OULUN AMMATTIKORKEAKOULU

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NEW STANDARDS FOR DEVELOPMENT OF LASER CUTTING MACHINES

NEW STANDARDS FOR DEVELOPMENT OF LASER CUTTING MACHINES

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ABSTRACT

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This thesis was commissioned by Bystronic laser AG, a large enterprise focused on sheet metal processing. The thesis included two projects: New BOM with standard machine & Use of digital tools.

A goal of New BOM with standard machine was to create a new manufacturing bill of material structure for laser cutting machine that includes a substructure, standard machine, and to test how the structure affects for departments operations.

The project collected information from a main users of the structure, created new versions and tested the new versions in use. As a result of the project, a new manufacturing bill of material structure was presented that included the standard machine substructure and its effects on department functions were tested.

A goal of the use of digital tools was to perform data analysis on product defects in laser cutting machines and to create development ideas that can reduce 50% of development-related errors in the industrialization phase without extending the time to market time.

The project carried out data analysis, planned technical reviews for the development phase and searched for development targets in digital tools. As a result of the work, a technical review plan and suggestions for improvements to digital tools were presented. The 50% reduction in development errors remained to be seen in subsequent machine development projects.

Keywords: laser cutting machine, bill of material, technical peer review, digital tools

TIIVISTELMÄ

Oulun ammattikorkeakoulu
Konetekniikka, tuotantotekniikka

Tekijä: Petteri Tyni
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Tämän opinnäytetyön tilasi Bystronic laser AG, joka on suuri ohutlevyjen käsittelyyn keskittynyt yritys. Opinnäytetyö sisälsi kaksi projektia: New BOM with standard machine ja Use of digital tools.

New BOM with standard machinen tavoitteena oli luoda tuotannon toimintoihin uusi tuoterakenne, joka sisältää standard machine -alakokoonpanon, sekä testata sen käytön vaikutuksia pääkäyttäjien toiminnoissa.

Projektissa kerättiin tietoa pääkäyttäjiltä sekä luotiin ja testattiin uusia tuoterakenteita. Projektin tuloksena esiteltiin uusi tuoterakenne tuotannon toimintoihin, joka sisalsi standard machine -alakokoonpanon ja sen vaikutuksia pääkäyttäjien toiminnoissa testattiin.

Use of digital toolsin tavoitteena oli suorittaa data-analyysi laserleikkauskoneiden kehitysvirheistä prototyyppikokoonpanossa ja luoda kehitysideoita, joilla voidaan vähentää 50 % kehitysvirheistä teollistamisvaiheessa pidentämättä läpimenoaikaa ideasta tuotteeksi.

Projektissa tehtiin data-analyysi, suunniteltiin teknisiä katselmuksia kehitysvaiheeseen ja etsittiin kehityskohteita käytössä olevista digitaalisista työkaluista. Työn tuloksena esiteltiin suunnitelma teknisistä katselmuksista sekä kehitysideoita digitaalisille työkaluille. 50 %:n vähentäminen kehitysvirheissä jäi nähtäväksi seuraaviin tuotekehitysprojekteihin, kun kehitysideoita testataan käytännössä.

Asiasanat: laserleikkauskone, osalistarakenne, tekninen katselmus, digitaaliset työkalut

CONTENTS

1 INTRODUCTION

This thesis is commissioned by Bystronic laser AG, a large international company focused on sheet metal processing. This thesis includes two separate development projects: New BOM with standard machine & Use of digital tools. The projects focused on improvement of bill of material structure of a sheet metal laser cutting machine and prototyping error reduction by use of digital tools.

This thesis was carried out at a Prototyping & ramp-up department, which is responsible for an assembly of prototypes, product development in cooperation with development department, testing of machines and ramp-up operations for preparing machines to series production.

The projects are divided into separate chapters and both have their own substructure. Both projects followed a structure of a planning task as they were development projects. The planning task structure is listed below:

1. introduction
2. description of the planning/design task, methods, standards and theory
3. description of process stage by stage, alternative solutions, justification of choices
4. critical evaluation of the results = conclusions
5. references (1).

Laser cutting machine

Bystronic's laser cutting machines use laser cutting technology to cut sheet metal efficiently. The laser cutting machines contain thousands of parts and require high precision in the development and manufacturing to achieve an accurate cut. Depending on the model, Bystronic's machines can cut up to 2500 mm wide, 12000 mm long and 50 mm thick sheet metal. The power of the laser source varies between 2 - 15 kW. The machines can be ordered in different layouts and optional equipment can be selected. The machines have a shuttle table system that enables series production of parts. As a continuation of the shuttle table system, an automation system for storage and material management can be ordered. In figure 1 Bystronic´s ByStar Fiber laser cutting machine is presented. (2; 3.)

FIGURE 1. Bystronic’s ByStar Fiber Laser cutting machine

2 NEW BOM WITH STANDARD MACHINE

Bystronic has a manufacturing bill of materials (MBOM) structure in enterprise resource planning system for the laser cutting machine’s material information handling. The current MBOM has been in use for roughly 30 years and it has many advantages but also its weaknesses. The MBOM structure is specifically tailored for production, logistics and purchasing actions. To facilitate price calculation and cost control, a MBOM structure with a standard machine substructure would be a great improvement.

With the current structure, calculation list creation requires a manual operation on the structure that makes the operation slow and increases a chance of errors. The need for manual operation is a result of that the calculation requires only a working machine without additional parts or options. In the current structure, a level one subassembly Laser cutting machine includes all the parts needed for a working machine, but also several unnecessary parts which need to be removed when the calculation list is created.

The aim of the project was to find out whether a standard machine substructure could be created in MBOM and what effects it has on the operation of user departments. The expected benefit of the project was a great relief in cost management. The risk of the project was that as cost management and calculation become easier, the operations of other departments could become more difficult.

The project was limited to be done locally, therefore sites in other countries were not specifically considered at this stage. The project was divided into four phases:

1. creation of new structure versions
2. comparison of new structure versions with the current version
3. questioning the main users on how the different structures affect their operations
4. preparing a proposal for a new structure.

2.1 Enterprise resource planning

Bystronic uses SAP as its ERP software. "SAP is the most-used ERP software on the market and contains hundreds of fully integrated modules that cover nearly every aspect of business management." (4). This section introduces enterprise resource planning.

> *Enterprise Resource Planning (ERP) is a software that is built to organizations belonging to different industrial sectors, regardless of their size and strength. The ERP package is designed to support and integrate almost every functional area of a business process such as procurement of goods and services, sale and distribution, finance, accountings, human resource, manufacturing, production planning, logistics & warehouse management. (5.)*

2.2 Bill of material

The main object of the project was the bill of material structure. This section introduces the purpose and uses of the bill of material.

> *A bill of materials (BOM) is a comprehensive inventory of the raw materials, assemblies, subassemblies, parts and components, as well as the quantities of each, needed to manufacture a product.*
> *In a nutshell, it is the complete list of all the items that are required to build a product. A BOM is sometimes also referred to as a product structure, assembly component list or production recipe (in process manufacturing industries).*
> *Take, for example, a bicycle manufacturer that wants to build 1,000 bicycles. A bill of materials for a bicycle will include all the parts that make up the bicycle such as seats, frames, brakes, handlebars, wheels, tires, chains, pedals and cranksets, including the quantities required of each component and their cost.*
> *A well-defined BOM helps companies: plan purchases of raw materials, estimate material costs, gain inventory control, track and plan material requirements, maintain accurate records, ensure supply robustness and reduce waste. (6.)*

2.2.1 BOM structure

The laser cutting machine is a complex product containing thousands of parts, therefore Bystronic's MBOM is structured as a multilevel BOM. In the figure 2 below, the multilevel BOM structure is expressed with a wheelbarrow example (6). This section introduces the definition of BOM Structure in detail.

> *Typically, a BOM is hierarchical in nature, with the finished product at the top. It includes product codes, part descriptions, quantities, costs and additional specifications.*

Among the most common methods of representing a BOM are the following: Single-level bill of materials, which is a relatively simple list for a product. In this type, each assembly or subassembly is shown only once, with the corresponding quantity required of each to make the product. Though easy to develop, this type of BOM is unsuitable for complex products because it does not specify the relationship between parent and child parts or between assemblies and subassemblies. If the product fails, a single-level BOM makes it difficult to determine which part needs to be replaced or repaired.
Multilevel bill of materials, which takes more work to create but offers greater details and specificity on the parent and child parts in the product. In a multilevel BOM, the total material required is shown. Additionally, the product structure is indented to show the relationship between the parent and child product, as well as assemblies and subassemblies. (6.)

The laser cutting machine is a complex product containing thousands of parts, therefore Bystronic’s MBOM is structured as the multilevel BOM. In the figure 2 below, the multilevel BOM structure is expressed with a wheelbarrow example (6).

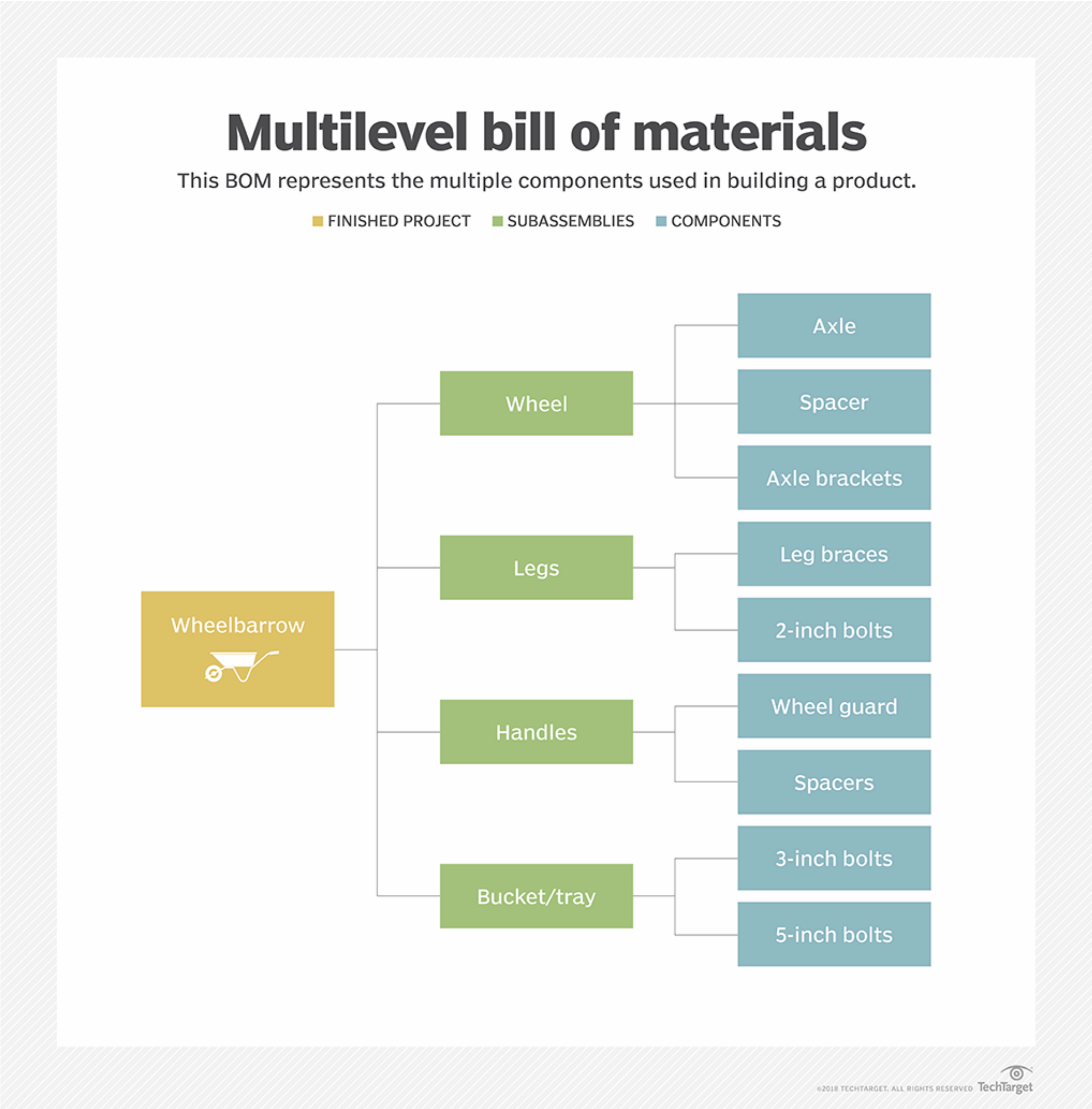

FIGURE 2. Multilevel bill of materials wheelbarrow example (6.)

2.2.2 Manufacturing BOM

The object of the project was to modify the manufacturing BOM. This section introduces the definition and purpose of the manufacturing BOM.

> *A manufacturing BOM (MBOM) includes a structured list of all the items or subassemblies required to make a manufactured, shippable finished product. The MBOM, in addition to the information on individual parts, also includes information on the parts that require processing prior to assembly and explains how various components relate to one another in a product. (6.)*

2.3 Creation of new structures

The aim of the first phase was to create new MBOM structures. The creation of structures began by learning the current structure in detail. The current structure is presented in a figure 3 (7). The studying of current MBOM structure revealed that options are not logically divided in the structure. A level one assembly Laser cutting machine had a subassembly for machine options, although the options were divided throughout the whole structure. The options were found on two different levels and different sub-assemblies below the Laser cutting machine, as well as below other level one assemblies.

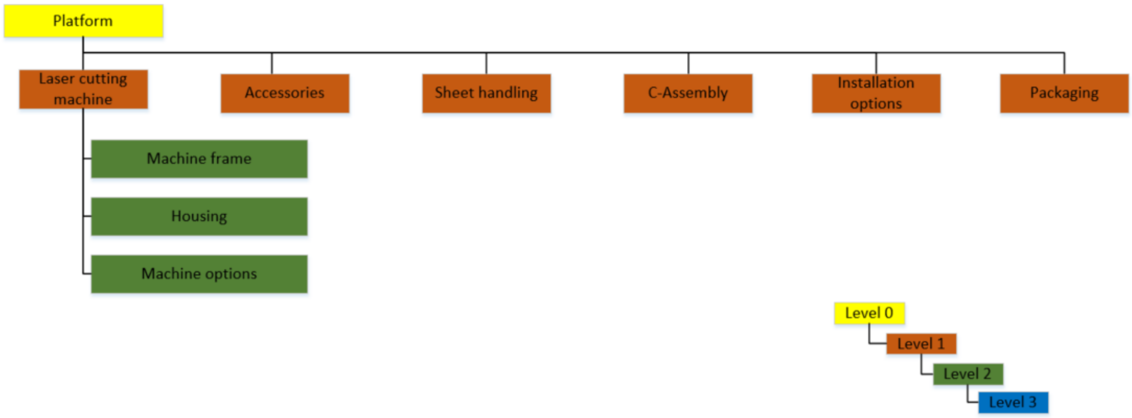

FIGURE 3. Simplified currently used MBOM structure

After studying the structure, requirements were collected from the main users of the MBOM. The main users were Cost management, Order engineering, Master data management, Production planning, Prototyping & ramp-up and Purchasing departments. When asked about the requirements, it became clear that the requirements are difficult to define and it was decided to make various versions, so that feedback could be given through examples. In addition to the before-mentioned departments, Market support was also included in the project, as the MBOM structure also appears in a spare part catalogue they provide.

When creating the structures, the intention was not to include the standard machine assembly in every version, but to make different structures and get broad feedback. The first three levels of the structure were redesigned, and frequently used assemblies were moved to a lower level to make them easier to find. The options were placed in single assembly, which was a great difference from the current structure, excluding a Production line model, where options were divided to their assembly spots. The versions differed significantly to provide more feedback from users. As a result of the creation, three new MBOM structures were created.

2.3.1 Core machine

The idea of Core machine (figure 4) was that the first level of the structure has a clear division between the parts always needed for the functional laser cutting machine, variant parts and options (7). The first level subassemblies were:

- Core machine, including all the parts that come into the machine, regardless of options or layout
- Variants, including all the parts from which you must choose one for a functional machine, such as layout-dependent parts of a machine housing
- Options, including all the optional parts of the machine
- Support material, including parts for production line, machine installation by customer and automation installation.

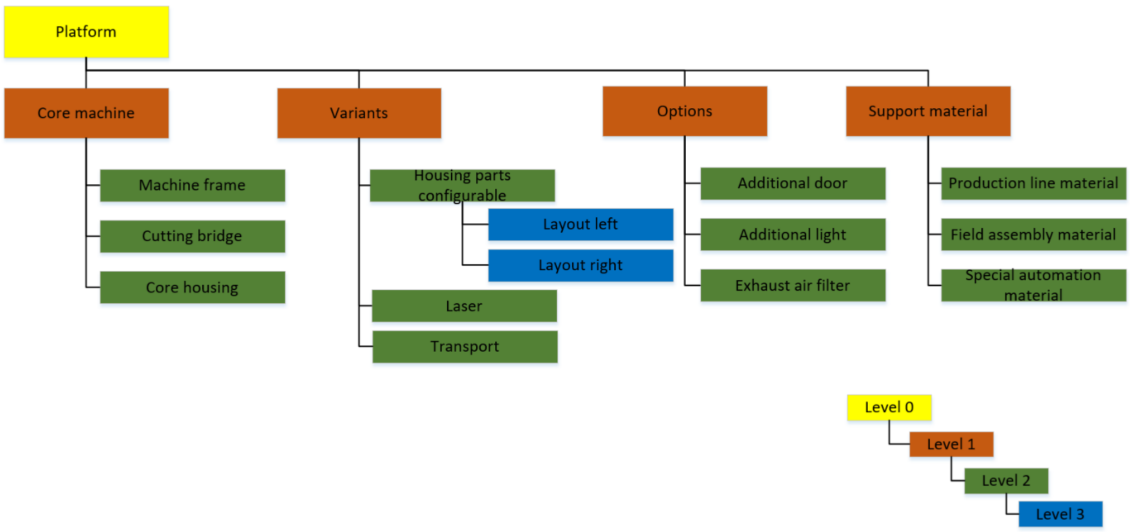

FIGURE 4. Simplified Core machine MBOM structure

2.3.2 Standard machine

The idea of Standard machine (figure 5) was to create the previously mentioned standard machine first level assembly for a 100% machine structure (7). The level one assemblies were divided as follows:

- Standard machine, including the cheapest and only required parts for the functional and shippable machine with standard layout
- Options, including all the variants and options which are not included in the Standard machine
- Support material, including parts for production line, machine installation by customer and automation installation.

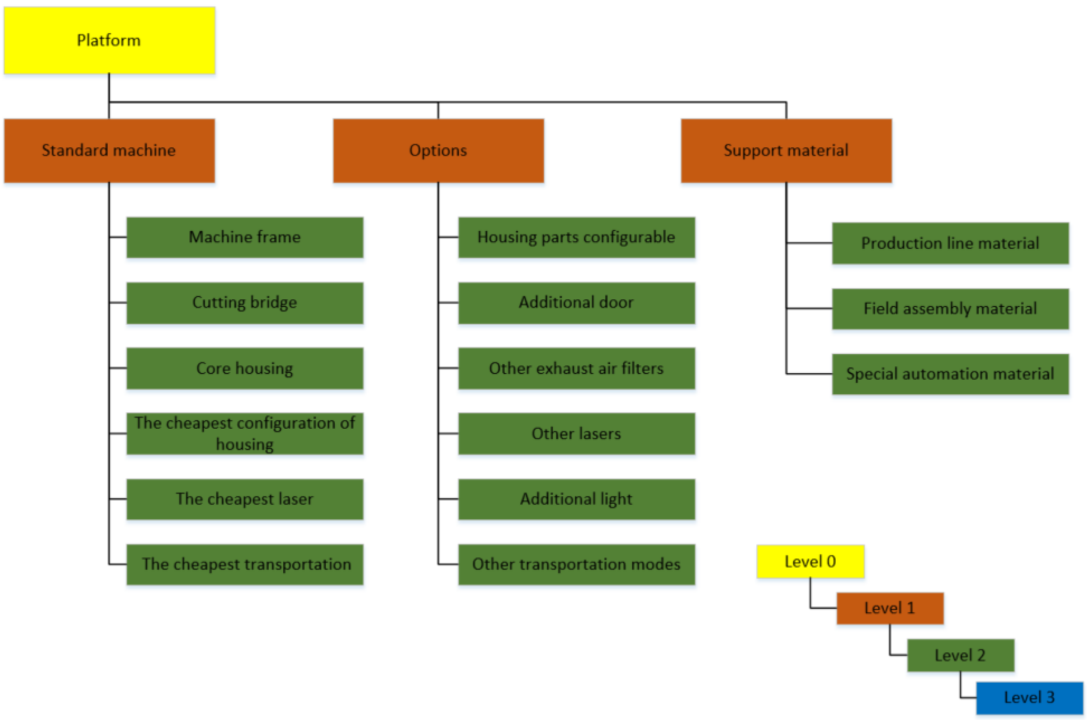

FIGURE 5. Simplified Standard machine MBOM structure

2.3.3 Production line model

The idea of the production line model (figure 6) was that materials are divided into the structure in assembly order (7). In addition to the assembly lines, the first level assemblies were: shipping parts, which included all parts not assembled on the assembly lines and support material, which included support parts for the production line, machine installation by customer and automation installation.

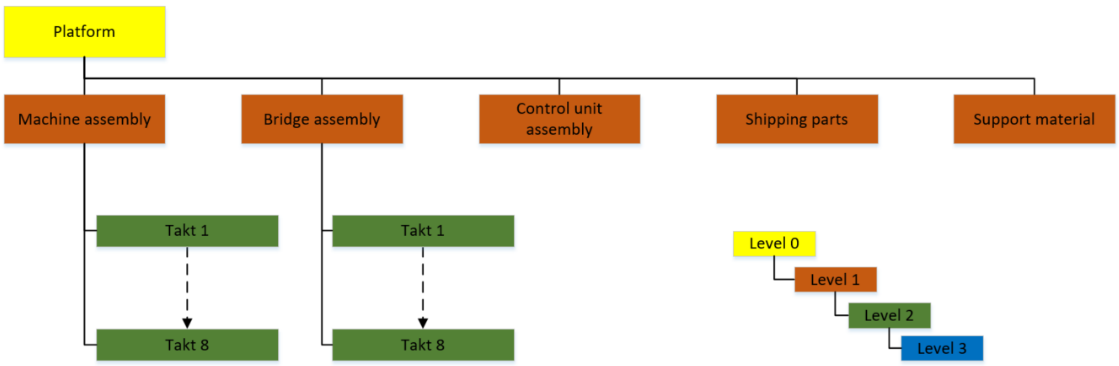

FIGURE 6. Simplified Production line model MBOM structure

2.4 Comparison of current and new versions

The aim of the second phase was to compare the new MBOM structures with the currently used. According to a project plan, the comparison and feedback query was to be organized as an online survey. Already during the first phase, when the requirements were asked, it became clear that it is difficult to answer qualitative questions by writing, therefore the survey was replaced by a workshop. The aim of the workshop was to compare new and existing versions, collect feedback on new versions and select at least one version to further development. The workshop was attended by the key users of MBOM.

MBOM workshop

Each structure to be discussed was printed on a paper and attached to a blackboard. The workshop began with an introduction where an agenda and each structure version were reviewed. The workshop continued with a feedback section where one structure was discussed at a time. For the feedback section, red and green feedback tags and stickers were distributed to each participant. The participants were asked to briefly write positive feedback on the green tag and negative feedback on the red tag, at least one of both. Participants took turns putting their feedback notes on the board and explained their feedback in detail.

After the feedback, the participants voted for the most important feedback on each version by attaching a sticker.

At the end of the workshop, the participants chose a structure to be further developed. Five of the six participating departments wanted to further develop one of the new versions. The Market support did not want to change the structure. Even the current structure does not serve their use in the spare parts catalogue, but its use has been adapted. The most support received structure was the Core machine. Structure-specific feedback is discussed in the following sections.

Feedback for current structure

The current version received positive feedback on its proven performance and that users are used to using it. It received negative feedback about the complexity of the structure and the fact that the options are not clearly divided. A positive feedback "Structure proven to work" was voted for the most important feedback.

Feedback for Core machine

The Core machine received mostly positive feedback for its clear structure, easy configuration, and easier pre-planning for standard materials. It received negative feedback on the difficulty of cost calculation and the difficulty of material steering and changes. A positive feedback "Easy preplanning for standard materials" was voted for the most important feedback.

Feedback for Standard machine

The standard machine received mostly positive feedback for its clear structure, easy configuration, and easy costing. It received negative feedback from difficult material changes, guidance, and pre-design. A positive "Simple configuration" was voted for the most important feedback.

Feedback for Production line model

The production line model only received good feedback on its benefits for production planning. It received negative feedback for its complexity, difficult edibility, and the fact that it serves only one department. A negative feedback "Serves only one department" was voted for the most important feedback.

2.5 Testing

After the first workshop, the Core machine received the most support. A second workshop was held to discuss the Core machine in detail. The workshop reviewed the challenges that emerged from the feedback from the first workshop. The structure did not change much as the data went into more detail and negative matters from first workshop were found to just seem difficult. At the end of the workshop, the main users discussed that there would be a lot of benefits in the Standard machine as well. Due to time constraints, it was decided to arrange another workshop which discuss the Standard machine and to decide which version would be tested.

While studying testing, it became clear that testing two versions instead of one requires only slightly additional effort. Therefore, it was decided to cancel the third workshop and start preparations for testing the Core Machine and Standard Machine versions. The main users were informed of the change of plan and no department objected.

The testing was performed in an SAP Quality-System (Q-System), which is the same system as a Productive System used in daily work, except data changes are not transmitted to the productive system. The aim of the testing was to determine the effects of MBOM structures on operations of the main users by following a customer ordering process parts where the MBOM is used the most. A data used in the testing was based on an older laser cutting machine already on the market, so that the new MBOM versions could be better compared to the current version. The testing was performed at user workstations and the author was present to gather direct feedback. In addition, part search tests were held for assemblers and test engineers in Q-System. The purpose was to find frequently searched parts easily.

The Market support, which opposed the change in the first workshop, was left out of the testing. Discussions were held and it was stated that the function of the spare parts catalogue is excluded from the project and another solution is sought to their problem due to the possibly changing MBOM structure.

2.5.1 Testing set up

Testing set up began by copying the MBOM used on the market machine and modify it to fit the test structures. The changes were made by copying the machine MBOM from SAP to a Microsoft Excel spreadsheet and arranging the materials.

After the materials were arranged, the spreadsheets were delivered to the SAP master data management department and product platforms were created in the SAP Q-System. After the platforms were created, a configuration was created for both platforms as well by same department.

After the configuration was complete, its function was tested at the Prototyping & ramp up department. The configuration was found to work, and a Platform planner made production plans for the test platforms.

The operations performed in a testing set up were done to enable customer ordering process testing. They were already an important part of MBOM structure testing as they are part of every machine project.

2.5.2 Testing in customer ordering process

Testing in the customer ordering process began at Back office management by creating two identical orders for both MBOM versions:

1. a simple configuration with minimal equipment and a low-power laser source
2. a complex configuration with abundant equipment and a high-power laser source.

After creating the orders, a customer specific BOM was released at Order Engineering. The functions included publishing only the parts related to the customer's order, in other words, checking that the SAP configuration selects the correct parts and materials for the ordered options and layout. At this stage, the MBOM structure is inspected manually and the ease of finding parts is very important.

Once the customer specific BOM was created, a production order was done. The Production Order was made by the Production planner and Platform planner. A purpose of the production order is to order the machine materials for the production line at the right place at the right time. At this point, it was found that only one of the published customer specific BOM´s works and that was the complex configuration of Standard Machine. An attempt was made to correct the error, still despite the help of Order Engineering, no solution was found.

The production order was successfully completed, and it was decided to continue testing with the complex configuration of Standard Machine. The main users thought the versions are so similar in structure that the Core machine would also work in SAP functions like the Standard Machine. The last part in customer ordering process testing was the creation of a purchase order. The purchase order was created successfully by Head of project Purchasing.

2.6 Results

Initially, three new MBOM versions were created and feedback was collected from main users. In the testing, the testing environment was set up in SAP and the most important functions of MBOM in the customer ordering process were tested, as well as the part search. The testing of the main functions was successful, although in the main part of the customer ordering process only the complex configuration of Standard machine was tested. The parts search test was in like manner successful, with users finding frequently searched parts effortlessly.

All the main users would have been able to work with both new versions, although the version chosen for further development was Standard Machine, yet with a minor change. In the tested Standard machine, the variants and options were in the same assembly called Options. They were divided into two assemblies as in the Core machine. The Standard machine and Support material assemblies remained the same. A simplified version of proposed Standard machine MBOM is shown in Figure 7 below (7).

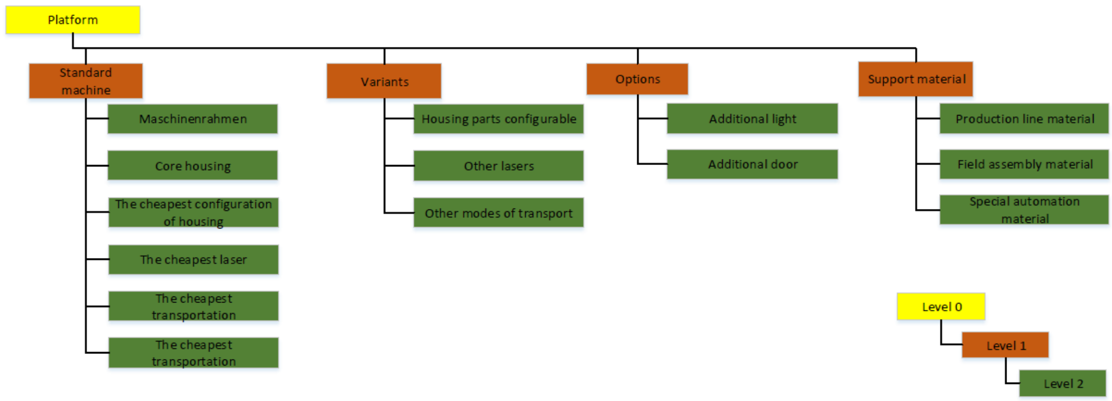

FIGURE 7. Simplified proposed Standard machine MBOM structure

Based on user experience, both tested MBOM versions were easier to configure and use compared to the current, by cause of the options were in the same configuration and frequently used materials were transferred to lower levels. The Core machine and Standard machine substructures were also an advantage over the previous Laser cutting machine substructure, as they were less or no more than 100% product structure. The standard machine substructure goes one-to-one into a calculation list and a prototype phase part order as well as does not require manual processing as before, in such wise it is assumed to be a great benefit.

2.7 Conclusions

The aim of the project was to find out whether a standard machine substructure can be created in MBOM and what effects it has on the operation of user departments. The expected benefit of the project was a great relief in cost management. The risk of the project was that as cost management and calculation become easier, the operations of other departments could become more difficult.

As a result of the project, the Standard machine substructure was created in MBOM and its effects on the operation of the departments were tested. As a result of the testing, the main users and stakeholders were willing to include the new MBOM version Standard machine in the further development of the laser cutting machines.

The testing tested the main operations where the MBOM structure is used, although its true functionality will be seen in further testing in a next machine development project. A realization of the expected relief in cost management will also be seen in further testing, nonetheless, based on the test results it should be proven. The main users of MBOM participated in the testing and their operations were not hampered when the cost management was facilitated, still further testing will see its impact on departments that do not directly use the MBOM structure.

The challenges in the project were collecting requirements from users at the beginning, inoperability of configurations in testing and the MBOM structure in the spare parts catalogue. The requirements for MBOM were collected by organizing a workshop comparing the new versions with the current version and giving users the opportunity to give feedback through examples.

In testing, the cause of the configuration failure was not determined due to the schedule. With the almost similar structures of the tested MBOM versions, the testing was completed by using the functioning complex configuration of Standard machine. The MBOM structure in the spare parts catalogue was demarcated out of the project before testing and another team began to address the challenge.

The goals of the project were achieved, and further testing shows what savings and relief it will result from the perspective of Bystronic. The expected benefits of the project are the easier configuration, the reduction of the manual processing of the structure as well as the facilitated cost management which were seen in the testing. The further testing may include challenges such as defining the division of materials for Options, Variants and Standard machine substructures. For future Q-System testing, the root cause of configuration failure should be determined.

3 USE OF DIGITAL TOOLS

Bystronic has a CAD system in use, which offers various possibilities. Development errors of laser cutting machine are discovered in idustrialization phase which could have been noticed earlier by the consequent use of the existing tools. Time and money could be saved in industrialization phase in case that the system would be used more optimally and consistently during a development phase. With currently used tools and methods, recurring errors are found in the prototype assembly after the machine parts have been manufactured. As a result, parts must be modified or even re-ordered. It would be a great saving when the errors could already be found at earlier phase in digital form.

The aim of the project was to make a detailed data analysis of the errors and plan an improvement idea for tools or methods to reduce 50 % of development relevant errors in industrialization phase without increasing a time to market lead time. The expected benefit of the project was to find development errors at the earlier stage and thereby reduce costs. The risks of the project were the use of extra time to deal with errors at an earlier stage, which would lead to an extension of the time to market lead as well as an attitude of a development staff to the project, as the developer would develop their functions while working at another department.

Data analysis was based on data from two machines. A development team consisted of employees from development, prototyping and production departments with plenty of experience in development error history. The project was done locally and divided into two main phases:

1. data analysis
2. creation of the improvement idea.

Figure 8 presents a simple version of development process. The development phase refers to the Concept and Development parts while the industrialization phase refers to the Prototyping, Testing and Pilot series parts in the development process.

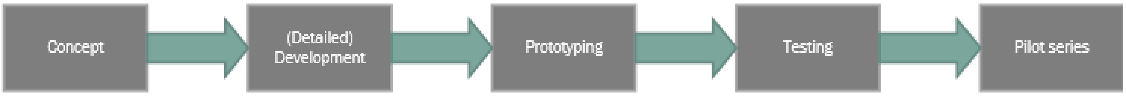

FIGURE 8. Simplified development process

3.1 Product errors in laser cutting machine development

Errors are always found in the product development of a laser cutting machines. In this project, 50 % of development relevant product errors were sought to be found prior to prototype assembly. In a Figure 9 the error distribution of two machine projects is presented (8). The error distribution presents that the peak of product errors in the development process occurs at the beginning of the prototype assembly.

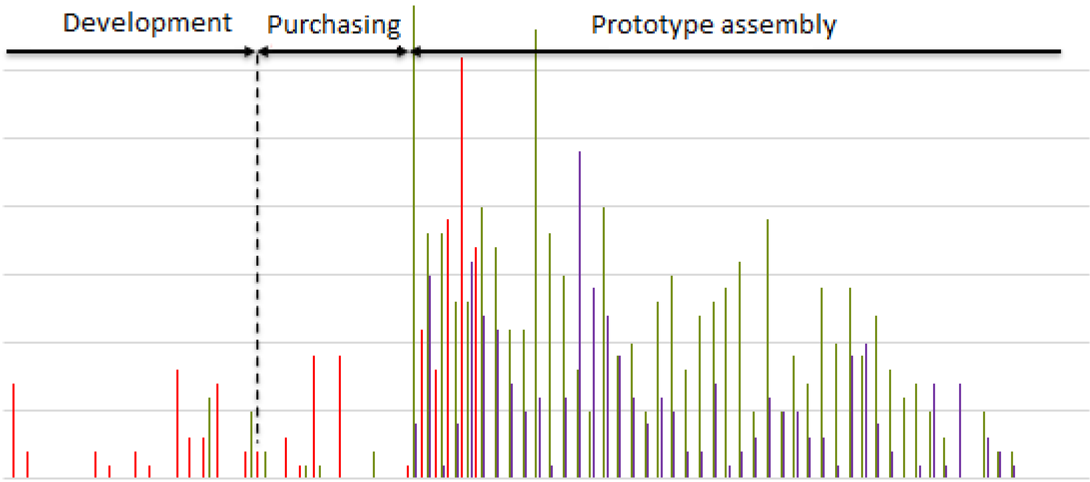

FIGURE 9. Error distribution in development process

It was assumed that potential savings would be made by not manufacturing defective parts and thus avoiding error processing time and part rework or remanufacturing. In addition, as a benefit of reduced errors, a reduction in the time spent on the prototype assembly was expected. However, some parts are not worth trying to design completely in their final form before the prototype assembly. For instance, cable lengths are wiser to only estimate before and repair during prototype assembly. Modelling and routing of cables with a 3D software would take more effort than correcting them in the prototype assembly.

Not all errors found during prototyping are due to design. Defects found in the configuration may also be due to a manufacturing defect, for instance. The project focused on mechanical and electrical development errors as well as improvement potential. Improvement potential can be for instance a tool hole in a machine frame that is too narrow.

3.2 Data analysis

The data analysis used data of two machine projects collected in an Excel spreadsheet. The data was collected during the industrialization phase, largely in prototype assembly. The aim of the data analysis was to analyse and classify an error processing time as working hours, error rates in quantities as well as identify error clusters. The error processing time consisted of time spent by searching, analysing, documenting, discussing, and correcting faults.

Data analysis began by calculating error processing times for the entire projects. The times were divided into three categories: mechanical/electrical, improvement potential and discussion. The discussion time consisted of daily shopfloor meetings. The working time used for discussion was calculated by using Formula 1. In addition, mechanical/electrical and improvement potential errors were divided into three size categories: small, medium and big.

$$wh = pd * mf * ml * np \qquad \text{FORMULA 1}$$

wh = working hours (hours/person)
pd = project duration (weeks)
mf = meeting frequency (1/week)
ml = meeting length (hours*)*
np = number of participants (person)

Once the project-specific total error processing times were calculated, the data began to be examined by subgroups. The subgroups were machine parts, subassemblies and, for instance, documents. The error distribution was calculated by quantity and time for the subgroups of both projects. The results were also expressed as a percentage to create better visualization.

The data analysis clearly highlighted three subgroups in which most errors occurred. The average of the two projects for these subgroups combined quantified 65% of mechanical/electrical errors and 57% of improvement potential errors.

Once the data analysis had identified the subgroups to focus on, the design of tools and methods to reduce errors in the industrialization phase began. Already in the initial plan of the project, technical review was mentioned as one of the possible ways to reduce errors. It was decided to start brainstorming technical reviews and the search for development ideas in digital tools was also started.

3.3 Technical peer review

One of the development ideas was a technical peer review. This section introduces the purpose of technical peer review.

> *The objective of technical peer reviews/inspections is to remove defects as early as possible in the development process. Peer reviews/inspections are a well-defined review process for finding and fixing defects, conducted by a team of peers with assigned roles. Peer reviews/inspections are held within development phases or between milestone reviews on completed products or completed portions of products. The results of peer reviews/inspections can be reported at milestone reviews. Checklists are heavily utilized in peer reviews/inspections to improve the quality of the review.*
>
> *Technical peer reviews/inspections have proven over time to be one of the most effective practices available for ensuring quality products and on-time deliveries. Many studies have demonstrated their benefits, both within NASA and across industry. Peer reviews/inspections improve quality and reduce cost by reducing rework. The studies have shown that the rework effort saved not only pays for the effort spent on inspections, but also provides additional cost savings on the project. By removing defects at their origin (e.g., requirements and design documents, test plans and procedures, software code, etc.), inspections prevent defects from propagating through multiple phases and work products, and reduce the overall amount of rework necessary on projects. In addition, improved team efficiency is a side effect of peer reviews/inspections; e.g., by improving team communication, more quickly bringing new members up to speed,*

and educating project members about effective development practices. (9, p. 206.)

Implementation

The design of the technical review began with an introduction to the theory. After discussions with the project team and project stakeholders, a technical peer review was concluded. The purpose of the technical peer review was completely suited to the objectives of the project. The purpose of the review was to meet among experts to go through a checklist and look for recurring errors in the laser cutting machine in 3D models as well as 2D drawings.

Planning continued with the compilation of checklists. Recurring errors in the subgroups were extracted from the data used in the data analysis, and prototype assemblers were interviewed. In the interviews, frequently recurring errors were found for the checklists. The interviews also highlighted a fourth subgroup that did not emerge in the data analysis but was perceived to cause recurring errors. It was also decided to plan the technical review for this subgroup.

Once the draft of the recurring errors was ready, it was started to be edited together with the project team and at the same time participant and sequence planning was already started. The participant plan was set up so that only the minimum required departments would participate in the review, because time management was known to be a challenge for profitability calculations. In the first draft, reviews were planned only once per subgroup. A mid-term discussion was held with the project stakeholders and it was noted that the topics are spread over a wide area in the development process and it was decided to divide the reviews into parts.

The reviews were divided into two per subgroup and the duration was from one to three hours. Review’s placement in the process began to be considered and was challenging, although it was completed as a result of several meetings. When the draft was ready, the time management was modified so that it would be profitable in terms of numbers as well. The savings from the potential benefits were difficult to quantify because there was no data available on the cost of reworking the parts, therefore participants and review lengths were slightly reduced. Once the use of time had been completed, a plan of participants, topics, time management and event time for four subgroup reviews was completed.

3.4 Improvement ideas for digital tools

Already with the technical reviews, digital tools are used to find errors, still the project also included looking for ways to prevent errors in the design software. Ways began to be explored by holding a meeting first with a mechanical engineer and then with an electrical engineer. The meetings reviewed the design and storage processes for mechanical and electronic components.

In the meeting with mechanical engineer, the process of creating and storing 3D models was discussed. Collision analysis was already mentioned in the project's initial data. Collision analysis could prevent many errors in the prototype, such as a frame beam at the screw hole that prevents the screw from rotating to the bottom. The meeting revealed that collision analysis can be done with the software in use, but no function forces users to do so and there is a possibility of forgetting it. Increasing the use of collision analysis began to be explored. One idea was that when storing assemblies, the program asks if a collision analysis has been done and thus at least cannot be forgotten.

In addition, the mechanical engineer had just received information about a welding module that was not yet in use. It was decided to start examining the welding module as a possible feature to be introduced. The operating principle of the welding module was to create welding seams in 3D models, by cause of at that time the seams were missing, therefore there was only an opening in the 3D model between two plates. Unnecessary gaps between materials and parts interfere with, for instance, the collision analysis. After discussing with the project stakeholder, it was decided to test the module. The object of the testing was the transfer of weld data to the 2D drawings of the parts. The benefit of the introduction of the module was expected to be an improvement in the quality of the 3D models and thus an improvement in the final product, without increasing the user´s workload.

No deficiencies were found in the storage process of parts directly causing product defects, but when storing parts and assemblies, it could be useful to provide additional information such as a density of the part. Determining the right density can even prevent errors in the design of the laser cutting machine, as much attention is paid to work ergonomics and the parts must not be too heavy for assemblers or service mechanics. It was possible to determine the density when editing a part, but it was no longer possible in the storage module. It was decided to find out from a CAD expert the possibility of entering additional information during storage and the possibility of checking the collision analysis.

A meeting with the CAD expert was arranged and matters were clarified. Both changes would be possible, but the storage process is the same for both, individual parts and assemblies. If the program were to ask a single part of a collision analysis every time it was stored, it could have a detrimental effect on user comfort therefore the matter was left for further consideration. The determination of the density of the piece during storage was taken into further investigation.

A meeting with the electrical engineer reviewed the software for creating cable drawings and storing them. The software had been updated to a new one recently and no challenges to solve were found.

3.5 Results

At the beginning of the project, a data analysis was performed, after which it was known how many errors occur, how much time it takes to process them and in which subgroups they occur. Based on the data analysis, it was decided to include three subgroups as areas for development. However, when looking for recurring errors for these three subgroups, it also turned out that the fourth subgroup should be taken as a target for development.

Technical reviews were designed for the subgroups selected for development, in which their recurring errors would be addressed already at the development phase. In addition, development ideas for digital tools were considered to prevent product defects.

Technical reviews

Technical reviews were planned for four subgroups. For each subgroup, would be arranged two reviews, lasting one to three hours, with only the required experts as participants. A profitability calculation was also made for the technical review development idea. A scenario was used in the calculation: how many errors need to be found per hour worked in reviews to reach a certain level of discovery. For the calculation the number of subgroup errors in history and invested time were the average of the two projects used in the data analysis. At the discovery level 50% reached close to one found error per hour and at the discovery level 80% reached close to two found errors per hour.

Improvement ideas for digital tools

Digital tools were found to be developed in 3D software and the use of its features. A check window was designed to use collision analysis, which asks a user when storing the assembly whether the collision analysis has been performed. However, at the end of the meeting with the CAD expert, it was decided to leave the idea to further consideration, by cause of the usability of the program would deteriorate. More use of collision analysis could reduce or prevent errors in the prototype assembly.

The possible use of a welding module was also considered. The transfer of weld data to a 2D drawing was tested. As a result of the testing, the data were transferred to a 2D drawing. It remains to be seen whether there are licenses for all users and whether the use of the module causes difficulties with finite element analysis. The use of the module, at least in assembly modelling, does not increase workload, but improves the quality of the 3D models and facilitates collision analysis and could thus eliminate errors in the prototype assembly.

In the storing of parts, the possible addition of additional information was considered. Adding information would not directly reduce or prevent errors, but it could be helpful not to design overly heavy parts, for instance. The possibility of adding additional information was also left to the development department for further consideration.

3.6 Conclusions

The aim of the project was to make a detailed data analysis of the errors and plan an improvement idea for tools or methods to reduce 50 % of development relevant errors in industrialization phase without increasing a time to market lead time. The expected benefit of the project was to find development errors at the earlier stage and thereby reduce costs. The risks of the project were the use of too much time to deal with errors at an earlier stage, which would lead to an extension of the time to market lead time as well as an attitude of a development staff to the project, as the developer would develop their functions while working at another department.

As a result of the project, development ideas were created to eliminate and prevent errors. In the technical reviews, at the 80% discovery level, two errors should be found per work hour. The assumption can be considered possible, as the experts involved in the review are experienced and can easily find the points of error in the material in use. An error rate for these four subgroups was 73% for mechanical/electrical errors and 62% for improvement potential errors, therefore the average of all errors is 67,5 %. At the discovery level 80% could thus be found 54% of the total errors. At the 60% discovery level, 40,5% of all errors would be found. That could be also enough to achieve 50 % of all errors, as in addition to the reviews, development ideas for the use of digital tools were planned.

After all, 100% of the error time was invested in the time spent on the review, thus in theory, at the discovery level 80%, the time to market lead time would increase slightly, but the discovery of errors would move into the development phase. Inevitably, the time to market would not even be extended, because the time required to rework or remanufacture parts is difficult to determine. According to the idea, most of the errors would already be found with the help of digital tools in the development phase, therefore the additional work would be only the modification work in the digital system. The technical reviews will be tested in next machine project and results can be seen in practice.

Improvement ideas for the digital tools included the use of a welding module, increasing the use of collision analysis, and enabling the provision of additional information in the storing of parts. During the project, it was not yet clear whether these ideas would be implemented, but the introduction of a welding module can be considered very likely. The welding module could be used without additional work, would be unlikely to incur additional costs, and would improve the quality of the 3D models. Bystronic´s laser cutting machines use a lot of plate parts and the weld is a very common way to join them together, so seeing the welds in 3D models would be a great benefit. Improving the quality of 3D models would also facilitate collision analysis and increase the ability to identify errors already in the development phase.

The collision analysis review and the possibility to add additional information remained to be studied further. However, increased use of collision analysis could detect errors already in the development phase, and providing additional information could avoid, for instance, the design of overweight parts.

The risks of the project were excessive use of time when planning improvement ideas to the development phase and that the development department would not easily accept the project because the developer was working from another department. As mentioned, based on the calculations, the time to market could be slightly extended, but the workload would still shift to the development phase. The project was well received by the development staff and this risk did not realise. The project was done closely together between the two departments and all worked professionally.

No major problems arose during the project, but challenges did. It was challenging for the author to plan development ideas for the development process because there was so little experience on the topic. The use of time could also have been better. In a large company, when doing a project between two departments, things have many variables in terms of schedule, but figuring out how to implement changes to digital tools would have been possible to complete during the project.

4 CONCLUSIONS

The topic of the thesis was New standards for the development of laser cutting machines, which included two projects, New BOM with standard machine and Use of digital tools. The thesis was not written in the author's mother tongue and the projects were done abroad. The projects were well suited to the topic of the thesis and provided a lot of challenges. The thesis taught project management, language skills, problem solving and working in an international work environment.

Completing two projects as a thesis brought additional challenges in the form of time management and reporting. A project plan had been drawn up for the time management at an early stage, although both projects involved a project team whose vacations and other duties made it difficult for the projects to progress. The author’s own limited experience in time management and managing two projects simultaneously also brought additional challenges to the thesis.

Reporting was challenged by a thesis template designed for one work or project. The hierarchical arrangement of headings was difficult when, due to two projects, the first headline level had to be used solely to name the projects. By cause of this, the structure was also difficult to make clear. The project New BOM with standard machine achieved the goals and the project Use of digital tools got close to the goal. The development ideas generated as a result of both projects will be implemented in the following machine projects and their operation in practice will be seen.

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