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APPLYING THE LEAN-TRIZ HYBRID APPROACH INTO TOYOTA KATA FOR MANUFACTURING SYSTEMS IMPROVEMENT

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Abstract.

Enterprises pursuit innovative manufacturing systems aiming to increase flexibility, productivity and profitability, while reducing operational cost and idle time. These issues have already been targeted and improved at the Japanese vehicle manufacturer Toyota. The solutions found at the Toyota Production System – TPS – were westernized and widely spread by the name Lean Manufacturing. This philosophy comprises tools and concepts, such as Kanbans, A3, Value Stream Mapping, derived from best practices encountered by Toyota team. The mentioned tools support the resolution of problems in which cause-effect relationship is well established. When complex and chaotic obstacles are encountered, the application of only those tools frequently results in unsustainable solutions. To address this scenario, the Improvement Kata – IK – was developed, stating the existence of learning routines based on the scientific method, where hypotheses are elaborated, performed, checked and assimilated, by all levels of command. Even with the IK major improvement on how to solve complex problems, there still is a deficiency of insight of where to start the pursuit for solutions. Therefore, the present research aims to empower users by a model that integrates the Lean philosophy with a systematic approach for problem solving called TRIZ – Theory of Inventive Problem Solving – in order to contribute to creativity and the range of novel solutions to complex manufacturing problems. A systematic literature review was performed to define the State of the Art of a hybrid Lean-TRIZ approach, and researches' results were analyzed in order to define the artefacts which compose an integration model. The proposed model was verified indicating that the developed model is prepared for further application study.

Keywords: TRIZ, Sustainable manufacturing improvement, Lean Manufacturing, Toyota Kata for Improvement.

1. INTRODUCTION

Competition for market share compels manufacturers to design and delivery better products to attend consumer needs – *Job to be done* – requiring the manufacturing system to be in constant mutation. In the past artisanal products accomplished the vast variety of products demanded, but in small quantity. The population growth ordered a scaled production system to fulfill needs – e.g. Ford Model-T – accepting for a short while small variety. Nowadays the consumer requirements claim for greater availability and variety of products, this may be translated in more agile productive means (Koren, 2010).

The Japanese vehicle manufacturer Toyota started operations in 1937, after 13 years the company almost ended operations due to management issues. At the time Eiji Toyoda and the chief engineer Taiichi Ohno profoundly studied their processes to state that mass production wasn't viable to the local market, initiating the Toyota Production System – TPS – concept (Womack et al, 1990). Due to interrelationship supply-market, the TPS pursuits constantly increase flexibility, productivity and profitability, while minimizing operational cost, idle time and other kinds of *Muda* – Japanese word for waste (Morgan and Liker, 2008).

TPS is unique and unparalleled, the base thinking for a production system based on order and methods of implementation were perfected through many years and innumerable tries (JMA, 1985). These patterns of success developed were westernized and widely spread as Lean Manufacturing – LM. Nowadays the advantages – e.g. balanced workload – and benefits – e.g. knowledge of the value flow – of adopting LM are comprehended by several manufacturers (Bashkite and Karaulova, 2012).

1.1 Lean Manufacturing

According to Womack (1996) there are five principles behind TPS success: identify value, map the value stream, create flow, establish pull and seek perfection. The value delivery is what characterizes a production system, where only client requests may be performed. Value stream map allows a cleaner view of process contents, for the current condition and base for improvement proposals. Flow creation means reduce the distance – space and time – between the supplier and consumer. As the customer – internal or external – is the user of the product or service, the demand order must come from its needs, not based on forecasts. Finally, the pursuit for perfection refers to improve the system toward a common vision, an improved operational condition.

At TPS these principles were systematically approached and obstacles were scientifically overcome. Over time this process revealed the cause-effect relationship for a series of before unknown issues, turning specific solutions into tools and best practices, such as *Kanbans*, *PokaYoke*, *Heijunka box*, *Value Stream Mapping – VSM* – and *A3*. The VSM aims to identify the product family, draw current and future state, and create implementation plan, it differs from traditional mapping once that considers delays between work steps (Toivonen and Siitonen, 2016).

Those concepts and tools were westernized and became available through books aiming to show benefits and instructions for tools application. Companies have announced the adoption of such tools, but only a few manufacturers were able to reach Toyota’s improvement successfully (Wang et al., 2016).

Reports of unsustainable improvement caused by the application of such tools began a new wave of research looking for the difference of system behavior and the root cause for this issue. The result identified that just appropriating Lean tools and concepts are not enough to sustain solutions, it is mandatory to change the users’ mindset.

1.2 Toyota kata for improvement

The details of how Toyota creates solutions and systematically improves were researched and the results revealed a different – from traditional – way of work and management, where routines form new skills and habits (Toivonen, 2015). The Toyota Kata – TK – approach was codified based on those routines and behaviors, pointing that daily work for a Toyota employee consists in two parts, the labor to be performed and improvement activities. This approach revealed the invisible part of Lean, not composed by tools, instead of by learning environment, scientific method and common goals for the team (Rother, 2010).

This approach may be considered in four parts: vision, challenge, coaching and improvement. The vision establishes a direction – true north – for the improvement activities, challenge is a condition for the system to operate within the vision path but tangible, Coaching Kata is a learning base management model to guide the effort to the right direction and Improvement Kata – IK – refers to systematic and scientific base routines to overcome problems (Toivonen, 2015). As manufacturing systems are highly dynamic, any parameters exchange may be tested, results collected and analysis performed in short amounts of time, becoming possible to insert daily routines of improvement for production level.

According to IK, improvement occurs interactively and involves all levels of the command chain. In which the highest levels are mostly responsible for molding the vision and establishing a future operation condition – long term strategy – and according to the deployment the period to improve decreases. For the production level a target such as increase 5 percent market share in one year may be considered vague, but reduce 5 seconds of packing time in one week is tangible. This relationship is described by Rother (2010) as mentors and mentees, where solutions are created by the learners guided by coaches, base for a learning environment. It is fractal throughout the system, where each one performs a specific function towards a common goal, searching for ways to guide the system and overcome obstacles from a current – undesirable – condition, towards a well-defined improved target condition within the vision path, as illustrated in Figure 1.

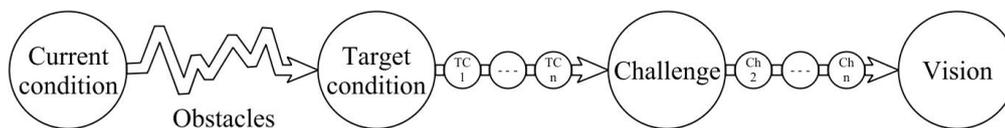


Figure 1. Improvement Kata
 Adapted from Rother (2010)

Comparing these two conditions users are able to foresee some obstacles, predominantly formed by problems with known cause-effect, solutions may be proposed based on previous knowledge – psychological inertia – and intuition, but inasmuch obstacles are overcome further restrictions are revealed beyond the knowledge frontier. So the evolution path may be seen as in Figure 2, before the grey zone lean tools may be applied successfully but after the frontier there are no off shelf solutions, instigating the creation of new solutions based on scientific method – PDCA cycle.

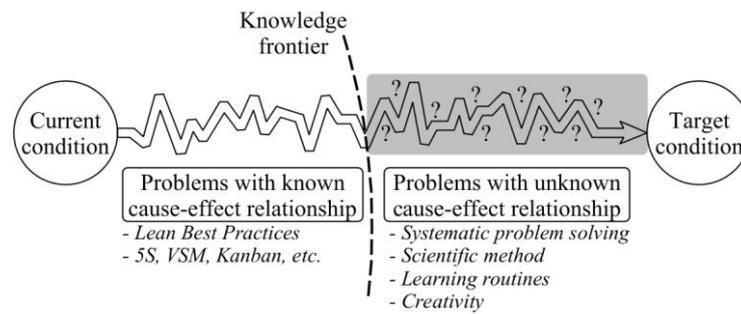


Figure 2. Improvement obstacles

Adopting the *Cynefin framework* for problem categorization, becomes recognizable the part of Lean tools in the problem solving process, as presented in Figure 3 best practices are limited and efficient to simple problems once it is a matter of sense, categorize and respond. Looking back, when TPS started there were no tools, so scientific based continuous improvement – as described by IK – supported overpass problems, originating practices. Over time the cause-effect relationship was consolidated and those became best practices. Hence, when tools were westernized companies acquired a toolbox mostly dedicated to simple problems, when deeper issues were encountered such tools were mistakenly used and resulted in unsustainable improvement. Adopting the scientific based continuous improvement approach supposedly unties practices from those into the comfort zone and new solutions may be created. According to Snowden and Boone (2007), a problem misclassified as simple has the potential to easily become chaotic, demanding profound effort and cost to restore its condition. Also contributes to explain reports of improvement unsustainability.

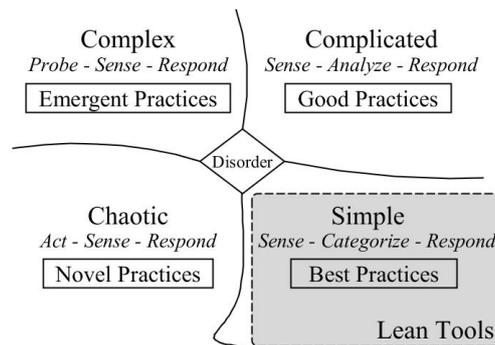


Figure 3. Lean tools characterization
Adapted from Snowden and Boone (2007)

With the internal procedures for improvement structured and identified, it becomes clear that cause identification of problems and new ideas to solve them are basically driven by intuitive means, such as brainstorm and benchmarking. The difficulty to determinate a problem, due to the quantity of variables and the amount of steps needed to an acceptable solution, the two-dimensional scheme shown in Table 1 introduces methods capable to satisfy cause-effect scenarios, highlighting that TRIZ permeates all scenarios, in which both – cause and effect – may be addressed simultaneously (Savransky, 2000, apud Zhang, 2004). Indicating that a hybrid model Lean-TRIZ may empower improvement process with systematic problem solving and insights for solutions.

Table 1. Cause-effect scenarios

Effect	Unknown	Brainstorm Lateral thinking Mental mapping Morphologic analysis TRIZ	TRIZ
	Known	Brainstorm Lateral thinking Mental mapping Morphologic analysis TRIZ	
		Known	Unknown
		Cause	

Adapted from Savransky (2000)

1.3 Theory of inventive problem solving

According to Savransky (2000), all known sciences acquired by mankind (except math and philosophy) can be classified into three major groups: nature study (e.g. physics), human behavior (e.g. psychology), and disciplines that study artificial objects (e.g. aerodynamics). TRIZ has the uniqueness to combine most of this knowledge, making TRIZ a human-oriented knowledge-based systematic methodology of inventive problem solving.

TRIZ – acronym for Theory of Inventive Problem Solving, in Russian – was substantiated on successful patents analysis performed by *Genrich Altshuller* and collaborators. The analysis aimed to identify correlations and common means that led to innovative solutions, hence codifying the theory (Stratton and Mann, 2003). One of the insights acknowledged was that solving problem meant removing contradictions – conflicts – in a system. Contradiction is defined as the presence of inconsistent elements, basically, when something is improved, another will be worsened (Rantanen and Domb, 2010).

The challenge infused in ideas creation is the psychological inertia, being defined by the tendency of an individual to consider only solutions within their personal comfort zone, resulting in inferior creation outputs and innovations (Fey and Rivin, 2005). In TRIZ these consequences are minimized due the thinking behind the pursuit for solutions, in which a specific problem does not link directly to a solution, Figure 4 exhibits the structure thinking behind inventive process (Gadd, 2011). Thereby the factual problem must be abstracted to a generic problem, accessing a larger field of solutions, when a conceptual solution be mature it is transcribed into the specific solution required (Annamalai et al. 2014). With access to worlds knowledge and innovative technology, TRIZ was designed to structure and operationalize natural creativity, allowing researchers to define and solve any problem in any system (Wang et al. 2016).

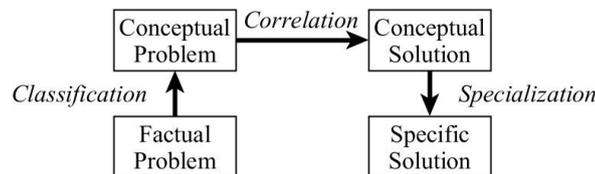


Figure 4. The structure of TRIZ
 Adapted from Stratton & Mann (2003)

After recognizing the significance of contradictions into inventive problem solving, Altshuller – and collaborators – classified 39 engineering parameters – EP – and identified 40 repeatedly used principles that solved such tradeoffs. Such are called inventive principles – IP – and are displayed through a 39x39 – EP x EP – matrix called Technical Contradiction Matrix (Stratton and Mann, 2003; Altshuller, 1999). As in Table 2 when a contradiction is encountered one feature improvement reflects on another EP worsening, for instance if the aim is to improve manufacturing precision, the time needed for the operation is increased – resulting on speed reduction – and this particular case reveals three inventive principles ordered according to its frequency of use: Previous Action (10), System replacement (28) and Change of color (32).

Table 2. Contradiction Matrix

	Worsening Feature →	...	9
Improving Feature ↓		...	Speed
...
29	Accuracy of manufacturing	...	10, 28, 32.

Adapted from Altshuller (1999)

Another tool presented by TRIZ for problem solving are the 76 Standard Solution, applied after the Substance-Field – analytical tool for modeling problem related to existing technological system – modeling. This tool correlates interactions between objects – substances – by types of effect – field – as desired, insufficient or harmful. Creating the grounds to search and apply standard solutions (Terninko, 2000). Such solutions were compiled by TRIZ creators and arranged into five categories (Terninko et al, 2000):

1. Improving the system with no or little change → 13 standard solutions
2. Improving the system by changing the system → 23 standard solutions
3. System transitions → 6 standard solutions
4. Detection and measurement → 17 standard solutions
5. Strategies for simplification and improvement → 17 standard solution

Class 4 of Standard Solutions – detection and measurement – is typically for control purposes, in many cases the most innovative solution is automatic control by taking advantage of physical, chemical, or geometrical effects. There are 17 indicated solutions – insights – for this class as in Table 3 (Terninko et al, 2000).

Table 3. Standard Solutions Class 4

Class	Trend	Standard Solution
Detection and measurement	Indirect Methods	<ul style="list-style-type: none"> • Modify the system instead of detecting or measuring so there is no longer a need for measurement • Measure a copy or an image; • Use two detections instead of continuous measurement;
	Create or synthesize a measurement system	<ul style="list-style-type: none"> • If the existing field is inadequate, change or enhance the field without interfering with the original system; • Measure an introduced additive; • If nothing can be added to the system, then detect or measure the external environment; • Decompose the state of the environment and measure the effect of the system on them;
	Enhancing the measurement system	<ul style="list-style-type: none"> • Use scientific effects that are known to occur in the system, and determine the state by observing changes in the effects; • If changes in a system cannot be determined directly, measure the excited resonant frequency of the system or an element in order to measure changes; • Measure the resonant frequency of the object joined to another of known properties;
	Measure Fe-field	<ul style="list-style-type: none"> • Add or make use of a magnetic field in a system to facilitate measurement; • Add magnetic particles to a system or change a substance to ferromagnetic particles to facilitate detect result magnetic field; • If ferromagnetic particles cannot be added construct a complex system, by putting ferromagnetic additives into the substance; • Add ferromagnetic particles to the environment, if they cannot be added to the system; • Measure the effects of natural phenomena associated with magnetism such as the Curie point, hysteresis, quenching of superconductivity and the Hall effect;
	Direction of Evolution of the Measuring Systems	<ul style="list-style-type: none"> • If a single measurement system does not give sufficient accuracy, use two or more measuring systems, or make multiple measurements; • Instead of a direct measurement of a phenomenon, measure the first and second derivatives in time or in space – e.g. measure velocity and acceleration instead of measuring position – to determine the velocity of the source.

Adapted from Terninko et al. (2000)

2. KNOWLEDGE FRONTIER FOR LEAN-TRIZ

Projects developed by other authors form the gross data for a research procedure, creating a list of material to be analyzed, however, no procedure is able to fully cover the knowledge, inasmuch dissertation and thesis are difficult to reach. Thus the researcher must cluster the knowledge limiting the search within time and material type (Feldman, 1971).

The review applied in this project is denominated integrative review and had the objective to form theoretical grounds and practices created by other authors, synthesizing the state of the art. For this reason, it was applied two formats of search – systematic and exploratory – and the results were clustered. For the systematic review the *SystematicSearchFlow* – SSF – methodology was adopted, composed by eight activities capable to fully support the process, from search strategy up until the results analysis (Ferenhof and Fernandes, 2014). Afterwards an exploratory search was performed with the search strategy – protocol – submitting to more comprehensive databases, collecting of articles, dissertations and books.

2.1 Systematic Literature Review

The first phase of the methodology presents five activities to compose the portfolio: search strategy, database consult, document management, standardization and assortment. The search strategy was designed due project's scope, forming the query subject, as shown in Figure 5 by logical diagram – with Boolean operators – and logical writing, within date range between 2001 and July 2017. To absorb writing variations, the notations *AND*, *OR*, “ ” – exactly sentence – and * – any termination – were needed.

This query was applied on the most relevant databases for engineering, *Scopus*®, *Web of Knowledge*®, *Ebsco*®, *Compendex*® and *ProQuest*®. Hence, the papers collected were managed through filter to form the portfolio, the filters, its description and results are presented at Table 4 with respective result quantity.

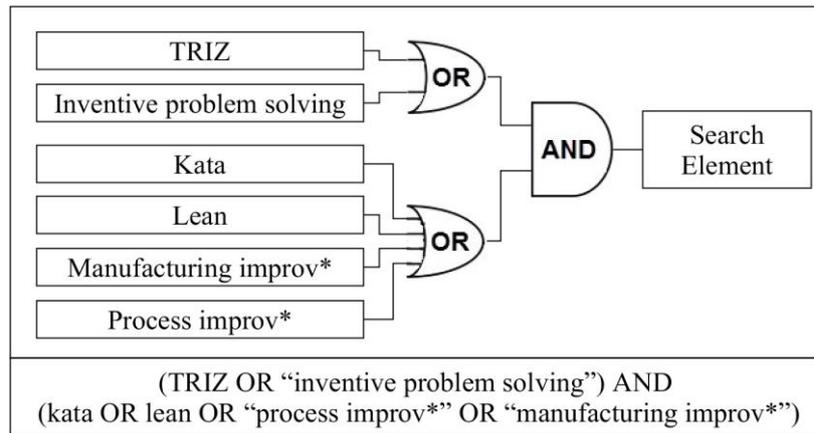


Figure 5. Search element

Table 4. SSF document management

Filter	Justification	Result quantity
None	Gross search result	109
Duplicates	Remove duplicated papers	96
Title / Key words / Abstract	Remove papers that did not present relevant data in those questions	23
Unavailable	Remove unavailable papers	15
Full paper analysis	Remove material that did not present alignment to the scope	8
Project alinement	Transfer files to the final portfolio	2

2.2 Exploratory Literature Review

Due to scarcity of publications related to Lean-TRIZ, an exploratory search was performed according to the systematic review protocol – as in Figure 5 – and time span, although into search engines, resulting congress papers, online publications, books and dissertations. This review focused in methodologies and applications, Table 5 contains the filters and result quantities.

Table 5. Exploratory search document management

Filter	Justification	Result quantity
Title / Key words / Abstract	Select papers that do present relevant data in those questions	17
Full paper analysis	Remove material that did not present alignment to the scope	3
Project alinement	Transfer files to the final portfolio	2

2.3 Research Portfolio

Research outputs aligned to this project were combined at Table 6. Aiming to facilitate the comprehension Table 7 briefly presents a summary and outcomes for the selected publications.

Table 6. Final portfolio regarding Lean-TRIZ

Cites	Type	Language	Authors	Date	Title	Nationality	
1S	3	Paper	English	TOIVONEN, T.	2015	<i>Continuous innovation - Combining Toyota Kata and TRIZ for sustained innovation</i>	Finland
2S	2	Paper	English	NAVAS, H. V. G. MACHADO, V. C.	2013	<i>Systematic innovation in a lean management environment</i>	Portugal
1E	27	Paper	English	I KOVENKO, S.; BRADLEY, J.	2004	<i>TRIZ as a Lean Thinking Tool</i>	EUA
2E	0	Book	English	HARRINGTON, J.	2017	<i>Lean TRIZ: How to Dramatically Reduce Product-Development Costs with This</i>	EUA

Table 7. Portfolio summary and outcomes

Id	Summary	Outcomes
1S	Proposal to improve TK approach by adding TRIZ technics to various parts of the method	Author correlated TRIZ tools that might be suitable to TK approach improvement model
2S	Proposal to permeate TRIZ tools into Lean manufacturing environment	Author correlated TRIZ standard solutions to Lean concepts and tools, aiming to solve problems
1E	Proposal to apply TRIZ- <i>plus</i> concepts and tools to solve Lean problems	Author correlated TRIZ- <i>plus</i> to Lean concepts and tools, aiming to provide alternative solutions
2E	Proposal of an integrated Lean-TRIZ model to solve product and process problems	Methodology based on workshops applying TRIZ tools and concepts

2.4 Establishing the State of the Art

Through the literature review it was confirmed that a hybrid approach is barely systematized, where TRIZ tools and concepts are mostly applied to devise solutions, rarely used for problem identification or system evolution. The only Lean-TRIZ methodology was published by Harrington J. (2017) stating a five phase process: improvement opportunity identification, prepare and conduct workshops, implement the changes and check results. Which meetings last between 1 and 2 days, and *S-curves* support the opportunity selection, contradiction matrix overcome obstacles and results are implemented within 30 days. Ikovenko & Bradley (2004), and Navas & Machado (2013) correlated Lean tools and concepts to TRIZ-*plus* methodology tools. Only Toivonen (2015) presented a TK integration proposal, correlating traditional TRIZ tools into IK approach artifacts.

3. INTEGRATION MODEL

Model design consists in construct and evaluate, the construction refers to the process of identifying artifacts and evaluating determines the inputs operability. The framework developed by March and Smith (1995) considers a model into ‘research outputs’ and ‘research activities’, the first dimension is based on the artifacts – constructs, models, methods and instantiations – and the second dimension presents activities – build, evaluate, theorize and justify – as show through Table 8.

Table 8. Model development framework

		Research Activities			
		Design science		Natural science	
		Build	Evaluate	Theorize	Justify
Research Outputs	Constructs	–	–	–	–
	Model	–	–	–	–
	Method	–	–	–	–
	Instantiation	–	–	–	–

Adapted from March and Smith (1995)

According to March & Smith (1995) a construct – or concept – defines terms to describe or conceive tasks within the domain and to specify their solutions, model is a set of propositions to express relationship among constructs and may be seen as descriptions, method is an algorithm – or a set of steps – for model operationalization, and instantiation is the perception of the feasibility and effectiveness of the method in its environment.

The correlations and relevant data regarding Lean-TRIZ from the literature review were adopted as constructs to design an integration model, Table 9 presents chosen constructs, motives and its source. The relationship among constructs and IK concepts formed the integration model.

Table 9. Constructs for the integration model

	Constructs	Motive	Source
A	Identify and Select Obstacles	Understand the current and future conditions. Identify what may be blocking the evolution	Rother, M. (2009) Toivonen, T. (2015)
B	Classify Problem	Characterize problem according to cause-effect	Snowden, D. J. (2007)
C	Identify Tradeoff	Define improving and worsening features	Stratton, R., Mann, D. (2003)
D	Consult Technical Contradiction Matrix	Consult matrix and collect IPs in order	Toivonen, T. (2015) Harrington, H. J. (2017)
E	Consult Standard Solutions	Consult Standard Solutions database	Ikovenko, S., Bradley, J. (2005) Navas, H. V., Machado, V. C. (2013)
F	Identify TRIZ insight	Define order to plan a solution	Authors

3.1 Lean-TRIZ applied into IK

Constructs were inserted into IK application framework, as illustrated in Figure 6. As the main goal for this project was to empower user's creativity and disrupt psychological inertia, for TRIZ integration two phases were added into the improvement framework: Problem characterization and TRIZ insights. Where the flag icon represents the constructs – presented in Table 9 – in the model and stars are decision points – according to TK mentor-mentee routines.

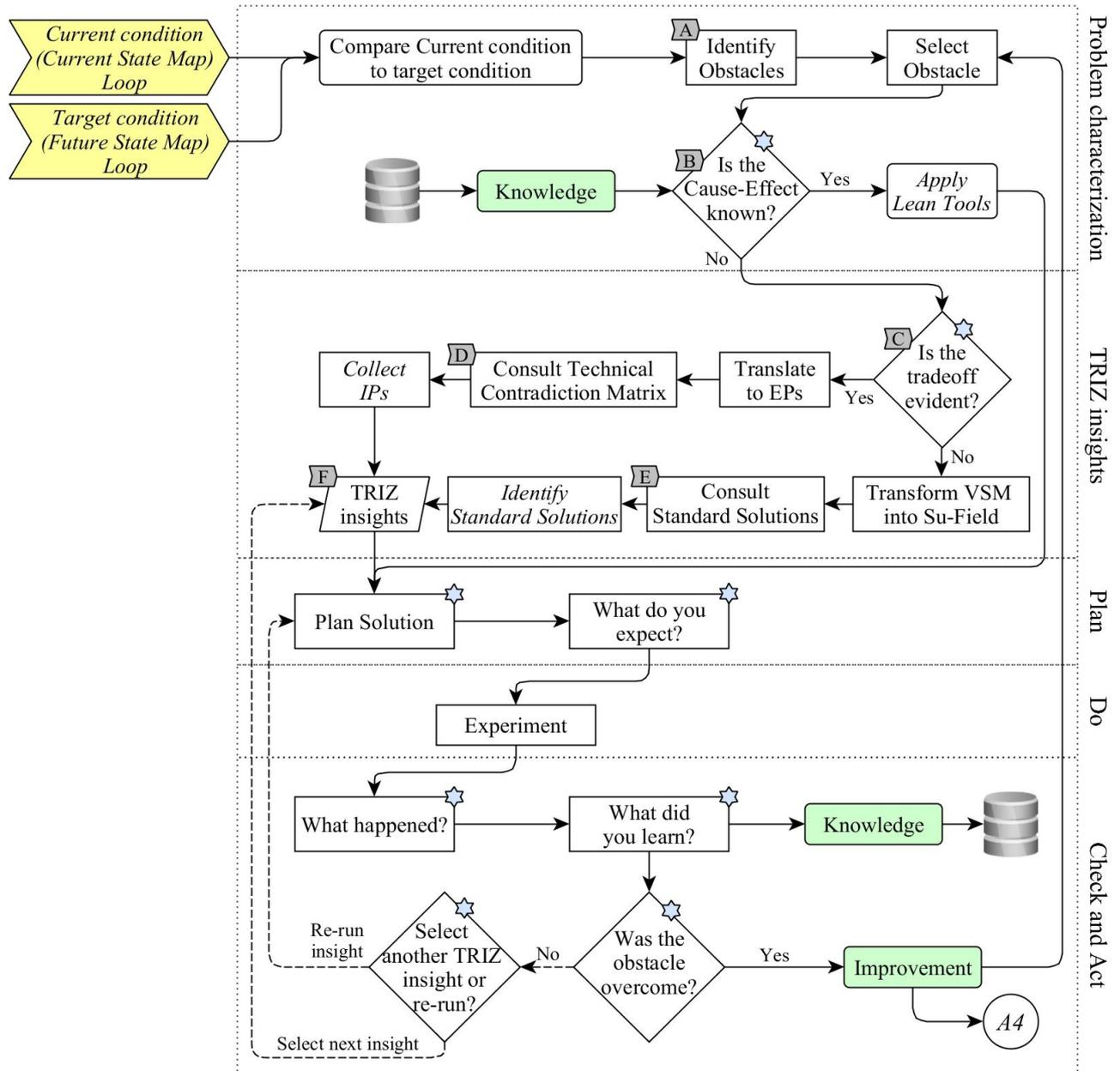


Figure 6. Integration method

3.2 Instantiation and verification

The method – Figure 6 – was verified based on the Validation Square approach. According to Pedersen et al. (2000) this proposal aims to validate methods based on qualitative and quantitative measures, it is composed by four field of validity: theoretical structural, empirical structural, empirical performance and theoretical performance.

Performance verification was performed based on an example, accepting the usefulness of the outcome and verifying that the premise contributes to the scientific knowledge. In which a simplified hypothetical current and target conditions were proposed, and Table 10 presents the deployment through the model towards a solution.

- Current condition: 4 workers; 35% of mean idle time, 10% of defects and 4 hours lead time.
- Target condition: 3 workers; 15% of mean idle time; 3% of defects and 4 hours lead time;

Table 9. Hypothetical based verification

Obstacle	Cause-Effect	Tradeoff	Standard Solution	Planning	Results	Obstacle evaluation	Next step
Unbalanced workload	Known	Not applied	Not applied	Balance workload based on <i>takt time</i>	Balanced workload with 3 employees	Overcome	Select another obstacle
Excess drilling defects	Unknown cause but affecting drilling positioning	Manufacturing accuracy vs. Speed	Not applied	Create a previous process for defect prevention	Unsuccessful due to excess workload	Not overcome	Select next insight
				Replace systems causing defects	Defects reduced	Overcome	Select another obstacle

4. CONCLUSION

Both Lean and TRIZ aim to improve systems towards ideal, Lean mostly with best practices for production environment and TRIZ frequently applied to technical systems. A hybrid method to enable the combination of continuous improvement and inventive problem solving is in early stages. So the main contribution of this research was to identify the state of the art Lean-TRIZ and embody the results into Improvement kata approach. A hypothetical scenario was performed in order to verify the proposal, indicating that the method support the users to overcome problems beyond simple problems, being considered prepared for further application study.

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6. RESPONSIBILITY NOTICE

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