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Identification and improvement of processes using selected quality tools: a case study

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Abstract

The aim of this work was to determine the effectiveness of using the FMEA method in the traditional and modern versions for a small company producing plastic toys. It also identified the production process of a plastic instrument toy selected for analysis by dividing operations into adding and not adding value, in accordance with the Lean concept. Through the FMEA sheets constructed and presented in this work in both versions of this method, the causes and effects of defects in the technological operations of the production process of the test subject were presented. A risk analysis was carried out using assessments available for the traditional and new versions, and preventive and detective actions were proposed. The result of the work was a comparison of risk indicators characteristic for both versions of the FMEA method and an assessment of the effectiveness of this method in the analysed enterprise. Emphasis was placed on the human factor in the research. Both the division of operations into adding and not adding value, as well as the FMEA method, were useful for further optimization and process improvement activities.

Introduction

The proper identification and improvement of processes in manufacturing enterprises are currently key success factors for growing customer needs and expectations, dynamic technology development, and constantly changing market trends. They enable quality improvement, effective resource management, cost reductions, and increased efficiency.

Process identification (Dumas et al., 2018) is related to a thorough knowledge of all activities and operations in a given enterprise. This enables noticing the connections and dependencies between them, their impact on the entire production system, and learning about the time and resources necessary for them. This helps to isolate areas where there are activities that do not bring value and only increase costs and time, i.e., waste (Shou et al., 2020). Identification of processes also enables setting effective performance standards for various activities, which ensures consistency in their implementation, as well as recognition and understanding of risk-related factors. This makes it possible to introduce appropriate risk control and management mechanisms. By identifying processes, the company can better manage its resources, such as time, staff, budget, and technology, as well as find areas where it is possible to introduce innovation and continuous improvement.

Process improvement, on the other hand, consists of introducing changes to streamline activities in the enterprise. Companies, bearing in mind the growing and diverse requirements of customers, systematically improve the quality of their products and services, which translates directly into the need to improve processes as the main element in the chain of processes for creating new value. There are many ways to improve processes, including methods, tools, or techniques related to Lean Thinking (Mazur & Momeni, 2019; Furman & Małysa, 2023), where the aim is to reduce costs and eliminate all activities that are wasteful and do not add value to a process. Identifying irregularities is an important element in process improvement and identification of a problem that may be an obstacle to improvement. Then, traditional quality management tools become extremely helpful (Pacana & Czerwińska, 2019, 2020; Siwiec & Pacana, 2019, 2021; Czerwińska, Pacana & Ulewicz, 2020; Czerwińska & Piwowarczyk, 2022).

This work focused on the implementation of two main goals. The first was to determine the effectiveness of the implementation of the FMEA method in a small company that mainly produces plastic toys. This method was used in both the traditional and modern versions of the assumptions and stages. The main differences between these versions are highlighted. There are many literatures in which this quality management method is used to analyze the process in terms of non-conformities, their causes, effects, and risk of occurrence, detection, or significance for the customer (Wolniak, 2019; Nedeliaková, Hranický & Valla, 2022). These are mainly analyzed in the automotive industry (Godina, Silva & Espadinha-Cruz, 2021; Plinta, Golińska & Dulina, 2021), where this method has found the widest application. However, there are no studies on the use of this method (also comparing the traditional and modern versions) in the small business sector, in a toy company. This work used the new version of the FMEA method, not only because it was possible to compare it with the traditional version, but also because of its advantages, including the analysis extended to 7 points or the risk analysis being based on an action priority matrix, which takes many variables into account. Another aim of the work was to identify the production process of the subject of research, which was a plastic toy instrument. Through the characteristics of this process, operations that add or do not add value are specified in accordance with the Lean concept. The result of the work is a comparison of risk indicators characteristic for both versions of the FMEA methods – the number of RPN and AP using the AP matrix and the assessment of the effectiveness of this method in the analyzed company. Emphasis is placed on the participation of company employees in the implementation of individual stages of the FMEA method.

Identification and improvement of processes – literature review

Every organization is a set of processes that intertwine and complement each other. The interdependence of and relations between processes dictate the functioning of the entire organization (Michalak, 2008). The term "process" is defined in various ways. It comes from the Latin word "processus" – proceeding, act. The process definition can be used in any area of life. The following definitions of the process are found most often in the literature (Table 1).

Summarizing the above definitions, the concept of a process can be formulated as follows: A process is a set of activities that transform inputs into outputs. A process can also be understood as a value chain that creates value that is delivered to the customer. G.A. Rummler and A.P. Brache argue that by contributing to the creation and delivery of a product or

Table 1. Process definitions by various authors

Definition (author)
• A series of events that follow each other in a causal relationship (W. Kopaliński)
• A series of interrelated activities that lead to the transformation of inputs into the product of the process (R.L. Manganelli, M. Klein)
• A dynamic set of activities (a sequence of events) ordered in time and space (sequence of events) with specific inputs and results, as well as a process is a set of functions ordered according to the criterion of the possibility of achieving the assumed goal (K. Szczepańska)
• A logical sequence of consecutive or parallel activities that lead to meeting a customer's expectations, both internal and external, by providing them with a product, service, or documentation in accordance with their requirements (E. Skrzypek)
• A series of steps (actions) designed and implemented to produce a product or service (J. Bagiński)
• A set of interrelated or interacting activities that transform inputs into outputs (J.S. Oakland)
• A natural determinant of achieving an increase in the efficiency of a modern organization (P. Grajewski)
• An activity or set of activities as a result of which a result is obtained from a certain initial value (input) (transformed input enriched with added value (process result). Each subsequent stage of the process consumes resources and adds value (E. Weiss)
• A set of activities that combined provide value to a customer (M. Hammer, J. Champy)

service, each subsequent step in the process should add value to the effect produced by the previous step.

Process components are subprocesses, and subprocess components are operations and activities. The goal of a process is to provide a specific customer with a product or service that meets their requirements. Input resources are used in the process (Biesok, 2019), undergo processing (transformation), and are transferred to the next processes or to the final customer. At the output of the process, a specific product or service is obtained with added value (contribution to the value for the customer). The input elements to the process (resources) include (Urbaniak, 2007, Knop & Ulewicz, 2022): raw materials, work instruments (machines, devices), energy, company personnel participating in the process (workforce), documentation (instructions, procedures, legal requirements, customer specifications), and capital. Appropriately qualified staff with knowledge and experience, as well as high-quality raw materials and materials, machinery and equipment, the environment (atmosphere in the company, appropriate parameters), and management in accordance with plans and procedures, are the resources necessary for effectively operating a process (Urbaniak, 2004, Urbaniak, 2007). The output elements of a process (the result) include products, services, shortages, waste, information, recipients, and customers.

Good communication based on feedback is important to any process and should come to management from both production and customers. Analysis of the process of product realization shows that it usually refers to a group of processes that create added value, but the process of managing an organization cannot be overlooked. Value-added processes are a chain of successive processes. There are three types of activities in every organization (Gochel, Gegeyehu & Abebe, 2022):

- value-adding activities – those activities that, from the customer's point of view, increase the value of a product or service;
- activities that do not add value – those activities which, from the customer's point of view, do not increase the value of the product or service and are redundant even under the current conditions of the company's operation. These activities are wasteful and, therefore, should be eliminated immediately or soon;
- necessary activities that do not add value – those activities which, from the customer's point of view, do not increase the value of the product or service, but are necessary unless there is a radical change in the supply chain or the company situation or environment. This type of waste is harder to eliminate in the short term and should be considered in long-term goals. The short-term solution is to shorten the time it takes to complete these activities.

Identification of waste (Arunagiri & Gnanavelbabu, 2014, Pandian et al., 2020, Memari et al., 2022) at each stage of the process is necessary to further improve activities. Possibilities of process improvement (Ulewicz, 2014; Brajer-Marczak, 2018) concern, e.g., the approach of employees and the process owner, greater efficiency and effectiveness, the use of measurements, repeating activities, or creating added value.

Methodology – FMEA method

The failure mode and effect analysis (FMEA) method is a quality management method that was developed in the USA by NASA in the 1960s during the implementation of the Apollo program. It was initially published under the name "Procedure for Performing a Failure Mode, Effects and Criticality Analysis." This method is used successfully in the automotive (Vanyi, 2016), aerospace (Shuyuan et al., 2014), chemical (Aires & Pimenta, 2019), and electronics industries (Cui et al., 2015), but it can also be used in other industries and even services (Altuntas & Kansu, 2019). FMEA consists of early detection, as well as the assessment and prevention of potential failures and their causes and consequences. The main objective of the FMEA method is to permanently and consistently eliminate inconsistencies and defects in products or production processes by identifying their underlying causes and applying appropriate preventive measures. The FMEA method consists of two types of analyses: product/design DFMEA and process PFMEA (Sharma & Srivastava, 2018).

In the classic version of the FMEA, it was necessary to estimate the risk priority number (RPN) (Ciani, Guidi & Patrizi, 2019), which is the product of three numbers: severity (S), detection (D), and occurrence (O). It has been assumed that if the product exceeds 100, it is an unacceptable value for a given company.

In the FMEA version, the book published by the Automotive Industry Action Group (AIAD) together with VDA (Verband der Automobil Industrie) introduced several changes (AIAG and VDA FMEA Handbook, 2019). First, the RPN was replaced with a number called action priority (AP), which takes into account many variables. The result is a value determined not on the basis of the product of three numbers, but a letter that is read from a specially constructed AP matrix. Replacing RPN with AP results from the fact that not every RPN value poses the same risk to an enterprise, and variables in the range of 3 categories may mean something else. AP includes a logical list of 1000 possible combinations of S, O, and D. Tasks are divided according to the AP indicator (Panyukov et al., 2022). When this indicator is H (high priority), the team must identify appropriate actions to correct or document occurrence and/or detect why necessary or possible improvement actions are missing. When AP receives Medium Priority (M), then the team should identify appropriate actions to correct or document occurrence and/or detection, and for Low Priority (L), the team can identify appropriate actions to correct or document occurrence and/or detection. In addition to this change, two additional points have been introduced in the creation of the FMEA analysis, so that the entire approach is based on seven points instead of five (these are points on defining the scope of the analysis at the beginning and additional documentation of the results in the last step). The new approach to FMEA also modifies and extends the tables on the numbers of severity, detection, and occurrence (the most important here is the assessment of the significance of the defect for the customer). A column is also added to the table, which includes examples of given enterprises. The new approach assumes planning using the 5T method, which consists of points such as:

- Target – precise determination of the purpose of the FMEA analysis;
- Time – precise planning of the FMEA analysis in time;
- Team – precise definition of the composition of the FMEA team;
- Tool (tools) – precise definition of how to perform the FMEA analysis;
- Task – precise definition of tasks, and workflow in FMEA analysis.

Results

Identification of operations in the production process divided into adding or not adding value and FMEA analysis using the traditional and new

Table 2. The manufacturing process of the toy instrument, divided into operations adding or not adding value

Operation no.	Operation name	Operation symbol	Duration/route (1 carton – 40 pieces)	Value adding operations	Non-value adding operations	Necessary operations that do not add value
1.	Storage of materials needed for production	▼			x	
2.	Transport to the production hall	⇏	5 minutes		x	
3.	Preparation of the plastic mixture for forming the instrument's skeleton	⊘	10 minutes	x		
4.	Knocking out metal jingles	⊘	15 minutes	x		
5.	Cleaning and burning metal jingles	⊘	40 minutes	x		
6.	Forming the instrument's skeleton	○	32 minutes	x		
7.	Forming the hoop for the instrument	○	20 minutes	x		
8.	Visual inspection of the form product	□	5 minutes			x
9.	Installation of metal jingles in the framework of the instrument	⨂	35 minutes	x		
10.	Transport to the instrument assembly station	⇨	5 minutes		x	
11.	Installation of the frame and membrane in the framework of the instrument	⨂	25 minutes	x		
12.	Transport to the packing station	⇨	5 minutes		x	
13.	Packing in the original packaging	⊗	20 minutes	x		
14.	Transportation to the toy warehouse	⇏	5 minutes		x	
15.	Storage of finished products	▼			x	

Table 3. FMEA method for the analysis of the production process of a toy instrument – traditional version

System number/system element: Preparation of the plastic mixture for forming the instrument's skeleton Function/task: preparation of the mixture with the right proportions					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
1.	Mold with a low gloss / not resistant to impact / not colored	4	Incorrect mixing ratio of the material with dye and grinding	Inaccurate scales /worker error	Employee training / work instructions	2	Scale control	1	8
System number/system element: Knocking out metal jingles Function/task: knocking out parts of the product					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
2.	Too much/ weakly bent, deformed metal jingle	5	Bending the element at the wrong angle	Inadequate bending force	Workstation instructions / setting the appropriate parameters of the press	4	Control of bending parameters	1	20
System number/system element: Cleaning and burning metal jingles Function/task: finishing part of the product					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
3.	Abnormal sound made by the metal jingles	5	Badly burned metal jingles	Low firing temperature	Setting appropriate burner parameters	3	Control of firing parameters	2	30
System number/system element: Forming the instrument's skeleton Function/task: forming part of the product					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
4.	Pigment agglomerates	1	Colored streaks	Uneven distribution of pigment	Checking the accuracy of the dispenser dispensing the color concentrate	5	Control of processing parameters	2	10
System number/system element: Forming the hoop for the instrument Function/task: forming parts of the product					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
5.	Skeleton connection is not possible with a hoop	6	Hoop deformation	Too much tension	Change of cooling time/ change of clamping pressure	4	Control of processing parameters	1	24
System number/system element: Installation of metal jingles in the instrument's frame Function/task: product assembly					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
6.	Incomplete product	7	Metal jingles are missing in the skeleton	Employee inattention	Job instructions	4	Visual inspection after assembly	3	84
System number/system element: Installation of the frame and membrane in the framework of the instrument Function/task: product assembly					Item no. Initial state:		Responsible: Company:	Department: Date:	
Failure no.	Potential effects of the failure	S	Potential failure	Potential causes of the failure	Preventive actions	O	Detection activities	D	RPN
7.	Defective product	8	Broken membrane	Employee inattention	Job instructions	3	Visual inspection after assembly	2	48

approach was carried out for a toy company located in the Opolskie Voivodeship that has been on the market since the 1990s. Toys produced by this company can be found in stores such as Auchan or Biedronka, and some toys are exported to the Czech Republic, Slovakia, Lithuania, Latvia, and Ukraine. To improve competitiveness and adapt the business profile to the changing and constantly growing needs of customers, i.e., children, the company tries to follow market trends and introduces various types of improvements by using various tools in the field of quality management and lean manufacturing, which may include process mapping or quality tools.

The production process of a toy made of plastic was analyzed. The manufacturing process is presented in Table 2, which includes the individual stages of manufacturing a given toy, specifying the duration, and marking operations adding or not adding value.

Table 2 shows that most operations in the process create value, for which the customer wants to pay. These are technological operations in which the product is produced. There are also operations that, according to the Lean approach, are wasteful and need to be minimized or eliminated. In this process, these are storage and transport operations, such as the visual control operation that does not bring value, but which are necessary under the current conditions under which the company operates.

The next step was to construct the FMEA method sheet according to the traditional and new approaches for the production process of a plastic toy instrument. The paper does not contain an optimization step 6, and this will be the subject of further research.

The traditional version of the FMEA sheet is presented in Table 3. For the purposes of this work, this sheet has been slightly modified to not contain specific information about the company, i.e., numbers assigned to specific parts, names of departments, responsible persons, or dates.

The analysis presented in Table 3 presents steps 2, 3, 4, and 5 (structure, function, defects, and risk analysis), while the new version of the FMEA method includes an additional step for defining the range using the 5T method. In the example, the

Table 4. FMEA method for the analysis of the production process of the toy instrument – new version (steps 2 and 3)

Process item	Structure analysis (step 2)		Function analysis (step 3)		
	Process step	Process work element	Function of the Process Item	Function of the Process Step and Product Characteristic	Function of the Process Work Element and Process Characteristic
Plastic toy manufacturing process	1. Preparation of the plastic mixture for forming the instrument's skeleton	Mold, concrete mixer / barrel on a manual turner, 2 types of polystyrene, dyes, regrind, scales, man	Ensuring that the ready mixture of materials will be able to cast the skeleton of the instrument	Material mix with the right proportions, ready for molding	Composition of the mixture, regrind addition, amount of dye
	2. Knocking out metal jingles	Press brake, sheet coils, nickel, man	Ensuring that the metal jingles are cut evenly	Cut metal jingles in the right size	Strip diameter, length of sheet rolls, sheet size
	3. Cleaning and burning metal jingles	Oven, drums with sawdust, man	Ensuring that the metal jingles make the right sound	Ready metal jingles subjected to cleaning	Firing temperature, amount of nickel
	4. Forming the instrument's skeleton	Screw injection molding machine, man	Ensuring that the molded will fulfill its basic functions	The skeleton of the instrument ready for the assembly of the metal jingles	Injection parameters
	5. Forming the hoop for the instrument	Screw injection molding machine, man	Ensuring that the molded will fulfill its basic functions	Hoop ready for installation	Injection parameters
	6. Installation of metal jingles in the instrument's frame	Nails, man	Ensuring that the product will fulfill its basic functions	Instrument with installed metal jingles	Number of metal jingles, number of nails
	7. Installation of the frame and membrane in the framework of the instrument	Press, man	Ensuring that the product will fulfill its basic functions	Finished instrument with frame and membrane	Press parameters

main objective (Target) was to analyze the risk in the production process of a plastic toy instrument, over a period of 6 months (Time), with the participation of production employees, production manager, quality director, and general manager (Team), using the FMEA method with 7 steps (Tool), with tasks assigned to each team member (Task).

For the purposes of this work, in the new version of the FMEA method, the table has been divided into two parts – the first one covers steps 2 and 3 of the FMEA method, i.e., structure and function analysis (Table 4), while the second part includes steps 4 and 5 (defect analysis and risk analysis; Table 5). As mentioned earlier, the FMEA analysis in this version does not include an optimization step 6. For the work in step 2 (structure analysis), the process phases were generally named, in the work elements of the process, and generic names of machines and devices were used. In the case of labor, the term "man" was used, not the name of the position. Step 4 includes the first assessment (severity), and step 5, in addition to assessing occurrence and detection, contains a description of preventive and detection activities and the AP indicator. The default tables defined in the FMEA book (AIAG and VDA FMEA Handbook) were used for the analysis.

Discussion

Seven failures were identified during the production process of the plastic toy instrument, which were detected during technological operations and were related to the subject of work, as well as machines and people. Based on publicly available tables, the severity, occurrence, and detection priority numbers were determined, and on their basis, the RPN was calculated, and the AP was determined. Based on Tables 4 and 5, a graph was created (Figure 1) presenting the LPR and AP values during the manufacturing process of a plastic instrument toy.

Figure 1 shows that five errors during the production process of a plastic instrument toy obtained an LPR index ranging from 10 to 30. The new approach of the FMEA method confirmed the low importance of these types of failures because by using the AP matrix, they were read as errors with a Low Priority

Table 5. FMEA method for the analysis of the production process of the toy instrument – new version (steps 4 and 5)

Failure analysis (step 4)				Risk analysis (step 5)				
Failure Effect	Severity (S)	Failure mode of the focus element	Failure Cause of the work element	Current Prevention Control	Occurrence (O)	Current Detection Control	Detection (D)	AP
mold with a low gloss / not resistant to impact / not colored	4	incorrect mixing ratio of the material with dye and grinding	inaccurate scales /worker error	employee training/ work instructions	2	scales control	1	L
too much/ weakly bent, deformed metal jingle	5	bending the element at the wrong angle	inadequate bending force	workstation instructions / setting the appropriate parameters of the press	4	control of bending parameters	1	L
abnormal sound made by the metal jingles	5	badly burned metal jingles	low firing temperature	setting appropriate burner parameters	3	control of firing parameters	2	L
pigment agglomerates	1	colored streaks	uneven distribution of pigme	checking the accuracy of the dispenser dispensing the color concentrate	5	control of processing parameters	2	L
skeleton connection is not possible with a hoop	6	hoop deformation	too much tension	change of cooling time/ change of clamping pressure	4	control of processing parameters	1	L
incomplete product	7	metal jingles are missing in the skeleton	employee's inattention	job instructions	4	visual inspection after assembly	3	M
defective product	8	broken membrane	employee's inattention	job instructions	3	visual inspection after assembly	2	M

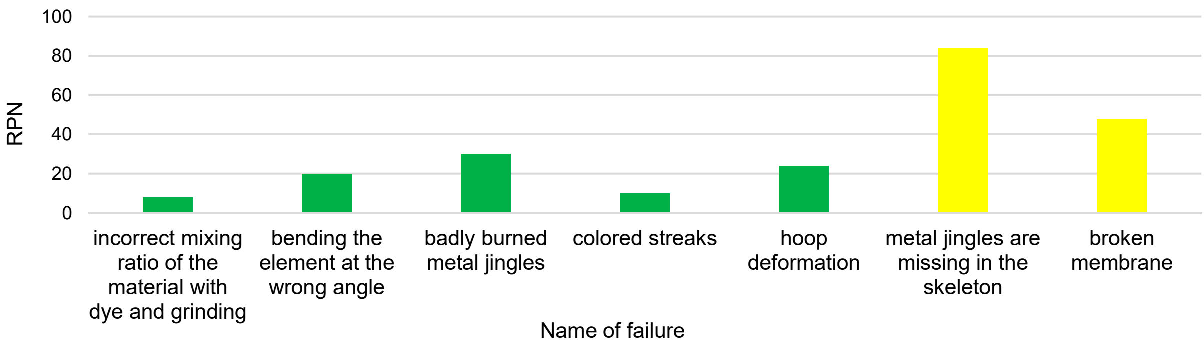

Figure 1. Graphical presentation of the LPR and AP values in the manufacturing process of a plastic instrument toy (green color – Low Priority, yellow color – Medium Priority)

indicator. However, in the case of errors such as "metal jingles are missing in the skeleton" and a broken membrane, the AP indicator was already marked as Medium Priority, which means that the FMEA analysis team should take preventive and detection activities. Particular attention should be paid to eliminating the causes of the "metal jingles are missing in the skeleton" defect because the LPR indicator is also approaching the limit of 100.

Conclusions

This work identified the production process of the plastic toy instrument, divided into operations adding or not adding value. In addition, the production process was analyzed using the traditional and new versions of the FMEA method. Both versions differed not only in the number of analysis steps but also in the risk analysis because, in the new version, the LPR indicator has been replaced with the Action Priority indicator. This indicator presented in the matrix contained 1000 possible combinations of S, O, and D ratings. Often, in the case of an analysis using the RPN indicator, it is unclear that not every value of this indicator poses the same threat to the company. Variables in the three categories often indicate something else. In this paper, the analysis showed that in the case of five failures during the production of a toy instrument, a low LPR value translated into the prioritization of the AP index, which assessed these failures as Low Priority. In the case of two errors, the analysis using the AP indicator showed that these were errors of Medium Priority, while the LPR indicator only, in the case of one error, approached the limit value of 100.

The work did not include the step of the FMEA method regarding the optimization of activities, which may be performed in further research. A certain limitation in further research may be because the surveyed enterprise is small and employs a small number of people. The management, although trying to implement modern methods of quality management or lean production, often encountered resistance from employees, many of whom have been associated with the company's operations from the very beginning and are reluctant to change.

Despite the low values of the RPN and AP indicators, it must be taken into account that the analyzed product is manufactured for children, and therefore, it must meet all quality and safety standards, as well as the frequently changing needs of young users.

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