A LEAN-TRIZ APPROACH FOR IMPROVING THE PERFOMANCE OF CONSTRUCTION PROJECTS

Brahian Román Cabrera[1] and Guillermo Juárez Li[2]

ABSTRACT

Process improvement and waste reduction are important in optimizing the performance of projects, to achieve these goals Continuous Improvement and Quality Management are methodologies which have been used successfully in construction. However, both are now no longer sufficient due to the competitiveness of the construction industry and the increasing complexity of projects, especially in infrastructure such as highways, tunnels and dams. Being also necessary to incorporate innovative elements. This paper proposes an optimization cycle that complements the principles of Lean and TRIZ (the Russian acronym for the "Theory of Inventive Problem Solving") as an alternative to improve the efficiency of resources. Then, the Lean tool Value Stream Mapping (VSM) to assess the issues and wastes during production and the principles of TRIZ to get innovative solutions to the most difficult problems will be used. The application of this "Lean-TRIZ" approach to a highway project of 50 km ($ 45 MM) located in the Peruvian Highlands whose scope included works of flexible pavement maintenance and rehabilitation is presented as a case study, in which paving works were thoroughly studied for 2 months. The results showed that TRIZ increases the effectiveness of Lean to improve the performance of the production flow through the generation of innovative ideas.

KEY WORDS

Continuous Improvement, Value Stream Mapping, Waste, TRIZ, Innovation

INTRODUCTION

A sustainable way to achieve the financial objectives of a construction project is by improving the productivity of the constructive processes, this will lead to increase profits because it streamlines the use of resources and assets, which are very expensive in construction, and it also increases the probability of finishing on time. However, the overall productivity levels within construction have not had significant improvements since the 60s (Wodalski et al, 2011). Peru is not unrelated to this trend, the percentage of the total time in which value-added work is performed is on average 28% in building projects at Lima (Ghio, 2001). Infrastructure projects such as tunnels, highways or hydroelectric power stations have been little studied in these terms, so it is easy to infer that their productivity levels are even lower as a result of their greater

[1] Bachelor of Civil Engineering, Department of Civil Engineering, National University of Engineering. E-Mail: broman@cosapi.com.pe

[2] Civil Engineer, Innovation Coordinator, Department of Construction Management, COSAPI Peru. E-Mail: gjuarez@cosapi.com.pe

complexity, these inherent particularities are commonly used as excuses for drawbacks in management and use of resources (Nam and Tatum, 1988).

There are several factors that may explain the aforementioned trend, but 2 stand out in the crowd: the lack of precision in estimating costs and the excessive use of resources. The first aspect is usually constrained to existing bidding regulations for tenders, being more effective to work on the second point in order to reduce cost overruns.

In this sense, the vast majority of efforts to improve the performance focus on increasing the resources and the pressure on the crews of a certain activity, this method are known as the traditional conversion model. The new production philosophy applied to the construction, however, considers the construction as a workflow, where there are 3 types of activities: the ones that add value –for which the customer is willing to pay-, contributory activities and unproductive activities also known as waste because they have a cost but they do not add value to the product (Koskela, 1992), therefore low productivity and its inherent additional costs are due to waste. There are 2 approaches to improve the performance of the flow, one focus on increasing the efficiency of the activities that add value and the other focus on the continuous elimination of waste.

In manufacturing has been possible to reduce systematically wastes through the implementation of cycles of Continuous Improvement and Total Quality Management (TQM), these tools have been incorporated in the techniques of monitoring and control of construction projects trough cycles of monitoring-assessment-intervention that emphasizes in the measurement of productivity using a system of management indicators -which are very similar to the technique of earned value of PMBOK- so it can be identified those processes with the poorest performance, then it is necessary to assess them in order to provide solutions (Serpell, 2003).

Nevertheless, the levels of complexity of the projects and competition among contractors have increased substantially as well, it is common to see construction projects with high technical requirements and with great number of tenders, furthermore, there is an increasing pressure on aspects such as costs, time, quality, environmental impact and occupational health. This fact leads to the need of even higher levels of productivity that cannot be achieved only with the cycles of continuous improvement and quality management described above, being necessary to incorporate concepts of process innovation and technologic development. Industrialization through pre-fabricated concrete elements and the automation of earthmoving equipment with global positioning techniques are good examples of innovation. But, the innovative ideas are not obtained using the work studies' data or with brainstorming which are the main sources of ideas in Continuous Improvement, but it follows a systematic order to materialize. TRIZ methodology (the Russian acronym for the general Theory of Inventive Problem Solving) provides a solid theoretical basis for the generation of innovative ideas and it has been successfully used to solve difficult constructive issues in processes of lifting slabs, precast pile sleeves and in the erection of steel silos (AbouRizk, 2005).

Lean is an exceptional methodology of analysis and evaluation to optimize the flow of production, TRIZ, in turn, provides 40 inventive principles to generate innovative solutions, but require identifying with precision the root cause of the problems. Therefore, we herewith propose a cycle of optimization that integrates both methodologies for improving the performance of the production systems, considering that they are complementary, continuous improvement will require innovation to periodically increase efficiency (otherwise it would not be competitive in the long term), but innovation also requires elements of continuous improvement, before the implementation to be able to get the full benefits of the innovation, during for a proper implementation and after for the respective maintenance of the advantages gained (Imai, 1986). In addition the great scientific and technological development that exists currently allows the development of innovative solutions that were not possible years ago and the amounts of investment of construction projects justify it.

The research highlights the implementation of the proposed cycle of optimization to the processes of paving in a highway construction project of 50 km ($ 45 MM) located in the Peruvian highlands whose scope included works of flexible pavement maintenance and rehabilitation, the project was selected as case study because it fits in with the objectives of the research without neglecting other important variables in productivity management. To safeguard sensitive information some procedures were followed, such as: the research objectives and methods of data collection were made clear to the project team, only information from consented participants was used and managers given their approval to the collected and processed data.

CYCLE OF OPTIMIZATION IN CONSTRUCTION

Through the analysis of the background it was possible to propose an optimization cycle for construction projects as shown in figure 1. The focus of the assessing is based on identifying the Value Stream and a component of innovation is included.

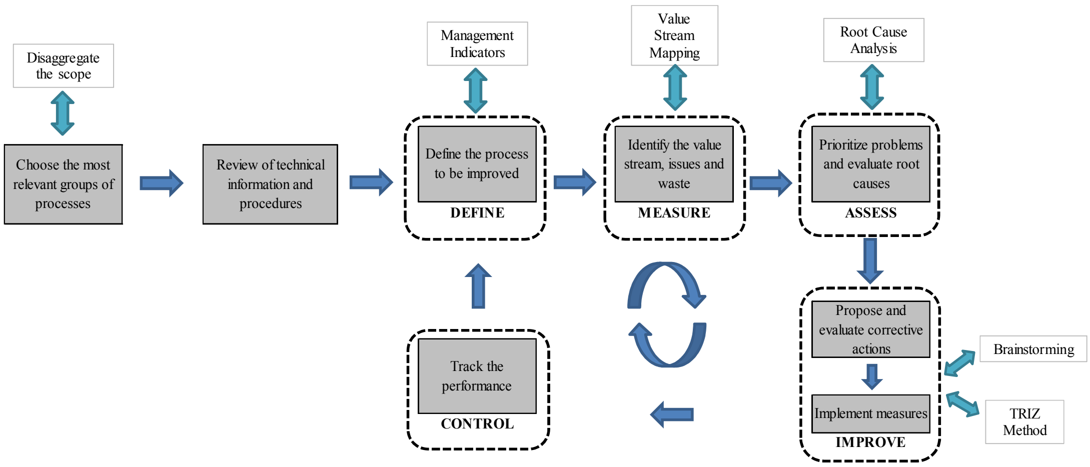

Figure 1: Cycle of optimization in construction

Defining: To provide an effective tracking, it is advantageous to group the processes according to their sequence and criticality in order to identify the one which subordinate the rest of processes at its own pace.

Measurement: At this stage the flow of production must be diagnosed in order to find out issues, waste and their root causes. Work Sampling techniques and Crew Balances studies are often used for assessing individual activities, these techniques provide reliable information but does not neither integrate the several steps belonging to the entire process nor give details about information and resources flows. It is very difficult to integrate all these steps only with the aforementioned studies and therefore some wastes and issues related to the flow such as the variability of production or inventories are pushed aside. An alternative to overcome these shortcomings is through the definition of value in terms of the customers and modeling all steps necessary to deliver the product. Value Stream Mapping as a management tool is very useful for assessing waste within the flow but must be adapted to the construction since it was originated in manufacturing (Rosenbaum, 2012), some constraints to apply successfully VSM to construction are: the uniqueness of products in construction and the need to collect a large amount of information (Yu et al, 2009). Both of these problems can be overcome through proper mapping processes, identifying responsible, defining a family of deliverables and designing appropriate measuring instruments and indicators to characterize common issues in construction.

Assessment: The mapping of processes and indicators will be used for drawing the respective Value Stream Mapping which will provide a better understanding of the flow, issues and existing waste. Then, the root cause of these issues must be determined in order to reduce their impact and eventually eliminate them. At this stage of the cycle it is recommended to hold a meeting with those who head the operations in the field along with the staff in planning and project engineering departments, so they could share different approaches for a particular problem and reach conclusions. The tools "Ishikawa Diagram", "Root Cause Analysis" and "5 why?" are suitable for this purpose.

Intervention: The intervention phase will be carried out only when the project team is fully convinced that root causes are known. Once there is an agreement on this, the strategy for the implementation of corrective actions will be divided in 3 levels according to the principles of Lean Thinking: Ensure the flow, create efficient flows and create efficient processes.

Many issues and waste can be solved immediately through the reduction of non-productive time according to the statistical data from the productivity studies and the improvement of flows of resources on-site, certain tools such as 5S, Daily Huddle Meetings, Batch Size Reduction among others are helpful. Brainstorming and past experiences are also helpful to quickly find solutions, a good alternative is seeking similar solutions within the company's knowledge management.

Other issues will take more time and work as improvements more difficult to implement are required, these problems are related to drawbacks in the management approaches followed for planning, design and supplying. Pull Planning Schedule, Last Planner, Just in Time and Constructability are the most appropriate tools in such cases.

Finally, once most of the waste found is reduced, other sources of inefficiency due to the own limitations of the working method currently used (mostly due to technological constraints) will require Process Innovation to improve. So the optimized flow plus the innovation will allow obtaining even higher performance levels which make the company competitive. The TRIZ technique is perhaps the most suitable in finding innovative solutions but it requires a collaborative work between universities, suppliers and the company since developing innovation is will need research, sources, design team and expertise. For those cases in which the technology already exists is advisable to seek available breakthroughs in the market.

In insight, the improvement plans will be based on the implementation of Lean principles through its tools and the generation and development of ideas. Figure 2 summarizes the techniques and tools the project team can use for overcoming issues.

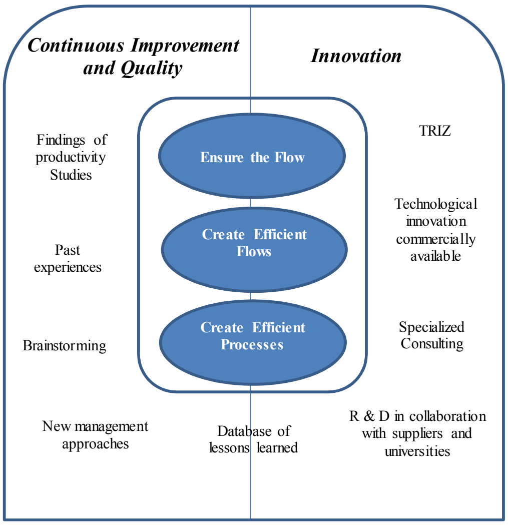

Figure 2: Tools and techniques for overcoming issues

IDENTIFICATION

Through grouping the processes related to paving works in accordance to the sequence of activities, it was easy to find out the one which is delaying the entire deliverable, the table 1 shows the results of the project tracking system at the 7th month (from 17 months in total).

Table 1: Identification of the critical process

Critical Processes

Process	Incidence	Responsible	Cumulative Quantity	CPI	SPI	NC	Performance Gap
Transport of filling material	10.5%	ERS	35.52%	1.22	-	-	6.5%
Laying and compaction of Sub Base	0.5%	JOA	23.57%	0.84	0.88	1	-5.3%
Laying and compaction of Base	0.8%	JOA	21.29%	0.78	0.93	2	-4.7%
Primer asphalt coat	0.2%	JOA	19.69%	0.92	0.96	-	0.2%
Ditch construction	2.0%	PEG	20.20%	1.01	0.9	-	2.0%
Placement and Compaction of asphalt mixtures	102.0%	PEG	13.70%	0.97	1.03	1	2.5%

Where:
CPI: Cumulative Cost Perfomance Index
SPI : Cumulative Schedule Perfomance Index
NC : Number of Non-conformances
Performance Gap : % Average monthly progress - % Planned monthly progress

The transport of filling material had excellent indicators, unlike the laying and compaction processes which were incurring in additional costs and they were delayed, furthermore their average progress was low in comparison to the subsequent processes and it is possible that the works of primer asphalt coat will stop due to the lack of available working area. Both, laying and compaction of Sub Base and Base, had been performing by the same crew, following the same procedure and even the deliverable was similar (only thickness was different), therefore they both were chosen as the critics. It is worth mentioning that the cost of equipment was higher in both processes (approximately 67% of the total cost).

MEASUREMENT AND ASSESSMENT

The indicators were selected in order to properly interpret the current state of the production flow which included flows of information and resources (e.g. supplying of laying material, quality, planning of the activities and equipment maintenance). These indicators should also facilitate the measurement of other relevant waste as the wastage of filling material. Table 2 shows the summary of the selected indicators.

Table 2: Management Indicators

TYPE	OBJECTIVE	NAME	ABV	UNT	DESCRIPTION
Efficiency	Establish a unit to a product family	-	-	ml	Production in meters
	Measure the rate of production of the equipments	Unitary Rate of production	URP	ml/HM	Production in meters per machine hour
	Measure the amount of work in process inventory	Inventory	INV	ml	Length of unfinished works
	Measure the amounts of wasted filling material	Waste of Material	WM	%	Percentage of the material used in excess relative to the planned
	Measure the efficiency in using the equipment	Non-Productive time	NPT	%	Percentage of time that a machine performs ineffective work
	Measure the mechanical availability of the machinery	Mechanical Availabilty	MA	%	Percentage of time in which the equipment is available
	Measure the total cycle time	Cycle Time	CT	Min/ml	The total amount of time it takes to produce a meter of Sub Grade or Grade
	Efficiency of the entire work cycle	Value-adding time	VT	Min/ml	Time within value is added during production
	Magnitude of the work cycle efficiency	Value-adding percentage	VP	Min/ml	Percentage of time within value is added during production
Efectiveness	Measure the level of average production	Average Production	AP	ml	Average of production in meters
	Estimate the variability of production	Variability of Production	VP	-	Standard deviation of the production
	Number of activities finished on time	Production goals achieved	PGA	%	Percentage of production goals in relation to planned
	Measuring the effectiveness in supplying filling material	Shortage of filling material	SFM	%	Percentage of waits due to lack of filling material in the field
Quality	Waste of time due to reworks	Time wasted in rework	TWR	%	Percentage of total time wasted in rework

The indicators shown in table 2 were used to find the necessary data in order to develop the Value Stream Mapping, data-collection procedures lasted 3 weeks.

Figure 3 shows the Value Stream Mapping for Laying and Compaction, the issues and waste found are highlighted in red.

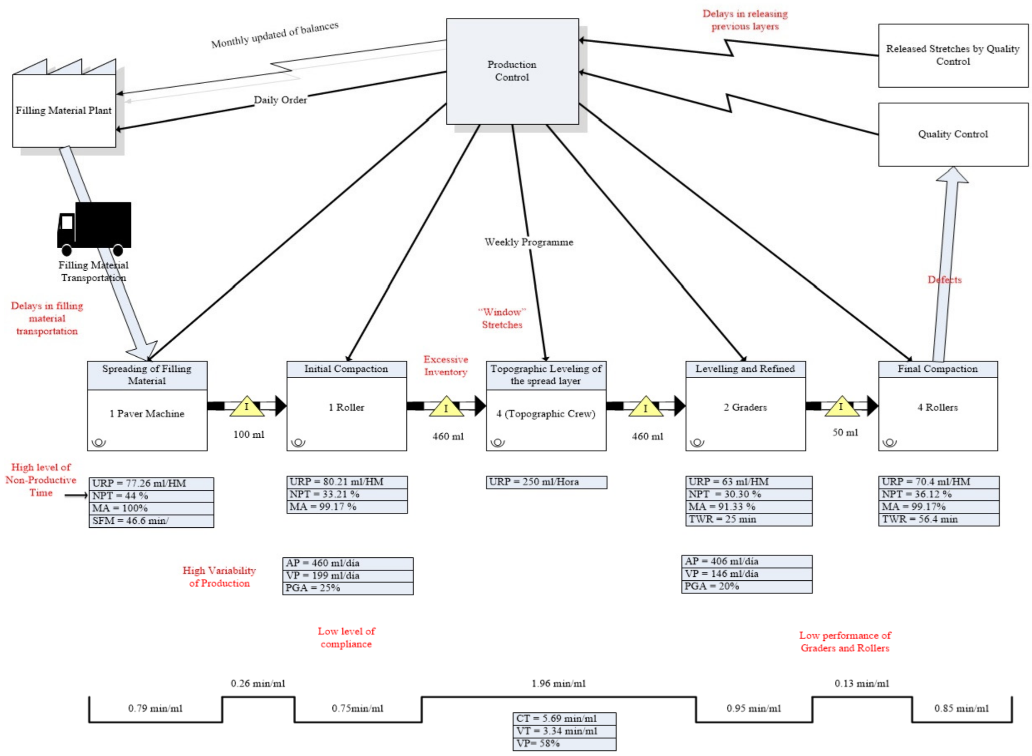

Figure 3: Current Value Stream Mapping of Laying and Compaction of Sub Base

High variability of production: It was noticed that the daily rate of production was highly variable, for instance the spreading of material with the paver machine could produce up to 740 m in one shift, whereas in the next few days only obtained 200 m -without considering adverse weather conditions or other external factors-, the standard deviation was almost a half of the average production. This happened as a consequence of delays in testing and releasing the previous layer by the quality control staff which was a very common issue that was causing unproductive time due to the lack of available working area.

Low performance of levelling, refined and final compaction: The rate of production of the paver machine were greater than the average production of the graders and rollers -which are the ones that delivers the product to its testing and subsequent delivery- irrespective of the fact that there were 2 graders and 4 rollers against 1 paver and despite that the graders and rollers had higher levels of Value-Adding work. It is clear that neither the method of work was the adequate nor there was a suitable management of resources in the field.

Shortcomings in planning: It was noticed during the study the existence of several stretches in which it was not allow working because there were unsolved constraints (stretches also known as "window stretches "). For instance, there were up to 600 m of sub grade layer that were not executed (considering the time and the chainages belonging to the study) because the crew of drainage and concrete works had not yet finished a concrete retaining wall and these, in turn, had not finished due to the lack of formwork. The Look Ahead planning of the three production departments (earthworks and pavements, drainage and concrete works and industrial plants) were revised, it turned out that there were stretches in the second and third week where the first 2 departments planned to carry out their works in the same place and at the same time, this was physically impossible and furthermore they did not take into account other constraints. This lack of coordination and long-term planning was creating flow detentions and waste due to excessive transportation.

Low level of compliance and reliability: The aforementioned problems were affecting the level of compliance with the contractual milestones. The PGA indicator (daily) indicates that only about 20-25% of the times the goals of progress desired by the customer were achieved. This issue was closely related to the high variability of production.

Drawbacks in management and coordination of the field operations: Values of NPT were of the order of 35-45%, whose main component were waits and stoppages due to the crew of topography, lack of tools and/or luminaries (night shift), interference with vehicles among others. The average times of waiting for trucks with filling material during the activity of spreading were high (almost 1 hour off every day). During the study, several crew's members complained that the pull of machineries remained with the same number of trucks until the waits were very noticeable.

Defects: There were problems related to quality such as segregation, deterioration of layers due to environmental conditions, levels above the tolerances and compaction levels under the required. It was noticed on several occasions that the equipment of laying and compaction were transported to another working area to rectify defects. This reworks took in average 0.41 hour per day (1 grader) and 0.93 hours per day (2 rollers), both with their inherent additional costs.

Others: There were also noted the excessive waste of filling material, mostly in banked curves and a grader with low mechanical availability.

All problems found were presented in the tracking weekly meeting for their validation and subsequent root cause analysis, two issues (poor performance of the grades and rollers and delays in releasing finished works) were thoroughly analyzed because they are the most incident ones. Figures 4 and 5 show the root causes.

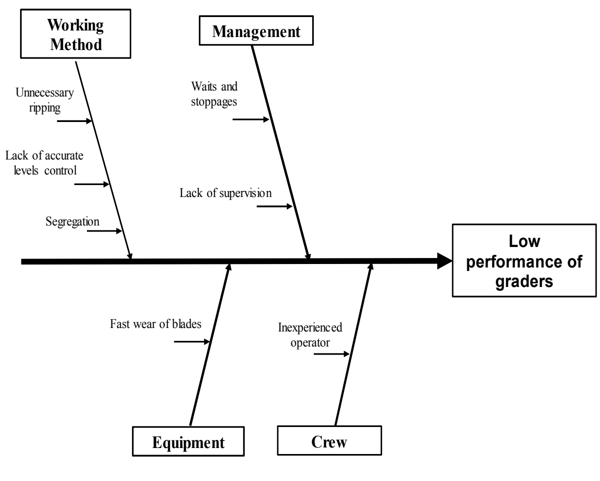

Figure 4: Cause-and-effect diagram

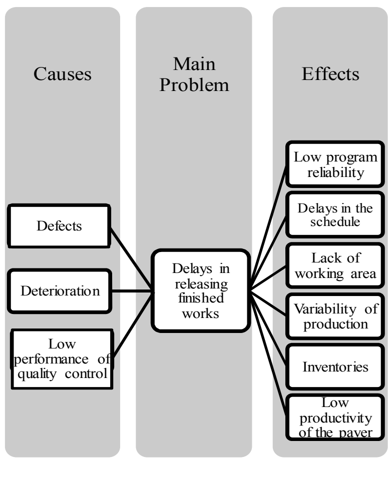

Figure 5: Root-Cause diagram

As seen in figures 4 and 5, the root causes of both problems were not only due to drawbacks in the production department, but also have a strong component of planning, organization, maintenance and quality management.

INTERVENTION

The future enhanced map is based on obtaining the following points:

Ensure the flow: The main issues against continuous flows of production were the defects and low performance of quality control activities. Another issue related is the poor planning that generates the "window" stretches. Then, corrective measures at are proposed:

Improvements to the processes of quality control and assurance: The improvement plan included the acquisition of 2 new rollers with higher capacity and the execution of new testing stretches. In addition, it was developed a new constructive procedure that included Poka Jokes made up with ropes for increasing the accuracy on the leveling works, the new procedure also included further points of quality inspection with recommendations of another project in the control of segregation. It was also necessary to increase the number of resources of the quality control crew (staff and equipment of testing) to reduce the inventory of finished products and prevent deterioration. The main objective of this item was to implement work standardization within the processes in order to reduce defects.

Pull Planning Schedule: The horizon of the Look Ahead planning was increased to 5 weeks and weekly meetings with Pull planning blackboards were implemented to facilitate the integrated planning of the areas of support with the 3 departments of production (earthworks and pavements, drainage and concrete works and industrial plants), as a consequence priorities and their constraints will be identified with greater time in advance. An example is the weekly update (it used to be monthly) of the production rates of filling and quarry run material.

Create efficient flows and efficient processes: In order to improve the performance of the whole system it was necessary to improve the poor performance of the processes of levelling, refined and final compaction which had the largest number of work-in-progress inventory.

Reduction of activities that do not add value: First of all, non-productive time were reduced through daily planning and meetings between the work fronts, also crews of supplying materials were implemented and the layout were redesigned in order to optimize times of transportation.

Simplification of levelling works: It was identified that the operators of the graders used to rip and cut the layer that had been spread, these caused that a great amount of the paver machine's work was destroyed and also increased the time of leveling and refined. Ripping and cutting had no more basis that the judge of some operators who felt that the layer was damaged due to environmental conditions, however the quality inspection showed that in normal conditions each layer could keep their physical and mechanical properties up to 4 days, by eliminating this step the number of passes dwindled.

Subordinating the process to the capacity of the bottleneck: once standardized the work of the new constructive procedure and applied the new points of quality management, the pace of production must be subordinated to the average pace of the graders and rollers, but leaving a small distance of advantage, because in highway construction is not recommended to eliminate all the work-in-progress inventories, the criticality of all the activities requires leave buffers that absorb the variability between processes.

Innovation: All the activities aforementioned helped to optimize the flow and the economic results started to recuperate, although having 6 machineries for 1 single process did not allow reaching the estimated cost because it was not possible to reduce the number of passes of the graders and rollers up to the originally estimated but without affecting the quality. This happened due to limitations of the working method, the graders lacked of an accurate control of topography levels (the visual control is a constraint) which did not allow working in night shift in order to accelerate the works (the delay of the project and the strong requirements of the customer so required). Furthermore the uncertainty of the level of compaction prevented decreasing the number of passes of the rollers without affecting the quality. These limitations of the current working method are contradictions which require the application of innovative solutions, TRIZ's principles can solve such contradictions. Table 3 shows the matrix of contradictions for the graders and rollers, the main idea is that an improvement in the waste of time through reduction of the number of passes will lead to defects (the manufacturing and measurement accuracy will plummet).

Table 3: Matrix of conflicts of TRIZ

	Worsening Features		
	Engineering Parameters	Measurement Accuracy (28)	Manufacturing Accuracy (29)
Improving Features	Waste of Time (25)	**6, 26**	**6, 18, 26, 28**
Inventive Principles of Solution	6. Universality	26. Copying	
	18. Mechanical Vibration	28. Mechanics Substitution	

Table 4 shows the principles applied to solve the problems and available technology (if any).

Table 4: General and specific solutions

Problem	Inventive Principle	General Solution	Specific Solution	Advantages	Availability of technology
Lack of accurate levels control	6 Universality	Make a part or object perform multiple function so the need for other parts is eliminated	Implement a system which gives to the Paver the capability of levelling and/or compaction	It will not be neccessary to use graders and also the number of rollers could decrease	Sonic sensors for pavers and pavers with pre-compaction system
	18 Vibración Mecánica	Use combined ultrasonic and/or electromagnetic field oscillations	Replace the not accurate visual control of levels with one using sound waves or ultrasound	Recution of the the number of passes of the graders and consequent productivity improvement	Sonic and laser systems for graders
Uncertainty of compaction levels	28 Mechanics substitution	Use electric, magentic and electromagnetic fields to interact with the object	Use electromagnetic waves to control the levels of compaction in real time	Areas requiring further compaction energy are known, therefore the number of passes and transportation decrease	Compaction control system for rollers

It should be clarified that before developing and implementing the innovative idea a full consensus among the entire crew of the project is required. In the case study an agreement was reached to implement an innovative solution, then the costs and benefits of each alternative were carefully assessed with the objective of determining the most convenient and consistent with the company's budget and if the inherent risks are controllable. The feasibility analysis concluded that incorporating ultrasonic sensors to the paver and, after the learning period, keep only a grader to correct possible imperfections is the most profitable option. The compaction control system in 2 rollers was also decided to implement, a comparative study of the productivity of the regular work method and the new one was decided to carry out along with the supplier.

CONTROL

Once the improvement plan started, it was very important to track it in order to find barriers and deviations. Productivity and other parameters related were controlled through the improved parameters of the future VSM, which were agreed upon between the production department and the project engineering area. The future state of the VSM had 2 stages, one is related to the measures obtained through Lean principles and the next one is after completing the processes for acquiring and developing the innovation.

Some barriers encountered were the resistance of some operators to change the traditional working method -especially the older ones- and the acceleration of the learning curve due to the pressure which the project was going through.

CONCLUSIONS AND RECOMMENDATIONS

Employing the principles of Lean Thinking, through the develop of the Value Stream Mapping, enabled the project team to get a broader view of the production flow because it allowed identifying issues and waste related to the production as well as management shortcomings such as poor planning and drawbacks in quality assurance. The VSM was also useful to involve and engage other areas of the project with the production department in order to achieve the productivity, cost and progress goals. It was easy to track these parameters since the future state of the VSM had specific indicators and responsible.

The principles of TRIZ complement Lean for improving the performance of projects as TRIZ allows finding innovative solutions to the problems -identified following the Lean approach-.

Applying Lean prior to and during the implementation of innovations is required in order to reduce flow waste and improve collaboration among the project team, otherwise these problems will reduce the innovation benefits.

The main contribution of this research is a methodology to complement Continuous Improvement and Innovation, so waste is constantly reduced and efficiency is highly improved by more advantageous working methods. Furthermore, continuous improvement allows keeping and increasing the benefits of the innovation through a proactively maintenance and a continuous learning environment.

The innovative solution, after overcoming the period of learning and adaptation, will possibly bring new issues and waste due to the uncertainty of working with a new method or technology, such waste should be evaluated according to the principles of the VSM entering into a new cycle of optimization.

The feasibility study to acquire the innovative technology, had considered a certain range of improvement which should be confirmed by a field study, the outcomes must be included within the knowledge management system of the company to ensure the learning of the entire organization.

The innovative solutions for the case study needed a strong technology component that was already available on the market. However, for those ideas which are in early stages or have not been developed yet, it would be advisable to run further research in a collaborative environment with suppliers and universities to come up with design proposals with more detail and functionality.

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