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Using functional approach to increase effectiveness of open innovation in chemical engineering

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ABSTRACT

Open innovation has been widely discussed ever since P&G publicly pronounced that “Open innovation is a way for companies to avoid the stale, repetitive thinking that can happen when employees are accustomed to their internal ways of solving problems”. The goal of open innovation is to connect innovation problem to the best existing technical solution to this problem that can be found outside of company’s R&D. The general concept of open innovation has been widely accepted and practiced. However, in practice, open innovation frequently works inefficiently because problem at the input is not formulated properly or is a wrong problem to be solved. The objective of this article is to discuss this challenge of open innovation and demonstrate – through the prism of chemical engineering – how one of the main TRIZ tools, functional approach, can increase the effectiveness of open innovation.

1. Introduction to open innovation

Companies have always been going through transformations to keep up with the ever-changing world of technology changes and customer demands. Today, however, the world of technology is changing faster than ever and the pace of change is accelerating (Kurtzweil, 2005). Different industries go through transformation at different pace driven by different forces and challenges (IT companies faster than industrial engineering, for instance). Some of the notable driving forces/challenges that make present-day chemical industry innovate faster are:

- Ecological and environmental concerns result in great demand for new materials and chemicals (e.g. biodegradable materials) (Chemical Top-Trends, 2014).
- Health concerns lead to increasing demand for new truly hypoallergenic and non-toxic materials and consumer products, such as cosmetics and food. (Erickson, 2014).
- Increasing demand for innovative nano-materials that have very attractive new features, such as self-healing materials (e.g. car paint) (Woodford, 2014).

Being able to make quick adjustments to account for these and other challenges will become a differentiator for chemical companies in the next several years. Agility is especially important considering that, compared with companies in other industries, chemical companies’ returns have fallen over the last 20 years for a number of reasons including waning interest in base chemicals and softening demand for agrochemicals and fertilizers (though the overall returns in the industry remain strong) (Gocke et al., 2013).

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Outside chemical industry, no matter where you look, product development cycles are shrinking, the number and complexity of products is increasing, manufacturing revolution is happening (additive manufacturing being a prime example), natural resources are decreasing, turnover rate is increasing and global competition puts more and more pressure on companies.

One way to minimize risk associated with these changes, and innovation in general, is to utilize resources available through so-called "open innovation" (OI), i.e., to leverage knowledge (technologies and ideas) that exists outside your company's R&D. Henry Chesbrough, who coined the term, defines open innovation as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation" (Chesborough, 2003).

Ideas and/or technologies in OI can come from individuals, universities or companies (conceptual design firms, crowd sourcing firms, start-ups and even competitors). Most people today equate OI with crowd sourcing (i.e., soliciting ideas from a large group of people, very often by internet), while, in fact, different formats can be employed (e.g., hiring a firm specializing in OI or a university professor).

Open innovation (OI) offers a number of advantages for corporations:

- *Access*: OI presents an opportunity to involve more brains from different disciplines/industries, and, as a result, dramatically increases pool of potential solutions. This is especially relevant today considering exponential growth in the number of technologies over the last half-century.
- *Speed*: OI presents an opportunity to accelerate innovation as internal development can take much longer than external.
- *Reduced risk*: solutions from outside need to be adopted rather than invented from scratch, and adaptation is inherently less risky than invention.
- *Flexibility*: effective size of R&D becomes instantly scalable depending on the needs of today.
- *Cost*: consultants costs are often much lower than hidden costs associated with internal expenditures.

To summarize, open innovation can and should be a great resource for product development and process improvement because it lowers the risk/cost of innovation while simultaneously increasing the benefit. There are indeed a number of examples of how OI has helped companies like, for example, GE and P&G achieve great results (e.g., Stinson, 2014; Huston and Sakkab, 2006).

Leveraging external knowledge (as technologies or ideas), however, is not as simple as it sounds. After initial euphoria that OI concept had brought into the corporate world, a lot of early adapters of OI are having a serious "buyer's remorse" because what had been promised to be easy, cost effective, easily adaptable and overall efficient turned out to be quite demanding in resources, generating a rather low yield and indeed requires special skills and organizational rearrangements. Thus, there is a strong desire and need to make OI widely accepted effective tool to accelerate the R&D process.

This paper focuses on one of the most significant challenges presented by OI – how to properly formulate the problem – and demonstrates how GEN3's functional approach helps overcome this particular pitfall.

2. What is the right problem for open innovation?

The goal of open innovation is, at the high level, to connect innovation problem to the best existing solution to this problem. In other words, OI can be viewed as a matching function between problems (inputs) and existing technical solutions (outputs). As such, OI challenges fall into five general categories: (1) How to properly formulate the problem? (2) How to access relevant pool of solutions? (3) How to find the best solution? (4) How to adapt identified solutions to the specific requirements of the original problem? (5) How to do the above effectively and efficiently.

While addressing organizational challenges (e.g., how to ensure alignment of capabilities, how to find the right external partner), legal challenges (who owns IP?) and "soft" challenges (e.g., how to deal with the "not invented here" syndrome) of OI is an important topic, this paper focuses on a particular challenge that, from our experience, technical professionals are dealing with most of the time. This challenge is how to properly formulate innovation problem for OI.

Our research and practice have shown that there are typically four major issues that need to be addressed during problem formulation:

(1) The originally stated problem is usually not the one you really need to attack. Typically, innovation problems are ill-defined and/or open-ended, ranging from strategic (e.g., "What is the next generation of products in my category?") to technical (e.g., "How to considerably reduce losses of energy during production of paper?"), or consumer needs-driven (e.g., "How to make commercial canned food taste like home made?"). Innovation challenges formulated in such way are not a proper input to some models of OI such as crowdsourcing because they are not specific or precise; they require too much contextual knowledge and are too high level.

(2) As discussed in the paragraph above, open-ended or ill-defined innovation challenges are rarely used as input to OI. Instead, specific narrow problems with clearly stated requirements and constraints are typically posted (e.g., Stinson, 2014). Such high level of specificity in problem formulation, however, implies tight connection to the specifics of the industry the problem originates in. In other words, if problem formulation uses language specific to a particular industry, technology search becomes largely limited to a search within company's own industry. This defeats the whole purpose of OI because the probability of finding a new solution in your own field of expertise is inherently low.

In other words, OI presents an interesting contradiction: on one hand, the problem has to be specific to avoid irrelevant solutions, but, on the other hand, the problem cannot be too specific because specificity often prevents technology search outside the industry that the problem originates from.

(3) The purpose of OI is to find solutions outside company's R&D expertise. However, the search field becomes almost infinite if you are trying to search for the right solution/technology outside your own area of expertise – i.e., output has high level of "noise". Companies can receive several thousand submissions to a given problem through

crowd sourcing. Yet most of these submissions are not relevant, difficult to understand or simply too low quality to consider. Yet, it takes highly educated (and, therefore, highly paid) professionals to sift through all submissions. As a result, OI increases the workload of internal R&D personnel because they have to evaluate, filter and adopt solutions that come from outside (i.e., spend considerable time and effort) on top of what they already have to work on.

The question is then how to effectively narrow down your search for solutions to *relevant* solutions.

(4) Finally, another common issue with problem formulation is how to present the problem without disclosing confidential information.

To summarize, problem formulation is one of the major challenges of OI today. Before asking a question, one has to make an essential additional step of thinking what to ask. Asking the right question will considerably reduce risk of OI because it will lead to (1) more precise problem definition, (2) more relevant solutions, and (3) fewer "filtration" efforts on the submissions.

To address this challenge – how to properly formulate the problem for OI – we propose to use the so-called functional approach (Hauptman et al., 2011; Litvin, 2005).

3. What is functional approach?

All systems – consumer goods products, medical devices, heavy industry machines, manufacturing equipment – are created to perform functions (e.g., water-purifying filter exists to perform function "stop contaminants"). Components in the systems exist only to enable performance of the functions, i.e., function precedes component. There are four major reasons why it is important and necessary to focus on functions rather than on components: (3.1) functional thinking enables "out-of-the-box" thinking, (3.2) functions are universal and, thus, functional thinking erases boundaries between industries, (3.3) functional approach helps translate an open-ended and/or ill-defined innovation problem into a set of specific problems, and (3.4) functional approach avoids issues related to disclosing of confidential information. Below, we will look at these in more details.

3.1. Functional thinking enables "out-of-the-box" thinking

Components-based thinking, on the other hand, introduces psychological inertia which is one of the primary innovation killers.

To demonstrate how functional thinking helps fight psychological inertia, consider this definition of a function used in modern TRIZ (Russian acronym for Theory of Inventive Problem Solving): *function is an action performed by component to change or maintain a parameter of another component* (Devoino et al., 2001; Fey and Rivin, 2005; Gerasimov et al., 1991; Tsourikov et al., 2000). For example, in the function "gas heats container", gas changes temperature of the container. In the function "container holds gas", container maintains position (and shape) of the gas. This definition is consistent with the typical "subject–action–object" linguistic topology that is used in a variety of search engines and ensures that interactions between objects are described through measurable parameters.

While seemingly trivial and obvious, the definition reveals just how much preconceived notions and psychological inertia people carry around when they talk about functions using normal everyday language. "I read newspaper", "eye glasses improve vision", "helmet protects the head" are all examples of how people typically describe what happens around them, yet these phrases do not reflect what is actually happening in reality. For example, eyeglasses do nothing to improve vision (instead, eyeglasses refract light), helmet does not do anything useful for the head, i.e., it does not change any parameter of the head (instead, helmet deflects a bullet), and "I" don't change any parameter of the newspaper (in contrast, newspaper informs me). In contrast, definition of the function introduced above enforces precision, specificity and objectivity in describing what exactly is happening in the system thus helping to avoid psychological inertia when describing how systems function.

3.2. Functions are universal and, thus, functional thinking erases boundaries between industries

Components are specific to systems (for example, filter in the water purification system has a different design then filter in the firefighter's gas mask). Components may differ even in the same category of systems, e.g., different models of gas masks will have different filter designs for different market niches or different generations of systems. Functions, on the other hand, are similar not only across different generations of systems, but also across categories. Filter in all systems – in the compressor, in the equipment that makes detergents, in the air conditioner, in laundry dryer, vacuum cleaner and ventilation systems in the chemical laboratories – performs the same function "stop contaminants". Additionally, statistical analysis shows that there is a limited – and small – number of typical functions (Fedosov, 2009). The fact that functions, unlike components, are similar across industries can and should play a pivotal role in open innovation.

Open innovation can be particularly powerful if one can transcend the boundaries of a particular field of expertise – *your* field of expertise, where you already know all the answers – and venture into remote disciplines. Solutions will be particularly powerful and/or elegant if, for example, mechanical problem is solved using chemical engineering or chemical problem is solved using optics. For example, a mechanical problem "how to inflate a life vest?" can be solved using gas-foaming reagents, when they come into contact with water (Van Mil et al., 2014). Or, a chemical problem in beer of deterioration of hop derivatives into undesirable components with "skunk-like" flavor under exposure to UV light can be solved by modifying optical properties of the beer bottle. Functional approach erases boundaries between disciplines because, as we showed above, functions are universal.

3.3. Functional approach helps to go from broad, open-ended problem statement to very specific problem statement

Analyzing systems from the functional perspective helps reveal functional disadvantages – harmful functions and useful functions that are not performed adequately. This analysis spells out what exactly is wrong in the system, at a very specific level. For example, Function Analysis translates a broad project goal "How to scale a process of capturing CO_2?" to such specific problems, among others, as (1) How to increase stability of carbonic acid to increase solubility of CO_2? (2) How to increase rate of photosynthesis to reduce energy consumption? (3) How to reduce contact surface area of particles to increase extraction rate of cations?

3.4. *Functional approach avoids issues related to disclosing confidential information*

Functional approach describes the problem in terms that are not specific to a particular system. For example, specific problems mentioned in the previous paragraph (e.g., "How to increase stability of carbonic acid?" are agnostic not only to a specific product, but also to specific industry. In fact, these functions are addressed in a number of industries including food production, paper making, oceanology, oil industry, geochemistry and agriculture.

All in all, functional approach helps with the critical piece of any innovation challenge – how to identify the "right problem" to solve.

It should be noted that, historically, the notion of functional thinking can be traced to value engineering originally developed by Lawrence Miles in the 1950s (Miles, 1961). Several schools of thought on the subject have since emerged independently and include FAST technique (Bytheway, 1971), TRIZ (Gerasimov et al., 1991) and a number of others (see, for example, comprehensive review in Hirtz et al., 2002). For clarity, we should note that while unified terminology and algorithms of functional approach are still in the process of being established, this paper uses terminology typically described by the TRIZ community.

4. Functional approach for framing the problem in the context of open innovation

This section will discuss how functional approach can be used to properly define and frame a problem to significantly increase benefits of OI. It will also provide an illustrative case study from chemical engineering on the subject.

The basic algorithm for proper problem formulation includes the following: (a) translating initial broad innovation problem into a set of non-trivial and specific problems using various analytical tools, including function analysis (Fey and Rivin, 2005; Gerasimov et al., 1991), (b) generalizing specific problem formulated as a function, and (c) identifying leading areas where the function of interest is performed. Note that steps (b) and (c) taken together are often referred to as function-oriented search (FOS) (Litvin, 2005). We will now look into this algorithm (Fig. 1) in more details in the context of OI.

4.1. *Translating initial broad innovation problem into a set of non-obvious specific problems*

Translating initial broad innovation problem into a set of non-obvious specific problems by applying analytical tools such as function analysis, flow analysis, cause-effect chain analysis, and trimming (Fey and Rivin, 2005; Gerasimov et al., 1991; Terninko et al., 1998). The idea here is to gain a deeper understanding of the system and identify "the right problems" to solve. These tools also enforce an objective and

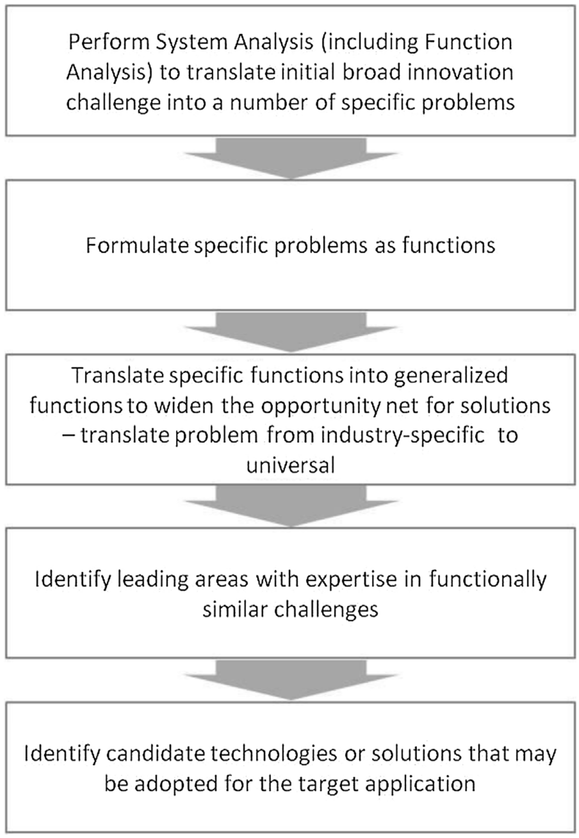

Fig. 1 – Roadmap for using functional approach in OI.

"out-of-the-box" view of the system that is often elusive to subject matter experts.

Let us illustrate how functional approach can help with problem formulation for OI using the example of pumping slurries in mining. In particular, centrifugal slurry pumps are used under difficult conditions during mill discharge, rock hoisting, ore dressing, transportation and waste management. Clogging of the pump in the course of operation with dense heterogenic mixtures of sand, loams, complex chemical wastes, and mud is one of the common problems during deep vertical slurry pumping. As a result of clogging, equipment experiences high failure rate that leads to increased operational costs: maintenance expenses and down-time increase considerably.

While this example presents a seemingly specific technical problem, it is actually not specific enough for OI, especially if we are looking for solutions in the remote areas. This is because mechanisms and parameters of clogging depend on the specifics of equipment, on the specifics of substances used and on specific conditions under which technology is used. To uncover these specifics, system analysis, including function analysis, is used.

In particular, system analysis of the pumping technology identified a number of much more narrow problems that lead to clogging including, for example, the following: (1) precipitation of solid particles happens because they are not mixed with water well, (2) precipitation of solid dirt particles happens because density of solid particles is different from the density of water, (3) precipitation of solid particles happens because viscosity of water is too low, (4) gravity causes agglomeration of slurry particles on the bottom of the vessel.

4.2. *Generalizing specific function in question*

The problems that were formulated in the previous step are specific to mining. If the goal is to ultimately find solution in a different industry, then problem formulation that uses language specific to your industry will not help. Problem has to be reformulated as function and then function has to be generalized by action and by object of the function. This step – generalization of the function – considerably broadens the pool of potential solutions by removing language specific to the industry of the original problem.

In particular, continuing with our case study on pump clogging, consider specific problem (1) from the previous section: "Precipitation of slurry particles happens because they are not mixed with water well", or, formulated as a function: "How to better mix slurry particles in the water (to prevent sticking/precipitation?)". This function is specific to mining industry because it describes components specific to mining industry. In order to reformulate this specific function into generalized function, we need to generalize action (mix) and object of the action (slurry particles in the water). As a result, the generalized function can be formulated as "How to move solid particles in liquid?" This generalized function is not specific to mining, does not disclose any confidential information and is performed in many industries as demonstrated in the next section.

4.3. *Identifying leading area for the performance of function of interest*

Generalizing the function places the problem "outside of the box" of a specific industry and broadens possibility of finding solutions in different areas of engineering or science. However, looking "outside of the box" means that there are now many more solutions to look at and the situation can easily become unmanageable. Somehow, we now need to narrow our field of view to solutions that are relevant and strong. The answer lies in finding/defining leading areas of science and engineering where the function of interest is more important or is performed under much more demanding conditions compared to the industry where the original problem came from (Litvin, 2005). It allows capitalizing on investments made in other industries where those challenges are more critical, and, hence, much more resources (manpower, capital, and time) were spent to address them.

In our example on pump clogging, such leading areas for the generalized function "How to move solid particles in liquid?" are, for example, construction, food and automotive industry.

One particular solution is the device that contains a mixing chamber, rotor with screw blades and vibrator installed on the crankshaft of the drive. Pump vibrator (placed on engine shaft instead of a spiral) will fluidize high-density depositions during a period of several seconds to the state of flowing suspension that could be easily sucked by the pump without it clogging. The mixer is capable of mixing viscous and bulk (free-running) components, as well as their combinations and, additionally, consumes much less energy as compared to other known mixers. The principle of operation of such mixer – vibration – ensures that energy is transmitted only to a medium being mixed (located near the source of vibration) without exerting force upon the components of the vibrator proper.

After several solutions from different leading areas are identified, the best solution – i.e., solution that fulfills project requirements and constraints better than others – has to be selected. Note that, typically, even the best solution presents adaptation challenges that have to be identified and resolved using, for example, TRIZ-based problem solving tools (Fey and Rivin, 2005; Terninko et al., 1998).

Another case study of how functional approach could be used to increase precision of problem formulation is presented here. The initial problem at hand is how to reduce the cost of mayonnaise production – another example of an open-ended problem that would not work as an input to the typical OI process such as crowd sourcing. System analysis (including function analysis and cause–effect chain analysis) of the manufacturing process reveals that one of the major factors that drive cost is utilization of two mixers instead of one. In particular, the equipment has to be cleaned several times per day when the mayonnaise formula is changed. As a result, time and ingredients are wasted. Using a single mixer instead of two would cut these losses in half (note that modification of the mixers is not allowed by project constraints).

The reason why two mixers are used is as follows. Mayonnaise contains three major ingredients, besides others: egg powder, vegetable oil and vinegar. These ingredients have to be mixed together but cannot because vinegar will chemically decompose the egg powder. Therefore, egg powder is first mixed with oil in Mixer 1 and then the resulting mixture is mixed with vinegar in Mixer 2 (at this point in time, oil already enveloped egg particles and thus protects them from vinegar). Therefore, one of the specific problems revealed by analysis and formulated as a function is this: "How to delay chemical reaction between the vinegar and the egg powder?"

The next step of the algorithm from Fig. 1 is to generalize this function: "How to control intensity of chemical reaction?" Again, we demonstrate here that formulating problems as generalized functions avoids confidentiality issues in OI as such problem formulations are industry-agnostic. This problem "How to control intensity of chemical reaction?" is well known to chemists and solutions to this problem are used in a number of chemical technologies including, among others, galvanic coatings and dyeing of textiles. In particular, using *pre-cooled* vinegar was recommended as it delays the reaction between vinegar and egg powder, requires minimal changes to the process and has no adverse effects. As a result, a single mixer can be used to mix vinegar, egg powder and oil.

Note that this solution seems almost trivial and obvious in retrospective. What is not trivial is translation of the initial broad problem "Cost of manufacturing is too high" to the specific problem "How to delay chemical reaction between the vinegar and the egg powder?" This specific problem was not at all obvious for the process engineers who "owned" the initial problem.

5. Conclusions

Open innovation is a powerful approach to accelerate, reduce risk and lower cost of innovation. Today, however, the advantages of OI are not fully exploited because the industry has not figured out yet how to implement this approach effectively and efficiently. Here, we showed how functional approach can resolve a significant bottleneck in OI: framing the problem. We also demonstrated how functional approach can provide these advantages to those who use it in the context of open innovation:

- Ability to address complex and broad rather than narrow problems.
- Better understanding of the problem through system analysis.
- Ability to transcend boundaries of a specific industry/discipline and find solutions in remote areas.
- Ability to reduce noise level and increase quality of output by looking for solutions only in leading areas of engineering and science.
- Ability to compare ideas from different disciplines because functions are universal.
- No confidentiality issues because generalized functions do not use industry-specific language.

It is important to note that proper problem formulation does not come for free. Companies have to be trained in the methods of system analysis, system analysis requires time and discipline, and time is always equated with money. However, failure to invest in the above ultimately leads to failure of identifying and realizing new business opportunities, enormous waste of R&D resources, inability to successfully leverage outside resources and global knowledge and, eventually, losing competitive advantage in the market place.

This paper discusses utilization of functional approach in the context of OI. Specifically, this paper is about using functional approach for reframing of the initial problem to allow for finding solutions outside of the initial area of expertise. However, it should be noted that functional approach has and should be used for a variety of applications including product and process improvement, new product and processes development, technology transfer, etc.

This paper focused on the input to OI – how to properly formulate a problem to better leverage outside knowledge and connect problems to solutions in a more effective manner. Another important (and largely not addressed) topic relates to the output of OI – how to select the best solution to the problem from a large pool of technologies and ideas submitted through OI, then identify and resolve adaptation challenges. TRIZ-based methodologies of systematic innovation offer a number of tools for addressing these challenges as well. This, however, is a topic for a different paper.

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