Chapter

Risk Assessment in the Monitoring of Works

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Abstract

The purpose of this chapter is to present a methodology for developing Control, Measurement and Monitoring Plans. It aims to apply risk-based thinking associated with the works control plan. The failures and rework of the works must not be accepted as inevitable or even as certainties. They must be considered permanent challenges to their management. The importance of using risk assessment techniques in the planning and control of the production activities of the works is evident. Control, measurement and monitoring process should provide the assessment of risks and failures, should demonstrate technical compliance of the work, and should improve operational efficiency. Thus, it is important to define a methodology for the preparation of the Control, Measurement and Monitoring Plan (PCMM), to be implemented in the execution of the works, in order to ensure the conformity of the works with its technical and regulatory requirements. It must establish which the trials and control inspections, its acceptance criteria, its purposes, frequencies and responsible and it must also identify and assess its risks.

Keywords: Control, Measurement and Monitoring Plan, analysis and risk assessment, building works

1. Introduction

Building works productivity is not only improved with more works and more companies. It improves with more competitive companies and with better organizational and technological capacity.

The work of the Construction is developed within a growing and demanding context where rigor and competence in production management are necessary conditions for the provision of the best service and product, being also essentials to maximize the profitability of the works [1].

For building companies, the logical choice to ensure competitive advantage with the rest of industry requires the use of new productivity tools and work production control methods. In many manufacturing industries, production processes have been modified with the implementation of systems that limit the existence of the failures and reworks along the production flow. These industries are confined to factories and can implement efficient monitoring systems that define any process accurately and subsequently monitor their implementation [2, 3].

Defects and rework should not be accepted as inevitable or even as certainties but considered as a permanent challenge to the management of the works, being important to use risk assessment techniques there its planning and control [2].

The "Operational Planning and Control" requirement specified in ISO 9001: 2015 indicates that organizations must plan, implement and manage the processes necessary for the supply of the product and service provision (Works) to ensure compliance with customer requirements (Owners) [4, 5].

Control, measurement and monitoring process of the works should provide the specific actions to address the risks and opportunities and achieve the objectives specified in their planning [4].

Thus, it is necessary to establish Plans of Control, Measurement and Monitoring Plans (PCMM), assess risk and define actions for its treatment, and implement the control of operational processes in accordance with the defined criteria. Plans of Control, Monitoring and Measurement (PCMM) are required to: i) demonstrate the technical compliance of the Work; ii) continuously improve operational effectiveness [2].

2. Risk assessment and plans of control

Risk assessment is an integral part to the various process of the works, aiming at prevention and its resilience.

To understand the risk assessment is necessary to know the definition adopted for "*risk*" in ISO Guide 73 (*Risk management – Vocabulary - Guidelines for use in standards*) and ISO 31000 (*Risk management - Principles and guidelines*). In according to these standards' "*risk*" is defined as the "*effect of uncertainty on objectives*" [6, 7].

This definition gives the possibility of we considering the risk as a threat or an opportunity. However, it is not gives clue as to how to quantify the risk. For this purpose, we must use the definition of the risk as being the combination of the probability of the occurrence an event (Likelihood or Frequency) and its consequences (Severity), something that is referred to in complementary notes these standards. The risk assessment compares the results of risk analysis with risk criteria (frequency and severity criteria) to determine whether the risk is acceptable or tolerable. It requires the identification and analysis of the events (occurrence or change of a set of circumstances) and to determine the risk level. The risk level is a function of its consequence (or Severity) with its likelihood (or Probability) and measures the magnitude of the risk. The risk valuation criteria are references in respect of which the significance of the risk is assessed [8].

The events that influence the results of processes under analysis can be identified and classified between risks and opportunities. The opportunities are directed to the organization's strategic planning processes and the risks are analyzed by quantifying the probability of occurrence and the severity its effects, to determine its level and the actions of mitigation [4].

Risk assessment may be made at difference degrees of depth and detail, we using various techniques ranging from simple to complex. We must use the risk criteria consistent with the scope of the process under analysis, as well as the technique and the assessment results. Likelihood/Consequence Matrix (LCM) and Failure Mode and Effects Analysis (FMEA) are two of several techniques of great application in risk assessment.

Likelihood/Consequence Matriz (LCM) is a technique that combines the probability of the event under analysis with its effects, to define a qualification of the level of risk. The form of the matrix and the definitions that apply to it depend on the context in which it is used. This technique is used to classify risks and their sources, and to identify your treatments. It can be used in situations where there is not enough data for a detailed analysis or when the situation does not justify the time and effort for a more quantitative analysis. It is relatively easy to use, and it provides quick ordering of risks at different levels of significance. Adequate scales of the likelihood and consequences criteria and the definition of risk matrix are the inputs essential the risk assessment process. The likelihood criteria scale (Probability) should cover the relevant domain for the case in analysis. The consequence criteria scale (Severity) should cover the range of different types of the consequences to be considered, from the maximum plausible consequence to the smallest plausible consequence to be considered. All scales can have any number of the levels, the most common being the scales of 3, 4 or 5 levels [7].

To order the risks, the consequence descriptor (Severity) that best suits the situation is chosen first, then the probability (Probability) of occurrence of these consequences is then defined. The risk level defined in the LCM may be associated with a decision rule, such as, for example, treating or not treating the risk.

Failure Mode and Effects Analysis (FMEA) is a technique for analyzing the reliability of the products, systems or processes. It is used to identify modes in which components of products, systems or processes may to fail to performance their functions. There are several FMEA applications: design FMEA which is used for components and products; system FMEA which is used for systems and process FMEA which is used for manufacturing processes and procedures and assembly. FMEA is also used in risk assessment and this requires detailed information on the phases of the case under study, to permit a significative analysis its failure modes. To perform a FMEA is fundamental the experience of the evaluators, the knowledge of the history of the failures and the causes, of the decision criteria and/or acceptance of the specific risks, and of the steps of the case under study [9].

Severity, Probability and Detection indices are the inputs for FMEA. Their scales must be adequate to the consequences and the likelihood of the events that combined define the risk matrix. Additionally, the level of risk combined with the failure detection index determines the Risk Priority Number (RPN). The scales these three criteria can have any number of levels, the most common being scales of 3, 5 or 10 levels [7, 8, 10–13].

To order the risks identifies, the consequence descriptor is chosen first, which best adapts to the situation, then the probability of occurrence of that consequence is defined. With the third detection descriptor, the Risk Priority Number (RPN) is defined. RPN is used to prioritize the of risk mitigation actions.

If we accept that all results of the building works processes are subject to uncertainty, then we can conclude that there is need a risk assessment for each of these. So, we can find the risk assessment in the reception of materials and the control of work in progress, in short, in all critical processes of the works, that it can ensure your technical and regulatory conformity.

According to ISO 9001 standard, production and service provision processes should be implemented under controlled conditions. This determines that the operational processes of the works are implemented a controlled mode, before, during and after its completion, particularly all its critical activities. Among other requirements, this condition includes the implementation of monitoring and measurement activities, in adequate steps, to verify if the criteria of the process or its outputs and the criteria for acceptance of the product and services were satisfied.

With this aim, it is essential to establish Plans of Control, Measurement and Monitoring (PCMM), assess the risk and define actions for its treatment, and implement the control of operational processes in conformity with the defined criteria. The PCMM is the document that specifies which are the trials and control inspections, the purposes, the acceptance criteria, the frequency, those responsible for the monitoring, and the records of the results obtained, in order to retain the objective evidence to the satisfaction of technical and regulatory requirements of the Work [2, 14].

3. PCCM form with risk assessment

This heading, on context of the building works processes, a methodology is proposed for elaboration of the PCMM, following the approach of risk-based thinking. It applies to operational processes considering the most critical work activities.

According to [2] the steps to be followed in the preparation of the PCMM require the definition of the: critical works activities that need to be controlled; inspections and tests to be performed in each critical activity; acceptance, frequency and sampling criteria of the inspections and tests; those responsible for control, measurement and monitoring; records of the results; risk assessment and its effects; and corrective and preventive actions to be implemented. **Figure 1** shows the flowchart of the methodology for preparing the PCMM.

3.1 Risk assessment with Likelihood/Consequence Matriz (LCM)

Table 1 shows the template PCMM with LCM which takes the form of a matrix of the columns and rows whose contents are explained below.

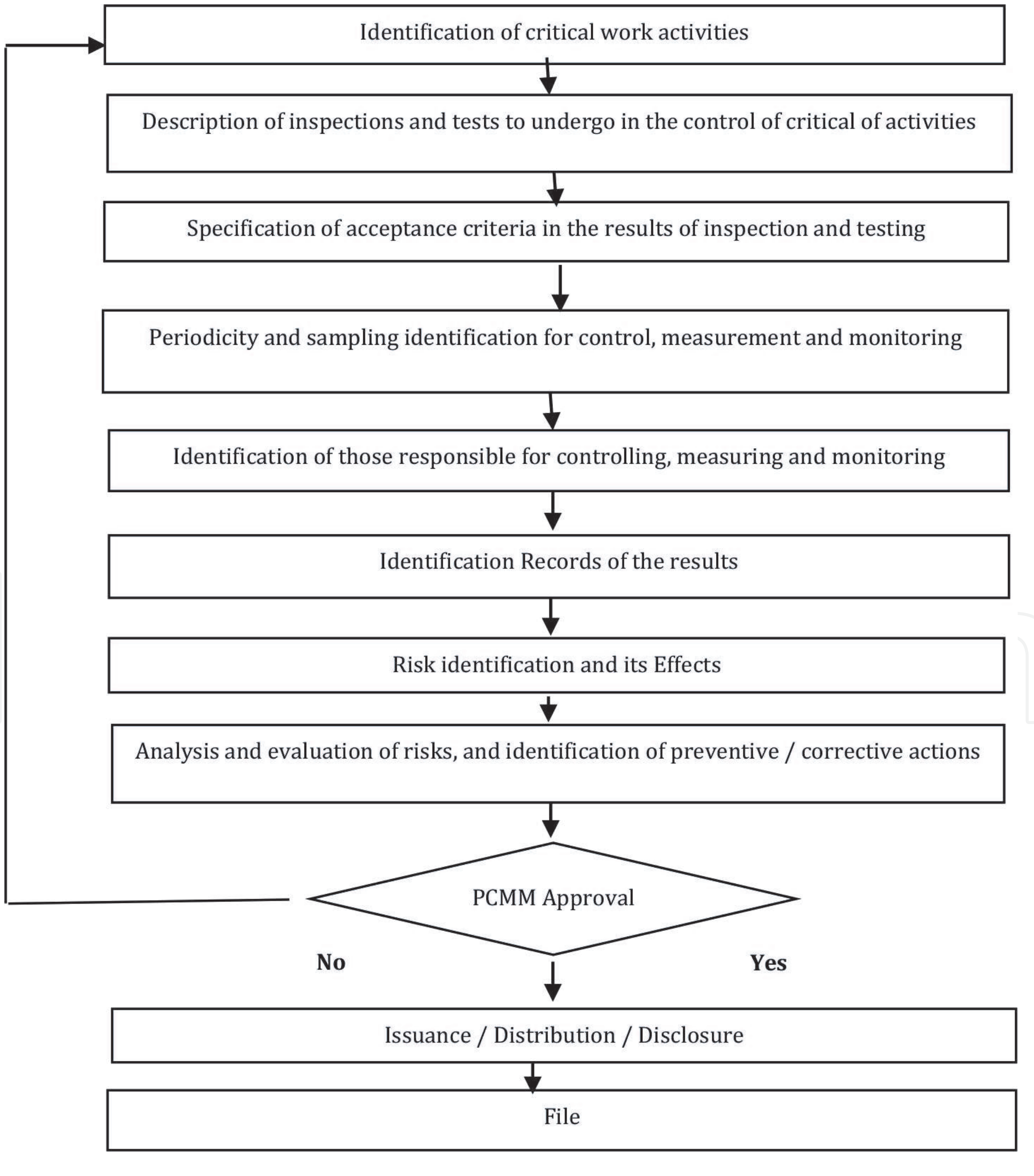

Figure 1.
Flowchart for preparing PCMM [2].

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Item (1)	**Activities (1)**	**Inspection/ Testing (2)**	**Purposes (3)**	**Acceptance criteria (4)**	**Frequency/ Sampling (5)**	**Responsible (6)**	**Re cords (7)**	**Risks (8)**	**Description (9)**	**Effects (10)**	**Risk Assessment (11)**			**Controlled Risks? (12)**	**Actions (13)**
											P	S	RN		

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											P	S	RN		

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Table 1.
PCMM template with LCM [2].

Using the LCM technique for risk assessment in the preparation of the PCMM, in according [2] the following guidelines must be used:

Columns (1) of the PCMM is identified the critical activities of the work that will be monitored. The critical activities are those ensure the technical conformity of the work with your design.

In the columns (2-3) are used to indicate the kind of the inspections and tests to be applied in quality control, their purpose and that is to be measured to monitor critical activity in analysis. The column (4) is used to propose which normative and regulatory references and criteria for acceptance that are used to analyze the results obtained in the inspections and in the tests carried out.

At each inspection/test, in the columns (5-7) are indicated their sampling frequency, who is responsible for carrying out the control and which record to use to compile their results. These items are intended to ensure the systematic control, measurement and monitoring in each critical activity.

Risk assessment is carried out at each stage of control, measurement and monitoring. Thus, for each critical activity is identified the events whose outputs may not be what expected.

The identification of risk and its effects is done on the columns (8-10) of the PCMM. For each critical activity and its control, the Risk is identified, its description is made and its effect is characterized. In this way, the event associated with it will be featured and you can review the respective controls, measurements and monitoring, especially in cases where it is not possible to act on the causes. This characterization will allow the reflection on the consequences of the effect, which will allow to assess its severity using the defined criteria. It is intended to briefly describe the effect of the risk previously identified in order to better identify the critical impact on its activity.

Finally, the risk identified in (8), described in (9) and with the effect identified in (10), it is assessed in columns (11) of the PCMM.

Risk assessment is carried out using two criteria: Probability (P) and Severity (S). According to [2], the score criteria to be used in the estimation of Probability (P) and Severity (S) are proposed in **Tables 2** and **3**.

Then, for each risk or failure mode, its Probability (P) is given it a score. After, the analysis of the consequences and its effects, the same is done for Severity (S).

The scale of these scores should be assigned based on our experience with the activity in question.

The Risk Number (RN) classifies the assessed risk. Thus, if the Probability (P) and Severity (S) scores are multiplied, we obtain the RN in each case. Using **Table 4** found in [2], the RN that we can obtain vary between the minimum value 1 and the maximum value 16.

Therefore, high risk is classified when the NB is higher than 9, medium risk is classified when the NB is 9 and the low risk is classified when the NB is lesser than 9.

Probability		
Category	**Description**	**Score**
High	Occurs often.	4
Medium	Probably, it has occurred several times.	3
Low	Probably, it has already occurred.	2
Remote	Probably, but never occurred.	1

Table 2.
Risk probability criteria (P) [2].

Severity		
Category	**Description**	**Score**
High	Requires the re-inspection/rework the whole lot	4
Medium	Requires the re-inspection/rework part of the lot	3
Low	Requires adjustments in inspection/inspection/testing	2
Negligible	Does not require specific actions	1

Table 3.
Risk severity criteria (G) [2].

Risk Number		**Severity (S)**			
		1	2	3	4
Probability (P)	1	*1*	*2*	*3*	*4*
	2	*2*	*4*	*6*	*8*
	3	*3*	*6*	*9*	*12*
	4	*4*	*8*	*12*	*16*

Table 4.
Risk number [2].

With the classification of the RN done, the appreciation of events is began whose outputs are not the desired. Thus, the undesired outputs will be characterized, making it possible to make revision the inspections/tests identified and to adopt another type of control, measurement and monitoring.

In the column (12) the RN high, medium or low is identified and whether adequately is controlled or not.

However, according to the criteria defined in [2], the risk is adequately controlled (Yes) if the NR is lesser than 9 (for medium or low risks) and uncontrolled (No) if NR is higher than 9. For the uncontrolled risks (No) are must indicate the action required to mitigate them.

In the column (13) of the PCMM the actions to mitigate uncontrolled risk are indicated, making it adequately controlled.

3.2 Risk assessment with failure and effect modes analysis (FMEA)

In **Table 5** we see the template of a PCMM with FMEA that takes too the form of a matrix, constituted by a set of columns and rows containing information relating to the same items already explained above.

Using the FMEA technique for risk assessment, in the preparation of the PCMM we can use the following guidelines:

On the PCMM with FMEA form the fields (1) to (10) are the same as those of PCMM with LCM form. Field (11) is used to assess the risk identified in (8), described in (9) and with the effects identified in (10). Here, risk assessment will be carried out according to the three FMEA criteria, described below. The classification of risk depends on the combination of probability (P), gravity (S) and detection (D).

Thus, for each risk or failure mode, we must analysis he consequences of their effects and to estimate its Severity (S). After to analysis its Probability (P) we must assign a it a score. Then, we must assign the Detection Index (D) to order the number priority of risk (NPR).

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Item (1)	Activities (1)	Inspection/ Testing (2)	Purposes (3)	Acceptance criteria (4)	Frequency/ Sampling (5)	Responsible (6)	Re cords (7)	Risks (8)	Description (9)	Effects (10)	Risk Assessment (11)				Controlled Risks? (12)	Actions (13)
											P	S	D	RPN		

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											P	S	D	RPN		

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Table 5.
PCMM template with FMEA.

Therefore, it is necessary to establish the criteria to be used in the estimation of Probability (P), Severity (S) and Detection (D) values. **Table 2** shows the values of Probability (P), **Table 3** shows the values of Severity (S) and **Table 6** shows the values for Detection (D).

For the assignment of the scale of these scores, the experience we have of the activity under analysis is too important. But we are looking for is the risk priority order. Thus, if the Probability, Severity and Detection scores are multiplied, we will obtain the Risk Priority Number (RPN) in each case.

In accordance with **Table 4** we can classify High Risk as values higher than 9, Medium Risk values of 9 and Low Risk values lower than 9. In each class of risk, we must appreciate the ranking of the priority, namely, which are the most priority events where the outputs may not be desired.

Fields (12) and (13) on the PCMM with FMEA form are the same too as the fields explained above (PCMM with LCM). Thus, according to the criteria defined for the Risk Number, in field (12) we must consider the Risk appropriately controlled if the RN is ≤9 (for Medium or Low Risks), otherwise we should consider it uncontrolled (N). For the uncontrolled risks. Then, we must then indicate the action required to mitigate them. In field (13) we should indicate what actions are necessary to mitigate the most priority uncontrolled Risk, making it adequately controlled.

4. Application examples

Then, a brief presentation of a PCMM used in a works is made. The objective is to present two practical examples of the use of PCMM with risk assessment, the first under the LCM technique and the second under the FMEA technique, both examples from the methodology above mentioned.

4.1 PCMM with LCM

This case PCMM were prepared for the critical activities of the building works. However, **Table 7** shows an excerpt of the PCMM with LCM prepared for the execution of reinforced concrete beams of the building's structure.

The methodology set out above was followed in preparing of the PCMM with LCM, and risk assessment was made under Likelihood/Consequence Matrix.

The use of this procedure allows, on the one hand to plan the inspections and tests to make the critical activities, so as to control, measure and monitor all the work, on the other hand, it helps mitigate the risk in the events with a negative impact on the development of work.

It is observed that the planned control for the activity of the "Installation Falsework" has the highest risk number (RN = 9), and it is classified as medium risk.

Detection		
Category	**Description**	**Score**
High	High difficulty detection	3
Moderate	Medium difficulty detection	2
Low	Low difficulty detection	1

Table 6.
Risk detection criteria (D).

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Item (1)	**Activities (1)**	**Inspection/ Testing (2)**	**Purposes (3)**	**Acceptance criteria (4)**	**Frequency/ Sampling (5)**	**Responsible (6)**	**Re cords (7)**	**Risks (8)**	**Description (9)**	**Effects (10)**	**Risk Assessment (11)**			**Controlled Risks? (12)**	**Actions (13)**
											P	**S**	**RN**		
1	Receipt Falsework	Visual inspection	C with Purchase Order	Purchase Oder	By Delivery By Lot	Overseer	Control Sheet	NC with Purchase Order	Variation in Quantities; Deviations in type Falsework	Deviation in Activity 3	2	2	4	Yes	NA
2	Receipt Reinforcement	Visual and Metric inspection	C Steel Class and ϕ	Project; Steel specification for concrete reinforcement	By Delivery By Lot	Overseer	Control Sheet	NC with Specification	Deviation in Classes and ϕ of steel	Deviations in Activity 4	1	3	3	Yes	NA
3	Installation Falsework	Visual and Metric inspection	C of Verticality, Planimetry and Stability	Structural Design	By Beam	Overseer	Control Sheet	NC of Verticality, Planimetry and Stability	Instability of the beam	Deviations in activities 4 and 6	3	3	9	Yes	NA
4	Installation Reinforcement	Visual and Metric inspection	C of the mooring and positioning	Structural Design	By Beam	Overseer and Construction Engineer	Control Sheet	NC of mooring and positioning	Deformation and instability of the Beam	Deviations in Activity 6	2	3	6	Yes	NA
5	Receipt Concrete	Visual inspection and Consistency Testing	C with Purchase Order and Class Consistency	Purchase Order Structural Design	By delivery	Overseer and Construction Engineer	Control Sheet	NC of Purchase Order and NC Class Consistency	Deviations in Concrete Class Deviations in Consistency	Activities 7 stop	2	3	6	Yes	NA

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Item (1)	**Activities (1)**	**Inspection/ Testing (2)**	**Purposes (3)**	**Acceptance criteria (4)**	**Frequency/ Sampling (5)**	**Responsible (6)**	**Re cords (7)**	**Risks (8)**	**Description (9)**	**Effects (10)**	**Risk Assessment (11)**			**Controlled Risks? (12)**	**Actions (13)**
											P	**S**	**RN**		
6	Placement Concrete	Visual inspection	C of Concrete Placement	Structural Design	By Placement Concrete	Overseer and Construction Engineer	Control Sheet	NC of Concrete Placement	Deviations in the final quality of the Beam	Pathologies in the Beam	1	5	5	Yes	NA
…	…														
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C - Compliance; NC - Not compliance; NA - Not Applicable.

Table 7.
PCMM with LCM for beams.

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Process/Work: Execution of Beams

Item (1)	Activities (1)	Inspection/ Testing (2)	Purposes (3)	Acceptance criteria (4)	Frequency/ Sampling (5)	Responsible (6)	Re cords (7)	Risks (8)	Description (9)	Effects (10)	Risk Assessment (11)				Controlled Risks? (12)	Actions (13)
											P	S	D	RPN		
1	Receipt Falsework	Visual inspection	C with Purchase Order	Purchase Oder	By Delivery By Lot	Overseer	Control Sheet	NC with Purchase Order	Variation in Quantities; Deviations in type Falsework	Deviation in Activity 3	2	2	1	4	Yes	NA
2	Receipt Reinforcement	Visual and Metric inspection	C Steel Class and ϕ	Project; Steel specification for concrete reinforcement	By Delivery By Lot	Overseer	Control Sheet	NC with Specification	Deviation in Classes and ϕ of steel	Deviations in Activity 4	1	3	1	3	Yes	NA
3	Installation Falsework	Visual and Metric inspection	C of Verticality, Planimetry and Stability	Structural Design	By Beam	Overseer	Control Sheet	NC of Verticality, Planimetry and Stability	Instability of the beam	Deviations in activities 4 and 6	3	3	3	27	Yes	NA
4	Installation Reinforcement	Visual and Metric inspection	C of the mooring and positioning	Structural Design	By Beam	Overseer and Construction Engineer	Control Sheet	NC of mooring and positioning	Deformation and instability of the Beam	Deviations in Activity 6	2	3	3	18	Yes	NA
5	Receipt Concrete	Visual inspection and Consistency Testing	C with Purchase Order and Class Consistency	Purchase Order Structural Design	By delivery	Overseer and Construction Engineer	Control Sheet	NC of Purchase Order and NC Class Consistency	Deviations in Concrete Class Deviations in Consistency	Activities 7 stop	2	3	3	18	Yes	NA

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							Process/Work: Execution of Beams									
Item (1)	**Activities (1)**	**Inspection/ Testing (2)**	**Purposes (3)**	**Acceptance criteria (4)**	**Frequency/ Sampling (5)**	**Responsible (6)**	**Re cords (7)**	**Risks (8)**	**Description (9)**	**Effects (10)**	**Risk Assessment (11)**				**Controlled Risks? (12)**	**Actions (13)**
											P	**S**	**D**	**RPN**		
6	Placement Concrete	Visual inspection	C of Concrete Placement	Structural Design	By Placement Concrete	Overseer and Construction Engineer	Control Sheet	NC of Concrete Placement	Deviations in the final quality of the Beam	Pathologies in the Beam	1	5	3	15	Yes	NA
...	...															
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Table 8.
PCMM with FMEA for beams.

Given the set decision rule in the methodology, this risk is controlled and does not require mitigation action.

It is seen too that the planned control for the activity “Receipt Reinforcement” has the lowest risks number (RN = 3), and it is classified as low risk. With the set decision rule defined in the methodology, this risk is also controlled and does not require any mitigation action.

It is seen that the planned control for the activity of the “Installation Falsework” has the highest risk number (RN = 9), and it is classified as medium risk. Given the set decision rule in the methodology, this risk is controlled and does not require mitigation action.

It is observed that the planned control for the activity “Receipt Reinforcement” has the lowest risks number (RN = 3), and it is classified as low risk. With the set decision rule defined in the methodology, this risk is also controlled and does not require any mitigation action.

4.2 PCMM with FMEA

Keeping the form of the PCMM with LCM shown above, the **Table 8** shows the part of the PCMM with FMEA prepared for the execution of reinforced concrete beams of the building’s structure.

The methodology set out above was followed in preparing PCMM with FMEA and risk assessment was made under Failure Mode and Effects Analysis (FMEA).

The use of this procedure also allows, on the one hand to plan the inspections and tests to make the critical activities, so as to control, measure and monitor all the work, on the other hand, it helps prevent the risk in the occurrence of monitoring events with a negative impact on the development of work.

It is seen that the planned control for the activity of the “Installation Falsework” continues to have the highest risk number and the highest risk priority number (RPN = 27). Since it is classified as medium risk, according to the set decision rule defined in the methodology, this risk is controlled and does not require any mitigation action.

It is observed that the planned control for the activity “Receipt Reinforcement” has the lowest risk number and the lowest risk priority number (RPN = 3), it being classified as low risk. With the set decision rule defined in the methodology, this risk is also controlled and does not require any mitigation action.

5. Conclusion

It was concluded the methodology presented for the preparation of Control, Measurement and Monitoring Plans (PCMM), can follow the approach on risk-based thinking and can help to assurance the compliance with technical and regulatory of the works. It was concluded too that measurement and monitoring process can promote the risks and failures assessment and can demonstrate the conformity of the works and can too improve operational efficiency.

The PCMM with risk assessment helps to identification the need for risk mitigation actions in the control of the works. Therefore, the use of risk assessment techniques is important in the planning and control of the works processes.

It was observed that Likelihood/Consequence Matrix (LCM) and Failure Mode and Effects Analysis (FMEA) are two techniques of the risk assessment applicable to PCMM, and introducing the probability, consequences and detection indices, they allow risk classification and priority of their mitigation.

It also was concluded that the use of the proposed methodology for of the PCMM can be a solution to prevent defects and reworks, since it allows you to easily identify which trials and inspections will be implement on the control, measurement and monitoring critical activities of the works.

If we are used to risk assessment for identify from the sources, events and causes and its possible consequences, then we can determine the level of risk and its acceptance or tolerance. Finally, the risk assessment applied to PCMM helps to indicate which actions are necessary to mitigate uncontrolled risks.

With the examples presented, it was possible to conclude that defects and rework of the works do not have to be accepted as inevitable or even as certainties and should be considered as a permanent challenge to the management of work.

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