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INTRODUCTION

Innovation Engineering can be regarded as a sort of a challenge for Production Engineering. It is understood as a technical dimension of the process of implementing innovative solutions. Innovation Engineering consists in using properties of the matter, energy and abstract objects for a creation of machinery and products, designed for executing determined functions or for solving a given problem. It can be assumed that engineering is the area of creating technosphere taking into account the requirements of ecosphere. Drucker P. (1992) stated that the words “innovation” and “innovativeness” often appear in everyday language and in our environment. For an entrepreneur and for a researcher a practical dimension of an innovation, generated in the result of collaboration between science and industry, is essential. An advantageous ecosystem of innovations is characterized by the atmosphere and conditions which are favourable for generating innovative ideas and innovative solutions. The main objective of the undertaken research work, described in this article, is a presentation of the methods facilitating a creation of innovative ideas, an analysis of their efficiency, basing on the experience gained by the authors at the KOMAG Institute of Mining Technology, as well as a preparation of guidelines and recommendations enabling to disseminate this knowledge. A realization of research-and-cognitive objectives enabled to obtain knowledge concerning an important aspect of scientific and technical activity. An utilitarian character of recommendations should be highlighted. They can be treated as a sort of a tool for the stakeholders of innovative processes representing research institutes, producers of mining machinery and equipment as well as end-users of innovative solutions in mines of minerals. The subject-matter of the article is limited to a research institute due to its important role in creating and implementing innovative solutions in the economy. It should be borne in mind that an innovative idea is an indispensable factor of a commercial success. In literature an innovative idea can be interpreted in different ways (Schumpeter 1997).

In the literature a lot of attention is paid to generating innovative ideas (Michalski 2003). A new idea in a form of an invention is changed into an innovative product offered to the market. An assessment of innovative solutions is related to the process of generating new ideas (Knosala et al., 2011). Assessment criteria of innovative solutions are shown in Fig. 1.

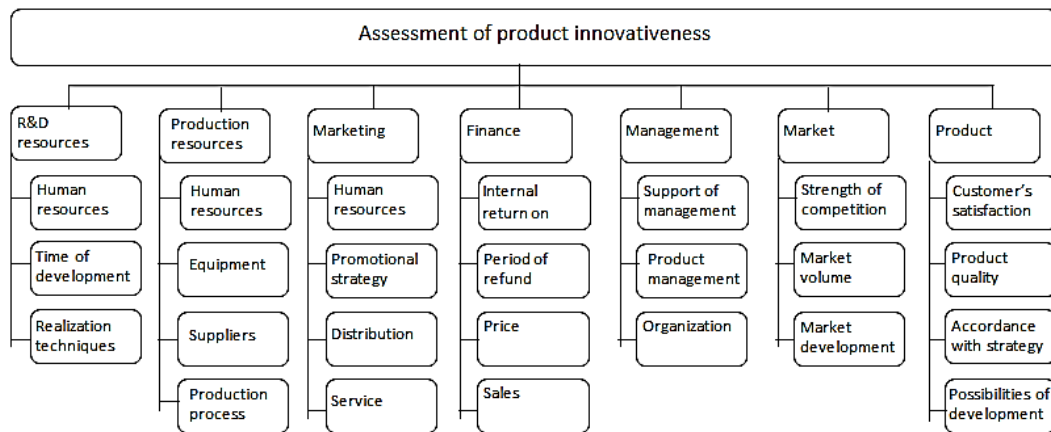


Fig. 1 Assessment criteria of innovative solutions

Source: (Knosala et al., 2011)

Creative organizations develop due to a generation of new ideas and their correct use in managing innovations. Four phases of a creative process are shown in Fig. 2.

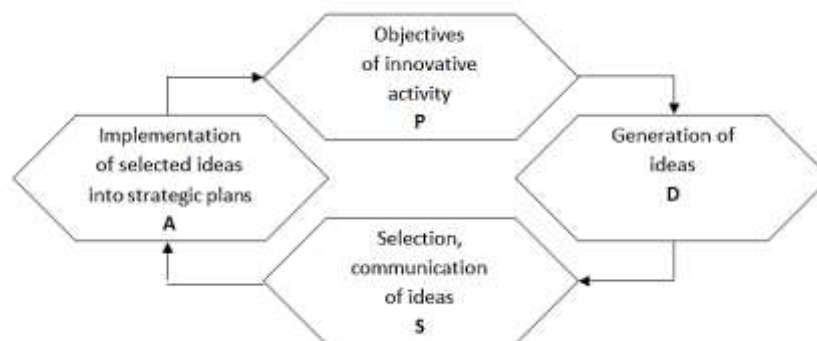


Fig. 2 Phases of a creative process according to PDSA model (PLAN-DO-STUDY-ACT)

Source: (Drucker 1992)

It is important to highlight the fact that at present a radical change in a development paradigm can be observed, in particular as regards product technologies. Instead of a periodic (Full Life Time) exchange of a product for a new, better one, its improvement Step by Step and Sustainable Development are preferred.

Three models of generating innovative ideas and solutions can be distinguished:

- open innovations which consist in sharing knowledge and in close collaboration with industrial partners and which are bi-directional “from outside – to inside” and “from inside – to outside”,
- innovations resulting from a user’s need which are based on market surveys;

they are of particular importance in the case of so called hidden needs,

- innovations stimulating new needs, in fact creating certain needs.
- Innovative ideas should be protected by patents, because only intellectually protected ideas or solutions have a commercial value.

The authors of this article analyzed different examples of generating innovative ideas, in particular brainstorming, brain-writing and brainsketching (Matthewes 2009, Van Der Lugt 2002, Wilson 2013). An improvisation is an effective tool enabling to enhance the effectiveness of brainstorming (Gerber 2009). Electronic brainstorming systems should be mentioned (Yuizono et al., 2014). Organizations in the 21st century find themselves in the culture of collaboration. Collaboration and knowledge sharing are fundamental aspects of problem solving, decision making as well as innovation and are therefore vital for success. Reverse brainstorming (Evans 2012) is a method where participants identify different ways to cause a problem. These negative ideas are then used to stimulate ideas for solving the problem.

Some attention should be given to business model innovation to create and capture resource value in future circular material chains basing on green business models (Roos 2014).

Generating new ideas, i.e. an ideation, is performed in three ways:

- overcoming the current business logic,
- thinking in business model,
- managing idea creation.

The following step includes an integration of all the activities to build a new business model as shown in Fig. 3.

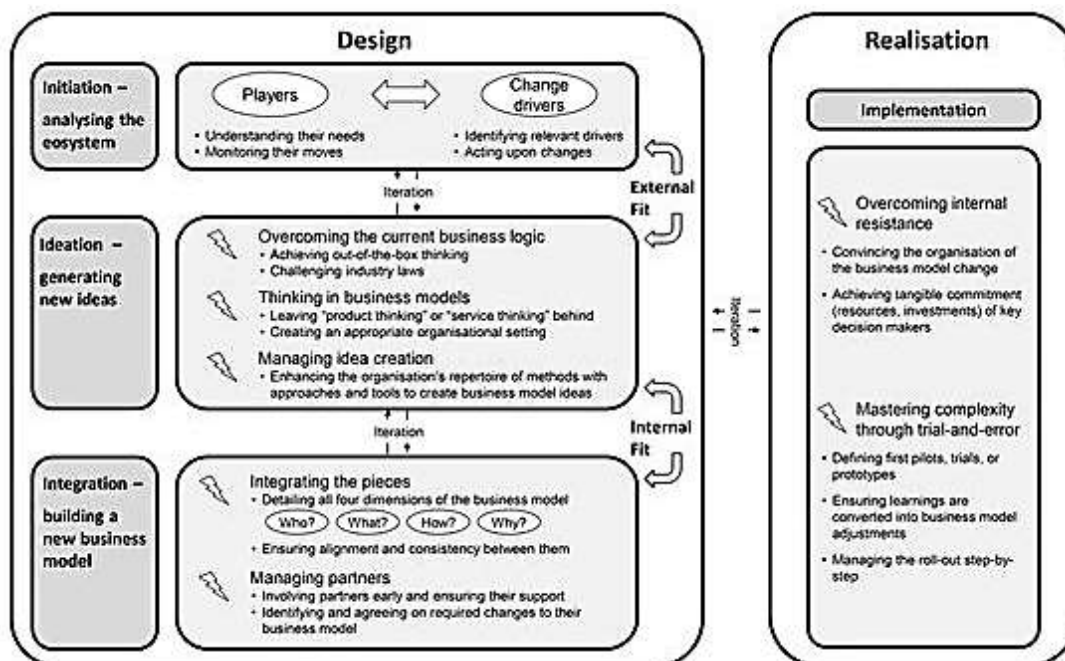


Fig. 3 Presentation of a business model innovation

Source: (Roos 2014)

Presenting the issue of generating innovative ideas special attention should be paid to the relationships among research institutes and all the stakeholders of an innovative process (Sojkin & Michalak 2018) as well as to the role of knowledge in the process of generating and implementing innovations (Baruk 2016, Baruk 2018).

STRATEGY OF INNOVATIVENESS AT THE KOMAG INSTITUTE OF MINING TECHNOLOGY

Scientific, research and technical projects, realized at the KOMAG Institute, are oriented onto machinery and equipment for underground exploitation and mechanical preparation of minerals. They concern anthropotechnical systems, smart mechatronic systems aiding a production and a beneficiation of minerals, interactive shaping of work environment in the mining industry, environmental management in post-industrial and urban areas, clean coal technologies ensuring ecological safety and use of the latest achievements of material engineering (Malec 2013). The methods, described as “Engineering of knowledge”, are used on a large scale. A development strategy of the KOMAG Institute incorporates forecasts of future needs of producers and users of mining machinery. A realization of the KOMAG strategy of innovativeness is of top priority, as it has a decisive impact on a position of the Institute in the domestic as well as in the European research area. The model STAGE-GATE is commonly used at KOMAG for generating new ideas and managing them. This method consists in an approach in which individual stages of a process are separated by decision points-gates. Three methods of generating new ideas are used: brainstorming, a method of discussion and a decision tree, to minimize a risk of an incorrect assessment of the innovative idea commercialization possibility. Pro-innovative thinking includes knowledge of researchers and needs as well as expectations of potential users in the aspect of technical, technological and financial possibilities. Due to such an approach innovative solutions are created and they are successfully implemented.

It is important to mention the KOMAG policy as regards generating new ideas. There are financial bonuses for creative researchers who achieve out-of-the-box thinking and are ready to suggest innovative ideas. Sometimes it is necessary to leave “product thinking” or “service thinking” behind which is not an easy task to accomplish. The KOMAG Management enhances the Institute’s repertoire of methods with approaches and tools to create innovative business model ideas.

There is no chance for a success if a mistake is made in the stage of integrating all the ideas to build a new business model. Four dimensions should be integrated: WHO? WHAT? HOW? WHY? and an alignment and consistency between them should be ensured. It is worth mentioning that involving industrial partners, at the very early stage of a collaboration and ensuring their support, plays an important role. Such an approach enables to identify and agree on the changes required by users, according to their needs and expectations.

GENERATING INNOVATIVE IDEAS AND SOLUTIONS AS A CRUCIAL FACTOR OF THE KOMAG STRATEGY

For a preparation of this article the following research methods were used:

- an analysis of texts, i.e. literature studies of domestic and foreign publications – cognitive and critical analysis of literature,
- a multiple case-study method – a description of two innovative technical solutions enabling to draw conclusions and to formulate recommendations of general character,
- a heuristic method enabling to detect new facts and relationships among them,
- a projection method stimulating creativity and innovative ideas, use of projection techniques enables to test hidden opinions and to find creative solutions.

In the process of generating innovative ideas it is essential to learn about user's needs. A visual conception of an innovative solution is usually assessed, bearing in mind an economic aspect as well.

An innovative idea is generated in the result of an inspiration from the environment and then it is transformed into an innovative product or service.

The sources of ideas, leading to a generation of innovative solutions, are as follows:

- KOMAG's own research and development projects,
- proposals of subjects suggested by industrial partners,
- information obtained in the result of marketing activities,
- opinions and suggestions of product users,
- information gained from surveys of scientific-and-technical literature and patent bases,
- a collaboration with scientific and research organizations,
- conferences, seminars, trainings, fairs and exhibitions.

Looking at the model of generating innovative technical ideas and solutions (Fig. 4), it can be clearly seen that an idea and a need of generating an innovative solution may appear in the research institute or at the industrial partner's organization. Very often it results from the company development strategy. Therefore, an innovative idea can be generated at the research institute or at the industrial partner's company. An analysis of available competitive solutions plays an important role. An incorrect assessment of the market situation, resulting from lack of efficient communication, mistakes in perception and an incorrect interpretation of the obtained results due to wrong reasoning, causes a failure of the whole innovative project, which is an activity of a high risk degree. It is worth mentioning that an assessment of the solution innovativeness should be conducted by specialists representing the research institute, the producer and the user. Such an approach guarantees a high degree of objectivism and it has a very advantageous impact on a collaboration of the research institute with the industrial partner and the user. The next stage includes an elaboration of a business-plan. Then the research institute prepares an offer and parties start negotiations which

lead to a formulation of the contract, exactly determining the terms and responsibilities of the parties.

From the presented model it can be seen that the market survey can be conducted by the research institute, by the producer and also by the user, who is a source of information about technical and technological problems experienced during an operation of a given technical solution or a system. The user usually informs the producer or the research institute about such problems, counting on their assistance in solving them. Quite often it happens that the user suggests how to solve a problem, hoping that an innovative solution will improve operational parameters or ergonomics.

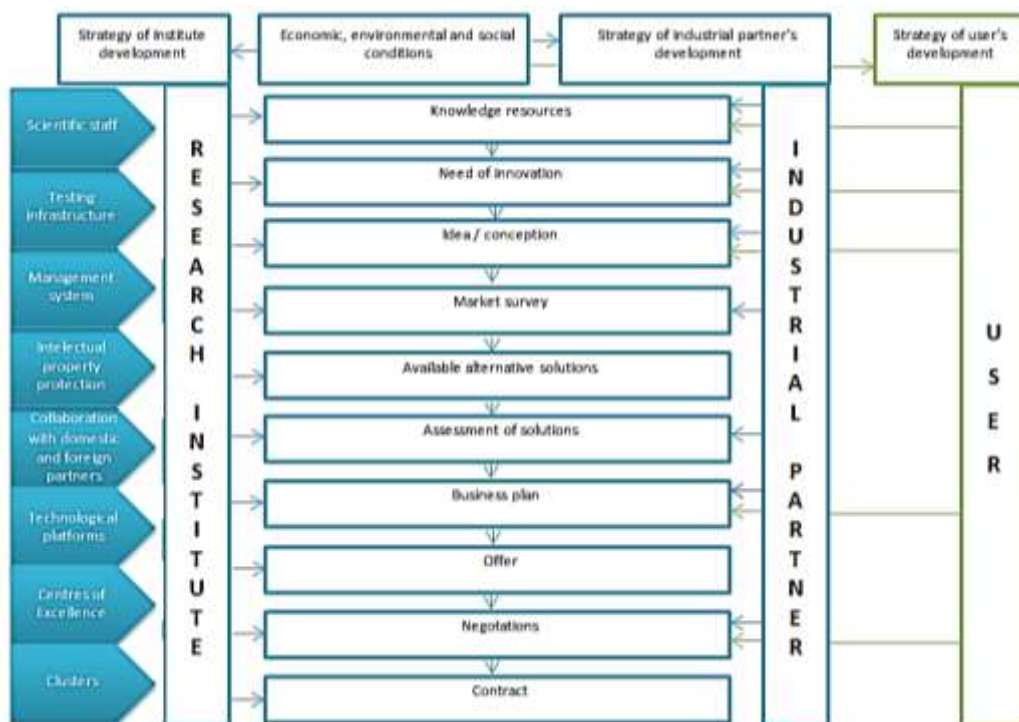


Fig. 4 Model of generating innovative technical ideas and solutions

A model of generating innovative technical ideas and solutions, used at the KOMAG Institute, is shown in Fig. 4.

Analyzing the model of generating innovative ideas and solutions, presented in Fig. 4, it can be seen that there is a clear impact of economic, environmental and social conditions on the development strategy of the research institute, the industrial partner i.e. producer of mining machinery and equipment as well as of the user representing a mine. An important activity concerns an assessment process of an innovative solution to evaluate its market potential. An exact verification of this assessment enables to formulate an opinion whether the innovative solution will be accepted by the market. The SWOT analysis, bench-marking or point-allocation system should be conducted at this stage. A good innovative idea is the first important, and to a big extent, decisive step in the process of research results commercialization. A regular contact with industry representatives, discussions with producers and users of machinery and equipment are a valuable source of

information and inspiration. An analysis of patent bases and a current follow-up of technical literature enables to check the level of knowledge. After having decided that the idea is of innovative character, it should be protected by a patent. An important activity includes an initial selection of ideas and a decision concerning technical and technological manufacturing possibilities as well as an assessment of the market potential.

In the process of generating new ideas and solutions three methods are used:

- Brainstorming which is a method of a team generation of ideas enabling to look for new solutions due to an activation of individual creative capabilities. Due to this method, a group of people uses their brains to attack a problem in a creative way getting a big number of ideas within a short period of time.
- Method of discussion enables an exchange of views on a given subject. Views are presented with use of arguments, which facilitate understanding of the other party's views and in most cases it leads to an elaboration of a common decision.
- Decision tree method which reflects a structure of data. Their processing enables to take a decision. A graphic form of a decision tree contains a description of the problem, possible solutions presented in a form of the tree branches, a description of positive and negative results of a given decision in the aspect of reaching objectives as well as the final result, i.e. a taken decision.

There are four operational procedures of generating ideas:

- Analysis of buyer's needs – the source of information coming directly from users, who give suggestions concerning expected changes and critical remarks about the products used so far.
- List of product features enabling to consider possibilities, methods and scope of its improvement due to using the latest technical and technological achievements.
- Analysis of competitors' products to improve own products.
- Monographic analysis enabling an identification of the problem and also testing of relationships among factors which have an impact on the method of solving this problem.

From the presented model it can be seen that a generation of innovative technical ideas and solutions is a complex process which requires a lot of knowledge and experience. It is very important to manage these processes in a correct way to avoid mistakes which may cause a failure of the whole innovative project oriented onto a commercialization of research results.

EXAMPLES OF IMPLEMENTED INNOVATIVE IDEAS GENERATED AT THE KOMAG INSTITUTE

KOMTRACK innovative haulage system

In the Polish hard coal mines an exploitation is conducted mainly with use of longwall systems in which shearers are incorporated. For more than 40 years shearers operate on the chainless haulage system of Eicotrack type (Fig. 5).

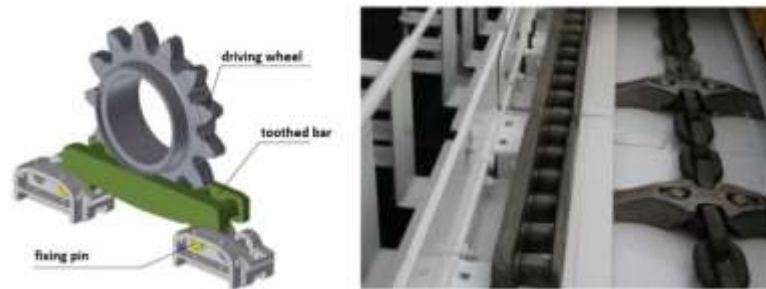


Fig. 5 Eicotrack haulage system

A displacement is realized due to an interaction of vertical toothed wheel of the shearer and the toothed bar of Eicotrack type, installed horizontally in the armoured face conveyor spill-plate. A stiff installation of toothed bars to brackets of spill-plate causes lack of their displacement, in particular, in the horizontal plane which causes a change of the toothed bar position in relation to the toothed wheel when bending of the armoured face conveyor occurs. Such a situation results in a disturbance of the pitch between the extreme pins of adjoining toothed bars and to a change of the distance between the pins of toothed bar segments and the rotation axis of the toothed wheel. Another disadvantageous phenomenon consists in so called edging of teeth causing a significant exceed of permissible pressure stresses between surface of toothed wheel and toothed bar. These disturbances generate dynamic forces causing an increased wear of toothed bars and of the shearer toothed wheel (Fig. 6).



Fig. 6 Wear of teeth in wheels and toothed bars

Source: (Kotwica et al., 2019)

The wear phenomena became more severe when the power of haulage units and weights of shearers increased. They caused numerous failures of haulage units causing very high financial losses.

Such a problem made KOMAG researchers develop a conception of an innovative haulage system consisting of segments of a toothed bar. Each segment has only one tooth and two side walls symmetric in relation to the longitudinal axis of the toothed bar (Kalita 2019, Kalita et al., 2019). Each of the side walls has raceways of spherical shape which gives a possibility of transverse and longitudinal displacement of adjoining segments. Such a toothed bar enables a flexible following-up adaptation to longitudinal and transverse bending of the armoured face conveyor. Applying a virtual prototyping technology and computer simulations an innovative, flexible haulage system of

a modular construction with a possibility of a follow-up adaptation to the shape of a longwall face was developed (Fig. 7). It also included tensioning system of the toothed bar system (Nieśpiałowski et al., 2019).

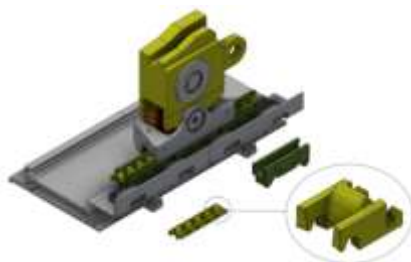


Fig. 7 Model of KOMTRACK haulage system

Source: (Kalita et al., 2019)

In the PIAST Hard Coal Mine a stand for conducting functional tests of the system was constructed (Fig. 8).



Fig. 8 Stand for functional testing of KOMTRACK haulage system

In 2021 it is planned to continue development activities oriented onto in-situ tests at the PIAST Mine.

In the case of the KOMTRACK innovative solution the idea was generated by the need of solving a problem expressed by industrial partners and multi-year observations made by researchers.

Air-and-water dust control installations

The first research activities were started as a reaction to disasters caused by methane explosions which happened during an exploitation of coal seams with use of longwall shearers. The work was oriented onto a reduction or even an elimination of methane or coal dust explosions as well as onto an improvement of mine air cleanness due to an implementation of air-and-water spraying system (Prostański & Vargova 2018). It also included new design solutions enabling to eliminate this hazard. In the result of research and development work an innovative approach to a control of these hazards, consisting in spraying systems taking advantage of air-and-water aerosols, was suggested.

The spraying installations efficiency tested at the Barbara Experimental Mine in Mikołów (Fig. 9) as well as at the Pniówek Hard Coal Mine. The obtained results were very good (Prostański 2018).



Fig. 9 KSW-460 NE shearer during the tests of extinguishing an ignition of combustible dust mixture, initiated by explosives, with use of air-and water spraying system

Source: (Prostański 2018)



Fig. 10 KSW-460 NE during the tests of the spraying installation in the Pniówek Hard Coal Mine

Source: (Prostański et al., 2007)



Fig. 11 Air-and-water curtain installed on the R-130 roadheader

Source: (Prostański 2018)

In the result of such a methodical approach, taking into consideration individual features of these solutions, their development in the direction of increasing operational safety, efficiency and reliability, 30 longwall shearers were equipped with air-and-water spraying installations: 26 shearers in 10 Polish mines, 3 in China and 1 in Argentina.

Some research results of American partners from the NIOSH (Colinet et al., 2010) and from the Barbara Experimental Mine (Cybulski et al., 2015, Libera et al., 2006) were extremely helpful for a development of the KOMAG air-and-water spraying system.

Basing on the experience and successful implementations of the spraying installations in longwall shearers, such innovative solutions were developed for roadheaders (Prostański 2013), because their former systems were very complicated and unreliable (Fig. 12).

Technical successes, achieved in the case of longwall shearers and roadheaders, encouraged KOMAG researchers to develop similar installations

for reducing dust in roadway workings, in areas of conveyors' transfer points, on powered roof support units and in mechanical preparation plants (Prostański 2012).

The air-and-water spraying system is also used in the UMID disinfecting installation, developed for controlling a propagation of the SARS-CoV-2 viruses in industrial objects, including mines (Fig. 12).



Fig. 12 UMID disinfecting installation

The UMID installation serves for a decontamination of viruses, bacteria and fungi. The main component is an air-and-water mist system, spraying a disinfectant – a colloid of silver. The compressed air, supplied to the installation, is a carrier of the disinfectant of the passers' –by clothes. The installation is equipped with an automatic control system started with a motion sensor.

Innovative ideas and solutions described above are protected by 51 patents, utility patterns and applications for inventions. Air-and-water spraying installations obtained 17 awards in Poland and abroad, including the World Exhibition on Innovations, Research and New Technologies Brussels Innova.

Both case-study examples, presented in the article, confirm the correctness of the KOMAG strategic policy in the field of generating new ideas and solutions. In the case of the KOMTRACK system it was an eagerness for developing more reliable haulage units and solving operational problems reported by industrial partners. As regards air-and-water spraying system an innovative idea was generated in the result of a disaster in underground mines and an urgent need of increasing work safety in mines.

PRACTICAL RECOMMENDATIONS AND GUIDELINES CONCERNING A GENERATION OF INNOVATIVE TECHNICAL IDEAS AND SOLUTIONS

Basing on the investigations performed within this research work, concerning a generation of innovative technical ideas and solutions at the KOMAG Institute of Mining Technology the following recommendations for the stakeholders of this process can be specified:

- A good recognition of economic, environmental and social conditions and circumstances.
- A good knowledge about the needs and reliabilities of a given industrial

- sector, including: knowledge resources, demand/need of innovations, observation of competitors' activities.
- A generation of innovative ideas:
 - research and development work conducted at the Institute,
 - analyses of users' needs and expectations,
 - analyses of products' features to consider possibilities, methods and scope of their improvement,
 - analyses of competitors' products,
 - suggestions reported by producers of a given product,
 - opinions of users,
 - information gained at conferences, seminars, fairs, exhibitions and trainings,
 - analyses of patent bases to check the state of knowledge,
 - market surveys – a determination of present and potential producers and users,
 - a collaboration with scientific and industrial partners, taking advantage of the synergy effect.
 - A determination of a market potential of the innovative solution:
 - an availability of alternative solutions,
 - an assessment of the solution from the point of view of its innovativeness, costs and manufacturing techniques etc. An assessment of the innovative solution can be conducted with an application of the SWOT analysis, bench-marking or point-allocation method. The solution should be treated as a potential investment, so the commercialization possibilities should be analyzed very thoroughly, as well as the chances of implementation and reaching a stable position on the market. After having confirmed the fact that an idea is of innovative character, it is indispensable to protect it by intellectual property rights.
 - A determination of barriers (legislative, financial, organizational, institutional).
 - An elaboration of a business plan.
 - A preparation of the offer for industrial partners.
 - Negotiations of the offer with industrial partners – a big flexibility is recommended.

Successful negotiations in the win-win system finalize the process of generating innovative ideas and they start a commercialization process of research and development work results.

The recommendations and guidelines, presented above, concern the process of generating innovative ideas and solutions based on the authors' model. Due to an active role of industrial partners in this process, it seems to be relatively easy to detect mistakes at a very early stage and undertake corrective measures.

SUMMARY AND FINAL CONCLUSIONS

The authors of the article presented a system of generating innovative technical ideas and solutions based on a strategic activities of the KOMAG Institute of Mining Technology in the field of designing, testing and implementing machinery and equipment for underground exploitation of minerals and for their beneficiation. Two examples of innovative technical solutions, developed at KOMAG, i.e. the water-and-air dust control system and the KOMTRACK haulage system for highly productive longwall systems of a new generation enabled to build a model reflecting individual stages of the process of generating innovative technical ideas and solutions. The article contains different examples of generating innovative ideas such as brainstorming, brain-writing and brain-sketching. While generating new ideas, it is essential to overcome the current business logic, think in business models and manage a process of innovative idea creation. Special attention should be paid to a close collaboration of research institutes with the end-users of their research results of innovative character. In the case of the KOMAG Institute there are two groups of industrial partners: mining machinery producers and representatives of mines. A development strategy of the Institute incorporates forecasts of future needs of producers and users of mining machinery.

The article contains not only theoretical analyses but it has also an utilitarian character as it gives practical recommendations for stakeholders of the process of generating innovative technical ideas and solutions. Final conclusions are as follows:

- A generation of innovative technical ideas and solutions is a complex and very sensitive process.
- Pro-innovative thinking requires interdisciplinary knowledge of researchers as regards needs as well as expectations of potential users in the aspect of technical, technological and financial possibilities. Due to such an approach innovative solutions are created and they are successfully implemented.
- An encouragement of the Institute managerial staff for out-of-the-box thinking and financial bonuses for creative researchers speed up pro-innovative thinking processes.
Researchers should leave “product thinking” or “service thinking” behind.
- Different ideas should be integrated to build a business model – four dimensions are important in this case: WHO? WHAT? HOW? WHY? and an alignment as well as a consistency among them should be ensured.
- A participation of industrial partners in the process of generating and assessing innovative ideas and solutions plays a key role in a successful realization of the whole process.
- The authors’ model of generating innovative technical ideas and solutions shows that innovations may appear at the research institute or at the industrial partner’s organization.
- An incorrect assessment of the market situation, resulting from lack of

efficient communication, mistakes in perception and an incorrect interpretation of obtained results due to wrong reasoning, causes a failure of the whole process.

- An assessment of the solution innovativeness should be conducted by specialists representing the research institute, the producer and the user, as such an approach guarantees a high degree of objectivism.

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Abstract: The article presents some strategic aspects of the KOMAG Institute of Mining Technology in the field of creating innovative ideas and innovative technical solutions concerning machinery and devices for mining and preparation of minerals as regards their operational safety, productivity and reliability. Special attention is paid to a process of stimulating innovative ideas in a creative atmosphere, as KOMAG researchers and engineers are encouraged to be open-minded and to think in an unconventional way. Two examples of innovative technical solutions are described in detail, i.e. the water-and-air dust control system and the KOMTRACK haulage system for highly productive longwall systems of a new generation. The article contributes significantly to Innovation Engineering which is an important component of Production Engineering in the scope of generating and implementing innovative solutions. The authors presented an ecosystem of innovations, describing several methods of creating innovative ideas. The article concentrates on a role of Polish research institutes which play a key role in creating and implementing innovative solutions, bridging science and industry. Due to an analysis of different methods of generating innovative technical ideas and solutions, it can be concluded that an idea and a need of generating an innovative solution may appear in the research institute or at the industrial partner's organization. In the case of the KOMAG multi-year experience and practice industrial partners include not only producers of mining machinery and equipment, but also representatives of mines of minerals. In general an innovative idea is generated in the result of an inspiration from the business environment and then it is transformed into an innovative product or service. The article contains the authors' practical recommendations as regards a creation of innovative technical solutions. It is ended with a summary of general character and with some final conclusions.

Keywords: innovative solution, management, stimulation of ideas, mining machinery, research institute