a suggestion for 3 engines of transportation belts continuously working, while there are no products to transport. The suggestion was to install sensors and turn engines on only when product boxes are detected on the transporter.

Safety and ergonomics are affected by suggestions like changing the construction of sugar supply pipe. The pipe was divided into 2 parts and SMS type connection was used. If the pipe gets clogged or during cleaning pipe must be dismantled at a height of 4 meters, weight of the pipe creates additional risk when working at height.

Elimination of hard-to-reach places. Identification and dismantling of unused pipes in caramel making and dosing system.

GE – change type of vacuum suction cups, that picks carton package material and supplies it into box folding unit. If cardboards were bent, old type of cups was not able to pick them.

4.11. Root cause analysis

Root cause analysis at the line was started in 2022. Line team, together with supporting functions identify problems and analyse problems to prevent recurrences. Initially, to stimulate the use of this new tool several criteria when RCA should be initiated were defined: for all repetitive problems, for problems, e.g., breakdowns when their influence is more than 2 hours (0,8% of daily GE) or causes of the problem are not clear.

An example of loss elimination and prevention is root cause analysis (RCA) for equipment breakdowns. RCA was initiated after a breakdown when a new transportation belt was damaged due to a failure of the centring. In total this failure has caused downtime of 4,5 hours within a period of 3 days: 4 times centring failed during production after short term corrective actions, which caused 2,5 hours of breakdown, additionally, 2 hours were necessary to change damaged belt into new, therefore, cost of the belt could be included into losses due to this breakdown. RCA was initiated on the line, because losses were relatively high, causes were not clear, and it was a repetitive issue. In RCA participated line packing operators, line technician and preventative maintenance specialist. RCA was filled during the time of belt change on the line and the team had a chance to observe all the current conditions on equipment and check possible causes, identified on a fishbone. After 5why it was identified that the angle of the centring cylinder was not correct. Also, it was identified that the original design of the equipment did not include a limiter for belt position, which could help to avoid belt damage. These 2 changes have been implemented to avoid reoccurrence of the problem.

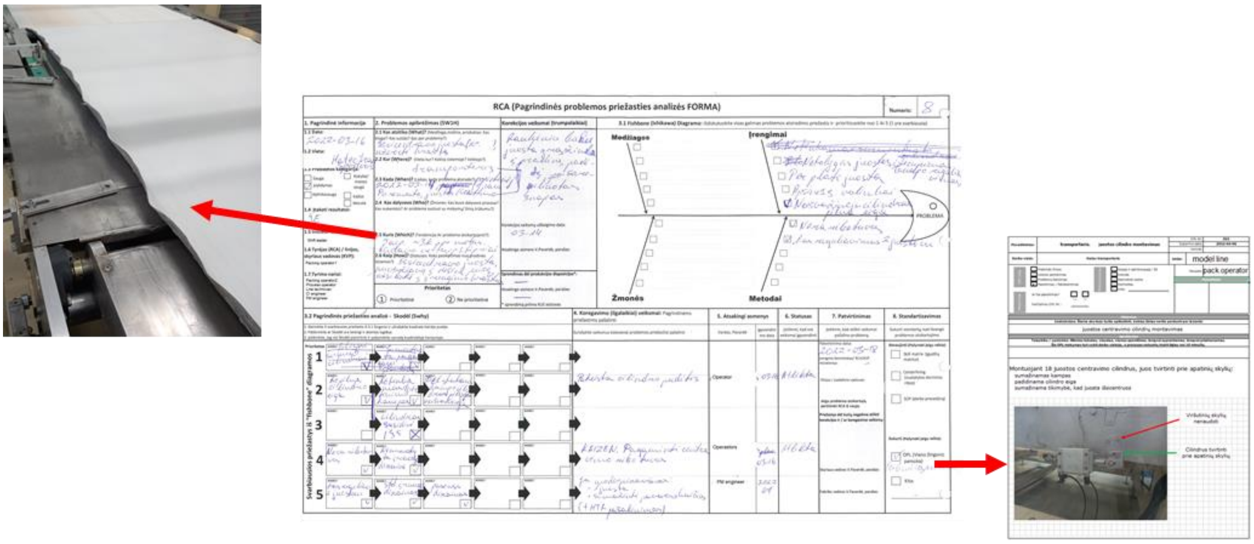

Fig. 29. RCA for damaged transportation belt

As it is widely recognized, AM is highly effective for improvement of equipment availability, which means, that number of short stoppages must be reduced. One of the examples in company „X“ is efforts to reduce minor stops at the process side. Data collection by equipment and failure mode clarified, that the most problematic equipment is longitudinal cutting. The most frequent type of stop was the cleaning of knives. Further analysis showed that it was most frequent during the production of product family2 products. The team started RCA to reduce minor stops related to cleaning knives. The team identified that mass of this product is specific, and sticky, therefore frequent cleaning is necessary. After discussing possibilities to increase cooling it was found out that mass would become too solid, which would cause problems in further operations: after transversal cutting bas will get dispositioned therefore after enrobing defects will appear. Changing mass change is also complicated, as it would change product taste, texture, and other specifications. Attention was focused on knives and scrappers and here three causes were identified: scrappers are damaged during cleaning; therefore, the method of cleaning must be changed, scrappers are not renewed regularly, therefore, cleaning quality naturally reduces during the time. Also, adjustment of scrappers is made differently by each operator, there were no clear directions, tools, or method to check if they are adjusted correctly. The set of scrappers for product family2 products was changed and immediate improvement was noticed. Before, stops for cleaning were necessary every 2 hours on average, after the change of scrappers, cleaning was done only after 4 hours. Consequently, periodical change, based on product family2 production time was defined after testing and close tracking of actual scrappers' performance. Also, OPL was created to inform everyone how and why scrappers must be cleaned to avoid damage and early deterioration. The number of minor stops to clean knives was reduced by 50%.

Fig. 30. Minor stops at longitudinal cutting

4.12. 12 step kaizen

12 step kaizen at the current phase of AM implementation is not widely used, only introduced to line employees as it is a more complex tool for complex problem-solving. The main difference from RCA is that 12 step kaizen is based on DMAIC cycle and requires a more detailed analysis of the current situation and possible causes. During the use of this tool strong support from the focused improvement pillar is necessary to develop capability of line employees.

Even though, it was one of the first attempts to use this tool, it is a great example and demonstrates the potential for solving long-term problems. In this specific example, operational losses during the production of the particular product (product family6) were reduced. The greatest of unplanned stops on the line is operational loss and it was observed, that during the production of product family6 line was stopped every 2 hours due to shortage of caramel. On average, 15% of production time was operational losses (Fig. 31), therefore it was an important contributor to operational losses. Even though the cause of this problem appeared obvious – too small intermediate tank, because of which caramel was made by using only 2 out of 3 boiling tanks, to avoid overflow, the team made efforts to look for a solution. The team measured times and compared quantities in different stages of caramel preparation to find out if the bottleneck is caramel boiling and not any other process. The line team together with process engineer and automation engineer had a Gemba walk to brainstorm ideas, on how to avoid overflow. A low-cost solution was found – level sensor installed into intermediate tank and program updated to stop caramel release from boiling to the intermediate tank. This improvement increased GE during product family6 production by 14% and, also created cost avoidance of more than 5000 EUR for a new tank and its installation at the cost of 500 EUR, as equipment program changes were accomplished by internal company engineers.

Fig. 31. SGA operational losses of product family6 reduction

4.13. Loss elimination through autonomous maintenance tools model

Loss elimination in autonomous maintenance consists of 2 main streams: one is line goals and projects identified through the Hoshin-Kanri process and deployed to the line level for implementation through SGA activities. These improvements are implemented by using RCA or 12 step problem-solving methodologies. Also, participation and support from line leadership and other functions are necessary to implement more complex improvements.

The other stream is loss identification, elimination and prevention during regular production and integration of these activities into daily work. Here AM tools are used in one or several stages. Even though, previously tools were discussed separately, they are part of the whole AM loss elimination system.

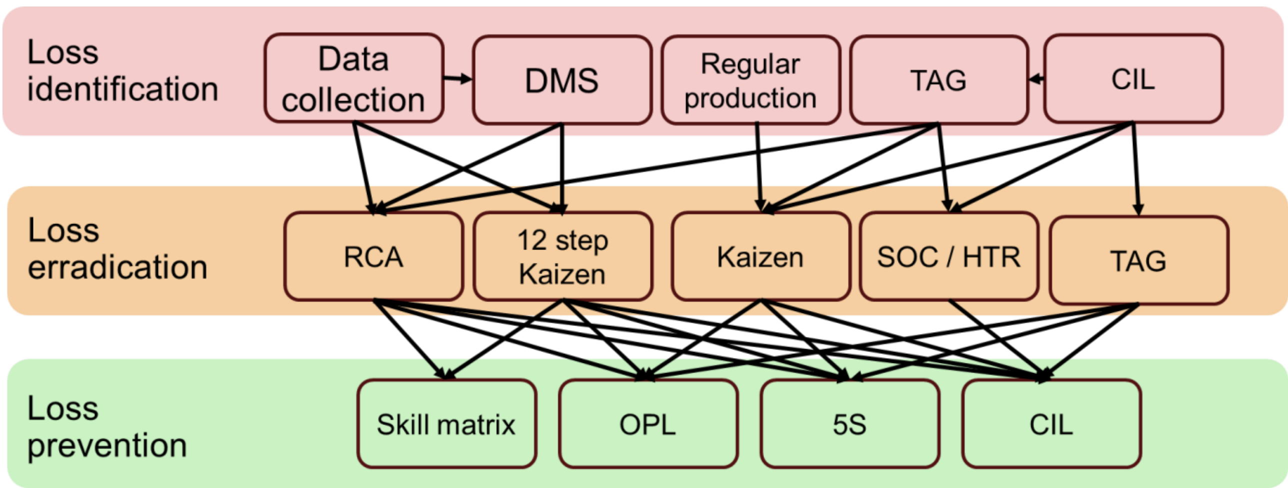

Fig. 32. AM tools relations and association to loss elimination steps

Fig. 32 represents AM tools associated with 3 steps of loss elimination: identification, eradication, and prevention, as well as possible interconnections between tools. Identification of loss could be accomplished by using data collection. Employees who enter data can notice an increased amount of rework, sanitary waste or stops. Also, they can compare it to previous production results and identify abnormalities and waste in the process. If an issue is not noticed immediately during production or by entering data, it could be captured during DMS meetings. Even though DMS1 is simplified, nonconformities of critical parameters and the number of stops are noted there. Daily DMS2 is a place where most often losses are identified, because the information is automatically retrieved from reports of shifts, results and general losses of the last day are quantified and displayed. After losses are identified, their eradication is performed by using continuous improvement tools, such as, root cause analysis, Kaizen, or elimination of SOC and HTR places, and prevention assured by OPLs, updates of 5S standards, CIL or skill matrix and training plan.

5. Economic benefits of autonomous maintenance

Implementation of AM brings benefits, which could be evaluated through several aspects: execution of specific improvement activities, such as Kaizen, root cause analysis, elimination of SOC and HTR as well as evaluation of AM tools' effect on total line effectiveness results and loss level reduction.

5.1. Effect of individual tools application

RCA presents immense potential for loss reduction. The specific example provided in section 4.11 eliminated recurrences of the breakdown. Before, the problem was repeating at least 3 times a year, each time with average losses of 4.5 hours breakdown (2,7% of weekly GE) and costs of 600 EUR for a new transportation belt. During the year losses sum up to 13.5 hours of production time loss and 1800 EUR for materials (transportation belt). No recurrences of the problem since actions, identified through RCA were implemented.

Another example is related to reduction of minor stops at the process side of the line, which was also presented before. Team, by identifying the period of scrappers wear and defining periodical change of the parts managed to reduce minor stops of this specific type by 50%. Before, the line was stopped every 2 hours to clean knives and scrappers and after, this time was increased to 4 hours.

Another great example of SGA project is 12 step kaizen in caramel making during the production of product family6 product. This improvement increased GE during product family6 production by 14% and, also created cost avoidance of more than 5000 EUR for a new tank and its installation, which at the beginning appeared to be the only obvious solution of the problem.

Elimination and simplification of SOC and HTR bring great benefits, as it has synergy with a lot of other activities, e.g., all types of changeovers, sanitation, maintenance, and CIL duration. The total amount of loss identified is over 75 000 minutes or 1251 hours of labour hours. All this information is converted into monetary losses (by evaluating only labour costs) with an average hourly pay rate of 9,4 EUR. The total amount of monetary loss is 11 759.4 EUR/ year which could be recovered by the elimination of SOC and HTR places.

Table 5. Potential GE improvement by elimination of SOC and HTR

Total time for GE calculations, weeks	50
Maximum work time, hours per week	7 * 24 = 168
Total work time, hours per year	168 * 50 = 8400
Potential from SOC and HTR elimination, hours per year	83,4
Potential for yearly GE improvement	83.4/ 8400 = 0,99 %

Timesaving is even more important than labour costs: labour hours could be assigned to other tasks, for example, to shorten changeover, maintenance, or sanitary cleaning and thus line capacity would increase. According to approximate calculations, it could be stated that there is a potential of 60 hours of additional production time per year to be recovered from nonvalue added activities. (1251 labour hours could be reassigned for other tasks, which are accomplished by 15 employees: 1251 / 15 = 83,4 hours) or 10,4 shifts, which, in terms of general efficiency is equal to a 0.99% increase in yearly GE of the line (calculating for maximum work time of 50 weeks/ 4shifts) (Table 5). This is a meaningful increase in efficiency and, also, a tool which helps to improve the work environment for employees, demonstrate that ongoing and upcoming changes are for the better and help to overcome their scepticism.

5.2. Effect of systematic autonomous maintenance implementation for efficiency losses

Systematic approach provided by the application of AM tools has a significant influence for line effectiveness. A comparison of the model line GE and OEE for 2021 and 2022 quarter 1 demonstrates a 2.4% increase in line GE, even though, the increase in OEE is minor – 0.1% (Fig. 33). Results imply that implementation of the initial 2 AM steps had most of the influence on reduction of planned GE losses, rather than unplanned, such as operational losses and breakdowns.

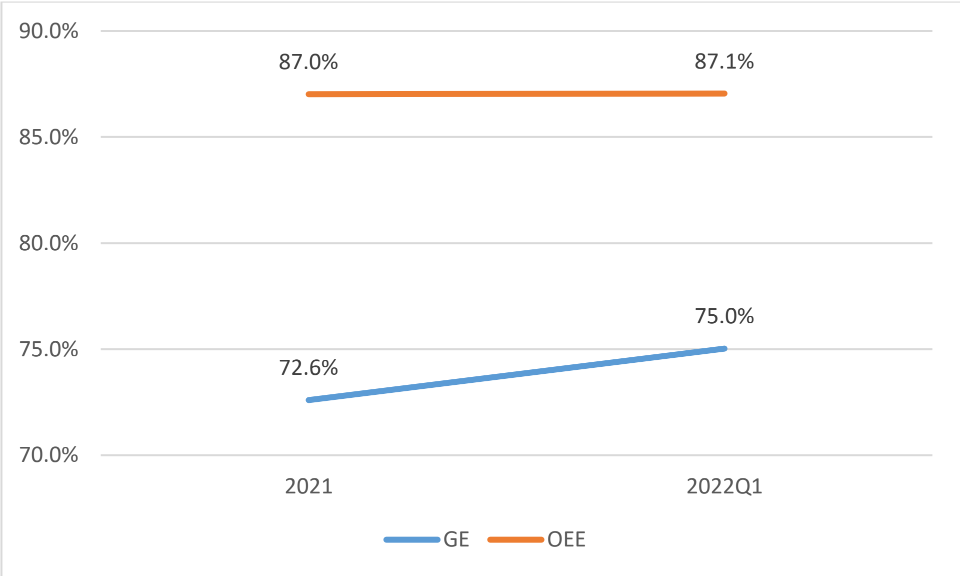

Fig. 33. GE and OEE of model line, 2021 - 2022

For further analysis of line planned and unplanned losses trends, the average quarterly amount of loss in 2021 was compared to the results of 2022 quarter 1. Fig. 34 represents loss types and their changes. Sanitation time was reduced by more than 19 hours per quarter: from 46 hours to 27 which is the effect of started SOC and HTR elimination as well as 5S. Production starts and stops were reduced by more than 10 hours quarterly, from 15 to 4 hours quarterly. Also, breakdown time was reduced by 6 hours quarterly from 27 to 21 hours, which is related to the start of CIL and TAG systems. Even though reduction in absolute numbers might appear insignificant, in percentage it is a 22.2% reduction in one quarter after defect handling systems and autonomous cleaning and inspection were introduced.

It is also important to note that some of the loss types have increased and analyse the causes of these changes. The largest increase is observed in changeover time, which in the first quarter of 2022 increased by more than 12 hours, from 158 to 163 hours. Even though absolute numbers show an increase, the root cause is related to number of changeovers, which in 2021 was 69 changeovers per quarter and in 2022 increased to 82, which is defined by market demand and planning. If considering average changeover duration, conclusions might be different and represent that the average duration of changeover reduced from 2 h 30 min in 2021 to 2 h in 2022. Even though part of this effect might be related to product mix and SMED activities were not directly applied, elimination of SOC and HTR together with 5S, OPLs and skill matrix affected this loss reduction. Another type of increased losses is autonomous maintenance (increase of 4 hours per quarter). This increase is expected, as autonomous maintenance was started to implement and in the next quarter it is expected to also increase or stay stable as new activities, such as lubrication will be introduced and SOC and HTR elimination will continue. This loss type is acceptable as it is compensated with the recovery of other loss types. The third greatest increase is loss due to material shortage which rise is 2 hours quarterly from 1 to almost 3 hours. Even though material shortage is one of the three losses that had the highest increase, it is out of AM scope and more related to supply chain management which will be addressed by other pillars during implementation of the company's Lean Six Sigma program.

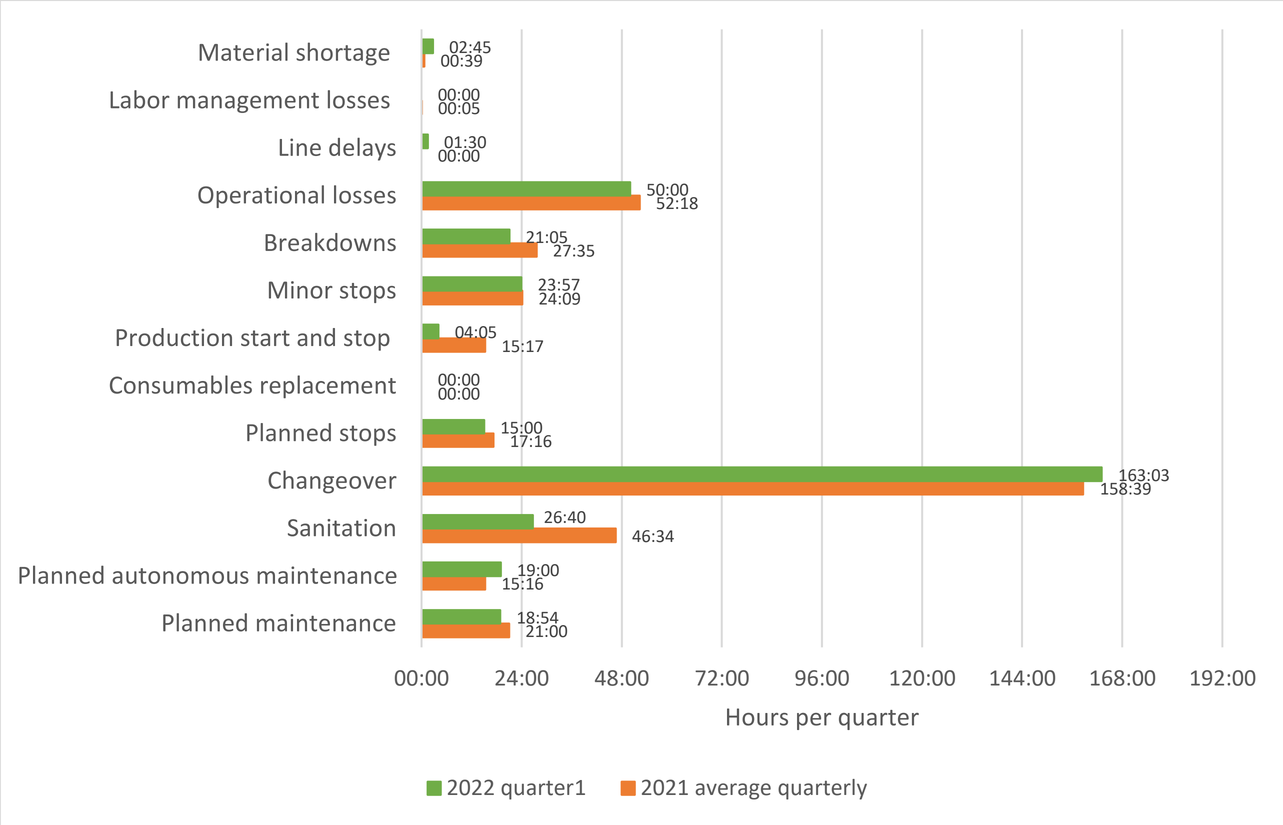

Fig. 34. Loss changes by type, hours per quarter

There are also several areas, where change was minor, for example, minor stoppages and operational losses, as these losses usually require a lot of manual work. For example, during each minor stop operator must clean jams in the machine, adjust it, etc., and most operational losses are related to variations in the process and materials due to which defects of forming or cutting appear and these visually defected products are manually collected from transportation belts, also, rework or sanitary waste are created in this way. These losses could be improved by continuing AM implementation and using SGA activities through the tools like RCA, 12 step kaizen, OPL and others.

Most of the loss types demonstrate a trend of decline, and the total amount of loss was reduced by 32 hours and 52 minutes, mostly affected by the increased number of changeovers, even though average duration of changeover has declined. Theoretically, it could be stated, that if the number of changeovers would be the same as in 2021, results would show an additional saving of 20 production hours, compared to 2021 (2h * 69 changeovers = 138 hours).

Calculation of monetary savings (Table 6) also includes calculation of avoided costs due to the influence of reduced changeover time, quarterly and yearly. Results imply that at the current AM implementation step cost avoidance exceeds actual monetary savings, as quarterly savings are 4512 EUR, while cost avoidance is 2820 EUR per quarter, yearly savings and cost avoidance are 9024 EUR and 11280 EUR accordingly. Even though monetary savings directly related to effectiveness of the model line still has potential to be improved, the company benefits from different areas, for example, reduced time between repetitive production of the product type due to more frequent and shorter changeovers (during 2022 model line has 20% more changeovers than average of 2021).

Table 6. Monetary savings from loss reduction

	Quarterly		**Yearly**	
	Saving	**Cost avoidance due to influence of changeovers**	**Saving**	**Cost avoidance due to influence of changeovers**
Hours saved, h	32	20	128	80
Number of employees per shift	15	15	15	15
Average pay rate EUR / h	9.4	9.4	9.4	9.4
Monetary savings, EUR	4 512	2 820	18 048	11 280

Conclusions

1. After analysis of literature, it was found out that Lean application in the food industry is low mostly due to industry specifics and requires adoption of tools. Most often used methods are value stream mapping, Ishikawa diagrams, 5S, problem-solving through define – measure – analyse – improve (DMAIC) cycle and Pareto chart. While frequency of Total Productive Maintenance use is lower than 4%, even though potential for cost-saving, and efficiency improvement is vast.
2. Analysis of general efficiency losses uncovered that according to Pareto principle, the highest losses in the model line are changeovers (41.9% of all losses), operational losses (13.8%), sanitation (12.3%), breakdowns (7.3%), and minor stops (6.4%). Main contributors to these loss types were identified: product groups 1, 2, 3 and 7.
3. Set of autonomous maintenance tools related to implementation steps 1 and 2 tools were implemented in model line: 3 SGA groups were created, 5S implemented in all line (including workplaces, storage of tools and auxiliary equipment, raw and packing materials), 53 SOC and HTR places were identified, 25 of them eliminated, cleaning and inspection standards for 24 most critical equipment were created and execution started, abnormalities handling system implemented:191 equipment defects were identified, 176 of them were repaired, as well as 11 root cause analysis accomplished during the period of 3 months.
4. After implementation of AM steps 1 and 2, general efficiency of the model line increased by 2.4%, which results in 128 hours of production time or 18 048 EUR labour cost savings per year. In addition, cost avoidance due to reduced duration and increased frequency of changeovers is 11 280 EUR per year. The high potential of labour cost savings identified during the process of SOC and HTR places elimination, which is up to 1251 labour hours or 11 759 EUR per year.

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Appendices

Appendix 1. Title of the appendix