Systematic Integration of Innovation in Process Improvement Projects Using the Enhanced Sigma-TRIZ Algorithm and Its Effective Use by Means of a Knowledge Management Software Platform

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In an evolving, highly turbulent and uncertain socio-economic environment, organizations must consider strategies of systematic and continuous integration of innovation within their business systems, as a fundamental condition for sustainable development. Adequate methodologies are required in this respect. A mature framework for integrating innovative problem solving approaches within business process improvement methodologies is proposed in this paper. It considers a TRIZ-centred algorithm in the improvement phase of the DMAIC methodology. The new tool is called enhanced sigma-TRIZ. A case study reveals the practical application of the proposed methodology. The integration of enhanced sigma-TRIZ within a knowledge management software platform (KMSP) is further described. Specific developments to support processes of knowledge creation, knowledge storage and retrieval, knowledge transfer and knowledge application in a friendly and effective way within the KMSP are also highlighted.

Keywords: *Process Innovation, Knowledge Management Software Platform, Innovative Problem Solving Methodology, sigma-TRIZ, DMAIC*

1 Introduction

In order to increase their competitiveness, global operating companies have a constant preoccupation on continuous process improvement [6], [7], [8], [14], [15]. Process improvement should increase the efficiency and effectiveness of the business processes [2], [3]. Nowadays, DMAIC methodology is widely used within process improvement projects [3], [6], [7], [12], [13]. However, the success of a DMAIC project is mainly determined by the quality of solutions proposed – therefore top experts in the field of application should be involved. This situation is not accessible to all companies, thus they must support the solution generation process with adequate tools in order to get reliable results [4]. Moreover, when significant noise factors act upon business processes, creative problem solving and innovation become key approaches to achieve high levels of process maturity and capability [3], [5]. A powerful tool for inventive problem solving that might be considered in this respect is TRIZ method [1], [9], [10], [11], [16], [17].

Integration of TRIZ method within DMAIC methodology has been analyzed by several researchers, recent results in this respect being reported in [5], [10], [11], [16] and [17]. However, none of these works presents a systematic algorithm for integrating TRIZ within DMAIC. For example, in [10] the focus is only on highlighting the positive effect of using TRIZ in connection with DMAIC in order to stimulate creativity and to reduce the time period up to the formulation of mature solutions to the problem under consideration. In the same spirit, the paperwork [16] insists on the necessity to use TRIZ together with DMAIC to accelerate the innovation process but it lacks in proposing a detailed solution of integration. In [17], the use of quality planning tools like QFD for identification of key processes where TRIZ should be applied with priority during the approach of DMAIC is put into evidence. Also, this research work does not reveal a way to inter-correlate TRIZ and DMAIC. The inclusion of TRIZ method within DMAIC methodology under a specific algorithm called sigma-TRIZ was first time proposed in [3] and [4], by the main author of this paper. The sigma-TRIZ algorithm considers the problem of process improvement from a comprehensive perspective, by creating a systematic framework of identification and prioritization of the conflicting zones within the analyzed process, starting from the perspective that any improvement should lead to the increase of both efficiency and effectiveness of the process without affecting in the same time the balance within the processes correlated with the analyzed one. From this point of view, sigma-TRIZ algorithm allows the formulation of balanced and robust improvement solutions with respect to the noise factors (attractors) acting upon the process [3], [4]. The sigma-TRIZ algorithm connects the multiple objectives with the innovation vectors generated by the TRIZ framework, considering a complex set of barriers and challenges from the "universe" of the analyzed process and starting from the prioritization of the intervention areas with respect to the criticality of the conflicts within the process [3].

In this paper, some enhancements of the sigma-TRIZ algorithm are introduced. They are related to the prioritization of the proposed solutions and identification of the correlations between them, as well as to the formulation of the algorithm in a way that is suitable for implementation in a software application. The mode in which the enhanced sigma-TRIZ algorithm is implemented in a knowledge management software platform (KMSP) to support processes of knowledge creation is also revealed in the paper. Specific developments of the KMSP for knowledge storage and retrieval, knowledge transfer and knowledge application in a friendly and effective manner are also highlighted. A case study showing a step-by-step application of the enhanced sigma-TRIZ algorithm within a DMAIC procedure is further illustrated in the paper. The paper ends with conclusions on the practical implications of these researches for improving the competitiveness of companies operating in a knowledge-based economic environment.

2 Enhanced sigma-TRIZ algorithm

Consideration of innovative problem solving tools like TRIZ within the improvement phase of the Six-Sigma DMAIC methodology leads to mature ways for systematic integration of innovation within process improvement projects [3], [16], [17]. It comes from the practical finding that most of the business-related problems are not simple and their solving requires consideration of several interrelated and convergent process improvement projects in relation to a given intended improvement objective.

Denoting with $P = \{p_1, p_2, p_3, ..., p_n\}$ the set of interrelated and convergent process improvement projects linked to the intended improvement objective O, where n is the number of improvement projects in the set P, the objective O is achieved if and only if P leads to a required level of process effectiveness E and efficiency e in a time horizon T, imposed by the dynamics of the competitive business environment. In order to achieve this goal, trade-offs and trial-and-errors approaches are not admitted [2]. From this perspective, creative tools like brainstorming are not very much feasible during the phase of solution formulation [1]. Moreover, between E and e a certain correlation concerning to their evolution along time must exist [2]:

$$E(t)\Big|_{E_0}^{E_1} = f\left(t\Big|_{t_0}^{t_1}, e(t)\Big|_{e_0}^{e_1}\right), \quad (1)$$

where: t is the time variable, E_0 is the level of process effectiveness at the initial moment t_0, E_1 is the expected level of process effectiveness at the moment t_1, e_0 is the level of process efficiency at the initial moment t_0, e_1 is the expected level of process efficiency at the moment t_1, and $T = t_1 - t_0$. The function f depends on the adopted innovation strategy (e.g. upsizing, downsizing).

Innovative solutions must also avoid mediocrity [2]. From this perspective, the focus within the process improvement projects should be all the time on two aspects: a) to target the ideal final result [1], [2]; b) to target the convergence paradigm [11]. The ideal final result (*IFR*) is the ratio between the sum of all useful functions and effects and the sum of all harmful functions and effects (including the related costs) [1]. The convergence paradigm focuses on reducing the difficulty of problem resolution [11]. In this respect, it operates with the ratio between the total number of possible variants and the total number of possible steps that lead to mature solutions (which solve the problem without compromises). The mathematical formulation of the law of ideality is [1], [2]:

$$I = \frac{\sum F_U}{\sum (F_H + C)}, \quad (2)$$

where: I is the ideality, ΣF_U is the sum of useful functions and effects, ΣF_H is the sum of harmful functions and effects, ΣC is the sum of costs because of poor-performances (losses). The goal is to have as low as possible harmful functions, effects and costs, and as much as possible useful functions and effects. Thus, in theory, when ideality is achieved, the result is: $I \rightarrow \infty$. In real systems this cannot happen, but the target is to move as close as possible to ideality (also called "local ideality"). The mathematical formulation of the law of convergence is [2], [11]:

$$D = \frac{TE}{ST}, \quad (3)$$

where: D is the difficulty in problem resolution, TE is the number of trial and error iterations of variants, ST is the number of steps leading to acceptable solutions. Obviously, the goal is $D \rightarrow 1$. These being said, formulation of highly mature process improvement projects require advanced tools of innovative problem solving, which follow the laws described in (2) and (3). The enhanced sigma-TRIZ algorithm is one of these possible tools. The following paragraphs of this section describe the algorithm. It consists of the following steps:

Step 1: Reenergize the major objective and reformulate it in a positive and target-oriented manner: The improvement objective O is very often expressed in a negative and/or vague and/or too large manner. Thus, a clear statement of the improvement objective is firstly required. After this process, a re-phrased objective O_p is worked out. For example, considering a software development company, a possible improvement objective O would be: reduction of the number of "bugs" for the work delivered to the customer. Its reformulation in a positive and target-oriented manner O_p would be: no "bug" in the software application when it is delivered to the customer. This reformulation includes the intended target: "zero bugs".

Step 2: Reformulation and highlighting the most critical aspects in achieving the declared objective: The set of significant barriers in achieving the objective O_p is identified. The set is denoted with B, where $B = \{b_1, b_2, \ldots, b_k\}$, b_j, $j = 1, \ldots, k$, being the process-related barriers (k is the number of barriers).

Step 3: Problem translation into TRIZ generic conflicting characteristics: For each barrier b_j, $j = 1, \ldots, k$, a set of TRIZ generic parameters that require improvements (maximized or minimized) should be determined. In this respect, reader is advised to consult the reference [1], pp. 169. Thus, each barrier b_j, $j = 1, \ldots, k$, has a corresponding set of generic improvement requests $GR(b_j)_i$, $i = 1, \ldots, h(b_j)$, $j = 1, \ldots, k$, where $h(b_j)$ is the number of generic improvement requests associated to the barrier b_j, $j = 1, \ldots, k$. For each generic parameter $GR(b_j)_i$, $i = 1, \ldots, h(b_j)$, $j = 1, \ldots, k$, a set of generic conflicting parameters should be further determined. They are extracted from the same table of TRIZ parameters (see reference [1], pp. 169). At the end, a number of k sets of generic conflicting parameters are determined. These sets are denoted with: $GC(GR(b_j)_i)_f$, $f = 1, \ldots, g(GR(b_j)_i)$, $i = 1, \ldots, h(b_j)$, $j = 1, \ldots, k$, where $g(GR(b_j)_i)$ is the number of generic conflicting parameters associated to the generic improvement request $GR(b_j)_i$, $i = 1, \ldots, h(b_j)$, $j = 1, \ldots, k$.

Step 4: Extraction of the most critical pairs of conflicting problems: From the pairs of conflicting problems formulated at step 3, the most critical ones are extracted for further transformations. It might be possible that a qualitative analysis to come up at the conclusion that none of the pairs should be eliminated. Thus, in the most general case, the result is a set of pairs of conflicting problems of the following manner: $PR_{1,1} = \{GR(b_1)_1 - GC(GR(b_1)_1)_1\}$; $PR_{1,2} = \{GR(b_1)_1 - GC(GR(b_1)_1)_2\}$; …; $PR_{1,g(GR(b_j)_i)} = \{GR(b_1)_1 - GC(GR(b_1)_1)_{g(GR(b_j)_i)}\}$; …; $PR_{h(b_k),g(GR(b_j)_i)} = \{GR(b_k)_{h(b_k)} - GC(GR(b_k)_{h(b_k)})_{g(GR(b_k)_{h(b_k)})}\}$.

In order to simplify the mathematical representation of the pairs of conflicting problems, from this point ahead the set is denoted $PR = \{PR_1, PR_2, \ldots, PR_m\}$, where m is the number of resulted pairs of conflicting problems.

Step 5: Define the gravity for each pair of conflicting problems: Using a scale from 1 (enough critical) to 5 (extremely critical), a factor of gravity fg_t, $t = 1, \ldots, m$ is associated to each pair PR_t, $t = 1, \ldots, m$.

Step 6: Identification and ranking of TRIZ inventive vectors: TRIZ method operates with a set of 40 inventive generic vectors (see references [1], [11]). For each pair of conflicting problems (that are actually generically formulated) a well-defined sub-set of inventive vectors from the complete set of 40 vectors (counted from 1 to 40) exists; this sub-set comprises between 0 and 4 inventive vectors (also called inventive principles) (see references [1], [11]). If a certain sub-set comprises 0 vectors the meaning is that the analyzed case is critical and only radical changes on the system would improve the situation [1]. Thus, for each pair PR_t, $t = 1, \ldots, m$, a set of inventive principles $V_t = \{V_{1,t}, V_{2,t}, V_{3,t}, V_{4,t}\}$, $t = 1, \ldots, m$, is associated. Each set V_t, $t = 1, \ldots, m$ is revealed by the so-called "TRIZ matrix of contradictions" (see references [1], [11]). According to the TRIZ matrix of contradictions (see references [1], [11]) some sets V_t, $t = 1, \ldots, m$, might be null or might have less then 4 members (i.e. only 1, 2 or 3 members). Once the sets V_t, $t = 1, \ldots, m$, are defined, a rank is given to each inventive vector. The rank is actually the sum of the gravity factors belonging to the pairs for which a certain inventive vector occurs in the sets V_t, $t = 1, \ldots, m$. Thus, if for example, a certain inventive vector V_e is present for the pairs PR_x, PR_y and PR_z, and if the factors of gravity for these pairs are fg_x, fg_y and fg_z, the rank of the vector V_e is $r_e = fg_x + fg_y + fg_z$. It is important to note that the TRIZ matrix of contradictions, as it is defined by its author (G. Altshuller), proposes a certain inventive vector not only once, but several times, depending on the combination of generic conflicting problems (see references [1], [11]). At the end of this process, a set of z unique, ranked inventive vectors is generated. This set is denoted with $U = \{U_1(r_1), U_2(r_2), .., U_z(r_z)\}$, $z < 40$, where each inventive vector U_l, $l = 1, \ldots, z$, has a rank r_l, $l = 1, \ldots, z$. For a better visualization, a certain inventive vector from the set U could be denoted as: $X(Y/Z)$, where X is the position of the inventive vector in the table of TRIZ inventive vectors (see, for example, reference [1], table 2.4, pp. 170-174), Y is the number of times the inventive vector is called in the set V_t, $t = 1, \ldots, m$, and Z is the rank of the respective inventive vector (the sum of the factors of gravity of the pairs of conflicting problems that have associated the respective inventive vector).

Step 7: Grouping inventive vectors on priorities: A qualitative analysis is done for each inventive vector $X(Y/Z)$. According to the value of Z and then of Y, the inventive vectors of the set U are grouped on priority groups. This grouping is not a mechanical process. The expert must analyze the potential impact of the vectors based on their Z and Y. Thus, vectors having a close value of their gravities (Z) and with close values of their occurrences (Y) could be grouped together. Each group has a certain priority. The group having the vectors with the highest gravities (Z) and number of occurrences (Y) is of first priority, and so on. Actually, each inventive vector comprises some generic directions of intervention where innovative solutions should be searched and defined. It is important to mention that, in the table of 40 TRIZ inventive vectors, each inventive vector has associated several sub-vectors (see, for example, references [1] and [11]). Thus, at the end of this process, for each priority group a number of generic directions of interventions will be revealed. The number of priority groups is not a fixed one; it comes up after the qualitative analysis done by the experts. The implementation of this task into a software application requires an algorithm where a group is generated, then a priority is associated to this group, and then vectors from the set U are selected and "tracked" in the respective group. Afterwards, the set of directions of intervention associated to the "tracked" vectors are revealed and the expert will select those that he/she considers suitable for the project under consideration. The process is then continued until all vectors of the set U are included in an affinity group. For a better visualization of the results, it is denoted with $a(s)$, $s = 1, ..., w$, the affinity groups, where s is the priority associated to the respective group and w is the number of groups generated at the end of the process. A direction of intervention of a certain group is symbolized $DI_{a(s),q}$, where $q = 1, \ldots, y(a(s))$, with $y(a(s))$ the number of directions of intervention in the group $a(s)$, $s = 1, \ldots, w$.

Step 8: Formulate innovative solutions: For each direction of intervention $DI_{a(s),q}$, $q = 1, \ldots, y(a(s))$, with $y(a(s))$ the number of directions of intervention in the group $a(s)$, $s = 1, \ldots, w$, and in the spirit of the direction of intervention, one or several innovative solutions might be proposed. A solution is innovative when it solves the conflict without compromises. The process of solution generation is a creative one; the team involved in this work should be enough "open" in "translating" the generic direction of intervention into effective, practical solutions. This thing requires adequate experience in the analyzed domain. The process should start with the directions of intervention from the first priority group and continue up to the last priority group. At the end of this step a set of solutions is generated. This set is denoted with $S = \{S_1(z_1), S_2(z_2), \ldots, S_d(z_d)\}$, where d is the number of solutions, z_i, $i = 1, \ldots, d$, is the factor of gravity associated to the inventive vector to which the direction of intervention DI_i, $i = 1, \ldots, d$, belongs, DI_i, $i = 1, \ldots, d$, being the direction of intervention to which the solution z_i, $i = 1, \ldots, d$, is associated.

Step 9: Establish the correlation types between solutions: It is important that all solutions to be positive correlated such as to respect the laws of ideality and convergence (see relationships (2) and (3)). Hence, each solution is analyzed with respect to all the other solutions in order to establish the type of correlations between them. To perform this task, a correlation matrix is worked out. It consists of a number of columns and rows equal with the number of solutions. The main diagonal of the matrix is not taken into account. Using this type of matrix, correlations are analyzed both from "right-to-left" and from "left-to-right". All the time, the correlation is analyzed following each column in turn, from top to bottom.

Step 10: Redefine solutions that are negative correlated: If there are two negative correlated solutions, the one having a lower value of the factor of gravity z will be primarily eliminated and a new solution will be proposed in place, such as the positive correlation to be established. It might be possible that some solutions to be not correlated each other. This is not necessarily a drawback in solution definition.

Step 11: Establish the correlation index of each solution: Using the same matrix of correlation from steps 9 and 10, the correlation level related to each pair of solutions is determined. In this respect the following scale is used: 0 – no correlation, 1 – weak/possible correlation, 3 – medium correlation; 9 – strong correlation; 27 – extremely strong correlation (almost indispensable each other). Denoting with a_{ij}, $i, j = 1, \ldots, d$, $i \neq j$, the correlation level between solution S_i and solution S_j, the correlation index C_i, $i = 1, \ldots, d$, of the solution S_i, $i = 1, \ldots, d$, is calculated with the following formula:

$$C_i = z_i \cdot \sum_{j=1;\, j \neq i}^{d} a_{ji};\ i = \overline{1,d}\,. \quad (4)$$

Step 12: Schedule solutions for implementation: Considering the correlations between solutions as qualitative indicators of prioritization and considering the correlation indexes as quantitative indicators of prioritization, experts should schedule the implementation of solutions. Actually, each solution is a kind of mini-project that requires planning and implementation. Results from a mini-project could influence the results in other mini-projects or are required to run other mini-projects, according to the correlations between mini-projects. For each mini-project several issues have to be clearly defined, like: time, costs, responsibilities, tools, etc.

3 Knowledge management platform for effective application of enhanced sigma-TRIZ algorithm in process improvement projects

In order to exploit properly the enhanced sigma-TRIZ algorithm, a knowledge management software platform has been developed. It deals with the knowledge creation (based on enhanced sigma-TRIZ/DMAIC procedure for systematic integration of innovation within business processes), knowledge storage and retrieval, knowledge transfer and knowledge application for process improvement projects within an organization. The platform was called INOVEX. INOVEX manages a flexible knowledge base of current problems (and adequate solutions) on business processes: the community (the INOVEX users) should be able to add problems related to business processes requesting help and should be able to search the knowledge base for specific solutions to problems encountered in their own business processes. The knowledge base should be reliable and quite easy to search through.

The way INOVEX handles the information mentioned above is by grouping problems and corresponding solutions in pairs. Thus, an INOVEX knowledge base entry is a pair formed of one business process problem and its corresponding solution (if any). Each such entry should be owned by a “parent” that would correspond to the business process. The knowledge base entries are categorized in a three-level business process tree, by dividing the 9 key business process blocks (according to EFQM model [8]). Each such tree node could “carry” enough knowledge base entries to be representative but not so many to confuse a user who explores it.

A knowledge base entry consists of a title, an abstract, a list of keywords, a relevance, a rich-format text that describes the problem, one that describes the solution (if any), one that describes the algorithm (if any) for obtaining the solution, the viewing rights and a validity flag (assigned by an expert user).

Solutions may be generated for a knowledge base entry problem via a problem solving tool (the Algorithm tab on the editor window); this tool is based on algorithms like TRIZ, ARIZ, ASIT, USIT, and – in version 2 of INOVEX, now in the beta stage – sigma-TRIZ. INOVEX was built on the client-server type architecture, but with one distinctive particularity: the application is completely web-based, but its interface consists of a desktop application. The server module is purely web-based, it is written in PHP and uses a MySQL database. Regarding the client module, instead of running it in a browser, which dramatically alters its performance and usability, a desktop application was developed. The initial version runs only on Windows, but it's now being improved and ported to other platforms too by recoding it in the open-source FreePascal/Lazarus environment. The client module communicates with the server as any web application, by HTTP GETs and POSTs, but it perfectly integrates onto the user's desktop.

INOVEX was built to be modular, so that code could easily be reused. Thus, the problem solving tools that it integrates (TRIZ, ARIZ, ASIT, USIT, and sigma-TRIZ) were built in their own library and are triggered by the INOVEX GUI by passing them the knowledge base entry and by requesting the solution (in the form of rich text – RTF for now but we're switching to HTML – and some specific meta-data). The next paragraphs describe how the sigma-TRIZ algorithm was implemented in the problem solving tool library. The 12 steps of the sigma-TRIZ algorithm were implemented in a page-control consisting of six tabs.

The re-definition of the major objective (step 1) is accomplished by two edit fields, one for the initial formulation of the main objective and the other for its re-energized version.

Steps 2 and 3 were merged by using a list-view component. The user can define the set of significant barriers in achieving the main objective by specifying the actual barrier (simple text information), the parameter to be improved and the undesired effect (TRIZ general conflicting parameters, selectable from a list). Thus, a list with barriers is built and automatically passed to the next step of the algorithm.

All critical aspects (barriers) in fulfilling the main objective, defined during step 3, are automatically passed to the first list-view of the second tab, which allows setting the gravity for each critical aspect (step 4 of the sigma-TRIZ algorithm). This is done by choosing a gravity level for each list entry (on a scale from 1 to 5, or 0 if the barrier is less relevant). By default, all entries have a gravity level of 0. To change it, the user selects a list entry and clicks on it to increase its gravity value with 1. Clicking on an entry with a value of 5 will reset it to 0 (“less relevant”).

Step 6 of the sigma-TRIZ algorithm is completely automated; the inventive vectors for each conflicting pairs are detected and sorted in the second list-view, according to the number of appearances and to the gravity of each corresponding barrier, as described in section before.

Step 7 groups the TRIZ inventive vectors on priorities. This is done in a list-view with information automatically taken over from the previous step. There is no limit in defining priority groups, but 3 or 4 groups would be of common sense. Technically, for the sake of simplicity, only four buttons are used. The user selects the desired inventive vector in the list-view, which is in the default priority group “0”, and uses the red “up” and “down” buttons to change this group. If a group does not yet exist, it is automatically created (the priority groups would be “0”, “1”, “2” and so on). Inventive vectors in the same priority group may also be sorted. This is done by using the gray “up” and “down” buttons. The previously prioritized vectors of innovation, now referred to as directions of intervention, are taken over automatically and placed as nodes in a tree-view component. Solutions may be defined for each direction of intervention by adding adequate child nodes. For now, each solution is represented by a simple text string.

To define a solution, the user selects the node corresponding to the desired direction of intervention and uses the “New” button at the left of the tree-view. Text corresponding to solutions can be edited as in any regular tree-view component, at any moment, by selecting it and pressing F2 or by clicking it once again. This tab automatically takes over the solutions defined in the previous step and places them in a matrix, as described by the sigma-TRIZ algorithm. Correlations between solutions can be defined by right-clicking the corresponding cell and selecting the desired value from a popup (which currently allows values of “no correlation” - a blank matrix cell, “weak” - a *w* symbol, “medium” - an *m* symbol, “strong” - an *S* symbol, and “extremely strong” - an *E* symbol). The correlation index for each solution is automatically computed according to formula (4). Solutions, as classified in the previous step, are placed in a list-view.

For each solution the user may define time, costs, and who is responsible (this version allows only text for these fields).

4 Case study

A case study was conducted in a Romanian company (here called Company A). The main business of the Company A is the production of low voltage apparatus (sockets, lengtheners, adaptors, etc.). The application of the enhanced sigma-TRIZ/DMAIC procedure to improve the performances of packaging is described in this section. It comprises three major phases: a) understanding the problem; b) generation of solutions; c) follow up actions. The problem understanding and formulation consists of the following steps:

1.1. Project: “Reducing Component Handling Due to Packaging” (many resources are engaged in handling and unpacking components as they travel from the receiving dock until they are ready for use at the line).

1.2. Intended objectives: a) Reduction of the amount of time taken in handling and unpacking production parts; b) Reduction of product cycle time from the moment a truck reaches the dock until the parts are ready for use; c) Reduction of packaging material that requires disposal.

1.3. Performance indicators: a) Amount of time taken in handling and unpacking production materials for low tension equipments; b) Product cycle time from the moment a truck reaches the dock until the components are ready for use; c) Amount of packaging material that requires disposal.

1.4. Actors (stakeholders): a) Assembly line operators/loaders; b) Stockroom personnel; c) Receiving personnel.

1.5. Key requirements and expectations: a) Assembly line operators/pallet loaders: correct parts ready to be assembled, in the proper location, undamaged, at the time they are needed; b) Stockroom personnel: easily identifiable packages/labels with accurate information as to the contents: part number, quantity, PO number, weight; c) Receiving personnel: lots or packages of components in the quantities that they are commonly used; pallets/packs that fit in the available racks (max height).

1.6. Process suppliers: a) Parts suppliers; b) Assembly line operators/pallet loaders; c) Stockroom personnel; d) Receiving personnel.

1.7. Constrains: a) Unmotivated stockroom and receiving personnel; b) Insufficient informed stockroom and receiving personnel; b) Not calibrated weight measuring devices; c) Incorrect registering dates.

1.8. Process [step-by-step] (see figure 1): (Step 1): Shipment from supplier; (Step 2): Unload truck, stage, receive; (Step 3): Info stockroom; (Step 4): Stockroom to line; (Step 5): Unpack, load the line – prepare for next processing step; (Step 5): Final assembly.

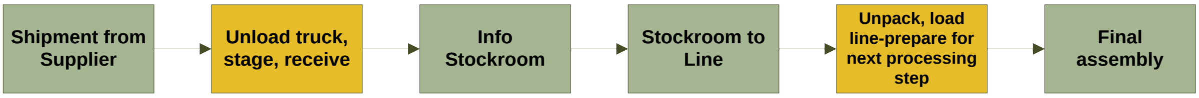

Fig. 1. Top level process map

1.9. Activities within the process (details):
Activity 1: Truck arrives at dock;
Activity 2: Unload truck stage parts for receiving;
Activity 3: Notify logistics;
Activity 4: Pull packing slip;
Activity 5: Locate extra skids/boxes;
Activity 6: Sort parts onto extra skids/boxes;
Activity 7: Write PO, PN, quantity on sorted boxes;
Activity 8: Sign and copy packing slip;
Activity 9: Packing slips to receiving and accounting departments;
Activity 10: Contact purchasing department;
Activity 11: Obtain corrected packing slip.

The logical order of activities within the unpacking production parts/materials process is put into evidence in figure 2. Some acronyms used in figure 2 are detailed here: PO – purchase order; PN – product number; QTY – quantity.

1.10. Expected results: Highlighted areas where improvement can be made by standardizing labeling, packaging, and implementing a bar code input/output to Oracle in order to reduce the time a truck reaches the dock until the parts/materials are ready for use on assembly line.

1.11. Beneficiaries of results: All actors directly or indirectly involved in handling and unpacking component parts/materials process.

1.12. Inputs necessary to ensure an adequate operation of the process: The most important inputs are: a) A good planning of the supplying process; b) Create a system for motivate the personnel involved in handling and unpacking component parts/ materials (put the accent on efficiency and work responsibility); c) The stockroom and receiving personnel to be well informed about the stockroom situation regarding parts and materials; d) The infrastructure to be sufficient and adequate (calibrated equipments, adequate space and labor conditions, etc.); d) Create an informatics system which manage the hole handling and unpacking production parts/materials process (identify rapidly a space where to rest the parts/materials or/and from where to take some kind of parts/ materials from stockroom); e) Reduce the "noise" factors (e.g. in many cases stockroom and receiving personnel are engaged in supplementary activities that have impact on their efficiency).

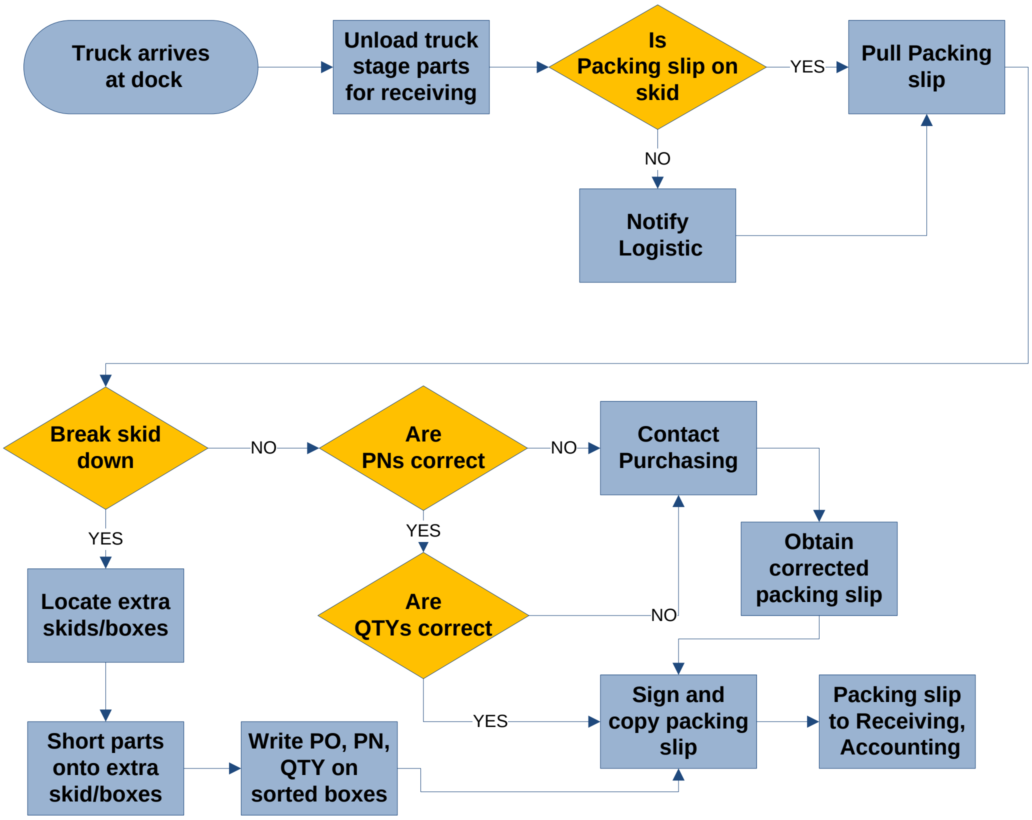

Fig. 2. Detailed process map (activities level)

1.13. Current non-conformities: Many human resources are engaged in handling and unpacking component parts as they travel from the receiving dock until they are ready for use at the line. A lot of mistakes are done in this process (uncompleted stock forms, inefficient space usage, inefficient trucks load and unload).

1.14. Root causes for the occurrence of current non-conformities: The main root causes are: a) Inefficient communication between departments (e.g. planning, stockroom and receiving department); b) Improper infrastructure for depositing the parts/ materials; c) Insufficient preparation of the personnel implicated in the process; d) Unclear agenda for supplying activities; e) Insufficient implication of the top and middle level management in these activities.

Once the root causes are identified, effective actions must be taken to overpass the problems or at least to minimize their effect. The solution generation process consists of the following steps:

2.1. Reenergize the major objective and reformulate it in a positive manner: High quality and efficiency of the handling and unpacking production parts/materials process.

2.2. Reformulation and highlighting of the most critical aspects in achieving the declared objective: The following barriers are seen of major significance in achieving the objective: a) Lack of proper infrastructure – there is no stated frame/system which assured a good coordination between departments; b) Too many possibilities to "elusion" the service tasks – that's way in some situations there is no concordance between registering and the real situation; c) Inexistence of a motivation system for the personnel implicated in the process – which highlight the efficiency; d) Insufficient/incomplete labeling of the parts/ materials.

2.3. Problem translation into TRIZ generic conflicting characteristics: Search for equivalence in the TRIZ parameters (the authors recommend using reference [1]: generic parameters causing conflicts). The following generic parameters causing conflicts in relation with the case study have been identified: 1) Energy spent by moving object; 2) Complexity of control 3) Loss of information; 4) Reliability; 5) Accuracy of measurement; 6) Accuracy of manufacturing; 7) Waste of time; 8) Level of system automation; 9) Convenience of use; 10) Harmful side effects; 11) Area of moving object; 12) Speed; 13) Capacity or productivity.

2.4. Extraction of the most critical pairs of conflicting problems: Analyzing the equivalent generic parameters from the step before in the context of the intended objectives, the most critical conflicts are between: a) 1-11; b) 1-3; c) 2-10; d) 4-12; e) 5-7; f) 6-8; g) 9-13.

2.5. Define the gravity for each pair of conflicting problems: The factor of gravity is given on a scale ranging from 1 (enough critical) to 5 (extremely critical). For the pairs in this case study, the results are: a) 1-11 (4); b) 3-4 (5); c) 2-10 (3); d) 4-12 (4); e) 5-7 (4); f) 6-8 (5); g) 9-13 (2).

2.6. Identification and ranking of TRIZ inventive vectors: The TRIZ methodology works with 40 generic vectors of innovation [1], [9]. For any pair of conflicting problems there is a well defined sub-set of vectors of innovation from the set of 40; usually from 0 to 4 vectors in a sub-set (0 is for the pairs where no kind of generic innovation is suggested; if this happens, the situation is considered somehow critical and only radical transformations on the system could improve the situation on long term) [1]. Once the TRIZ vectors of innovation are extracted, they are further counted, thus a rank will be allocated to each vector of innovation by summing the gravity factors of the pairs which called the respective vector of innovation. All vectors are important, but the vectors with the highest rank should be of first priority (with the highest relevance) when formulating solutions for innovative problem solving. The following vectors of innovation are shown by TRIZ with respect to each pair of conflicting generic characteristics of the system (the numbers correspond to the position of these vectors in the TRIZ-table of inventive principles (see table 2.4 in reference [1]): a) 15, 19, 25; b) 10, 28, 23; c) 22, 19, 29, 28; d) 21, 35, 11, 28; e) 24, 34, 28, 32; f) 26, 28, 18, 23; g) 15, 1, 28.

Taking into account the gravity factor of each pair and the number of occurrences of each vector of innovation, the following results are revealed: [28 (6/ 23); 23 (2/10)]; [19 (2/7); 15 (2/6)]; [10 (1/5); 18 (1/5); 26 (1/5); 25 (1/4); 11 (1/4); 24 (1/4); 32 (1/4); 35 (1/4); 34 (1/4); 21 (1/4)]; [22 (1/3); 29 (1/3); 1 (1/2)]. In the sets X (Y/Z), X represents the position of the vector in the TRIZ table of inventive principles [1], Y shows the number of calls of that vector to solve the conflicting problems and Z is the sum of the gravity factors of the pairs which called the respective vector of innovation. Here, the vectors of innovation are grouped into 4 sets, according to their rank. As the above results reveal, where the rank of two vectors are close, but the one with the lower rank has some more occurrences, the two vectors are considered of the same importance.

2.7. Grouping inventive vectors on priorities: Thus, the following generic directions of intervention have to be taken into account in order to achieve the proposed objectives:

Priority 1:

Mechanics substitution: Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means; Change from static to movable fields, from unstructured fields to those having structure; Use electric, magnetic and electromagnetic fields to interact with the object (28).

Feedback: Introduce feedback (referring back, cross-checking) to improve a process or action (23).

Priority 2:

Periodic action: Instead of continuous action, use periodic or pulsating actions; Use pauses between impulses to perform a different action (19).

Dynamics: Allow the characteristics of a process to change to be optimal or to find an optimal operating condition (15).

Priority 3:

Skipping: Conduct a process or certain stages (e.g. destructible, harmful or hazardous operations) at high speed (21).

Preliminary action: Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery (10).

Self-service: Use waste resources, energy, or substances (25).

Copying: Replace an object or process with optical copies (26).

Beforehand cushioning: Prepare emergency means, beforehand compensating for the relatively low reliability of the process (11).

Discarding and recovering: Make phases of a process that have fulfilled their functions go away or modify these directly during operations (34).

Parameter changes: Change an object's physical state (35).

Priority 4:

Segmentation: Increase the degree of fragmentation or segmentation (1).

"Turn Lemons into Lemonade": Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect (22).

It is important to understand that, if it possible, all the above presented directions of intervention must be tackled quasi-simultaneously such as to maximize the chances in achieving the declared objective.

2.8. Formulate innovative solutions: This process is somehow creative by itself because the team involved in the process of solution formulation must be enough “open” to interpret the generic guidelines offered by the directions of intervention into effective, concrete solutions. This also requires a relative good background and practical experience in the field under consideration. In the next paragraph it is proposed a set of solutions, which the authors of this paper saw appropriate in relation with the directions of intervention mentioned in the previous section (in the brackets {} it is introduced the number of the direction of intervention as it is counted in the set of 13 directions mentioned above; for example, {6} means the direction of intervention 6 “Preliminary action - Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery”):

Develop a proper and safety infrastructure for unload trucks and deposit the parts/ materials (e.g. create a dedicated road and dock for trucks that came for supplying parts/ materials; create a proper space for depositing the parts and materials with electronically controlled access) {1}, {2}, {7}, {11};

Generate new forms of ordering (clear, detailed with image, etc.) to avoid misunderstanding from suppliers {1}, {2}, {4}, {5}, {8};

Develop an integrated electronic identification system which will be capable to operate in the stock data base every modification and transmit the operation to all implicated departments {8}, {11}, {13}, {1};

Realize by time-to-time the own tests and evaluations to be sure by the quality of the materials and parts {6}, {11}, {13}, {10};

Develop a close collaboration with the providers/suppliers for a realistic preparation of the production plan {7}, {3}, {5};

Develop an internal motivational system based on efficiency and quality (correlate the personal efficiency with the salary) {4}, {2};

Design a realistic and anonymous internal complains system; based on it rearrange and reorganize the Stockroom and Receiving department for reducing the waste and improve the performance {2}, {6}, {13};

Encourage and sustain the development of a proper organizational culture that sustain performance, innovation and continuous learning and training of the employees {7}, {11}, {13}, {9};

Establish clear procedures and instructions for every activity within the company and assure that every employee knows them {9}, {8};

Innovative solution 1			++		++					++
Innovative solution 2					++		++			
Innovative solution 3	++			++						++
Innovative solution 4					++	++		++	++	++
Innovative solution 5	++	++				++			++	
Innovative solution 6		++	++				++	++	++	
Innovative solution 7				++	++	++		++		
Innovative solution 8	++	++			++	++	++		++	
Innovative solution 9		++	++	++				++		++
Innovative solution 10	++			++						
Legend: ++ positive correlation -- negative correlation	Innovative solution 1	Innovative solution 2	Innovative solution 3	Innovative solution 4	Innovative solution 5	Innovative solution 6	Innovative solution 7	Innovative solution 8	Innovative solution 9	Innovative solution 10

Fig. 3. Solutions correlation matrix

Automation all possible activities and sub-processes within Stockroom and Receiving department – for this solution to be realistic it must do first an economic evaluation and a value analysis of the process to reveal the costs and benefices of this demarche {11}, {7}, {10}, {12}, {5}.

Innovative solution 1	**4**			27		1					9
Innovative solution 2	**3**					27		9			
Innovative solution 3	**5**	27			9						9
Innovative solution 4	**2**					1	1		1	1	3
Innovative solution 5	**3**	3	27				3			1	
Innovative solution 6	**3**		9	1				9	27	27	
Innovative solution 7	**2**				1	1	9		9		
Innovative solution 8	**5**	3	3			9	27	27		3	
Innovative solution 9	**4**		9	3	27				27		3
Innovative solution 10	**2**	9			3						
Correlation index		**177**	**144**	**123**	**161**	**134**	**164**	**189**	**209**	**101**	**99**
	Factor of gravity	Innovative solution 1	Innovative solution 2	Innovative solution 3	Innovative solution 4	Innovative solution 5	Innovative solution 6	Innovative solution 7	Innovative solution 8	Innovative solution 9	Innovative solution 10

Fig. 4. Solutions correlation index

To these solutions several others could be added. As the algorithm reveals, for this case study the solutions 8, 6, 1 are extremely important, 2, 4, 9 and 3 are very important, 5, 7 and 10 are somehow more than important for achieving the declared objective. However, to implement these solutions, an adequate implementation plan is required, this being the next step of the "Improve" phase of the DMAIC cycle.

3.1. Establish the correlation type between solutions: Each solution was analyzed with respect to all the other solutions in order to establish the type of correlations between them. As it can be seen in figure 3, all solutions are positive correlated.

3.3. Establish the correlation index of each solution: Using the same matrix of correlation from step 3.1, the correlation level related to each pair of solutions is determined. In figure 4, the correlation index can be seen.

3.4. Schedule solutions for implementation: The ten proposed solutions are schedule for implementation as it is shown in table 1.

3.5. Prepare the implementation plan: This section is not described in this paper.

3.6. Develop the monitoring plan: Monitoring plan consists of those processes performed to observe project execution so that potential problems can be identified in a timely manner and corrective action can be taken, when necessary, to control the execution of the project.

Table 1. Scheduling the innovative solutions

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
Innov. sol. 1	■	■	■	■					
Innov. sol. 2	■	■							
Innov. sol. 3					■	■	■		
Innov. sol. 4	■		■		■		■		■
Innov. sol. 5		■	■	■	■	■	■	■	■
Innov. sol. 6		■	■	■		■	■	■	■
Innov. sol. 7	■	■	■	■	■	■	■	■	■
Innov. sol. 8	■	■	■	■	■	■	■	■	■
Innov. sol. 9	■	■							
Innov. sol. 10		■			■	■	■	■	

The key benefit is that project performance is observed and measured regularly to identify variances from the project management plan.

Table 2. Monitoring plan

Performance Indicator	Definition of terms & Unit of Analysis	Data source	Data collection			Data Analysis		Cost (€)
			Approach or method of data collection	Schedule/ Frequency	Person or Entity Responsible	Type/ Frequency	Person or Entity Responsible	
Scope: Generate new forms of ordering (clear, detailed with image, etc.) to avoid misunderstanding from suppliers								
Number of complains/ misunderstanding from suppliers	Unit of Analysis: Number of complains statements by different suppliers	Project records	Observational study	As available	Monitoring and Evaluation (M&E) Specialist	As available	(M&E) Specialist	Staff Time

Monitoring plan includes: a) Measuring the ongoing project activities (where we are); b)

Monitoring the project variables (cost, effort, scope, etc.) against the project management plan and the project performance baseline (where we should be); c) Identify corrective actions to address issues and risks properly (How can we get on track again); d) Influencing the factors that could circumvent integrated change control so only approved changes are implemented. Due to the limited space of the paper, this topic will be restrictive, focusing on an example (example refers to the innovative solution 2). The graphical support for the monitoring plan is shown in table 2.

3.7. Implement the plan: The solutions proposed at step 2.8 clearly lead to an effective process for increasing the quality of handling and unpacking component parts/ materials process and reducing the time necessary to move the parts/materials from the receiving dock until they are ready for use at the line. Their implementation mainly requires top level management implication and allocation minimum financial resources for transpose into practice the solutions. Also, the solutions can be integrated relatively fast in the company.

3.8. Institutionalize the improvements: Improvements should be further documented in procedures and work-instructions, as well as integrated within the quality management system of the company.

5 Conclusions

The integration of innovative problem solving tools within the DMAIC methodology is explored in this paper. The approach here proposed leads to effective solutions, by concentrating the effort of solution elaboration on the major barriers and conflicts within the analyzed process, taking in the same time into account the principles of efficiency, effectiveness, balance and excellence. On this way, the improvement phase within the DMAIC cycle is tackled in a systematic way, not empirically; and stronger arguments can be brought to justify the proposed improvements.

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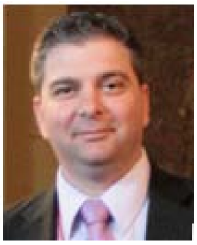

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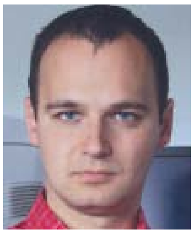

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