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PLANNING QUALITY CONTROL IN THE IMPLEMENTATION OF 3D PRINTING PROCESSES. A CASE STUDY

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Abstract:
Industry manufactories spent more resources on optimizing the processes of faultless production, satisfying customers with a high new level of quality. Due to this new reality companies are making a focus on methodologies that will help to control production waste, cost, production time, etc. More rational application of both quality control, and scheduling is in need. The article presents analyzes that concern a detailed assessment of the quality control of the tested process. The analyzes used typical quality control tools that are commonly used in control processes. Qualitative analyzes were performed using three basic tools: Pareto-Lorenz diagram (quantitative analysis), Ishikawa diagram (qualitative analysis for causes), and risk analysis (FMEA). The quality analyzes presented in this article show the tasks of the quality control department in detecting production non-conformities and preparing for preventive actions in manufacturing processes. The authors present analyzes both in the control process, but also at the planning stage of these processes. The defects in the 3D printing process can be physical or software-related, and their causes need to be analysed constantly. It also provides examples of defects that can occur during 3D printing, such as plastic overheating, web formation, and software setup errors. The importance of proper calibration of the 3D printing machine, choosing the right plastic and environmental conditions, such as temperature and moisture, for avoiding defects is mentioned. The moisture contained in the air can spoil plastic filaments, and the plastic needs to be dried before loading into the 3D printer. The research results are guidelines for further actions in the scope of improving procedures. A plan of changes necessary in the process of quality assurance, with particular consideration of mass production. The results of the analyses focus on the stage of process preparation and control of the first batch.

Key words: 3D printing process, quality control tools, process quality supervision, risk analysis

INTRODUCTION

The case study presented in this article concerns a 3D printing company. This 3D printing Studio is high quality services, individual approach to each client, compliance with the specified deadlines, pleasant pricing policy and high-precision equipment. Company is aimed for individual orders, so it is usual to see that they are making unique and complicated projects. In most cases, the products that are produced are used without any problems. The difficulty of the projects plays a huge role to the quality and usage duration, because the form of the product (3D model) determines the strength of product to a greater extent. In fact – the product dictates strength. The aim of this article is to provide practical analysis of production defects and utilize quality management tools to develop an improvement plan. Even without a formal quality system, effective use of tools for improvement changes is possible.

For the company, the most important element of cooperation with the client is the prototype implementation time. After the client's acceptance, prototype elements are launched for mass production. This stage is crucial for the quality of the received production and meeting the order completion deadline. Therefore, cooperation is mainly based on the analysis of the production preparation procedure (prototypes) and a full risk analysis of this stage. Risk analysis in each production cycle allows for the improvement of the procedure. The aim of cooperation is to determine risk elements, develop preventive measures for emerging defects, and indicate opportunities for improvement. The improvement process is carried out not only in relation to production defects but also the efficiency of using materials in production [1, 2, 3, 4].

CURRENT STATUS OF THE ISSUE

The concept of quality assurance in an organization is of key importance, not only due to the requirements of quality standards, for example ISO, but also due to the effective use of resources and the increase in production efficiency factors [1, 5, 6]. The quality assurance system includes the following issues: verification of the quality of materials, monitoring of their storage parameters and ensuring appropriate transport conditions, quality verification for production stages, random quality control of special parameters, final verification, process approach to quality management. The decision to use the quality assurance system in an enterprise (according to the guidelines of system standards) is related to customer requirements, market requirements (industry branches), or beliefs about the usefulness of the guidelines for the effective use of company resources [7, 8].

Tips, suggestions and examples of solutions for improving the organization in production processes are not reserved only for systems. An entrepreneur can use selected tools for changes in their organization. There is no need for formal implementation of the system (LEAN, TPS, Six Sigma, ISO). Knowledge about the usability of quality management tools allows their use in every case. The most important element of quality management tools is input data that will allow their effective use [2, 9, 10, 11, 12, 13]. The possibilities of choice are very wide, both in terms of tools, methods and techniques [10]. The lack of the need for formal implementation of the quality management system does not rule out the possibility of using useful tools. Using quality management tools, the entrepreneur analyzes and determines the method of changes in their organization [10, 14, 15]. An important element in this respect is maintaining the continuity of work that is focused on improvement. The second element of the quality assurance system is documenting activities aimed at improving quality (which are required by customers). The aim of the activities is to increase the efficiency indicators of the functioning of the company's internal processes [16, 17]. The practical application of selected quality management tools ends with consideration of the possibility of implementing a system according to ISO standards, which, in addition to the effects of changes in the organization, also provides tangible benefits for the company's image on the market [18].

METHODOLOGY OF WORK

The basis for starting the cooperation was the quantitative analysis of production defects appearing in 3D printing. Data collection sheets on the type of defects were prepared, and workshops indicating the causes of production problems were defined. The results of this cooperation are a list of defects and an Excel form in which quantitative data on the types of production defects appearing are collected. The article presents a case study analysis, which was conducted in cooperation with a manufacturing company. The results of the work include a quantitative analysis, which became the basis for implementing improvement activities. These activities are aimed at changing the work environment and defining performance indicators, which will be analyzed in a continuous system [19].

The analysis included a standard quantitative analysis (Pareto-Lorenz) and qualitative analysis of the effects of the 3D printing process. The qualitative analysis included the characteristics of the causes of defects (those that were the most numerous), using the Ishikawa diagram. The types of defects were also classified according to risk in accordance with the FMEA analysis methodology. The results of the analyses became the basis for defining improvement actions.

RESULTS OF WORK

The main purpose to use Pareto method in the given production – to detect a number of defects that occurring throughout the process of production according to method's principles. Time that is declared to perform process is 76 working hours (approximately one week of consist work). The analyzed process started on Monday (14th week of 2025), for two-shift work. The analysis included production downtime (approximately 4 working hours). When the process has been completed, as the outcome – 240 pieces of the product were produced. And 190 pieces of product were produced in right way, with any of emerged defects. It is almost satisfying result for the client, as the client ordered 190 pieces of the product. From company' side more pieces were produced because of the obvious problems with product production quality. All types of complaint that were written according to the practice surveys were moved to the Excel spreadsheet dataset (including the date and time of occurrence of the defect).

Complaints and time data are documented and gathered by workers, these data are very important to show complaints and precise time of defect occurring. After completing the aggregate data in the excel table, defects were categorized. The number of defective products in the analyzed period was counted. This data allowed for estimating which defects occur most often. There are 16 separate defects has occurred (Bad infill; Plastic over-extruded; Layers split; Low temperature of the bed; Scratches on the top layer surface; Web occurance; Deformation; Absence of extrusion in printing; Plastic overheating; Curved or uneven corners and edges; Holes in the top layer of the printout; Irregular extrusion; Layer offset, no alignment; Plastic stucked; Plastic extruded not enough; Others). And their total sum is 50 pieces. In accordance to provided data we can calculate the distribution and cumulative percentage. And when all calculations are done, we can build a Pareto Chart to detect issues that should be fixed at the first. Consequently, after doing all calculations and building a Pareto Chart, it is possible to see what issues cause the most of the defects in our product. The Pareto Chart gives an understanding in issues that should be solved immediately and what problems can be solved in a second place. There is realizable that cumulative percentage of 80% belongs to the 2 biggest defects from the most occurring – bad filling that occurs 21% times during the production to plastic over-extrusion with detection rate of 16%.

According to Pareto method presented above, it has been defined that the production suffers due to two main defects occurrence – bad infill printing process and over-extrusion of the plastic that comes from the nozzle. Assumption lies in the fact that these two defects may connected. To define root causes that lead to process results – two Ishikawa Diagrams (Figure 1, Figure 2) with matched defects are built with further explanation.

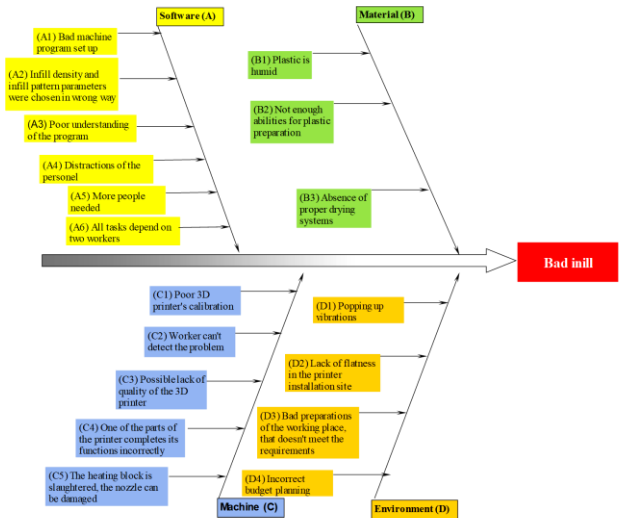

Fig. 1 Ishikawa Diagram for the first defect – Bad infill

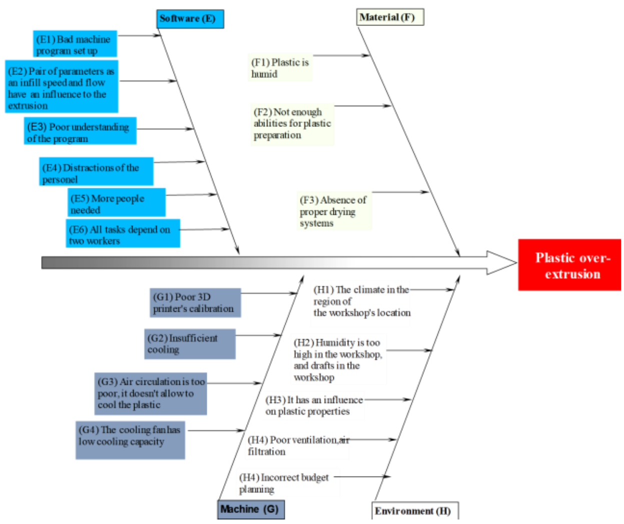

Fig. 2. Ishikawa Diagram for the second defect – Plastic over-extrusion

The first problem that we were encountered to define, is there any problem that are connected with the software. The programming setup is always fragile part of work because of its complexity. The main setups for infill printing process were defined – infill density and infill pattern. After defining the first of first cause to our defect, it was easy to find the root problem – not enough workers are in the workshop, it means that it is too much processes depends on a two workers.

The last thing to mention is the 3D printing machine calibration. The company has a vast variety of printers in the own. Because of the poor availability of staff, different errors can occur during the long process such as creating 3D printing models. The key root was also defined: the nozzle can be damaged and heating block can slaughter through the process, because of continuous process and fragility of 3D printing machines.

Very unexpected results emerged when the environment in the workshop had been checked. Problem lies in the fact that vibrations emerges at the printer 3D installation site, these vibrations cause the destabilization of the all machine. Following the first issue, it be-came possible to examine that the surface was set up in a wrong way, that the direct cause of the bad preparation of the working place that is tightly connected, in the team opinion with the lack of employees amount in the workshop, the lack of understanding of the 3D printing process has led to the erroneous diversification of budget funds between primary (enclosure – thermal camera, filament drying systems) and secondary devices (filtrating systems).

The next step is to verify potential causes listed in the Ishikawa Diagram. It also allows to draw up an action plan for specific people. In the Table 1 verifying process of the actual impact of each cause on the problem with the appropriate verification activity. The person responsible for taking the verification action and the status of this action is indicated.

According to "Status column", the "OK" status means that the given cause did not (after verification) actually affect the problem, the "In progress" status means that the verification is still in progress (not completed yet), and the "nOK" status means that the given cause actually affected the failure's problem (this was shown by the verification action).

In regards to the Table 1, all the potential causes with their direct numeration form Figure 1 Ishikawa Diagram had been transmitted to the table, after that regulated verification actions were labeled to the causes. For example, "Assessment of Employee Skills" is a label that means the actions connected with employee's behavior should be considered as a possible solution of the problem. The IDs of causes are A1-A3, C2, C5 and D3. And responsible person in this case is O. Szar. who is a human resource worker in the company.

All the activities connected with management belong to O. Skar: "Management System Verification" activity in causes A5, A6 and D4 give the direct target action for employee where to start the process of cause" verification. And all further activities are defined in that way.

In this verification process we already defined 2 causes that definitely affect the production causing the defect of bad infill – B1 and C3. B1 is a plastic humidity and C3 is a possible lack of quality or malfunction of a given machine. The verification of causes A1, B2, B3, C4 and D1 are still in process of the verification, the rest have status OK, it means that causes aren't defined in the process.

Table 1
Verification Ishikawa Diagram for bad infill (#1)

LOGO		*Machine/Line: 3D printer FDM Anycubic i3 Mega S*		**Verification Ishikawa diagram**	#1
		Data: **10.04.2025**			
		Analysis team: **O. Szar**.			
Attacked problem name:	***Bad plastic infill of the product***				
VERIFYING POTENTIAL CAUSES IN THE ISHIKAWA DIAGRAM					
ID	**Potential cause**	**Verification action**	**Responsible**	**Deadline**	**Status**
A1	Bad machine program set up	ASSESSMENT OF EMPLOYEE SKILLS	O. Szar.	15.06.2025	In progress
A2	Infill density and infill pattern parameters were chosen in	ASSESSMENT OF EMPLOYEE SKILLS	O. Szar.	10.04.2025	OK
A3	Poor understanding of the program	ASSESSMENT OF EMPLOYEE SKILLS	O. Szar.	10.04.2025	OK
A4	Distractions f the personel	ENVIRONMENTAL MANAGEMENT	O. Skar.	10.04.2025	OK
A5	More people needed	MANAGEMENT SYSTEM VERIFICATION	O. Skar.	10.04.2025	OK
A6	All tasks depend on two workers	MANAGEMENT SYSTEM VERIFICATION	O. Skar.	10.04.2025	OK
B1	Plastic is humid	VERIFICATION OF COMPLIANCE	I. Barg.	10.04.2025	NOK
B2	Not enough abilities for plastic preparation	WITH REGULATION	I. Barg.	10.06.2025	In progress
B3	Absence of proper drying systems	REQUIREMENTS	I. Barg.	10.06.2025	In progress
C1	Poor 3D printer's calibration	VERIFICATION OF COMPLIANCE	O. Szar.	10.04.2025	OK
C2	Worker can't detect the problem	WITH REGULATION	O. Szar.	10.04.2025	OK
C3	Possible lack of quality of the 3D printer	REQUIREMENTS	I. Barg.	10.04.2025	NOK
C4	One of the parts of the printer completes its functions incorrectly	VERIFICATION OF COMPLIANCE	I. Barg.	10.06.2025	In progress
C5	The heating block is slaughtered, the nozzle can be damaged	WITH REGULATION	O. Szar.	10.04.2025	OK
D1	Popping up vibrations	REQUIREMENTS	I. Barg.	10.06.2025	In progress
D2	Lack of flatness in the printer installation site	MEASUREMENT	I. Barg.	10.04.2025	OK
D3	Bad preparations of the working place, that doesn't meet the requirements	ASSESSMENT OF EMPLOYEE SKILLS	O. Szar.	10.04.2025	OK
D4	Incorrect budget planning	VERIFICATION OF CONTROL CARDS	O. Szar.	10.04.2025	OK

The second Ishikawa Diagram is shown on Figure 2 below. This diagram relates to the defect – Plastic over-extrusion that happens during the process.

For the second case defect it worth to mention that two of main defects have the same obstacles that causes them. The same problem appears on the stage of setup. The parameters were chosen wrong and this can cause defect emergence.

Problem with material is still the same here – plastic is over-humid, that significantly decreases quality of 3D printing process, low material quality also affects other smaller defects. Also the most common problem that can cause over-extrusion – the plastic doesn't cool fast enough. When this happens, the hot plastic, when cooled, has time to take unexpected forms.

The next issue that was defined is plastic is moisture, over-humid. The decision was made to include this problem to two groups: Material quality and Environment to make a research more accurately. In the conclusion two root problems were defined: at first, no drying systems to store materials are provided at the company. At second, weather in the region is wet and it causes humidity problem in the warehouse and workshop, and also it's no proper ventilation systems. The main lesson was learnt that company is on low budget with problems that are connected with environment, such as moisture.

Similarly, for the second type of manufacturing defects, guidelines for corrective actions have been prepared. The changes were defined in four task groups, and the persons responsible for their implementation and deadline were designated.

In the second case, the same causes were verified – F1 and H1. Causes relates to the humidity of plastic and inside of the workshop. That mean that it is common problem for both of defects (bad infill and over-extrusion) – humidity. That is the point when actions should be taken immediately. Causes with the ID numbers F2, F3 and H3, H4 are still in the process of the verification up to the date of deadline. All the other causes are disproved by verification and no actions needed.

RISK ANALYSIS IN THE MANUFACTURING PROCESS – 3D PRINTING

The last step in our research is the ability to define significance of the defects with using FMEA of a process. The defect data for FMEA analysis, which are presented in Table 2, are the result of previous studies aimed at defining major defects. It is an extension of the quantitative Pareto-Lorenz analysis. This analysis aims to define the level of risk taking into account, not only the number but also the significance of the defects [12, 14, 19].

In Pareto chart the all defects were included to the list. On the basis of previous survey, it comes possible to create the FMEA diagram, where all the failures are precisely described and give an opportunity to create possible solution according to teamwork research.

In the table presented, the FMEA method gave an opportunity to see the full-scale pic-ture of the process failures. The whole production process was divided into 3 more specific processes: "Setting of the program", "Calibration of the printer" and "Printing". After that, it became possible to classify each of the 15 defects and their nature. Defects – an effect of poor preparation and is the end cause, that's why they are included in the "Potential causes" column.

"Type of failure" – is the nature of the defect. The table it is presented 3 groups to show this: Environment, Software and Machine.

Table 2

FMEA analysis results for the 3D printing process

Failure Mode and Effects Analysis (FMEA)

Item: 3D printing model -- tree
ID: 001
Responsibility: Orest Shkromyda
Core Team: EASY3DPRINT
FMEA No.: 001
Date: 01.02.2023
Results:

Failure causes analysis

Process	Type of failure	Potential Failure Mode	Potential Effect(s)	Class	Potential Cause	Current Control Methods	Action Priority	Recommended Action	Actions	Severity	Occurance	Detection	RPN
Settings of the program	Software	Settings run wrong	Bad infilling of model	CC	Bad set up	Technical	H	Analyse the process carefully	Establish the schedchule of settings quality control	7	9	7	441
Settings of the program	Software	Settings run wrong	Plastic-overextrusion	CC	Bad set up	Technical	H	Analyse the process carefully	Establish the schedchule of settings quality control	9	7	5	315
Settings of the program	Software	G-code failrure	Layer offset, no aligment	SC	Wrong formatting of the code	Technical and Behavioral	L	Training of workers	Introduce advanced training to empl, or find more proffesional worker	4	2	1	8
Settings of the program	Software	G-code failrure	Layers split	SC	Too much layer height, Too low printing temperature	Technical	L	Change parameters	Change parameters -- layer height and printing temperature	3	5	4	60
Printing	Environment	Inappropriate Environment	Low temperature of the bed	SC	No enclosure	Technical	L	Reduce heat loss	Install the enclosure, reduce heat loss by room islolation	2	4	4	32
Settings of the program	Software	G-code failrure	Scratches on the top layer surface	SC	Overextrusion, Z axis wrong setting	Technical	L	Change parameters	Decrease parameters of extrusion and set parameters for Z axis	2	5	4	40
Settings of the program	Software	G-code failrure	Web occurance	SC	Length and speed of retraction, too high temperature, idling of the nozzle	Technical	L	Change parameters	Increase length and speed of retract of fillament, reduce heat temperatire of extruder, reduce length of idling	1	5	4	20
Calibration of the printer	Machine	Technical conditions		SC	Exhausted retract mechanism			Displace details of the printer	Displace feed rollers with new one				
Printing	Software	G-code failrure	Deformation	SC	Bad set up	Technical	L	Change parameters	Set the fields or rafts	2	4	3	24
Printing	Software	Technical conditions		SC	No enclosure			Prevent process from a draft	Install the enclosure				
Calibration of the printer	Machine	Technical conditions	Absence of extrusion in printing	SC	Printer machine is calibrated wrong	Technical and Behavioral	L	Efficient callibration of the machine	Increase distance between nozzle and bed relative to nozzle (Z axis), feed roller should be replaced	2	3	2	12
Printing	Software	G-code failrure	Plastic overheating	SC	Weak cooling, printing heat temperature to high	Technical	L	Change parameters	Improve cooling system parameters and printing temperature	2	3	2	12
Printing	Machine	Technical conditions	Curved or uneven corners and edges	SC	Plastic overheating	Technical	L	Change parameters	Improve cooling system parameters and printing temperature	3	2	1	6
Settings of the program	Software	G-code failrure	Holes in the top layer of the printout	SC	Bad infilling of model	Technical	L	Change parameters	See the Potential Effect 'Bad infilling of model'	5	2	1	10
Calibration of the printer	Machine	Technical conditions	Plastic stucked	SC	Extruder had been expoited to long without maintenance	Technical and Behavioral	L	Clean out the machine parts	Push the filament into the extruder, reinstall the filament, create the scedchule for keeping maintanace of	3	2	1	6
Machine	Machine	Technical conditions	Irregular extrusion	SC	Extruder motor was overheated, extruder was clogged	Technical and Behavioral	L	Clean out machine, check motor engine	Extruder should be cleaned, hire a person to repair motor issue	4	2	1	8
Calibration of the printer	Software	G-code failrure	Plastic extruded not enough	SC	Wrong filament diameter, extrusion ratio is too low	Technical	L	Parameter should be changed slightly	Should be cheked out diameter and extruder settings, tested and start process again	2	2	1	4

Source: company's own research. Excel form.

“Potential Failure Mode” shows where the failure can emerge more precisely in regard to failure types. It can be a code writing failure or technical conditions of the machine in our cases.
In the “Class” column – according to the severity matrix, CC (critical cause) are characteristic with a severity of 9 or 10 (with the implication of safety) and SC (significant cause) with a severity less than 9. CC are the most dangerous for production because of their high severity and occurrence.
After the “Class”, “Potential causes” of the problem were defined. It is an assumption about the actions that can possibly cause the defect occurrence. For instance, defects as holes in the top layer of the printout, are potentially caused by another defect – bad infill of the model. This is the way how to define these potential causes.
“Current control methods” depicts the area of control type. It can be Technical or behavioral and shows the area where the control is working and quality control can be improved.
The “Action Priority” column is a representation of the priority level that defines the most significant failures. Calculated from the AP matrix. In our case, the High Action Priority level is labelled to defects as Bad Infill and Plastic over-extrusion.
When determining the effectiveness of recommended actions, it’s significant to consider whether technical preventive measures are used (use of machines, tool durability and maintenance, tool material, etc. or best practices (attachments, tool design, calibration processes, error-proofing, preventive maintenance, etc.). work instructions, process control statistics sheets, process monitoring, product design, etc.) or behavioral measures (use of certified or uncertified operators, trained craftsmen). From this consideration, the most valuable recommendations were included in the “Recommended actions” column.
“Actions” is the considered final method to apply, on the basis of the recommendation column. And so, after defining the APN, the basic idea to quickly move to defect-solving action is already created.
To define the RPN (Risk Priority Number) of each failure – Occurrence, Severity and Detection should be multiplied by each other. Each of the elements is assessed on a scale of 1 to 10, in accordance with the guidelines of the FMEA method. And the simple formula of multiplying the indicators has been supplemented with the analysis of the priority indicator (new guidelines of the FMEA analysis).
The optimal value of the RPN in this company is 50. If the RPN is higher than this value we should immediately react to the situation and start the search for the solution to the emerged defects due to their importance. Everything that is below the value of 50 – should be examined in the second place. The following description of the process failures from Table 3 will show a situation where the main failures will be explained in detail.
The red color boxes mean that the Potential causes such as Bad infilling of the model (with a rate of 441), and Plastic over-extrusion (with a rate of 315), have the highest bad impact influence on our production. These causes are high severity, occurrence and detection level. Bad infilling of the product is important to solve because it is a very huge loss of material and time of production. The same with plastic-over extrusion, more plastic is used during production, and this extra material destroys the product structure and creates a huge loss of performance. The thing here is that these top defects can be solved in a short term. Because, during the research, it was found that the main cause of these defects is the wrong setup of the software program. The main action to decrease the occurrence of these types of defects is to carefully set up the system settings. The Action Priority of the given two defects was chosen to be High, which means that actions to solve this problem should be applied immediately.
The third harmful potential effect is layer’s splitting. RPN rate of these defect is equal to 60. This means that this potential effect should be considered to repair in a nearest time. The potential cause of this defect is too much layer height and too low printing temperature, that is connected with wrong setup of the program

DISCUSSION

To show the progress of the Ishikawa diagrams, all the outcomes were added to the Mind map that is in Figure 3, this map were built to track down the process of learning and defining solutions.

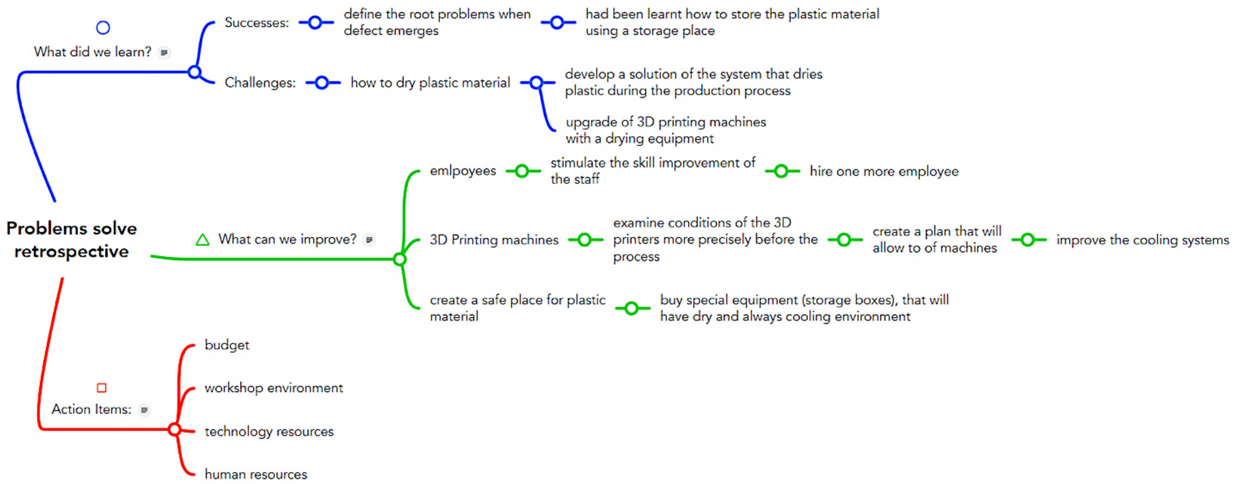

Fig. 3 Mind map for Ishikawa diagram solutions

The given mind map provides the information about: what has been learnt to this point, what could be improved to decrease defect levels and optimize the company's processes, and items and tools that are involved [12, 14].

CONCLUSION

Restating the article statement, technological innovation and its other outcomes cre-ate new norms and demands. Industry manufacturers are involved in developing faultless production processes, providing customers with a high new level of quality. Companies are focusing on methodologies that will help them control production waste, cost, production time, and so on as a result of this new reality. More rational quality control and scheduling are required.

The current research aimed to define the defects and find the best solutions for their resolution.

The core question is provided as follows:

1. What is quality and quality control in practice example?
2. What is the process of production using a 3D printer?
3. How to apply methods of quality control effectively?

Quality is all about finding solutions to improve itself. Quality control is helping to find these solutions. Quality control is a complex task that needs different sources of information and long-term observation, an approach to all different angles of the specific problems.

By analysing the processes in production, this article has shown how to use various types of methods of quality control in the workspace. Based on the given methods it can be concluded that it provides a possibility for effective data structuring and defining of the failures at the production line. The outcomes indicate the weak sides of the production process, their occurring intensiveness and defining the severity of the failures.

The chosen methods of quality control provide new insight into the process view from the side, giving the opportunity to understand nuances of the process to all working stuff. It is also worth mentioning that to achieve the highest positive results, the involvement of a larger amount of employees is necessary needed. It is important to see the picture from all views and give fresh ideas for future improvements.

The limitation of research includes an approach to the analysis because such research as quality control is a group activity and it requires a large number of qualified employees to see more sides of the problem, which is not obvious [21, 22]. The same issue is described in his contribution byobvious [23].

Further experimentation is needed to implement calculated and defined solutions in the processes and observe their effectiveness. Using the data provided, it becomes possible to implement new solutions, calculate its costs, measure the performance power increase, and check out the new behaviours at the workshop. The very informative research about budget and expenses of the production have to bee done too. The plan is about the 3 surveys were completed to find the most effective parameters for the process all are related to plastic infill of model. There are 3 cases: 15% infill, 10% infill and 5% infill. To complete this part of work we calculated energy bills – electrical energy consump-tion, costs of plastic that was used during the production, and of course, salary of the workers was included to our list. In the second case, the infill level is 10% and the changes in time of printing decreased, that had affected the production speed and in accordance the price of electricity, plastic amount and salary expenses. The process with infill rate of 5% is the cheapest options with all subjects: salary, energy and material price. Because of that low intensiveness of infilling, it can be possible to get a lower number of defects connected with bad infill failure in future [24]. But the durability of the product would be lessened, which can affect the fragility of the product.

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