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ADVANCED INNOVATION DESIGN APPROACH FOR PROCESS ENGINEERING

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Abstract

Process engineering focuses on the design, operation, control and optimization of chemical, physical and biological processes and has applications in many industries. Process Intensification is the key development approach in the modern process engineering. The proposed Advanced Innovation Design Approach (AIDA) combines the holistic innovation process with the systematic analytical and problem solving tools of the theory of inventive problem solving TRIZ. The present paper conceptualizes the AIDA application in the field of process engineering and especially in combination with the Process Intensification. It defines the AIDA innovation algorithm for process engineering and describes process mapping, problem ranking, and concept design techniques. The approach has been validated in several industrial case studies. The presented research work is a part of the European project "Intensified by Design® platform for the intensification of processes involving solids handling".

Keywords: Design methodology, Innovation, Process modelling, TRIZ, Process intensification

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1 INTRODUCTION

The Advanced Innovation Design Approach (AIDA) has been conceptualized in Germany as a new mindset and methodology for enhancing innovative and competitive capacity of industrial companies in new product development, combining the holistic innovation process, organizational measures, and IT-solutions with the individually adaptable, analytical and problem solving tools primarily of the theory of inventive problem solving TRIZ. The AIDA innovation process includes following typical phases with feedback loops and simultaneous auxiliary or follow-up sub-processes: uncovering of solution-neutral customer needs, technology and market trends, identification of the needs and problems with high market or innovation potential and formulation of the innovation tasks and strategy, systematic idea generation and problem solving, evaluation and enhancement of solution ideas, creation of innovation concepts based on solution ideas, evaluation of the innovation concepts as well as optimization, implementation, validation and market launch of chosen innovation concepts (Livotov, 2016). The article analyses the opportunities of AIDA application in the field of process engineering and especially in combination with the Process Intensification.

Process engineering (PE) deals with the design, operation, control, and optimization of chemical, physical, and biological processes. It has applications in a wide range of industries, such as chemical, petrochemical, and pharmaceutical industries. In order to remain competitive in future these industries have to establish a systematic approach for process intensification and to enable continuous and disruptive innovation. The Process Intensification (PI) is understood as a part of the knowledge-based engineering (KBE) and can be defined as any significant technological development leading to more efficient and safer processes. The PI databases of new technologies and equipment allow to faster achieve the goals of innovation.

Among different innovation approaches, the modern Theory of Inventive Problem Solving (TRIZ) is today considered as one of the most comprehensive, systematically organized invention and creative thinking methodologies for the knowledge-based innovation (KBI) (Cavallucci et al., 2015; VDI, 2016). One of the main advantages of TRIZ is that it allows to find new inventive solutions for a given problem in a systematic way by using the entire potential of science and engineering, also outside of the field of originally formulated problem (Altshuller, 1984).

Since any manufactory process in PE typically consists of numerous steps involving appropriate equipment, an isolated case of successful TRIZ application does not automatically guarantee satisfactory results on the process level. Therefore, the holistic Advanced Innovation Design Approach can be recommended in the field of process engineering with the following steps:

- Identification and ranking of solution-neutral requirements of the industry, society, and customers/users for process intensification.
- Formulation of the innovation tasks and problems, including identification of engineering contradictions or contradictory requirements.
- Systematic generation of ideas and inventive problem solving with TRIZ tools enhanced and adapted for application in PE.
- Creation and optimization of innovative PI concepts on the basis of solution ideas.

The paper is divided in four sections. Section 2 illustrates the concept of process intensification and the current state of the application-oriented research on TRIZ in PE. The Section 3 introduces the components and the innovation algorithm of the proposed Advanced Innovation Design Approach for PE. Section 4 presents the AIDA process mapping techniques, the problem ranking method, and the concept design and optimization method, finally followed by Section 5 with brief conclusions and outlook for future research.

The work presented in this paper is part of the research project “Intensified by Design® platform for the intensification of processes involving solids handling”, granted by the European Commission within international consortium under H2020 SPIRE program (SPIRE 8 - 2015 Solids handling for intensified process technology - Grant Agreement Nr. 680565).

2 TRIZ AND PROCESS INTENSIFICATION (PI)

2.1 Process Intensification

Process Intensification (PI) dates back to the research of Prof. Ramshaw and his co-workers (Reay et al., 2013) in the late 1970s and is "commonly seen as one of the most promising development paths for the chemical process industry and one of the most important progress areas for modern chemical engineering" (Gerven and Stankiewicz, 2009). It can be also defined as "the strategy for dramatic reducing the size of chemical plant needed to achieve a given production objective" (Reay et al., 2013) and as "any chemical engineering development that leads to a substantially smaller, cleaner, safer and more energy efficient technology" (Stankiewicz and Moulijn, 2000). As stated in (Reay et al., 2013), PI satisfies at least one of the seven key objectives of industrial growth, defined in (Keller and Bryan, 2000):

- Capital investment reduction
- Energy use reduction
- Raw material cost reduction
- Increased process flexibility and inventory reduction
- Ever-greater emphasis on process safety
- Increased attention to quality
- Better environmental performance.

PI covers a wide range of processing equipment and methodologies (Boodhoo and Harvey, 2013; Reay et al., 2013; Stankiewicz and Moulijn, 2000). As shown in Figure 1, Process Intensification can be divided into the following two categories:

- Equipment (reactors, mixing, heat or mass-transfer devices, etc.)
- Processing methods (extraction, separation, absorption, techniques using alternative energy sources and new process-control methods, etc.).

It is also relevant to note that some technological PI principles presented in (Boodhoo and Harvey, 2013) are highly consistent with the evolution laws of technical systems in the TRIZ methodology, developed by G. S. Altshuller (first publication in 1956) and his co-workers (Altshuller, 1984). Such PI principles include the following (Boodhoo and Harvey, 2013):

- Miniaturization of process equipment
- Transition from the macro- to meso- and micro-level
- Enhancement of the force fields (mechanic - acoustic - electric - electromagnetic - light energy)
- Enhanced surface configurations.

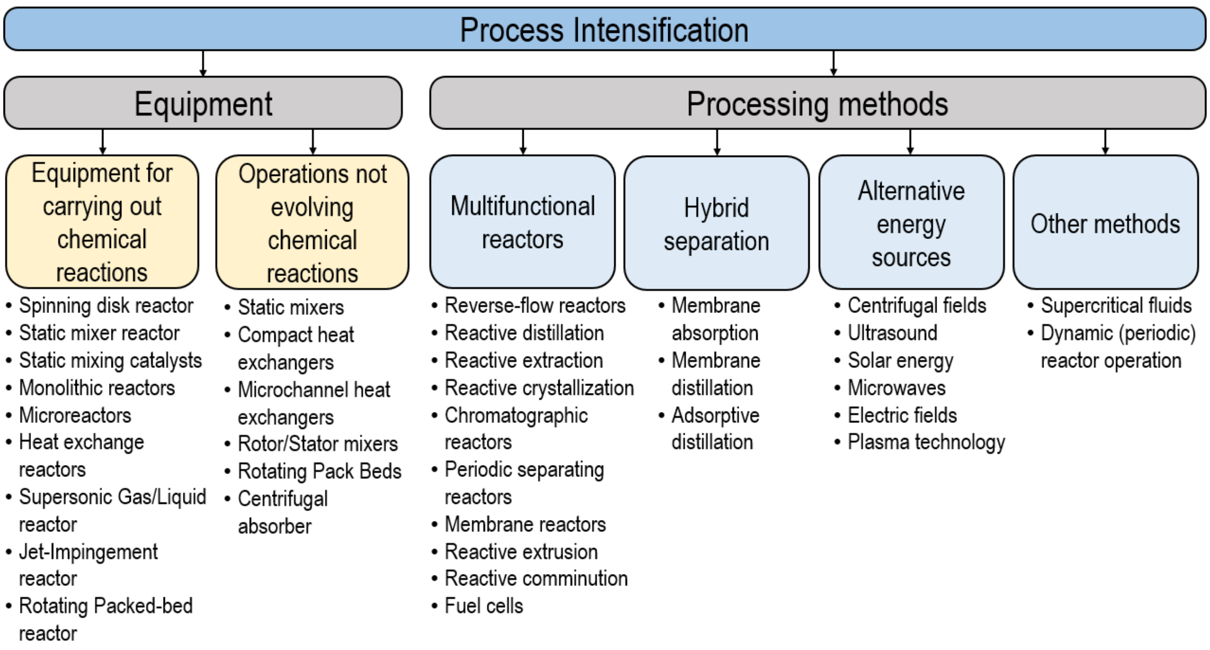

Figure 1. Process intensification equipment and methods (Boodhoo and Harvey, 2013; Stankiewicz and Moulijn, 2000)

The existing PI databases with intensified equipment types, methods, and applications enable engineers to identify and implement appropriate process-intensifying solutions faster in accordance with the objectives and constraints of their development tasks. The application of these processing methods can however lead to contradictory effects, i.e. the intensification of one property may cause the worsening of another parameter as outlined in (Benali and Kudra, 2008; Kardashev, 1990). The recent analysis of 100 full-text patent documents with the application date between 2008 and 2015 in the field of solid handling in PE demonstrates that all inventions promise to solve numerous problems (more than 125 unique issues in total, such as low yield, high energy and water consumption, variation of the granule size etc.) but also generate negative side effects or the so-called secondary problems (Casner et al., 2016). Therefore, the existing TRIZ problem solving tools, developed for identification and elimination of the engineering contradictions, can help to avoid secondary problems of PI and lead to new inventive design concepts in PE instead of trying to find a compromise solution.

2.2 TRIZ for Process Intensification: state of application-oriented research

Since process engineering industries have only recently started to apply TRIZ for the development of new processes, only a few studies can be cited in this context. Among the recent research works related with the development of new chemical, physical, and biological processes, there has been one proposal to combine TRIZ and Case-Based Reasoning (CBR) in chemical engineering (Robles et al., 2009): in this joint approach, the CBR would be applied to solve new problems using the experience obtained from previous successful solutions in the same technical domain, and it would be further enhanced by TRIZ to access other engineering fields. However, more recent investigations have shown that directly merging CBR and TRIZ do not result in positive synergy effects and have even outlined the risk of one approach weakening the other (Houssin et al., 2014).

A few studies on the application of TRIZ in process engineering have focused on the problem-solving step, such as the development of adapted contradiction matrix (Pokhrel et al., 2015), or on the application of TRIZ inventive principles and standard solutions in chemical engineering (Abramov et al., 2015; Ferrer et al., 2012; Kim et al., 2009; Rahim et al., 2015; Srinivasan and Kraslawski, 2006). Fourteen technical parameters for the formulation of contradictions and additional 8 inventive principles to be applied in chemical engineering, and in particular in mixing operation are proposed in (Pokhrel et al., 2015).

The study (Srinivasan and Kraslawski, 2006) outlines the necessity to adapt TRIZ for the domain of process engineering and illustrates the proposed TRIZ modifications with a case study dealing with safety issues of chemical processes. The application of TRIZ for safety issues in chemical reactors has been discussed in a case study (Kim et al., 2009), in which 39 engineering parameters for formulating contradictions are condensed to 6 categories such as process disturbance, design, mechanics, human operator, natural hazard, and materials.

The skilled TRIZ practitioners report successful application of different TRIZ methods and tools, such as inventive algorithm ARIZ, Function Oriented Search, and Cause–Effect Chain Analysis (CECA) in the development of chemical or bio-chemical products and technologies (Abramov et al., 2015). Another work illustrates the application of TRIZ-based tools in problem solving and forecasting in the field of applied chemical engineering in the automotive industry (Rahim et al., 2015).

Based on analysis of the relationship between creative and standard approaches in the design of process control in PE, a new systematic approach to heuristic control design systems is proposed in (Yakovis and Chechurin, 2015), which is illustrated with several examples related to the cement manufacturing.

In order to reduce the negative environmental impact of the chemical industry, a TRIZ-based computer aided eco-innovation system has been developed to support the engineers in the preliminary design (Ferrer et al., 2012). The approach involves a number of steps, starting with the initial problem analysis and problem formulation through to generation of possible and feasible ideas. It reduces the level of TRIZ abstraction and applies TRIZ tools, such as physical, chemical, biological, and geometrical effects, on the level of concrete solutions, which is typical for the Case-Based Reasoning (Robles et al., 2009).

A forecast of PE-equipment evolution with TRIZ, including inventive solutions and resolved contradictions, has been demonstrated with the example of black oil coking unit evolution from horizontal vessels to delayed coker units and then to continuous carbonizers (Berdonosov et al., 2015).

A scheme for reorganizing TRIZ databases for the search of solution principles for unit operations in food processing has been proposed in (Totobesola-Barbier et al., 2002). Two practitioner’s studies

present chemical examples (Grierson et al., 2003) and interpretations (Hipple, 2005) for 40 TRIZ inventive principles, relevant for process engineering.
The study (Cascini et al., 2009) illustrates the function analysis aimed at building the network of TRIZ evolutionary trends using the example of tablet production in the pharmaceutical industry. The papers cited above and some earlier publications (Li et al., 2001; Poppe and Gras, 2001; Rong et al., 2000) report good TRIZ applicability in the resolution of localized design problems in PE equipment but hardly mention the issues of process analysis and process intensification comprehensively.

3 ADVANCED INNOVATION DESIGN APPROACH FOR PE

The proposed Advanced Innovation Design Approach (AIDA) for process engineering comprises following components:

- General innovation algorithm for process engineering (AIDA innovation process, see Figure 2)
- Basic problem solving algorithm for PI with TRIZ, originally presented in (Casner et al., 2016)
- Method for identification and prediction of engineering contradictions
- Process mapping technique
- Method for ranking of problems and innovation tasks.
- Design and optimization of the solution concepts
- TRIZ-based toolbox for fast inventive problem solving in PE (inventive principles adapted for PE; standard solutions for PI, elimination of harmful effects and for measurement problems; database of physical, chemical, biological, and geometrical effects; principles for cost reduction and others)
- TRIZ-based methods for specific applications (inventive algorithm, anticipatory failure identification, prediction of technical evolution, patent circumvention) and others.

The general AIDA algorithm for process engineering extends the phase of inventive problem solving with the phase of the comprehensive problem analysis, definition, and ranking as well as with the phase of design and optimization of PI-solution concepts, as presented in Figure 2. Its main phases are described in the following subsections.

3.1 Phase I - Definition and ranking of PI tasks and problems

In the Phase I – “Definition and ranking of PI tasks and problems”, this approach starts with a fuzzy PI situation or problem, followed by the comprehensive problem analysis including components and functional analysis of the process and corresponding equipment (process mapping), analysis of general requirements of the customers and market, under consideration of existing solutions (patent literature, PI-databases), technological and social trends.
Based on the obtained information, in the next step it extracts and prioritize the partial problems $P_1 \ldots P_N$, formulated as solution-neutral PI-requirements in accordance to the method presented in (Livotov, 2008). The requirements with higher importance and lower current performance have reasonably the highest ranking for the Process Intensification as illustrated in the Section 4.2.

3.2 Phase II - Problem solving

In the Phase II – “Problem solving” for each of selected and defined problems $P_1 \ldots P_N$, the systematic search for solution can be performed in accordance to the basic problem solving algorithm, presented in Figure 2. At first it should be checked whether these problems can be considered as already known, standard problems in PE. If yes, the corresponding available PI-solutions can be selected for implementation.
If the implementation of this PI-solution faces negative side effects or secondary problems, the appropriate TRIZ tools for PE can be applied. After the detailed analysis of cause-effect chains and engineering contradictions responsible for the specific problem situation, the solution ideas have to be developed for overcoming secondary problems.
If the initial problem is completely new or not typical, its inventive solution should be supported by the application of TRIZ, which can be lead to two complementary solutions: a) optimization of existing PI-solution (resources-oriented and thus costs-saving) and b) development of completely new PI solution or technology.

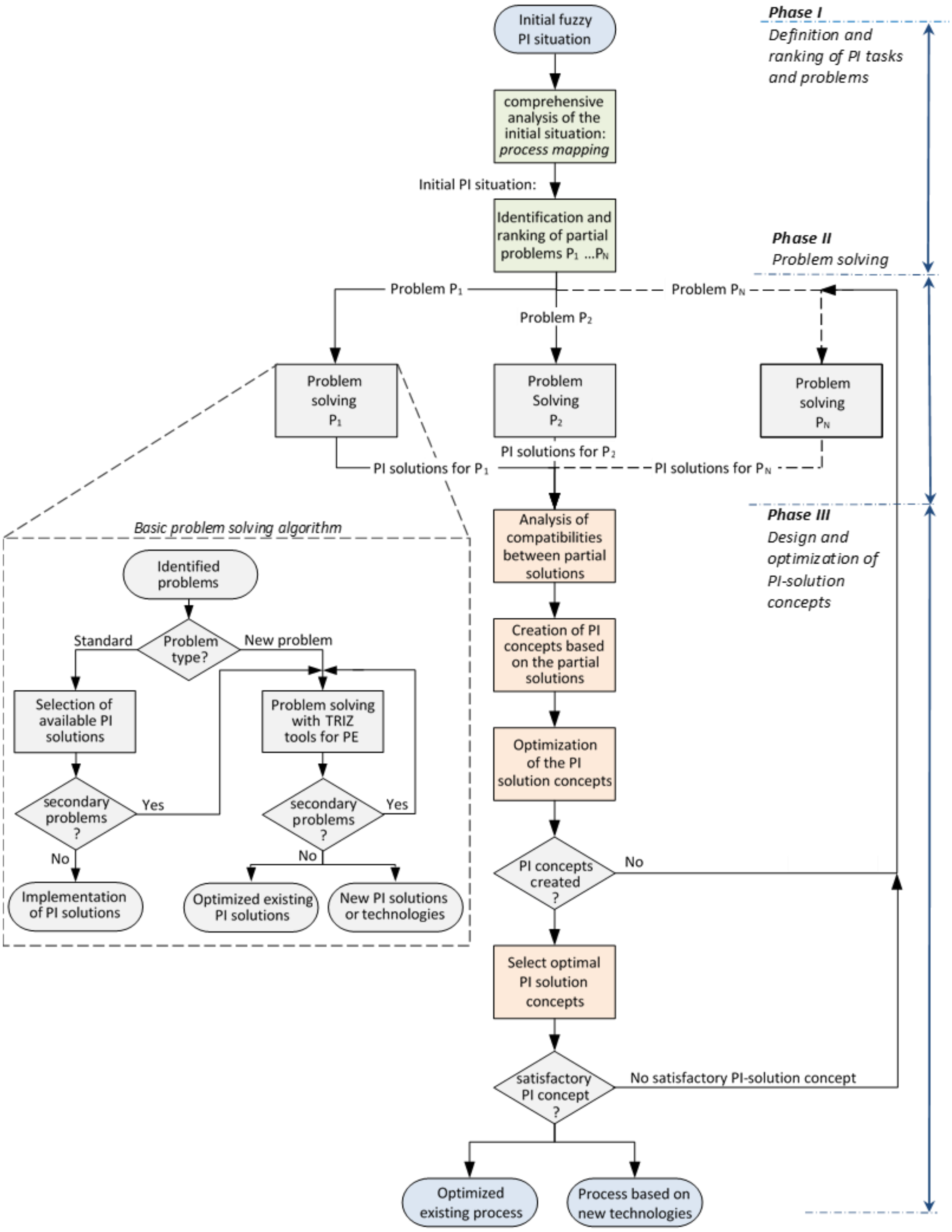

Figure 2. General AIDA innovation algorithm for process engineering

3.3 Phase III - Design and optimization of PI-solution concepts

The Phase III – "Design and optimization of PI-solution concepts" also consists of several steps. The PI-solution concept is understood as a combination of compatible solutions for the partial problems $P_1 \ldots P_N$. For each problem, the basic algorithm presented in Section 3.2 provides a set of possible solutions that should be combined to solution concepts. Thus, the generated partial solutions undergo the compatibility analysis, followed by the creation and optimization of several solutions concepts, based on the specific sets of the partial solutions. For example, a sustainable solution concept should contain a solution for each selected partial problem.

Due to the multi-objective aspect of the concepts creation and optimization, more than one optimal solution concept can be designed in this phase. Therefore, the AIDA evaluates the created PI solution concepts and selects e.g. the "best performance", "minimum cost" or "optimal performance to cost ratio" alternatives. A possible application of the multi-criteria decision analysis MCDA (Saaty, 1990) at this step can be a subject of further investigations.

4 TOOLS FOR AIDA

This section exposes tools, developed for the Advanced Innovation Design Approach for PE in order to:

- Analyse an existing process, identify problems and engineering contradictions (process mapping).
- Rank the problems and identify those with the highest innovation need (problem ranking).
- Design and optimize the solution concepts.

4.1 Process mapping

The process mapping technique has been developed to provide an easy-to-use method to capture the solution-neutral requirements for PI and to identify problems and the contradictions in an existing process completely. Figure 3 visualises the architecture of the process mapping for one process step, which is characterized by:

- Applied equipment and processing methods with their positive and negative functions or properties.
- Input/Output and quality process parameters to be controlled or achieved, such as pressure, temperature, humidity, particle size, concentration, flow rate etc.
- Product with its physical state (e.g. solid, liquid, gas) and energy state, material flow, possible physical transformations or chemical reactions, undesired properties.
- Available resources within the system and environment.

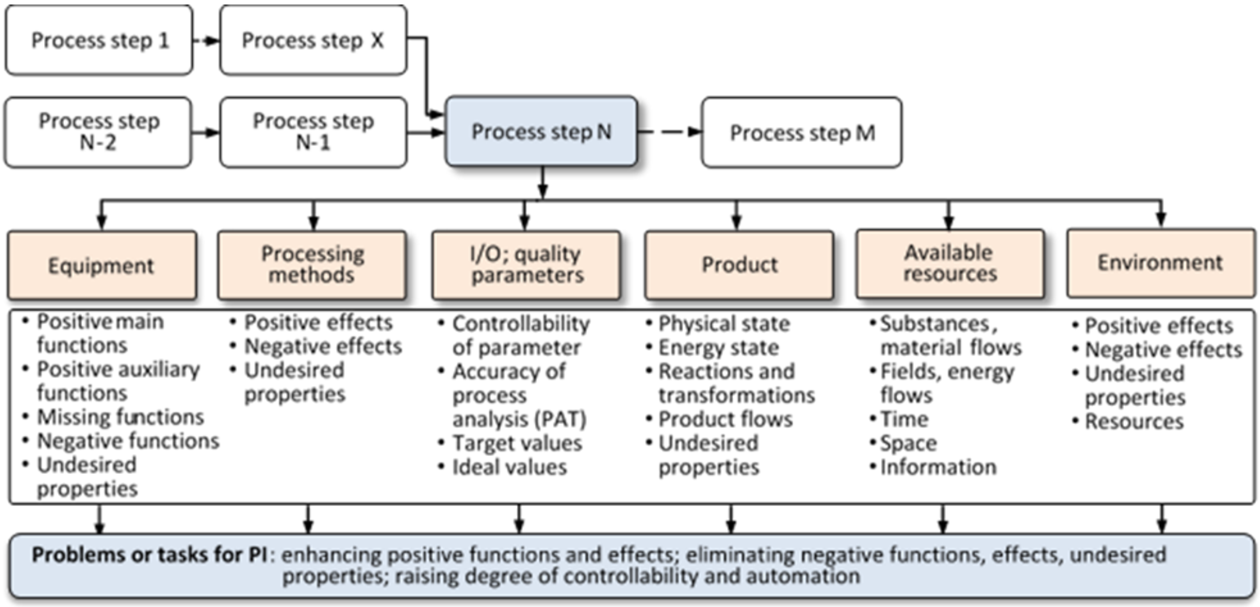

Figure 3. Architecture of the process mapping technique (fragment)

The identification of all functions and corresponding effects is the basis for the formulation of complete list of the solution-neutral requirements as innovation tasks for PI. These tasks can be separated in three types of problems: a) enhancement of positive functions or effects, b) elimination of negative functions, effects or undesired properties, c) raising degree of controllability, accuracy, and automation of the process step. As the number of problems for each process step can be between 10 and 30 or even more, the proposed problem ranking technique helps to identify problems with higher need for action, as presented in Section 4.2. Moreover, each valid combination of one positive effect with one negative effect enables to identify a corresponding engineering contradiction, which should be re-solved with appropriate TRIZ tools to achieve the stronger solutions on later steps.

4.2 Problem ranking

In order to select problems with higher priority, two parameters - the importance of each problem and the current satisfaction with the existing performance in the process - must be evaluated by the experts with following scale from 0% (lowest value) to 100% (highest value) with interval of 25%. The problems with higher importance and lower satisfaction have reasonably the higher ranking for the

Process Intensification. Obtained importance and satisfaction mean values allow one to calculate the ranking of each problem r_i, defined as maximum contribution of the problem solution to the growth of current total process performance or total process value V as presented in Equation (1), proposed in (Livotov, 2008) and applied here for identification of innovation tasks in PE:

$$\begin{cases} r_i = \frac{(R_i + aR_i(R_i - S_i))(1 - S_i)}{\sum_{i=1}^{i=n}(R_i + aR_i(R_i - S_i))} \\ V = \sum_{i=1}^{i=n} \frac{S_i(R_i + aR_i(R_i - S_i))}{\sum_{i=1}^{i=n}(R_i + aR_i(R_i - S_i))} \end{cases} \quad (1)$$

where:

- r_i – ranking of the problem, %;
- V - total process performance or value, %;
- R_i - mean importance of a problem, 0…100%;
- S_i - mean satisfaction with current solution (performance), 0…100%;
- n - total number of problems or innovation tasks;
- a - adjustment coefficient, a = 1 recommended for PE problems.

An example of problem ranking in the process engineering is illustrated in the Table 1 below. The innovation tasks (problems) of a pharmaceutical drying process of extruded products are sorted in accordance to their ranking, that helps to bundle innovation activities, focusing them on the most essential aspects.

Table 1. Example of problem ranking in a pharmaceutical drying process (fragment)

Problem (Innovation task for PI)	***Priority (importance) R_i***	***Performance (satisfaction) S_i***	***Problem Ranking r_i***
1. Reduce energy consumption	75%	50%	3,5%
2. Avoid contamination of the product	75%	58%	3,2%
3. Control density deviation of product	79%	80%	1,6%
4. Reduce air consumption	78%	82%	1,5%
5. Reduce cleaning & maintenance time	70%	74%	1,2%
...	...	...	...
26. Increase productivity	71%	86%	0,7%
27. Reduce noise and vibration level	62%	76%	0,5%

4.3 Concept design and optimization

To develop a new solution concept the appropriate idea must be selected for each partial problem. Therefore, the creation of solution concepts in a situation comprising several problems remains one of the challenging questions in the innovation design. On the one hand, each partial problem P_i can have several corresponding solutions S_{i1}, S_{i2}, S_{i3} etc., and on the other hand, the preferred partial solutions of different problems may be incompatible to each other. Moreover, the selection of solutions with help of some pre-defined criteria always brings a risk of subjective evaluation.

Table 2 presents the results of the problem-solving phase with more than one solution for each partial problem P_1 ... P_N. Formally, each solution concept CS_1 can be represented in the morphological matrix as a combination of individual solutions, for example $CS_1 = S_{13} + S_{22} + \ldots + S_{N2}$.

Table 2. Concept creation with help of morphological solution matrix (example)

	1	2	3	…	M
PROBLEM *P_1*	S_{11}	S_{12}	**S_{13}**		
PROBLEM *P_2*	S_{21}	**S_{22}**			
…					
PROBLEM *P_N*	S_{N1}	**S_{N2}**	S_{N3}	…	S_{NM}

The choice of the solutions for a concept can be made intuitively, with the help of evaluation criteria or by use of optimization algorithms. In any case, the compatibility analysis of all or at least selected solutions should be performed. Development of the appropriate mathematical optimization algorithm for concept creation can be a subject of further research. A possible optimization approach is for example defined in (Casner et al., 2016). Based on combinatorial multi-objective optimization, it helps to find the best combination between the evaluated individual solutions.

5 CONCLUSION AND OUTLOOK

The application of the Advanced Innovation Design Approach in process engineering helps to identify and to solve secondary problems and thus to limit the negative side effects of Process Intensification technologies. AIDA can predict engineering contradictions in advance and enables a smooth loss-free shift to a new technology without "teething" problems. On the other hand, AIDA helps to mobilize resources of the existing processes and to reach the maximum efficiency with a minimum of expenditures, increasing the maturity level of existing technologies in terms of low investment and resources-oriented innovation. Appling TRIZ as a complex innovation methodology, AIDA can be also used to develop completely new breakthrough solutions for PI, to forecast evolution of processes and equipment, and to inventively solve the bottle-neck problems. The future work will focus on the development of the TRIZ-based toolbox adapted for PI, including its computerized realization in the context of Computer-Aided Innovation Design.

REFERENCES

Abramov, O., Kogan, S., Mitnik-Gankin, L., Sigalovsky, I., Smirnov, A. (2015), TRIZ-based approach for accelerating innovation in chemical engineering. Chemical Engineering Research and Design. Volume 103, Nov. 2015, Pages 25–31, doi: http://dx.doi.org/10.1016/j.cherd.2015.06.012

Altshuller, G.S. (1984), Creativity as an Exact Science. The Theory of the Solution of Inventive Problems. Gordon & Breach Science Publishers, 1984, ISSN 0275-5807

Benali, M., Kudra, T. (2008), Drying process intensification: Application to food processing. Retrieved on 11.09.2016 from https://www.researchgate.net/publication/266211018

Berdonosov, V.D., Kozlita, A.N., Zhivotova, A.A. (2015), TRIZ evolution of black oil coker units. Chemical Engineering Research and Design. Volume 103, Nov. 2015, Pages 61-73. doi: http://dx.doi.org/10.1016/j.cherd.2015.08.013

Boodhoo, K., Harvey, A. (2013), Process Intensification: An Overview of Principles and Practice, in: Process Intensification for Green Chemistry. John Wiley & Sons, Ltd, pp. 1–31.

Cascini, G., Rotini, F., Russo, D. (2009), Functional Modeling for TRIZ-Based Evolutionary Analyses. DS 58-5: Proceedings of ICED 09, the 17th International Conference on Engineering Design, Vol. 5, Design Methods and Tools (pt. 1), Palo Alto, CA, USA, 24.-27.08.2009.

Casner, D., Houssin, R., Renaud, J., Knittel, D. (2016), A Multiobjective Optimization Framework for the Embodiment Design of Mechatronic Products Based on Morphological and Design Structure Matrices, in: Bouras, A., Eynard, B., Foufou, S., Thoben, K.-D. (Eds.), Product Lifecycle Management in the Era of Internet of Things: 12th IFIP WG 5.1 International Conference, PLM 2015, Doha, Qatar, October 19-21, 2015, Revised Selected Papers. Springer International Publishing, Cham, pp. 813–825.

Casner, D., Livotov, P., Mas'udah, Kely da Silva, P. (2016), TRIZ-based approach for process intensification and problem solving in process engineering: concepts and research agenda. Presented at the TRIZ Future Conference 2016, Wroclaw, Poland.

Cavallucci, D., Cascini, G., Duflou, J., Livotov, P., Vaneker, T. (2015), TRIZ and Knowledge-Based Innovation in Science and Industry. Procedia Engineering 131 (2015) 1–2, doi: 10.1016/j.proeng.2015.12.341

Ferrer, J.B., Negny, S., Robles, G.C., Le Lann, J.M. (2012), Eco-innovative design method for process engineering. Computers & Chemical Engineering 45, 137–151. doi:10.1016/j.compchemeng.2012.06.020

Gerven, T.V., Stankiewicz, A. (2009), Structure, Energy, Synergy, Time - The Fundamentals of Process Intensification. Industrial & Engineering Chemistry Research 48, 2465–2474, doi: 10.1021/ie801501y

Grierson, B., Fraser, I., Morrison, A., Chisholm, G. (2003), 40 Principles – Chemical Illustrations. *The Triz Journal*. Retrieved on 11.09.2016 from https://triz-journal.com/40-principles-chemical-illustrations/

Hipple, J. (2005), 40 Inventive Principles for Chemical Engineering. *The Triz Journal*. Retrieved on 11.09.2016 from https://triz-journal.com/40-inventive-principles-for-chemical-engineering/

Houssin, R., Renaud, J., Coulibaly, A., Cavallucci, D., Rousselot, F. (2014), TRIZ theory and case based reasoning: synergies and oppositions. *The International Journal on Interactive Design and Manufacturing* (IJIDeM) 9, 177–183. doi:10.1007/s12008-014-0252-1

Kardashev, G.A. (1990), Physical Methods of Process Intensification in Chemical Technology, Moscow, Khimia, 208p. (in Russian).

Keller, G.E., Bryan, P.F. (2000), Process engineering: Moving in new directions, Chemical engineering progress. American Institute of Chemical Engineers, New York, NY, USA.

Kim, J., Kim, J., Lee, Y., Lim, W., Moon, I. (2009), Application of TRIZ creativity intensification approach to chemical process safety. *Journal of Loss Prevention in the Process Industries* 22, 1039–1043. doi: http://dx.doi.org/10.1016/j.jlp.2009.06.015

Li, X.-N., Rong, B.-G., Kraslawski, A. (2001), TRIZ-based creative retrofitting of complex distillation processes - An industrial case study, in: Gani, R., Jørgensen, S.B. (Eds.), European Symposium on Computer Aided Process Engineering, Computer Aided Chemical Engineering. Volume 9, 2001, Elsevier, pp. 439–444, doi: 10.1016/S1570-7946(01)80068-7

Livotov, P. (2008), Method for Quantitative Evaluation of Innovation Tasks for Technical Systems, Products and Processes. Proceedings of ETRIA World Conference 2008 "Synthesis in Innovation", 5-7 Nov. 2008, University of Twente, Enschede, The Netherlands, pp. 197-199, ISBN 978-90-365-2749-1

Livotov, P. (2016), Systemic Approach for Enhancing Innovative and Competitive Capability of Industrial Companies - Research Concept. *Journal of the European TRIZ Association*, ISSN 1866-4180, 01/2016 (02), pp. 163-169.

Pokhrel, C., Cruz, C., Ramirez, Y., Kraslawski, A. (2015), Adaptation of TRIZ contradiction matrix for solving problems in process engineering. Chemical Engineering Research and Design 103, 3–10. doi: http://dx.doi.org/10.1016/j.cherd.2015.10.012

Poppe, G., Gras, B. (2001), TRIZ in the Process Industry. Proceedings of the European TRIZ Association Conference "TRIZ Future 2001", Bath UK, 7-9 Nov. 2001, pp. 44-56, ISBN 90-77071-01-6

Rahim, Z.A., Sheng, I.L.S., Nooh, A.B. (2015), TRIZ methodology for applied chemical engineering: A case study of new product development. Chemical Engineering Research and Design 103, pp.11–24. doi: http://dx.doi.org/10.1016/j.cherd.2015.08.027

Reay, D., Ramshaw, C., Harvey, A. (2013), Process Intensification (Second edition). Butterworth-Heinemann, Oxford.

Robles, G.C., Negny, S., Lann, J.M.L. (2009), Case-based reasoning and TRIZ: A coupling for innovative conception in Chemical Engineering. Chemical Engineering and Processing: Process Intensification 48, 239–249. doi: http://dx.doi.org/10.1016/j.cep.2008.03.016

Rong, B.G., Kraslawski, A., Nyström, L. (2000), Creative design of distillation flowsheets based on theory of solving inventive problems, in: Pierucci, S. (Ed.), Computer Aided Chemical Engineering, European Symposium on Computer Aided Process Engineering – vol. 10. Elsevier 2000, pp. 625–630.

Saaty, T.L. (1990), Multicriteria Decision Making: The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. RWS Publications.

Srinivasan, R., Kraslawski, A. (2006), Application of the TRIZ creativity enhancement approach to design of inherently safer chemical processes. Chemical Engineering and Processing: Process Intensification 45 (2006), pp. 507–514. doi: http://dx.doi.org/10.1016/j.cep.2005.11.009

Stankiewicz, A.I., Moulijn, J.A. (2000), Process intensification: transforming chemical engineering. Chemical Engineering Progress 96 (1), pp. 22–34.

Totobesola-Barbier, M., Marouz, C., Giroux, F. (2002), A TRIZ-based Creativity Tool for Food Processing Equipment Design. The Triz Journal. Retrieved on 11.09.2016 from http://www.trizjournal.com/archives/2002/10/b

VDI (2016), VDI Standard 4521. Inventive problem solving with TRIZ. Fundamentals, terms and definitions. Berlin.

Yakovis, L., Chechurin, L. (2015), Creativity and heuristics in process control engineering. Chemical Engineering Research and Design, Inventive Design and Systematic Engineering Creativity, vol. 103, Nov. 2015, 40–49. doi: 10.1016/j.cherd.2015.07.010