LOOKING FOR WHAT COULD BE WRONG: AN APPROACH TO LEAN THINKING

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ABSTRACT

The present paper points out the idea that in order to achieve quality assurance and reliability improvement in construction processes, lean thinking practice should incorporate a rarely used method in civil construction process design. It requires to consider "what shall we do to make things go on" and also an effort to searching for "what could be wrong (and we do not know)". This approach to process design contains the basic idea that some failures causes are implicit in building procedures, and an analysis of potential failure root causes may be done in order to find them out, thus anticipating future problems. This approach to process design - "searching for what could be wrong"- will provide a filter to "time bombs", built-in problems in the construction conversions and flows activities. The analysis will involve the establishment of counter-measures to potential failure modes.

The use of failure analysis methods (FMEA - Failure Modes and Effects Analysis and FTA - Fault Tree Analysis) in order to implement this approach is proposed and a strategy for the application of those tools, as well as some difficulties in their application, are presented and discussed.

KEY WORDS

Process design review, failure analysis, construction process reliability.

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INTRODUCTION AND REVIEW OF CONCEPTS

The lean production philosophy applied to construction, as clearly pointed out by Koskela, Ballard, Howell and others, emphasizes the maximization of the effectiveness of production processes. Simultaneously, their efficiency, understood as the ratio of actual outputs to inputs, should also be maximized.

While this principle is common to many other production systems, the lean thinking school has a different conceptual framework, which introduces the concept of waste in conversions (transformation activities), as well as in flows (activities that are not purely conversions).

This approach involves the basic idea that activities other than pure conversion are non-value-adding tasks, thus generating waste. In that sense, a working principle states that the cost share of non-value-adding activities must be continuously reduced. Here it becomes important the concept of optimization of flows which generate waste. In the lean thinking approach, management and optimization of construction processes focus not only the improvement of conversion activities—which is a common goal to other production systems—but also concentrate the efforts at reducing inefficient flows.

As stated by Koskela (1997), the theory of production flows is not totally developed, but provides a way to manage unnecessary work and uncertainties, not usually kept in mind in the common building construction practice. In other words, to improve the building construction systems, both aspects—optimizing conversion activities as well as reduction of waste, by reducing unnecessary flows—have to be monitored.

In order to consolidate this philosophy, the lean construction thinking sets up some principles for flow design and production improvement, as outlined by Koskela and others. Some of them are:

a) The reduction of variability.

b) A continuous improvement of the processes.

c) Control on the whole process (conversion + flows).

Most people understand quite well the last two features. But the first, reduction of variability, can be considered as one of the most important challenges in lean thinking. The effort to bring each process under control (“ we know what we can do”) is one way to reduce variability. But there is another way to eliminate variation: to anticipate the variation root causes. The approach presented in this paper may also introduce robustness into the building construction processes, thus being less sensitive to changes in environmental conditions, clients modifications in “product” design, contingent drawbacks, as well as upstream conditions in production not meeting actual expectations.

With these aims, some methods, mainly regarding planning and control/management activities of construction projects, were developed and implemented, with encouraging results.

Howell and Ballard (1997 a, b) pointed out that control of construction tasks must be dynamic. Control, as understood in conventional thinking, is “a matter of preventing bad changes”, but in lean thinking it must be considered with a different mental attitude. It is important to learn from the recent past in order to better deal with future tasks (Ballard and Howell 1997 a, b). Management effort involves a continuous assessment of the degree of compatibility between targets ("what we should do") and resources ("what we are able to do"). The planning and monitoring process involves a continuous evaluation of at what extent our capability is suitable to our aims. Attention is given to upstream conversions and flows, as well as supplier's inputs into process, and how they will affect downstream tasks. In that way, production management presumes a continuous feedback of scheduled activities, plans, procedures, internal standards and productivity measurements, aiming at the dynamical adjustment of ends and means.

In connection with this control approach, Faniran and his colleagues (1997) presented a new challenge: the necessity of building firms to gradually change their planning concepts, shifting from a satisfying planning to contingency planning. There is a need to anticipate future difficulties and adverse environments conditions to the project.

This paper refers to the above mentioned concepts, and remarks the basic idea that construction, specially production design, has to incorporate counter-measures for minimizing the consequences of potential failure modes: problems that have not still arised, but that may be inherent to construction processes (and, unfortunately, we do not know).

The outlined ideas may be considered as a first approach to further discussion. They intend to constitute a draft to be submitted to researchers and practitioners engaged to lean thinking, and might be useful to complement a more comprehensive approach to planning and design of construction procedures.

FAILURE ANALYSIS: IN SEARCH OF WHAT COULD BE WRONG—AN APPROACH TO LEAN THINKING

Lean thinking theory and practice clearly pointed out that Total Quality Management (TQM) methods and tools are powerful instruments to improve conversions and to reduce unnecessary flows in building construction projects.

Deming, Juran and other "gurus" stated a methodology to process management which in Brazil—following the Japanese school—is known as "daily routine management" (Juran 1988, Falconi 1992). This methodology establishes a step by step sequence of actions, based on the PDCA cycle, with some basic features:

a) The standardization of repetitive work;

b) The determination of parameters (control items) describing output goals of the process, thus being an objective way to decide if a particular result meets the client needs and expectations;

c) A comprehensive set of process variables (verification items), associated to the control items, that when within tolerances, will warrant the expected results of the process;

d) The set up of control activities—including statistical control, whenever possible—in order to quickly identify sources of deviations between programmed results and actual outputs of a process;

e) A step by step sequence of actions for problem solving in order to find out root causes of problems (that were observed by control activities), and point out action plans to prevent further repetition of such problems, normally resulting in changes on the procedures, or in the training of employees.

Building construction firms are gradually using the TQM principles, and many interesting experiences are found in literature (Gaarslev 1997, Serpell 1996, and other papers).

Summing up, the efforts of daily routine management are oriented to eliminate special (or contingent) causes of variation in processes outputs, or, eventually, at reducing common-cause variations, thus resulting in an improvement of the system.

This TQM approach to processes stands out actions that intend to result in what some authors call "quality of compliance": actual outputs will meet designed specifications to processes results, because processes parameters are continuously monitored and **corrective** actions are carried out.

Nevertheless, every process presents problems (failures) that generates unnecessary rework, material lost, cost increase, etc., or, in a word, waste. Some of these failures result from a mismatch between planned procedures and the real way things are performed, that may be detected—normally *a posteriori*—by the daily routine management. This approach based on the plan-do-check-act (PDCA) cycle will reduce undesired results (outputs) by blocking failure occurrences to happen again. The corrective actions are directed to prevent standard deviations or mistakes.

In order to achieve quality assurance, which will lead to a more effective waste reduction, lean thinking practice should incorporate a rarely used method in building construction process design. It requires to consider "what shall we do to make things go on", and also an effort to searching for "what could be wrong (and we do not know)". This approach will lead to a different attitude: "how can we set up some counter-measures to potential failure modes".

This approach to process design contains the basic idea that there are many failure causes that can not be detected by conventional controls (even dynamic ones), because this controls and management tools are based on our present knowledge of process variables. This kind of failures are **implicit** in building construction plans, schedules and procedures, usually deriving from cause-effect relations that are technically unsuspected at first sight. The control procedures in order to adjust ends and means, inspection activities, gathering of data in order to detect waste sources, and other management activities will not provide a reduction in the probability of occurrence of such failures, unless basic changes in process procedures are adopted, in order to prevent potential and implicit causes of failure.

In other words, "in search of what could be wrong" (an analysis of potential failures modes inborn in process design or building construction circumstances) will provide a 'filter' to "time bombs", built-in problems, as mentioned before, in the construction conversions and flows processes.

This approach to process design, considered as a filter to internal standards and procedures, aims at a process reliability improvement. Reliability is here understood not merely as a "feeling of respectability", but in its full technical meaning: *the probability of a system to fulfill its function under previously established circumstances and conditions, during a given period of time*. Accordingly, the prevention of potential failure causes will lead to an increase in reliability, by anticipating and blocking cause failure sources.

The search for what is likely to be wrong should be, mainly, a principle of lean design and planning. In some cases, structured and formal tools aiming at failure analysis will be used. In other circumstances, there may be no need or possibility of using such tools. It should be kept in mind the general approach which involves a special effort to ensure that as many potential problems as possible have been considered. As Drucker stated, “one of the most important managerial skills during times of turbulence is anticipation”.

Furthermore, there is another advantage in this mental attitude that looks not only at actions that will ensure a “job well done condition”, but also looks for what is likely to go wrong. As it was previously mentioned, potential failure analysis will lead to set up action plans that point out counter-measures, anticipating failure occurrence. Another approach to potential failure analysis considers **robustness** of construction design processes. The search for potential failure causes will develop a tendency to use processes with internal mechanisms that will make them less sensitive to unpredictable variations in flows. Reliability and robustness are complementary features: a robust process is likely to perform as expected, because preventive actions have been taken. But there is a difference between **potential failure causes prevention** and **process design insensitive to upstream variations in flows.** In the last case, the action plans will have to introduce mistake-proof mechanisms, such as construction procedures less prone to suffer human errors, as well as measures to anticipate contingencies. In any case, the underlying mental attitude is the same.

Additionally, this form of lean thinking will complement other developed methods. As recalled earlier, Ballard and Howell outlined the necessity of improving the quality of management of processes, by controlling work flow: those responsible for a construction project “can try to anticipate the future by looking upstream in the project work flow”. The search for what is likely to be wrong in future activities, especially regarding construction procedures and tasks, will complement this dynamic approach to control. More than that, there will be a synergy between the proposed control system of dynamic projects and future potential failure causes prevention.

On the other hand, our proposed approach to process design will allow for contingency planning, as stated by Faniran and his colleagues, because it makes clear how counter-measures to possible adverse future events can be implemented, making more feasible the preparation of alternative plans to anticipate project environment.

In both cases, failure analysis may be implemented not only in analyzing construction procedures, but also other construction project variables, such as cost, scheduled activities, control mechanisms and parameters that point out the expected quality.

USE OF FAILURE ANALYSIS METHODS

In order to implement this reasoning on design review of products and processes, researchers engaged in manufacturing projects developed some useful methods of failure analysis. The more frequently used are FMEA (Failure Modes and Effects Analysis) and FTA (Fault Tree Analysis). They were used for the first time almost four decades ago, in the US government aerospace program, and were later embraced by other industries, especially by suppliers of electronic and automotive components. In the eighties, those methods were widely used all over. Recently, FMEA has become a compulsory tool for design review in automobile industry, as a recommendation of QS-9000 standard. A detailed description of these methods can be found in literature (Helman and Andery 1995, Kapur 1988, Jakuba 1997, AIAG 1996).

FMEA is a formal, documented and structured analysis method applied to product and/or process design. Its main objective is to identify failure modes, their root-causes and their effects, and how these effects impact on process outputs. Being a “bottom-up” analysis, the method begins describing the relations between causes, failure modes and its effects for every single component of the system/process. After that, an assessment of the failure causes probability of occurring, the seriousness of its effects and the possibility of failure prevention by the actual existing controls is performed. These facts are ranked, resulting in a “risk priority number”, allowing the failure causes hierarchization and the prioritization of the preventive actions. Every analysis of the process activities, however small, must be examined, thus providing a diagnosis of the process as a whole. **In this sense, both conversions and flows are critically analyzed.**

The FTA study is based on diagrams developed by using formal deductive logic. It provides a “top-down” analysis, beginning with a “top event”—a failure situation or a problem—and continues by determining the combination of events that might lead to the failure occurrence. The analysis ends when the basic causes of the problems are found. Complete fault tree structures can be combined with available data regarding past failure occurrences, providing an assessment of failure probabilities. Additionally, FTA addresses multiple sequences of events that determine the same failure, thus making possible the evaluation of the critical combination of events that may induce failure modes.

The application of FMEA and FTA will therefore imply:

- the hierarchization of the failure causes regarding their potential risk;
- the establishment of an action plan to prevent failure causes;
- and additionally, the establishment of a strategy for the implementation and follow up of that action plan.

As those tools can provide a diagnosis and a critical analysis of the whole process, they will not only be applied in conversion activities, but also in the analysis of intrinsic failure causes of the processes related to flow activities. The consideration of a separate part of a process will involve in the search of failure causes that are implicit in it and, because of that, not always evident. On the other hand, the intermediary activities among the process components, that usually represent flows of information, material, etc., can also be examined, resulting in a possible optimization of those flows. In that way, it constitutes a holistic approach to the process, exactly in the context of the “lean thinking” philosophy.

It is also important to remark that the use of those tools will naturally boil down into an economy of resources, since it is easier and cheaper to block failure causes before they arise, when there is more flexibility for introducing alterations in the different stages of the processes.

At the same time, a set of documents will be produced on the evolution of the processes performance, with the consequent support for future analyses. Each FMEA and FTA analysis carried out will facilitate further jobs and reduce the costs in the development of future studies in similar activities.

STRATEGY FOR THE APPLICATION OF THOSE TOOLS

As it was already mentioned, a great advantage in the use of those tools lies on the fact that they can analyze the activities of production in a systemic way, including conversions and flows. Three interlinked applications are suggested:

a) The analysis of constructive activities described in the process flowchart that involves either conversions or productive technical activities. Both tools can be used.

b) The analysis of intermediary activities between productive phases, including their intrinsic flows. If the flow activities are clearly identified, FTA can be used to point out waste sources and to propose preventive measures, without affecting a global analysis through FMEA.

c) The analysis of the managerial activity of the processes: what is likely to go wrong in the schedule of the activities, in the destination of inputs, materials and previous work availability, execution time, etc., in accordance with the dynamic control method of projects proposed by Howell and Ballard.

On the other hand, the authors' experience in the application of those tools, mainly in industrial processes, suggests an integrated use of both of them. That will result in:

a) A synergetic effect obtained as a consequence of the integrated use of both tools. As a start, FTA may be used in the analysis of specific failure causes, detected from critical analysis of former projects. The use of FMEA can be addressed to a comprehensive review of the process (or part of it), eventually using data obtained through FTA. This last method can be applied again in failure causes that present high criticality.

b) The use of both tools will be mainly oriented to the elaboration of action plans. Its implementation will produce a continuous feedback in the project design of the processes, with an approach that includes conversions and flows. In that way, the application of those tools will serve simultaneously to purposes of auditing and continuous improvement of the processes in operation.

As an example of application it is presented further on, part of an analysis using FMEA for the process of placement of ceramic coatings on buildings facades. The study was carried out in the metropolitan area of Belo Horizonte, Capital City of the state of Minas Gerais, Brazil. The analysis involved:

a) Technical visits to different places in which activities ceramic coating were performed.

b) Technical visits to places in which failures in the sticking process of ceramic coating were observed.

c) In situ research of the failure causes with the participation of field personnel: foremen, bricklayers, etc.

d) Research in the specialized literature

e) Elaboration of the flowchart of the process

f) Elaboration of the FMEA. The attribution of the indexes was done taking into account the data collected in the places visited.

As a consequence of the analysis, action plans were elaborated, in agreement with the propositions of the FMEA. The implementation of those plans is still in progress.

DIFFICULTIES IN THE APPLICATION OF THOSE TOOLS

The authors' experience in the use of those methods, mainly in processes related to the manufacture industry, suggests that some difficulties may eventually arise by the time those tools are used. Some of them are listed next:

a) Lack of operational standards.

It is well known that the civil construction industry presents a low level of standardized activities. This situation creates a serious difficulty in the application of the mentioned tools. If the processes are not stable and repetitive, any improvement activity such as including the prevention of failure causes becomes almost impossible. However, the implantation of the proposed methods will increase with the progressive cultural changes taking place in the construction industry. The cases mentioned in previous IGLC conferences are an important example.

On the other hand, the methods of analysis of failure causes can be used in construction activities that present a high standardization level although informal, that is to say, without the existence of documented procedures. Typical examples can be observed in the industrial assemblies of metallic structures, in the elaboration of prefabricated components and in the finishing stages of building construction.

b) Bureaucratic vision in the application of the tools.

In the manufacturing industry, the methods of analysis of failure causes are frequently used only in response to contractual demands by the customers. Consequently, they are applied without a real concern of "filtering" possible failure causes and increasing the reliability of the processes. That attitude turns the analyses inconsistent and, what is still worse, it creates a false image regarding the underlying approach to those activities. It is feared that people involved in the construction activities do not convince themselves of the convenience of using those methods and adopt an attitude type "I have plenty of work to do with the problems that appear, and you want me to think on problems that still have not arisen?" Therefore, it becomes necessary to make an effort to enlighte construction people regarding the benefits and limitations in the use of those tools.

c) Lack of time to perform the analyses

FMEA and FTA are methods that demand a considerable execution effort, especially at the beginning. That happens not so much for the complexity of the methods, but for the thoroughness required by the analyses. The working groups should have enough time for their execution and revision. The use of those tools is particularly recommended in repetitive activities that, once executed will introduce improvements in other processes with similar characteristics.

d) Lack of information

The civil construction industry does not have a rooted habit of collecting data seeking an effective control of the projects. Obviously, that hinders the determination of causes of failure and especially the determination of its occurrence probability. The cultural change being promoted in the construction industry will have to overcome that practice and to make room for the analysis of failure causes.

On the other hand, it is very important that the teams involved in the execution of FMEA/FTA are multidisciplinary. The presence of people involved in different tasks provides a wide control of the "know how" and the technology involved in each process, as well as a global vision of the consequences of the failure causes faced by the construction system as a whole.

CONCLUSION

This work presents an introductory and panoramic vision of a not very common way of reasoning in the lean production: the need to think in terms of "what can go wrong? ", mainly as an attitude of the permanent reviewing of operational procedures in the construction industry.

It was remarked the fact, not always taken into account, that the construction processes need to pass through "filters" that represent a systematic search for potential failure causes. Those failure causes will arise independently of an appropriate execution of the Daily Routine Management, unless structural changes are incorporated in the projects of the processes. That will represent an increase in the reliability of the processes. For the implementation of that attitude it was suggested the use of two tools currently used by the manufacturing industry, FMEA and FTA.

It was pointed out that those analyses must end up in the setting of action plans, involving an activity of continuous feedback in the projects of processes and in the control activities. The approach must be systemic, considering conversion and flow activities.

It is expected that these ideas might contribute to the elaboration of strategies, seeking the optimization of the processes in the context of the lean production.

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EXAMPLE OF A FMEA: EXTERNAL COVERING OF BUILDING FACADES WITH

Step	Function	Failure mode	Cause	Effect	O	S	D	R
1.Subsurface preparation for walls exteriors covering	Attainment of vertical plane	Insufficient bond to masonry	Masonry not humidified before mortar application	Mortar ungluing	5	4	7	140
		Insufficient bond to concrete surfaces	Absence of gross plaster	Mortar ungluing	2	7	4	56
		General cracking	Mix proportion too strong; materials with thin granulometry used	Stress development on the wall	4	5	8	160
		Local cracking	Big irregularities (holes) on masonry	Stress development on the wall	6	3	8	144
		Excessive mortar thickness	Error on the masonry: lack of plumb. Excessive mortar self weight.	Mortar ungluing	6	8	4	192

Ranges: (O) Occurrence:
9 - 10: Very high; failure almost inevitable
7 - 8 : High
6 - 4 : Moderate
3 : Low, isolated failures
1 - 2 : Very low or remote

(S) Severity:
9 - 10: Very high, catastrophic effects
8 - 7 : High, intensive rework
6 - 4 : Moderate
3: Low severity
1 - 2 : Almost imperceptible

(D) Detec
10: Impos
9: Very re
7 - 8: Ver
5 - 6: Mo
4 - 3: Mo
1 - 2 : Al

R = risk priority number = O x S x D

Step	**Function**	**Failure mode**	**Cause**	**Effect**	**O**	**S**	**D**	**R**
2. Execution of joint cuts	Subdivision of the ceramic planes	Error on placing joint cuts	Design error. Lack of following up of drawings during execution	Cracking in transition region (structure/mason ry) where joint should be located	1	5	8	40
	Subdivision of the ceramic planes	Error on performing joint cuts: wrong with and deepness	Errors during cut equipment adjustment and operation. Errors on cuts marking	-Elastomeric sealant rupture -Water infiltrate. Mortar ungluing -Reduction of designed elast.	4	4	8	128
3. Placement of ceramic tiles	Finishing of external wall covering	Unsuitable subsurface for receiving ceramic tiles	No observation of curing time	Subsurface movement. Ungluing of ceramic tiles, that can not absorb that movement	4	6	3	72
		Ditto	Subsurface impregnated by pulverulent materials, fungus, microorganisms, greasy or efflorescence	Insufficient bond strength to masonry, causing ceramic ungluing	5	8	6	240

Ranges: (O) Occurrence:
9 - 10: Very high; failure almost inevitable
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1 - 2 : Very low or remote

(S) Severity:
9 - 10: Very high, catastrophic effects
8 - 7 : High, intensive rework
6 - 4 : Moderate
3: Low severity
1 - 2 : Almost imperceptible

(D) Detec
10: Impos
9: Very re
7 - 8: Ver
5 - 6: Mo
4 - 3: Mo
1 - 2 : Almost certain

R = risk priority number = O x S x D