CALCULATION OF PROCESS' IDEALITY DEGREE THROUGH IDEALITY EQUATION OF TRIZ

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Abstract: The state of processes and their improvement progress could be measured by many parameters or indicators. When the overall state of the process is needed several indicators must be determined. In case that there are two states of the process, or two processes to compare, it could be confusing to determine which state, or process, is better. A solution for that can be a concept of Ideality from TRIZ (Theory of Inventive Problem Solving). The concept of Ideality is based on the improvement of the Technical System in a way of Ideality or Ideal Final Result. The use of Ideality brings better improvements of the system in a way of technical evolution. The basic Ideality equation from TRIZ is unfortunately hard for practical use. That is why a more specific solution is needed. This paper aims to present a new way for the definition of the Ideality equation for production processes. This equation contains parameters as production time, costs, quality but also process aspects as safety, ergonomics, and ecology of the process. This way of determination of the process state can help with the comparison of process states, but it also pushes us to focus our improvement efforts in a way of Ideal process.

Keywords: Process improvement, Ideality, TRIZ, Process indicator, Lean.

1 Introduction

Improvement of the process could be measured and managed by many parameters and indicators. Common indicators of process state are often focusing on one parameter. There is no indicator that considers all crucial aspects of the process [1], [2].

TRIZ (Theory of Inventive Problem Solving) could help with this problem. One of the ground principles of TRIZ is the concept of Ideality. Ideality is the best state of the technical system and in our effort to improve or innovate the system we should try to be closer and closer to the Ideal state of the system. Problem is that the general equation for a degree of Ideality is more or less theoretical and it is hard to use it in practice. Even harder for manufacturing or other processes.

The aim of this paper is to present the Ideality equation of TRIZ as a way to calculate a degree of process' Ideality for use as an indicator of process' state for process improvement.

2 Background

2.1 TRIZ

TRIZ is an acronym for Russian теория решения изобретательских задачог, in English Theory of Inventive Problem Solving. TRIZ is an umbrella term for many tools and techniques used for innovative solving of problems. It is based on the research of more than three million patents, where repeating patterns were found [3]. There is a finite number of most appearing types of problems and there is a finite number of general solutions for these problems. From these Patterns, tools and techniques were designed. The use of these tools helps to achieve a better solution in a shorter time.

2.2 Ideality

Ideality is one of the key principles of TRIZ. It helps to seek a perfect solution. As a tool for seeking Ideality in the Technical system, an Ideal Final Result (IFR) is used. Ideal Final Result is a state where a function of the system is achieved without any system.

Concept of Ideality with Ideal Final Result has been used in many publications before. Domb [4], [5] is focusing on the concept of Ideal Final Result which should have all the benefits, no harms, and no costs. She uses the concept of Ideality and Ideal Final Result for better problem-solving. Belski [6], [7] uses Method of Ideal Result and list of available resources for innovative solutions to problems. Duepen [8] uses Ideality for achieving a higher degree of creativity in art. In [9] Ideality is used for better Software development. Navas [10] shows ways for increasing Ideality for complex systems.

Soderlin [11] is comparing Ideality and Value, to decide if the Ideality is scientifically correct. He mentioned that Ideality is very similar to Value, but Ideality goes in its concept further than Value. Mann in [12], [13], and [14] discuss the importance of Ideality and the word "self" in the context of searching for a better solution, which he also demonstrated on several case studies. The word "itself" in a way of Ideality is also discussed in [15] by Domb.

The degree of system's Ideality can be theoretically calculated from equation (1), mentioned in [11] or [16].

$$I = \frac{\sum Benefits}{\sum Harms} \tag{1}$$

Where *I*, is the degree of Ideality, *Benefits* are all positive functions' effects, and *Harms* are all negative functions' effects.

In other papers ([4], [11], [17], [18], and [19]), the Ideality is defined as

$$I = \frac{\sum Benefits}{\sum Harms + \sum Costs} \tag{2}$$

Where *Costs* are all costs for the implementation of an innovative solution. This equation has a problem with dimension because the result is [1/$]. Both equations (1) and (2) are mainly used only for theoretical purposes. Not for real calculation of Ideality level. As Soderlin in [11] shows these equations work well until we try to calculate real values.

Fact that Ideality equation is not ideal is supported by many attempts for a better definition of the system's degree of Ideality. Slocum, Lundberg, and Walter in [17] defined equation based on equation (2) and they tried to determine a more complex equation for Ideality combined with Reangularity and Semangularity from Axiomatic Design. Petrov and Seredinski in [20] dividing the ideality equation (2) on numerator and denominator, and show which ways could be used for achieving a higher degree of Ideality. They give us a list of scenarios for the increase of numerator and decrease of the denominator. Mishra shows similar results in [19], where he also discusses concepts of Ideal Final Solution, Goal, Product, Process Technique, and System. In [21] Mishra criticizes the concept of Ideality for its subjectivity because the Ideal state can be different for everyone. In [18] there is an equation reformulated in a way that solution of the problem is the desired result with (Ideal) correcting system. Dai and Ma in [16] show a new method of how to define Ideality, where the definition of functions is based on Engineering Parameters. Lyubomirskiy in [22] also shows the limitations of the current equation, and presenting a new way of how to calculate not Ideality but Practical Value of the system. Which is basically multiplication of user satisfaction with all parameters of the system.

2.3. Lean Production

Lean Production is an organizational management methodology with its roots in Toyota Production System [23], [24]. Continuous improvement and respect for people are the central aspects of this system. This system is, many times, represented as a house with two main pillars: Just-in-time (JIT) and Jidoka or

autonomation that require a bunch of tools to support the house [25]. In the roof of this house are the objectives to attain: best quality, lowest cost, shortest lead time, best safety, and high morale (Liker and Morgan) [26]. To achieve these, companies must continuously improve, which means to continuously eliminate waste [27]. There three types of activities: 1) Value-added activities that are all activities that the client is willing to pay for; 2) Non-Value added activities or waste that are all the activities that do not adds value from the client point of view and that he/she is not willing to pay; 3) Non-Value added activities are activities that do not adds value but are necessary activities. Producing with wastes means overburdening people and machines and the planet, retrieving from it more than is needed.
This is why some authors considered that Lean Production contributes for better work conditions and better environment [28], [29] To provide sustainable solutions, Lean have been associating with important methodologies such as TRIZ [30]. Value concept is the first principle of Lean Thinking principles, [31]. That is the philosophy behind Lean Production. The other four principles are Value Stream, Flow, Pull production and pursuit perfection. This concept of perfection is similar to Ideality concept reviewed in the previous section (2.2), where Ideality goes even more further.

3 Development of the ideality equation

3.1 Ideality for processes

In this paper, the goal is to determine an Ideality equation useable for processes. First, crucial parameters for the state of the process should be set. In manufacturing processes, we are mainly focusing on the time of production, quality of production, and the cost of production. Because Productivity and quality are not everything, we should also look for safety, ergonomics, and ecology of the process. These are the six main aspects of each process. To have a process in a better state we need to have shorter production time, better quality, less cost, higher safety, less ergonomics, and environmental impact. These aspects are inspired by Toyota's house from [26], described above.. Ergonomics and ecology aspects of the process have been added for the health of workers and the better environmental impact of the processes.

For final Process' Ideality, we should consider all of these aspects and at the same time keep the properties of the original TRIZ Ideality from equation (1) without changes.

3.2 Ideality equation for processes

The easiest way of how to formulate an Ideality equation for processes including all six key aspects is to put all six aspects into the original equation (1). In case that we would try to only decide which of parameters is beneficial and which is harmful, the result will be that all parameters could be defined as harmful for the process because we want to have it in ideal on zero levels (no time, no defects, no costs, no safety risks, no ergonomics or ecology impact). Every aspect should be defined as a positive and negative part and these values should be put into equation (1), then a theoretical Process' Ideality equation appears.

$$PI_{theoretical} = \frac{\sum B_T + \sum B_Q + \sum B_C + \sum B_S + \sum B_{ERG} + \sum B_{ECO}}{\sum H_T + \sum H_Q + \sum H_C + \sum H_S + \sum H_{ERG} + \sum H_{ECO}} \quad (3)$$

Where *B's* are representing beneficial parts, *H's* representing harmful parts. Index *T* is for time, *Q* for quality, *C* for Costs, *S* for safety, *ERG* for ergonomics, and *ECO* for ecology.

The problem with equation (3) is the same as with equations (1) and (2), it works only in theory. In practice, each aspect, time, quality, costs, etc., have a different dimension, and these dimensions could not be added together. One way to solve this problem is to recalculate every aspect into costs. That is possible, time for production can be represented by costs, the cost for defects can be also calculated, even safety, ergonomics, and ecology could be determined as costs. This recalculation to costs could be hard but mainly it is time-consuming. That is why a different approach was chosen.

To reach dimensionless of the result, the equation must be divided into a sum of partial Ideality for each aspect.

$$PI = \sum_{i=1}^{6} pPI_i \quad (4)$$

Where *PI* is overall Process' Ideality and pPI_i representing partial Ideality for all six aspects (time, quality, costs, safety, ergonomics, and ecology). In longer form equation (4) looks like this

$$PI = pPI_T + pPI_Q + pPI_C + pPI_S + pPI_{ERG} + pPI_{ECO} \quad (5)$$

Partial Ideality should be determined for each process' parameter (time, quality, costs, safety, ergonomics, and ecology). Partial Ideality equation should look like

$$pPI_i = \frac{\sum_{j=1}^{n} B_j}{\sum_{k=1}^{m} H_k} \quad (6)$$

Where index *i* represents aspects as time, quality, costs, safety, ergonomics, and ecology of the process, *n* is a number of benefits for aspect *i*, *j* is specific benefit, *m* is a number of harms for aspect *i*, and *k* is specific harm. For calculation of Ideality of each parameter, we need to determine the beneficial and harmful part of the parameter. The numerators and denominators for each partial equation should have the same dimension, so the result will be dimensionless.

3.3 Partial Process' Ideality for time

A beneficial part of time connected to the process could be time spend on Value Added activities (*VA time*). On the other side, harmful time is time spent for the rest of the time or we can say on Non-Value Added activities (*NVA time*). Partial Process' Ideality equation for time is then

$$pPI_T = \frac{\sum VA\ time}{\sum NVA\ time} \quad (7)$$

Where pPI_T is Partial Process' Ideality for time. The ideal state of the process from the perspective of time is that we do not spend any time but the process outcome is done. Formulation near to this ideal state is that all time spent in production is productive and only value-adding activities are made. In other words, more time is spent on productive activities and less on unproductive ones, the use of time is more ideal. NVA time contains activities without value, i.e., waste activities and also activities without value but necessary ones (as machine settings, maintenance, etc.).

3.4 Partial Process' Ideality for quality

The quality of the process could be represented by a number of good and bad pieces. Good pieces (*OK pcs.*) are beneficial and defects (*NOK pcs.*) are harmful. From that the Partial Process' Ideality for quality (pPI_Q) is

$$pPI_Q = \frac{\sum OK\ \ pcs.}{\sum NOK\ \ pcs.} \quad (8)$$

The ideal state of the process from a quality point of view is that no defects are made, and only good parts are produced. The next harmful part of quality could be also considered a number of defect opportunities. This metric could give better information about defect possibilities of the process which goes deeper and closer to the quality root cause than only the count of good and bad pieces.

3.5 Partial Process' Ideality for costs

It is hard to imagine what should be in the equation for costs' ideality. Costs are clear harms, but we need to have some positive part of costs to have a dimensionless result. For that, we must think more outside of the box. Costs are part of financial resources, and what is positive in a financial way. Now it is clear that a positive part of finances is profit from the process. Partial Process' Ideality for costs (pPI_C) is then

$$pPI_C = \frac{\sum Profits}{\sum Costs} \quad (9)$$

The result is obviously dimensionless, and the ideal state of the process from a financial point of view is that the process is without any production costs and in the same time process generates profits. Bigger profits and lower costs mean more ideal process.

3.6 Partial Process' Ideality for safety

State of safety, ergonomics, and ecology is harder for a clear determination that previous process' factors. To evaluate a safety level of the process one must analyze all steps of the process and determine all possible safety risks. For each safety problem, there should be calculated safety risks. Risk is defined as the Probability of safety problem occurrence multiplied by the Severity of the danger. The positive side of safety is all activities without any safety risk. Then the equation for Partial Process' Ideality for safety (pPI_S) is

$$pPI_S = \frac{\sum activities\ without\ safety\ risk}{\sum safety\ risks} \quad (10)$$

The ideal state of the process in a way of safety is when there are no safety risks and all activities in the process are safe. For determination of risk, safety danger must be categorized by its Probability of occurrence and its Severity. For this, the easiest model is to determine Probability on a scale from improbable to frequent, where frequent has the highest score. For Severity it is the same principle there should be categories from very minor impact to a catastrophic result, where catastrophic is with the highest score. The Sum of safety risks can be calculated as

$$\sum safety\ risks = Risk_S = \sum_{x=1}^{n} (P_x * S_x) \quad (11)$$

Where P_x is the probability that danger occurs, and S_x is the severity of that danger. The index x represents specific safety danger in the process, n is a number of process' steps with any danger.

The coefficient or score for Probability and Severity could be chosen from table Tab. 1, where the Risk number based on chosen Probability and Severity can be also found.

*Risk = P*S*			**Severity**					
			none	**minor**	**middle**	**major**	**hazardous**	**catastrophic**
		score	**0**	**0.2**	**0.4**	**0.6**	**0.8**	**1**
Probability	**incredible**	**0**	0	0	0	0	0	0
	improbable	**0.2**	0	0.04	0.08	0.12	0.16	0.20
	remote	**0.4**	0	0.08	0.16	0.24	0.32	0.40
	occasional	**0.6**	0	0.12	0.24	0.36	0.48	0.60
	probable	**0.8**	0	0.16	0.32	0.48	0.64	0.80
	frequent	**1**	0	0.20	0.40	0.60	0.80	1

Tab. 1: Example of Risk determination by Probability and Severity

3.6 Partial Process' Ideality for ergonomics

Calculation of the Ideality for ergonomics of the process is based on the same principle as calculation of Ideality in a way for safety. The process must be analyzed and for every step, it should be decided if there is no problem with ergonomics. The negative part of ergonomics is a sum of all ergonomics risks, which could be calculated the same way as risks for safety. Probability and Severity of the ergonomic risk can be also chosen from Table 1. Partial Process' Ideality for ergonomics is then

$$pPI_{ERG} = \frac{\sum activities\ without\ ergonomic\ risk}{\sum ergonomics\ risks} \quad (12)$$

The ideal state of the process from an ergonomic point of view is when all steps in the process are without ergonomic risk.

3.6 Partial Process' Ideality for ecology

Calculation of the Partial Process' Ideality for ecology is based on the same principle as a calculation for safety or ergonomics. The equation for Partial Process' Ideality for ecology is

$$pPI_{ECO} = \frac{\sum activities\ without\ environmental\ impact}{\sum ecology\ risks} \quad (13)$$

The ideal state of the process in a way of ecology is when the process works without any environmental impact. In special cases, there could be also some benefits like positive environmental impact. Calculation of ecology risk is the same as for safety and ergonomics risks and values from Table 1 could be used.

4 Results and Discussion

4.1 Final Process' Ideality equation

After all Partial Process' Ideality equations were defined, they can be taken together into one final Process' Ideality equation. From equation (4) we can define a new equation for Process' Ideality. When we put equations (7), (8), (9), (10), (12), and (13) into the equation (5). We can calculate a final Process' Ideality equation. This final equation looks in its general form like this

$$PI = \sum_{i=1}^{6} pPI_i = \sum_{i=1}^{6} \left(\frac{\sum_{j=1}^{n} B_j}{\sum_{k=1}^{m} H_k} \right)_i \quad (14)$$

Where *PI* is a degree of Process' Ideality, *i* are six main aspects of the process (time, quality, costs, safety, ergonomics, and ecology), *n* is a number of benefits for aspect *i*, *j* is a specific benefit, *m* is a number of harms for aspect *i*, and *k* is specific harm.

Process' Ideality can be used in many ways. For instance, when we calculate degrees of Process' Ideality for all processes in a company we can easily decide which process is best and worst. That can help to decide on which process we should focus our improvement efforts. Process' Ideality could be also used for comparison of the current and new improved state of the process. Or, based on Process' Ideality the best possible solution for process' improvement could be chosen. Process' Ideality has advantages that include the main parameters of the process, decisions based on Process' Ideality are based on six process' parameters. The main difference is that instead of focusing only on technical parameters of the process as time, and quality, Process' Ideality also includes parameters as costs, safety, ergonomics, and ecology.

4.2 Application to a case study

A case study for a demonstration of the use of the Process' Ideality calculation was made. The process of glass-metal assemblies was chosen. Improvement of this process is described in [32]. Glass and metal parts and assemblies are packed in three ways which are depending on the properties of parts, mainly on weight and size. For this demonstration, only one path of the process is considered. For each step, an average time for activity its cost, quality, safety, ergonomics, and ecology risk should be determined. Parameters of the process and its steps are described in the table Tab. 2 below. Symbol *X* in the table represents that its impossible or very hard to determinate a parameter for a specific activity in the process, so there must be a different way of how to calculate or determine desired values for that column. If we do not know a parameter value for steps, values can be determined for the whole process. For example, we do not need to sum ecology risks from all steps if we do not know these values we can determine an overall ecology risk for the whole process instead.

	activity	category	time [min]	number of defects	costs [CZK]	safety risk	ergonomics risk	ecology risk
1	walk for parts	NVA	0.5	X	1.67	0.04	0.04	X
2	bring it to workplace	NVA	0.5	X	1.67	0.04	0.04	X
3	walk for box	NVA	1.0	X	3.33	0.04	0.04	X
4	bring it back	NVA	1.0	X	3.33	0.04	0.04	X
5	walk for packing mat.	NVA	1.0	X	3.33	0.04	0.04	X
6	bring it back	NVA	0.5	X	1.67	0.04	0.04	X
7	built the box	NVA	0.5	X	1.67	0.04	0.04	X
8	tape the box	NVA	0.5	X	1.67	0.04	0.04	X
9	packing	**VA**	5.5	X	18.33	0.08	0.6	X
10	documentation	NVA	0.5	X	1.67	OK	OK	X
11	close the box / tape it	NVA	0.5	X	1.67	0.04	0.04	X
12	bring it to strapping machine	NVA	0.5	X	1.67	0.04	0.4	X
13	strapping	NVA	1	X	3.33	0.04	OK	X
14	writing on box	NVA	0.5	X	1.67	OK	0.04	X
15	bring it to weighing-machine	NVA	0.5	X	1.67	0.04	0.4	X
16	weighing	NVA	1.0	X	3.33	OK	0.04	X
17	waiting for printing	NVA	1.0	X	3.33	OK	OK	X
18	stick information	NVA	2.0	X	6.67	OK	OK	X
19	bring the package on palette	NVA	2.0	X	6.67	0.04	0.04	X
20	fix it together	NVA	5.0	X	16.67	0.08	0.04	X

Tab. 2: Original state of the packing process

When information about the process is collected, the calculation of partial Idealities can begin. For calculation, equations for partial Process' Ideality from above are used. It is very hard to determine quality for every step, for our purposes a relative number of defects is enough. In our case, there are approximately 4 defects per 100 produced parts. Most appeared defect is broken glass part during packing or manipulation in process. From that, we can calculate Partial Process' Ideality for quality, where the number of OK pieces is 4, and the number of NOK pieces is then 96. For the determination of process' profits, average profit per package is needed. This value was determined as 20 [CZK] per package. Steps in this process have a relatively small environmental impact, but a number of several wastes should be included. In this case, Partial Process' Ideality for ecology is calculated for the whole process, wherein the numerator is 1 (as one whole process), and in the denominator is overall ecology risk from wastes, which was for this case determined as 0.04. Ecology risk of the process is quite low because in the process recyclable materials are used, and residual material could be used again and waste material is sorted for recycling. Results of Partials Process' Idealities for the original state are summarized in Table 4.

After the improvement, a new table with information about the process should be done. The process was mainly improved by the shortening of material and people flows [33]. As a result, the layout of the workshop was re-designed and several other improvements were applied. After improvement, there is much shorter walking, most of the materials are stored on the packing workshop, so several movements and walks were eliminated. For better ergonomics packing tables were bought. These tables allow to set optimal packing height for each worker, and it also allows to transport packages to the next operation. When the process is improved, the collection of information about the new state of the process could be done again. The procedure of collecting the information should be the same as for the original state. Several activities were eliminated and other activities had shorter lead time, or its ergonomics risk is lower

Collected information about the improved process is summed in Table 3.

	activity	category	time [min]	number of defects	costs [CZK]	safety risk	ergonomics risk	ecology risk
1	walk for parts	NVA	0.5	X	1.67	0.04	0.04	X
2	bring it to workplace	NVA	0.5	X	1.67	0.04	0.04	X
3	built the box	NVA	0.5	X	1.67	0.04	0.04	X
4	tape the box	NVA	0.5	X	1.67	0.04	0.04	X
5	packing	**VA**	5.5	X	18.33	0.08	0.08	X
6	documentation	NVA	0.5	X	1.67	OK	OK	X
7	close the box / tape it	NVA	0.5	X	1.67	0.04	0.04	X

8	bring it to strapping machine	NVA	0.5	X	1.67	0.04	OK	X
9	strapping	NVA	1	X	3.33	0.04	OK	X
10	writing on box	NVA	0.5	X	1.67	OK	0.04	X
11	bring it to weighing-machine	NVA	0.5	X	1.67	0.04	0.4	X
12	weighing	NVA	1.0	X	3.33	OK	0.04	X
13	waiting for printing	NVA	1.0	X	3.33	OK	OK	X
14	stick information	NVA	2.0	X	6.67	OK	OK	X
15	bring the package on palette	NVA	2.0	X	6.67	0.04	0.04	X
16	fix it together	NVA	5.0	X	16.67	0.08	0.04	X

Tab. 3: Improved state of the packing process

Same way as for original state, partial Process' Idealities were calculated and summed for a new degree of Process' Ideality, results are in Table 4.

Table 4 below compares the original and improved process in a way of partial, and overall Process Idealities.

process' state	**time (pPI_T)**	**quality (pPI_Q)**	**costs (pPI_C)**	**safety (pPI_S)**	**ergonomics (pPI_{ERG})**	**ecology (pPI_{ECO})**	**Process' Ideality**
original	0.275	24.000	0.235	7.353	2.604	25.000	**59.467**
improved	0.333	24.000	0.273	9.615	13.636	25.000	**72.858**

Tab. 4: Comparison of the original and improved state of the packing process

As can be seen, partial Idealities can also serve as an indicator, of what factor we should focus on in our improvement efforts. In the original state, time, costs, and ergonomics are the worst factors. Improvement is most significant on ergonomics but the main point of improvement was on time. If the Ideality concept would be used, the improvement of the process could be achieved in all aspects of Ideality.

4.1 Limitations

Calculation of some parameters from real processes could be a challenging and time-consuming task. That is why there is a possibility to make some simplifications for complex processes. The main point should be to do the calculation with the same rules for the current state and also for all other states for comparison.

From a case study, there was shown that quality, for example, can be calculated for the whole process not only as a sum of defects for each step. The same is with the ecology of the process, sometimes there is hard to determine parameters for each step, overall determination for the whole process is then possible.

These equations and procedures are not the bulletproof methods of how we should determine an Ideality degree of processes. They should help us with the calculation of Process' Ideality in real processes because original equations are too theoretical. They should also help us to focus on all aspects of the process and achieve better and more complex improvements.

Determination of values for specific parameters could be described in a more detailed way, but that is out of the frame of this paper.

4 Conclusion

As it was seen before, Ideality can be a good way how to achieve better results in attempts for process' improvement. For manufacturing processes, it is hard to determine the degree of Ideality by standard equation from TRIZ. That is why a new model for Ideality calculation especially for processes was made. This Equation includes parameters as process time, quality, costs, but also safety, ergonomics, and ecology of the process. That allows us to use only one parameter – the degree of Ideality to determine a state of the current process, or to compare it with a new proposal for process' improvements. This method also pushes us to focus, not only on parameters connected with time and cost, but also on parameters connected to safety, health, and environment which is nowadays more and more needed. Partial Process' Idealities can also help us to focus our improvement efforts mainly on one or several worst aspects of the process.

By focusing on Process' Ideality, better results on process' improvement could be achieved. Shorter time of production, fewer defects, lower costs, better safety, better ergonomics, and lower environmental impact of the processes will positively affect the economic state of the company.

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