Management and Production Engineering Review
Volume 5 • Number 4 • December 2014 • pp. 76–84
DOI: 10.2478/mper-2014-0038

METHODS FOR STIMULATING CREATIVITY IN PRODUCTION ENGINEERING

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Received: 22 September 2014
Accepted: 10 October 2014

Abstract
The article presents possibilities of using fields of creative problem solving in engineering issues. Fields associated with so-called advanced creativity allow to combine stimulation of creativity with seeking innovative solutions. The article introduces stages leading to creative ideas as shown by two case studies of studied companies. The authors, in line with their research activity, highlighted the merits of forming creative sessions and creative teams in the company.

Keywords
creativity, stimulating methods, case study, innovation management.

Introduction

Creative problem solving for engineering questions becomes possible thanks to introducing and taking from achievements of psychology of creativity, creative methods and techniques. The existing state of knowledge of the subject matter (mainly in Poland) is still small and inadequate. Potential of methods, which will be verified by the authors, is still not adequately utilized. Creative management, forming new solutions requires extraordinary skills and extensive knowledge, however, this does not mean it can be achieved only be few. However, due to the difficult subject area, i.e. creativity, it is necessary to first present together its broadness and multitude of subjects and demonstrate the relationships between them.

Creativity precedes innovation. There is a relatively small number of innovations based on own solutions of the companies. However, it seems it is not due to the lack of such need. The future of many companies requires creative thinking and creative actions. In the constantly changing environment, current goals change as well and there is a continuous search for the best solutions to arising problems.

One shall understand the multitude of different elements, which are necessary to start solving the problem and to use appropriate methods to that end. Even at the very first stage of application of heuristic methods, there are difficulties related to the formulation of the problem. The proper formulation of the problem requires also previous experience and practice, so it can be as specific and detailed as possible without containing too many different issues [1, 2].

The psychology of creativity has now many different applications. Because creativity is an ability to easily create new ideas in order to solve practical problems. Thanks to thought processes, perceptivity and ability to ask adequate questions, it allows to solve problems on many levels. Mednick [3] brings here the attention to the associative approach, which states that mechanism of creation boils down to distant associations, involving combining two ideas, which usually occur separately. The most distant associations are considered to be the most creative ones. While Kosslyn [4] highlights the role of transformative thinking, which aims to transform the object in such a way that its transformation is significant.

Creativity can be trained [5, 6]. It means that there are ways to develop it. Developmental models of creations were formed for example by Feldman [7]. This work will focus on so-called advanced creativity [8]. However, this might require first to obtain creative powers and proper management of creative potential in the company, by creation of creative sessions or teams. To answer the question: what additional knowledge is required to that end, one must say, creativity barriers must be understood (mainly not perceiving the goals, which prevents from undertaking creative process, and impatience, which causes untimely interruption of the creative process), but work style and group functioning strategies must be known as well, and finally it is important to know how to great proper atmosphere in the organization. The creativity shall be properly supported in the company. Favourable atmosphere for creativity in a work place plays an important role for the development of ability to benefit from such techniques. In this case two factors seem to be crucial: internal and external motivation. Immanent motivation [9], i.e. sense of satisfaction arising from creation itself, would be more desirable than resorting to various manners of rewarding employee for his efforts by the employer. The knowledge, both expert and employee's common knowledge, does not inhibit creativity, but rather promotes it [10].

Selected areas of knowledge and skills are essential for the development of advanced creativity

It is impossible to enumerate and discuss all the areas of psychology of creativity, which are suitable for getting to advanced creativity. Advanced creativity is equal to the methods of creative problem solving. This involves advanced cognitive demands of creativity stimulating methods, which are associated with creative problem solving [8].

Heuristics

The starting point is heuristics as a set of creative methods of problem solving. Heuristic methods can be seen as a related concept – methods that have in common creative approach to the phenomena [11]. The creativity requires organization. This can be facilitated by proper use of methods in individual and group manner (Fig. 1). Individual problem solving allows to manage own creative potential and obtain great powers in that scope. For the team problem solving, it seems better to become a member of such interdisciplinary team, which continuously analyses internal and external environment, where it finds sources of innovative ideas, which allow formation of new knowledge. One may also decide to participate in session, in which specified problem to solve is set by a group of people - representatives of departments, shifts, experts from other departments and third-parties. These are usually people, who are directly affected by the discussed problem and possible change in their current way of work. They participate in the meeting, so they can influence these changes, understand them better and finally accept them. The completed task ends a session.

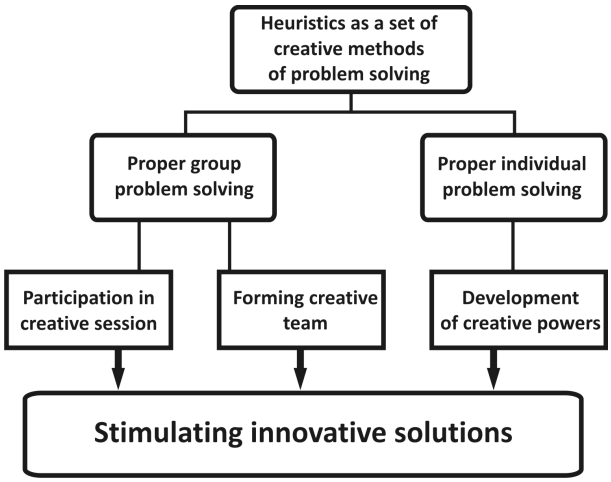

Fig. 1. General diagram of application of heuristic methods.

Creative designing

Although designing in technology is seen as creative activity [12], it seems that traditional designing does not change the patterns of thinking. Creative designing allows to continuously and systematically improve this process. It seems particularly important in searching for product unctionality, ergonomic designing, ecodesigning or developing design. Despite of certain work scheme, it may be transformed for own purposes. Creative designing assumes application of methods stimulating creating of innovative solutions. However, it is preceded by the development of creative potential at individual level and improvement of team work. In this exact order the effectiveness of thinking in a transparent and constructive manner is increased. Figure 2 illustrates the sequence of acquiring particular knowledge and skills.

Realization of creative potential should start from the stage of realizing what "I" can, what "I" know and know how and where use my knowledge and skills. This stage is a kind of compilation of assessment of strength and weaknesses. Still, it is characterized by passivity. What is needed is a motivation

to start the action – set the goal, set the way, select the strategy. Only this impulse allows to manage oneself and own creativity. Realization stage ends in activity in form of creation – application of creativity in daily life. It is characterized by a variety of behaviours and the need for stimulation. Then, the choice of members of the team is crucial, as it often determines the outcome of their work. Finally, in the creative designing creativity stimulating methods are used. They appear under such names as:

- innovative methods, e.g. brainstorm and synectics,
- systemic and algorithmic methods, such as Altshuller method and Nadler method.

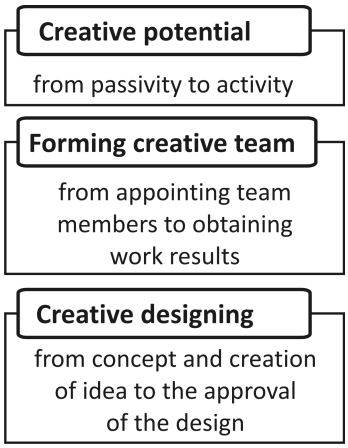

Fig. 2. Creative steps facilitating designing.

Stimulating methods in research activities

The methods are described mainly in the field of psychology and in then in pedagogy – psychopedagogy of creativity. However, they are more and more often described in papers from the fields of management and marketing. These methods are used also in the training of creative thinking. However, we learn little of them from technical fields, despite the existence of the concept of technical creativity. The methods themselves are quite well-known and popular. They appear under the names of heuristic methods, inventics, creative problem solving methods, etc. and it has been described by the authors, like T. Proctor [13], E. de Bono [14] or K. Szmidt [8].

The authors have counted 174 methods/techniques of creative problem solving. The first step was to classify them in order to organize and facilitate the use of the methods. The subsequent step was to diagnose the most common creativity barriers among company employees. These include: anticreative beliefs, schematicity, mental inertia and excessive knowledge. Awareness of barriers facilitates the process of creative problem solving. Only these steps allowed for the collection of research material on practical application of these methods in form of case studies, as a method, in which a subject of research is at the same time single person or group using method or technique, as well as company, and the processes that happen within. Possible sources of information include, e.g. surveys, direct observation, participating observation, data obtained from the studied company.

In the cooperation with companies usually the process of reaching innovative solution usually involved seven following stages:

1. individual interviews with company employees,
2. direct observation, combining participating and non-participating observation,
3. identification barriers of company employees,
4. determination of employees' creative potential,
5. recognition of creative process flow,
6. matching creative method to defined problem,
7. submitting feasible propositions of improvements and modernization in the company.

What are possible expected final outcomes of the application of the methods in companies?

Studied companies and their employees are able:

- to skilfully and consciously use the variety of methods,
- to plan and forecast company goals and objectives based on selected methods,
- to perform critical assessment and evaluation of the environment (opportunities and risks) and the working environment,
- to independently develop creative attitude, out-of-box thinking, self-awareness of own needs and needs of workplace,
- to perceive new applications for existing objects, technologies, products and services,
- not to waste organization resources.

Experience from observation of company employees' work involving methods helped to make an attempt to answer the question: what shall be done to ensure effectiveness of methods/techniques. It helped to create a list of tips how to perceive and formulate problems, list of questions helping to go through subsequent stages of the creative process and what to look for when evaluating method effectiveness. All these in order to simplify the work with a variety of methods. Based on, inter alia, existing classification methods and case studies, we have created our own classification: levels of methods based on their degree of innovation (Fig. 3).

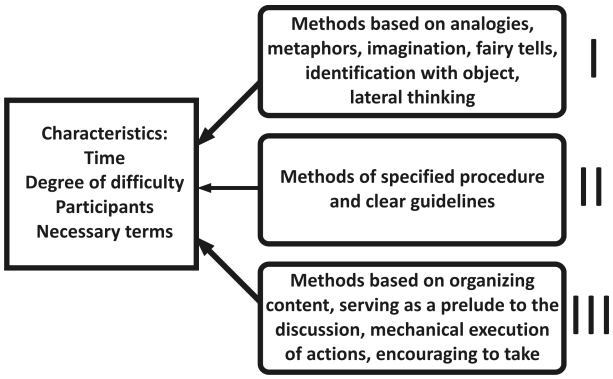

Fig. 3. Levels of methods based on their degree of innovation [15].

Three different levels show in which methods one should "invest". Achieving the most unconventional idea for an innovative solution is provided by the first level. Methods on that level are associated with non-schematic thinking and include analogies, metaphors and lateral thinking. Choice of appropriate method for the type of a task requires analysis of many more or less well-known heuristic methods. Góralski [16] emphasizes that the choice must be rational. In order to select the best method, i.e. the method that is most satisfactory for the user, one should not decide to choose "any random" matching method, as it is possible that one of the omitted methods may have been much more suitable. Matching stimulation method to the task is simpler, if one knows of their possible divisions into:

- individual/group methods (e.g. crushing/brainstorm),
- combined – set of methods (e.g. control question list and guiding questions),
- intuitve/analytical (e.g. superposition/morphological method),
- based on the degree of difficulty (e.g. synectics),
- used in creativity thinking (e.g. six thinking hats),
- product/process/organisation (e.g. CERMA).

This division shows that there are definitely methods, which are more effective, when used in a group. They will be valuable, when quantity of ideas will be important and not their quality and variety. In other cases, it is valuable to have individual approach to the solution, one based on own powers.

Combining both methods provides certain constant sequence of problem approach. It also helps to supplement research material with new data.

Intuitive and analytical methods are in a manner opposite to each other, but can be also seen as complementary. Two different approaches help to see one problem from different perspectives.

The synectics is believed to be one of the methods of higher difficulty. Usually, it is not recommended in initial stages of creative thinking. Authors experience recommends that it shall become a part of a process during creativity sessions only at the moment, when the team is stabilized and has psychological safety ensured. Degree of its difficulty manifests itself in analogies, which are rarely used in everyday life, but are the foundation of the method. It requires the use of imagination, knowledge and humour.

While the use of methods in training allows without pressure for verifying own skills without fear that they will be insufficient and will have no value for solving the problem. This allows overcoming creativity barriers.

The last distinction shows that variety of methods allows to match them to the specifics of the problem. Currently, the authors are attempting to create database of methods, dividing them into appropriate for the product manufacturing and for the process. At the same time, there might exist methods universal for both types of innovation (Table 1). Thanks to the detailed research work on methods, it is possible to develop their methodology of proper application to many different problems, including technical ones. The studied companies are already using them and the database of methods is continuously expanded with new case studies.

Table 1

Examples of methods supporting innovative process and product.

Innovation in process	Innovation in product
Brainstorm – universal method, in which quantity translates into quality. In form of a creative discussion.	**Brainstorm** – universal method, in which quantity translates into quality. In form of a creative discussion.
Crushing an idea – claims of which correctness we are sure are submitted to criticism in order to reject them or to reinforce them well.	**Crushing an object** – criticism of existing object in order to search for possible and desirable way of its improvement.
Worst solution + 6 thinking hats (only red hat) – look for worst solution of the problem in analysed process. Then ridiculous proposals should be converted into innovative ones. Additionally, red hat allows discovering true feelings and beliefs, which will "cleanse" the atmosphere of working on the task.	**Morphological method** – allows analysing individual elements that form the product, combine them to bring new values. Multiple versions of the product may be identified.

Application of selected methods and problems for solving first engineering problem

The methods were applied during the creative session in the studied food company. Main characteristics of the creative session include giving inspiration and achieving new, possibly better results, as well as supporting employee experience exchange, enhancing cooperation and improving the working atmosphere. It should also support ability of solving problems of the company, i.e. correctly respond to anomalies in current system, analyse causes of disturbances, search for better solutions. Each of applied methods has been planned in a particular sequence. Control question list with supplementary discussion was used to define the problem. Then an attempt was made to "break" petrified habitual rules regarding considered problem to finally complete the session with a solution, which was satisfactory for the group. The proposed methods and techniques supporting solving of engineering problem named: "reorganization of picking portions to ensure feeding of appropriate amount of frozen found" were following:

- control question list,
- round table,
- rule breaker,
- "exploration network".

Control question list

This technique involves answering to five main questions in order to define the problem and verify, whether all participants understand the problem in the same way. Each of the participants in the beginning answered independently to particular questions, which were later discussed with the team. Few participants' answers were selected to show the core of the problem.

1) Wording of existing problem?

Incorrect picking of portion/Correct filling of frozen vegetables

2) Why is this an issue?

Habits and change of approach – expectations for the ability to trace the history of the problem/No control over filling/Lack of assurance that at this moment the dedicated amount is filled properly/Errors during picking.

3) Who is affected?

Two operators of vegetable filling/Kitchen operators/Technologists and store-keeper.

4) What was already tried?

Elimination of so called remnants of frozen food in portion/I don't know/There were no major changes.

5) What is expected?

The right solution – possibility of controlling of what is being filled; shifting the picking responsibility to one operator; ergonomics of work at filling/determination of which palette matches which portion. Till then, portions were picked based on the "naked eye" assessment, once there was more, other times there was less filling, without precise control, without knowledge if the correct amount of frozen food was filled.

Round table

The round table is a didactic method that has many advantages and helps to activate to work. The biggest advantages seems to be maintaining time discipline and commitment of all participants. The participants were given the task to generate in 5 minutes three problems to solve, which would be related to the control of amount of filled frozen food. Then, everyone, one by one, read his proposals in order to finally establish common issue. The round table was used by the team to discuss results obtained using previous technique and generated following problems related to the amount of filled frozen food:

- marking frozen food with knife,
- not all operators were sure about the number of filled bags (one person means end of one portion),
- presence of number of various frozen foods (multitude of recipes) means it's easy to confuse them,
- feeding remnants (no standard).

Rule breaker

Every reorganization requires a fresh perspective on many issues. Thus, the choice of rule breaker technique seemed to be reasonable, because its task is to call attention to the fact that our assumptions and prejudices influences our way of thinking and solving problems. And this reduces greatly number of found solutions [8]. The technique proceeded in three stages:

1. List all suppositions/assumptions about solutions to the problem.
2. Break each of these assumptions and deny every formulated principle.
3. Use rules and assumptions broken in such a manner for creation of new ideas.

Below are examples given by two chosen participants of the session.

1) List all suppositions/assumptions about solutions to the problem.

Person 1.

- 2–3 people at the station,
- the same responsibilities + preparation of portion,

- ergonomics – person picking the portion is to walk as little as possible and not to toil too much,
- special person, who would take care only of feeding vegetables.

Person 2.

- there is one more person needed in the kitchen area in this option – one prepares the portion, other fills,
- double work – both persons have to pass the bags (the same amount).

2) Break each of these assumptions and deny every formulated principle:

Person 1.

- automatic device for picking the portion,
- automatic device for cutting and spread the bags.

Person 2.

- low confidence, one only counts, the other only fills.

3) Use rules and assumptions broken in such a manner for creation of new ideas:

Person 1.

- moving parts during picking of the portion,
- picking in the feeding line.

Person 2.

- operators switch at their stations (rotation).

The task has not proved easy for the group. Other than the usual approach met with little resistance and temporary withdrawal. However, it seems that it became a good field to look for and develop practical ideas, i.e. using the last techniques – "exploration network".

"Exploration network"

The work in group was conducted in the order presented in Fig. 4.

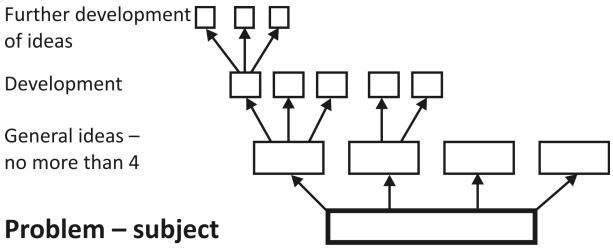

Fig. 4. Workflow of the technique "exploration network" [8].

The problem has been already introduced to the team, therefore each participant can rethink his general ideas. What is worth noting – ideas quickly began to develop, but ideas of different people were also combined. They worked using drawings and not writing down the ideas. Each possible option was drawn, which greatly helped to understand the idea and to modify it continuously. In fact, it was observed that any further development of the idea brought the group closer to the idea, which would be satisfactory for all participants.

The only thing left was to examine in detail functioning of the idea in actual conditions and decide what would be the stages of implementation. The solution resolves all the issues generated during round table discussion. The group wants to establish new standard, but it will take place after presentation of group session outcome and its acceptance by the sponsor. Finally, the solution was satisfactory for all the participants (Fig. 5). The solution was rated as not too complicated, but facilitating work of operators, who are the ones most affected by the change.

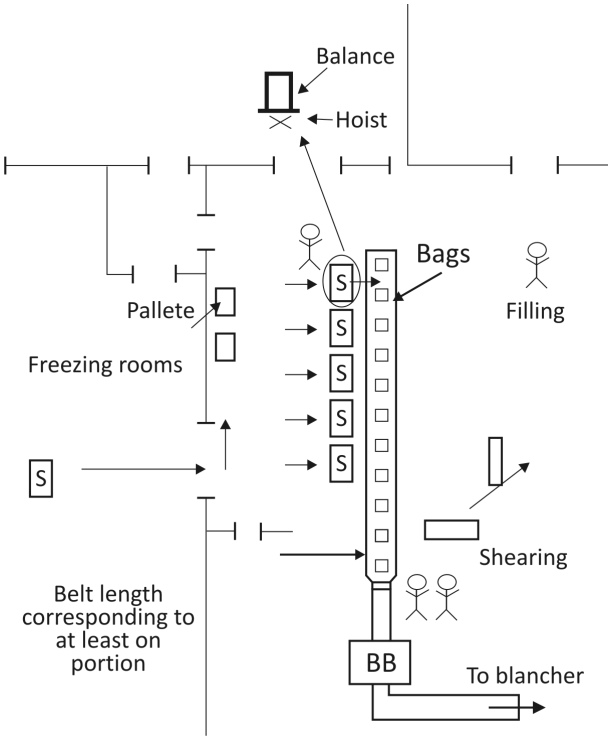

Fig. 5. Diagram of reorganization of frozen food portion picking in the production hall [17].

Application of selected methods and problems for solving second engineering problem

Also this time, each of applied methods has been planned in a particular sequence. The proposed methods and techniques supporting solving of engineering problem named: "improvement of the production line" were following:

- crushing,
- "exploration network".

- ALoU,
- homework supported with creative assessment.

Problem solving accounted for priorities of company activities, which in order to continuously improve itself focuses on five main areas:

- number of activities improving safety,
- number of intervention of Maintenance Department employees,
- number of failures lasting more than 1 hour,
- number of executed tasks, including tasks of preventive maintenance,
- number of zoning inconsistencies.

The subject matter was manufacturing process, which undergoes improvement and search for methods for continuous learning to cope with difficulties in the production hall. The problem is complex and requires analysis of previously structured solutions. However, it does allow to attempt bringing improvements based on own solutions of the company.

Crushing

The essence of crushing is to destroy existing ideas and beliefs on the subject. The merit of applying it in the initial state of the creative process is a possibility of identifying whether one has sufficient knowledge, tools or methods that would help one to solve the problem. This is a possibility to ask a question: Do I know how to fix the problem? What is the number of information gaps? Crushing idea or object allows determination of problem flaws. The Table 2 presents stage of discovering problems by company employees. Subproblems of main problem defined in such a problem and formation of preliminary proposals for their improvement were then dealt with the "network" method.

Table 2

Issue flaws and their remediation.

Flaws	Remediation
High risk of forklift hitting employee.	Redefining or defining new zones in production halls.
Increase of production costs during last year.	Development of strategy of reducing the production costs – specific designation of the level of reduction.
The increase of number of non-conforming products with quantity declared by the producer and incorrect mixture of ingredients.	Decrease of work rate by process controllers, but not at the expense of reducing proper supervision of production process and decrease of product quality.

"Exploration network"

Method description and its steps are already presented in the previous study case. It is assumed that problems arisen in the previous stage can be assigned to two subproblems, namely: elimination of unnecessary movements and reduction of production costs. The Fig. 6 illustrates stage of creating new ideas for solutions. Most commonly reported ideas are presented here. It is well known that manufacturing process generates costs. The posed task is to lead to attempt to reduce manufacturing costs without need to introduce radical changes, which as a result of modernization could generate unnecessary additional costs, and consequently worsen the current situation. The elimination of unnecessary movements will prevent squandering resources of the organization.

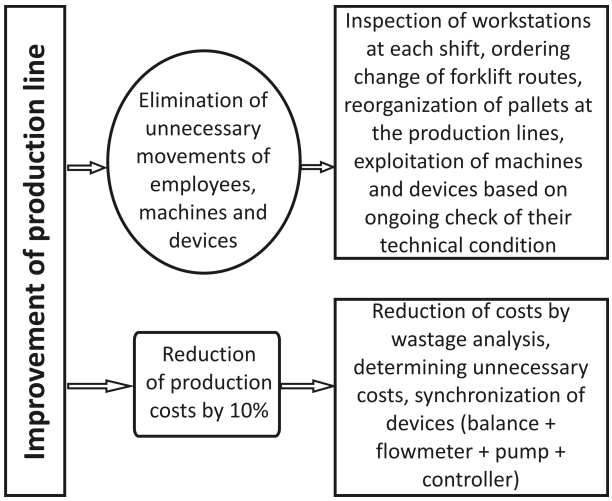

Fig. 6. "Exploration network" supporting creation of new ideas.

ALoU method

ALoU is not the most well-known or commonly used method. Despite its simplicity, it allows for a good selection of ideas and perceiving their valuable components (Table 3). The abbreviation has the following meaning: A – advantages, Lo – limitations and how to overcome them and U – unique features.

For categories defined in such a manner, two arisen issues has been analysed. Every analysed component of the problem has advantages. They shall be isolated, while due the unique features each problem is deepened. In such a manner clear picture of given problem may be obtained. It is possible to try to envisage difficulties in task execution. In order to attempt to solve the problem, the homework method assisted by elements of creative assessment method was applied.

Table 3
ALoU method procedure.

Problem	Advantages	Limitations and how to overcome them	Unique features
Elimination of unnecessary movements	Smooth manufacturing process, easiness of identifying defective units, placing pallets not closer than 15 m from the next manufacturing line.	Small production area, lack of search for a long-term solutions, only for immediate ones, increase of number of work standards, search for simple methods of diagnosis and control.	Regularity, planned downtimes, higher work flexibility, worker relief, safety, no wastage (superfluous movements).
Reduction of production costs by 10%.	Development of an effective inspection system, possibility of increasing profit per unit of product, reduction of losses, greater automation of lines, better use of the budget.	Cost of new manufacturing machines is not excluded, labour-intensive method of inspection, company reorganization, retraining workers.	Continuous development, increased public interest, transparency of the company situation and activities.

Homework method assisted by elements of creative assessment method

The choice of homework method results from the necessity of good preparation of workers to use it. It requires the collection of possibly current and available knowledge regarding problem: expertise of the selected expert, common knowledge – worker's own knowledge based on experience and theoretical (textbook) knowledge. The method of assessment was divided into two perspectives of ideas to create, i.e. time and finances. This is useful in a case of large number of ideas, as it divides them into three categories: easy, difficult and very difficult. The three positions (Table 4, 5 and 6) will be illustrated by only one subproblem: defining unnecessary costs and a method of their elimination, which was considered an easy task. Understanding three different perspectives broadens the knowledge and allows one to take optimal decisions and determine the next actions.

Due to the fact that the implementation of ideas in the company shall be a multi-stage process, they are presented in approximate order, taking into account time and costs. This will allow for thoughtful and fully complete implementation. The ideas formed after in-depth analysis included:

1. Implementation of the work style based on so-called "management by walking around" resulting in "walking" through the process and observing work of the employees. This also involves taking pictures of machine and device defects along with description and a selection of basic causes.
2. Determination of standard for reduction of losses and errors for manufacturing workers (e.g. keeping tools in a particular order).
3. Determination of limitations and requirements for the machines and workstations, taking into account handling properties, time, power conditions, surroundings and possibilities and limitations of the person. Assigning flaws to manufacturing stations, not to the people.
4. Introduction of department of ongoing preventive maintenance with elements of mentoring: analysis of exploitation cost based on technical conditions, decreasing costs of overhauls and downtimes. The observation of objects in order to create their timeline and identification of the most common problems.

Table 4
Expert's knowledge.

Time	Finances
Time horizon is relatively short. Improvement of cost reporting from individual departments and increase of determination of detailed standards. Implementation time is approx. two weeks.	It does not require huge amounts of money, but only change of habit, hence the immediate inclusion of the employees in the change process in the form of group problem solving. Requires supervision of the expert.

Table 5
Own knowledge of manufacturing worker.

Time	Finances
The idea involves scrupulous observation of the line for a given time. Time may differ and will depend on current state of the line. It will load employees with new responsibilities.	If properly controlled may require only employing a new worker.

Table 6
Theoretical knowledge.

Time	Finances
Determination of unnecessary costs is a time-consuming process due to the need to observe, monitor and record spent money for a certain period of time including the designation of the purpose, for which they were intended. The time will be extended depending on the number of people involved	Only if the company has a group of staff dedicated for such type of activities (Finance Department).

Finally, two important terms for such type of activities shall be mentioned [18]. We will talk about the diffusion of innovation, if the company undertakes following steps: realization of the need to change, making an attempt to change, possibility of verification, assessment and assimilation of the changes. We will talk about innovation maturity, when innovation will be based on the company's own resources and it will combine both tangible and intangible assets.

Conclusions

The paper describes a original research combining field of psychology of creativity with technical fields. It presented method for stimulating creativity in production engineering. The presented cases show that creation of single solutions may give solution for other problems existing within the company. It also gives a signal that complex problems require in-depth analyses and force predicting of various implementation scenarios for created ideas. The systematic activation of company employees to think creatively may result in his individual development, as well as in his development as a part of the team. As a result, it contributes to the creation of methodology of seeking innovative solutions, and thus the technical creativity is constantly evolving.

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