INTEGRATING PRODUCTION AND QUALITY CONTROL WITH THE SUPPORT OF INFORMATION TECHNOLOGY

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ABSTRACT

The construction industry has faced major changes in the last few decades including a reduction in profit margins, the government's requirements for quality management certification and an increasing level of quality demanded by consumers. Moreover, intense competition between companies has stimulated interest in developing innovations in managerial systems, seeking to improve product quality while reducing its cost. Recent studies have pointed out a category of waste, called making-do, which occurs when a task starts before all inputs are available. There is evidence that this type of waste is closely related to the execution of informal packages, and that it is the root cause of other types of waste in construction, such as accidents, material waste and rework. Integration between production control and quality management has been pointed out as a means to reduce the incidence of informal packages and, hence, making-do. This type of integration needs the support of information technology, due to the amount of data that needs to be processed by the same person, and also the need to synchronize the application of some controls. Hence, this research study explores the use of information technology in production control systems. A control model was devised and tested in a Brazilian construction company involved in the development and construction of low-cost housing projects. The control model was implemented in one of the company's construction sites, where a set of quantitative and qualitative data were collected, including making-do events, the occurrence of informal work-packages, project completion and quality control indicators. The paper will present some production control data that were produced in the empirical study, as well as a preliminary assessment of the model that was devised.

KEYWORDS

integrated control, production control, quality, making-do, informal packages

INTRODUCTION

In the past few decades, the construction industry has been faced with many challenges for improving performance in terms of quality, safety, project duration, and low productivity. Despite the successful implementation of Lean ideas in

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different countries, those problems still persist in the industry at large. In emerging economies like Brazil, there is currently much concern with the lack of reliability of the construction industry in terms of product quality, and the impact that this problem has in project duration, costs, and customer satisfaction.

The literature has pointed out that a major problem in quality management systems is the lack of integration with production control (Arentsen et al. 1996; Bij and Ekert 1999; Fernandes et al. 2009; Fireman et al. 2013; Soares et al. 2002). In other words, quality control is performed independently of production planning and control. As a result, sometimes a task is considered to be completed in short-term control, but no quality checking has been performed (Sukster 2005). Fireman et al. (2013) pointed out that this is a major cause of a type of waste named unfinished work.

Moreover, non-completion of tasks with quality checking stems primarily from defective execution of the preceding task, so, if the tasks are inspected by quality control while they are being executed, the defects are corrected in time, preventing propagation of the problems to the subsequent tasks (Fireman et al. 2013). For Bij and Ekert (1999), production control and quality control interact in such a way that the good performance of one often influences or inhibits the performance of the other.

According to Arentsen et al. (1996), it becomes easier to ensure the delivery on schedule and efficient use of resources when quality control is properly integrated with task completion control. Those authors pointed out that, since production control must deal with variability and uncertainty, it is impossible to rely strongly on planned deadlines when nonconforming products are produced. Hence, the integration of both types of control leads to more transparency concerning the coordination of the different tasks, creating favourable conditions for keeping the project on schedule and using the team's skills efficiently (Arentsen et al. 1996).

Fireman et al. (2013) highlights the existence of informal rework packages that occur to correct work not approved by the quality system. In most cases, these rework packages are not included in the short-term plan and end up being done informally. Hence, these tasks are subject to uncertainties and they also lead to a decline in the performance of the planned work packages, since the prerequisites for a formal package are perhaps being used by an informal rework package (Fireman et al. 2013).

There is evidence that the execution of informal packages also leads to an increase in making-do waste, which, according to Koskela (2004), occurs when a task is initiated before all items necessary for its completion are available. As informal packages are executed before the removal of constraints and, due to the dispersion of the teams on site, it becomes difficult to plan and control access to areas of work, circulation and storage of materials (Fireman et al. 2013). Making-do waste is frequent in the construction industry and leads to other wastes in production, such as reduced safety, rework, quality problems and material waste (Fireman et al. 2013; Formoso et al. 2011).

Therefore, the integration between production control and quality control is considered a means to reduce the incidence of informal packages and waste by making-do. However, in order to facilitate that integration, it is necessary to use information technology to help to process the amount of data that needs to be processed by the same person and also due to the need to synchronise some controls. According to Park et al. (2012), in the past decade, major advances have been made in information technology and it could be used to improve management practices in the construction industry. There is still need for further studies to find out more about the needs of the construction industry and about the efforts that need to be made to meet those needs. Most studies so far have been concerned with finding applications for new technologies in construction, rather than seeking for alternative solutions for construction problems (Navon and Sacks 2007). For Bowden et al. (2006), information technology must be explored and implemented to facilitate the improvements that are needed in the construction industry.

Therefore, the aim of this study is to develop an integrated quality and production control model, connected with the Last Planner System, capable of monitoring novel categories of waste in construction, such as unfinished work and making-do. In this investigation, the use of information technology has been explored as a support in the data collection on building sites, data processing and storage.

LITERATURE REVIEW

WASTE IN THE CONSTRUCTION INDUSTRY

The literature presents several different definitions of waste in the construction industry, such as excessive consumption of material, execution of non-value adding activities, rework and quality deviations, indicating that waste is understood in many different ways (Viana et al. 2012). For Koskela (1992), the occurrence of waste in construction is related to the occurrence of non-value adding activities, such as waiting, moving, transportation, accidents and rework caused by design or construction errors.

Koskela (2004) also highlights the existence of a type of waste, called making-do, which occurs when a task is initiated before all the inputs necessary for its completion are available. Making-do is also defined in an implicit way by Ronen (1992) when he proposes the complete kit method, which is the set of components, drawings, documents and information required to complete a process. That author suggests that tasks should not be released for execution before the necessary set for its completion is available. The complete kit plays an important role in the planning and control process, as it forces managers to better plan the tasks and their components and it also creates a control point in the initial stage of the process, when corrective actions can still be taken (Ronen 1992).

Despite the benefits of the complete kit, making-do occurs due to the efficiency syndrome, pressure for immediate response, and improper division of the levels of assembly (Ronen 1992). Koskela (2004) also states that the main cause of making-do is production variability, which happens when an input is unexpectedly unavailable. This unavailability of inputs can lead to interruption of the work or to improvisation (Formoso et al. 2011). According to Formoso et al. (2011), making-do and improvisation are two strongly related concepts, since, when people are faced with difficulty or uncertainty, they tend to use any resource that is available to them in order to achieve their objectives, or, alternatively, the objectives may be redefined based on the inputs available.

Formoso et al. (2011) have investigated the occurrence of making-do waste in the construction industry. Based on observations conducted in building sites, the following categories of waste by improvisation were identified: access and mobility, adjustment of components, work areas, storage areas, equipment and tools, temporary facilities and protection. Fireman et al. (2013) also proposed the inclusion of a new category, defined as sequencing, referring to the alterations in the production order of a specific process, or when there is a rearrangement of the work sequence. Based on the creation of this new category, the evidences of the relationship between informal packages and making-do increased, as this type of waste can be the root cause for the existence of some informal packages (Fireman et al. 2013).

Making-do waste was also evaluated by Formoso et al. (2011) with regards to its origin by identifying the prerequisites necessary for the execution of the tasks. The criteria adopted to identify the nature of those types of waste were: information, materials and components, labour, equipment or tools, space, interdependent services, external conditions and facilities.

According to Ronen (1992), starting a job with an incomplete kit has several consequences for production, such as longer lead times, more work in progress, poor quality, more rework, decline in productivity and in workers' motivation, as well as making the control of the processes more complex.

INTEGRATED PRODUCTION AND QUALITY CONTROL

According to Laufer and Tucker (1987), control involves measuring and evaluating performance, taking corrective action when the performance is not as expected. The control model used in the construction industry, which monitors solely whether the planning specifications are being met, has been criticised by Ballard and Howell (1998), because it is not a production control model, but rather a project control model. According to those authors, the construction industry should follow the control model used by the manufacturing industry, which goal is to look at and act directly on the production processes, and not just identify the occurrence of errors. Hence, Ballard (2000) proposes the Last Planner System of Production Control, defined by the author as a philosophy and a set of tools that facilitate the implementation of more effective control.

The LPS has two main functions: production unit control and workflow control. The role of the first one is to make better assignments to workers through continuous learning and corrective action. The role of the second one is to cause work to flow across production units in the best possible sequence and rate (Ballard 2000).

The hierarchical structure of the Last Planner system is established on three levels: master planning, lookahead planning and short-term Planning. The master plan is a schedule developed before the start of construction and it should have a low degree of detail, due to the uncertainties related to the actual duration and deliveries (Ballard 1997). The goals of this plan are to describe the work to be undertaken through general targets, to maintain high management informed about the activities being undertaken and to establish contracts. The lookahead planning is a mobile planning that "looks" a few weeks into the future, paying attention to the tasks that will supposedly happen in a specific time period and identifying which actions are necessary to allow the execution of those tasks in the period desired (Ballard 1997).

The LPS can be understood as a device to turn something which should be done into something that can be done (Ballard 2000). This is done in the lookahead plan by forming an inventory of ready work, from which the weekly work plan, or short-term plan, is formed. The short-term plan is a commitment of the last planners with what they actually will do (Ballard 2000). According to the author, the LPS is considered a pulled production system, where the materials and information are released for a process only if that process is capable of doing the work.

The application of the LPS in the construction industry is aimed at reducing variability, improving the workflow and reducing various types of waste (Sacks et al. 2010). According to Koskela (2004), LPS contributes to the elimination of making-do waste as a means to reduce variability and to improve the production system as a whole.

During a study conducted by Sukster (2005) in a Brazilian construction company, some changes were suggested for integrating the production control and quality management systems: (a) holding regular meetings for the integration of the two systems at the medium and short term planning levels, (b) the use of the quality management procedures for constraint analysis and checking task completion, (c) inclusion of production planning and control in the quality management system, (d) the use of indicators to evaluate the degree on integration of both systems, and (e) the creation of mechanisms to increase the crew's participation in the planning and control of work packages. Those changes had a positive impact in terms of getting the crews committed with quality control, as well in terms of reducing non-conformities (Sukster 2005).

Sukster (2005) also proposed two new indicators that evaluate not only the completion of the tasks, but also their quality according to the requirements specified in the quality management system. These are:

- PPCQ (percentage of packages concluded with quality), which consists of the relation between the number of packages concluded with quality and the total number of packages concluded;
- PPCR (percentage of packages really concluded), calculated by the ratio between the number of packages concluded with quality and the total number of planned packages. It represents a more accurate measure of PPC.

Those indicators have been proposed due to the fact that some work packages are often considered to be concluded but do not pass quality inspection. Therefore, PPCQ indicates whether the existing PPC is reliable, while PPCR represents a more accurate measure of PPC, after quality inspection.

The integrated control model proposed by Fireman et al. (2013) uses the two metrics proposed by Sukster (2005) and also the analysis of the causes of work concluded without quality. The identification of the root cause of quality problems is often neglected, causing the propagation of problems to subsequent tasks (Fireman et al. 2013). According to Sukster (2005), it is possible to reduce the number of rework tasks and waste by acting on the causes of the problems, regardless of whether these are planning or quality problems.

Sukster (2005) pointed out to the importance of look-ahead and short-term planning meetings for integrating task completion and quality control. The implementation of the look-ahead plan is important in order to avoid the occurrence of some problems in the execution of work packages, such as the non removal of constraints that can cause making-do waste and quality problems. The short-term plan can help organizing tasks and improving the commitment of the crews in the implementation of quality inspection, and avoiding unfinished work (Sukster 2005).

Moreover, such integration can be supported by the use of visual devices that display control instructions and metrics (Sukster 2005).

RESEARCH METHOD

The research approach adopted in this study is constructive (or design science) research, which, according to Lukka (2003), is a strategy used to produce innovative constructions with the goal of solving real world problems and making a contribution to the theory of the discipline in which it is being applied.

The control model was devised and tested in an empirical study carried out in a construction company involved in the development and construction of social housing projects in Porto Alegre, South of Brazil. This study was divided into four cycles of development, including understanding the problem, devising the solution, and testing it. This paper presents the first full version of the integrated control model, which was implemented in one of the company's projects, a condominium of 298 two-bedroom houses of 43m².

PROPOSAL FOR INTEGRATED CONTROL MODEL

The model is formed by a data model (Figure) and a process model (Figure 2), which were tested by applying a very simple prototype, built in two digital spreadsheets, using tablets. There was a data collection form for performing integrated production and quality control (Figure 3) in which all planned work packages are entered, so that their conclusion can be monitored. In addition, informal packages identified in the construction site can also be monitored. Its role is to control the execution of informal packages, the completion of work packages and the approval by quality control.

There was another form for monitoring making-do events identified during the execution of work packages (Figure 2). The method for identifying making-do waste was based on previous work (Formoso et al. 2011, Fireman et al. 2013). Besides including a written description of the making-do event, a photo was taken of each improvisation. Making-do events were classified in categories, causes, type of work package (formally planned or informal), whether there was any kind of positive innovation, and possible impacts.

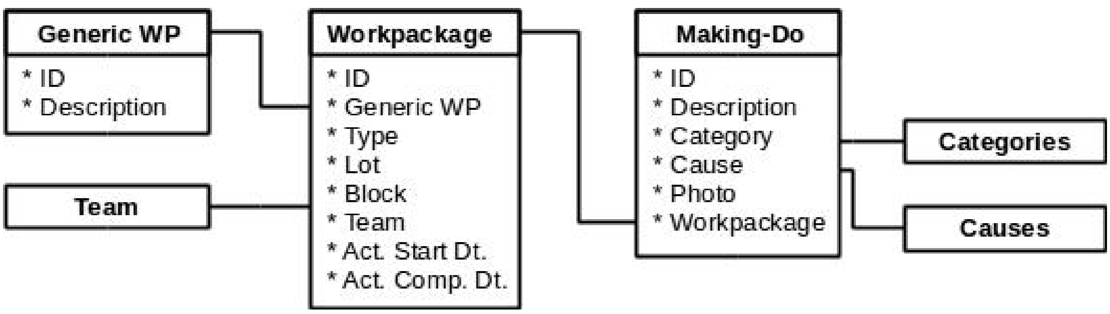

Figure 1: Data model

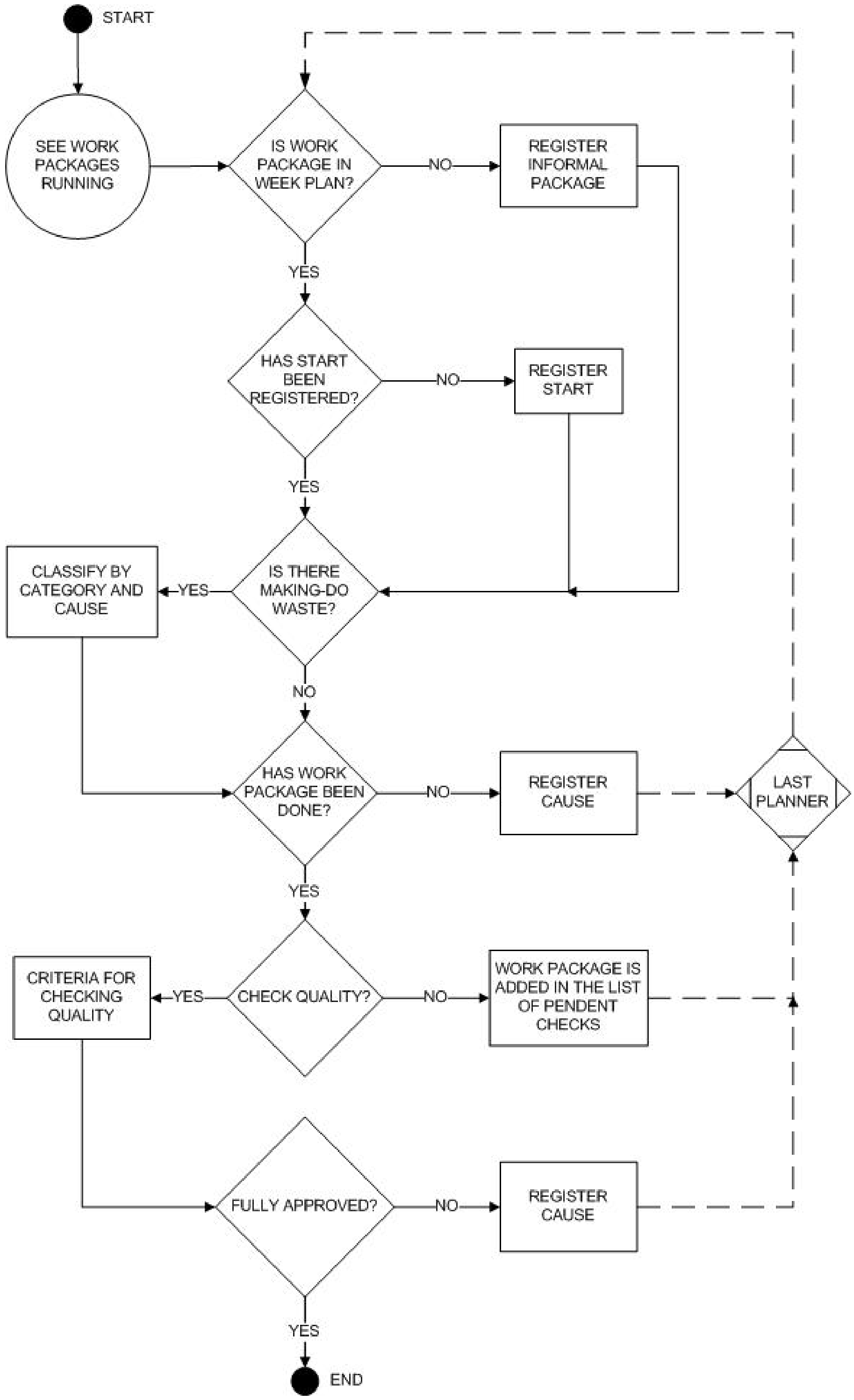

Figure 2: Process model

ID PTSpecifi	Type	PTGeneric	Lot	Block	Team	Actual Start date	Actual Completion date	Comment
38.134.48	Formal	Grounting ceramic tiles	Houses 289/290	Block O	Engenhar team1	2013-11-26	2013-11-29	
42.134.48	Formal	Apply sealer	Houses 289/290	Block O	Engenhar team1	2013-11-27	2013-11-28	
52.134.48	Formal	Apply internal mass	Houses 289/290	Block O	Engenhar team1			
36.134.48	Formal	Gypsum liner	Houses 289/290	Block O	ChicoGesso team1		2013-11-28	
36.135.48	Formal	Gypsum liner	Houses 291/292	Block O	ChicoGesso team1	2013-11-29		
37.136.48	Formal	Put ceramic	Houses 293/294	Block O	Tafarel team1			
36.136.48	Formal	Gypsum liner	Houses 293/294	Block O	ChicoGesso team1	2013-11-27	2013-11-29	
37.137.48	Formal	Put ceramic	Houses 295/296	Block O	Tafarel team1		2013-11-28	
38.137.48	Formal	Grounting ceramic tiles	Houses 295/296	Block O	Tafarel team1	2013-11-27	2013-11-29	
36.137.48	Formal	Gypsum liner	Houses 295/296	Block O	ChicoGesso team1		2013-11-26	
37.138.48	Formal	Put ceramic	Houses 297/298	Block O	Tafarel team1	2013-11-26	2013-11-28	
38.138.48	Formal	Grounting ceramic tiles	Houses 297/298	Block O	Tafarel team1		2013-11-28	
20.54.48	Inf UW	Finish wall	House 154	Block M	Tafarel team1	2013-11-27	2013-11-28	
74.60.48	Inf UW	Electrical repairs	House 160	Block M	Taigor team1	2013-11-27	2013-11-28	
78.127.48	Inf New	Apply sealer	Houses 168/170	Block M	A Marinho eq1	2013-11-27	2013-11-28	
37.128.48	Inf New	Put ceramic	Houses 277/278	Block O	Tafarel team1	2013-11-28	2013-12-02	
40.126.48	Inf New	Install baseboard	Houses 167/169	Block N	JAM team1	2013-11-28	2013-12-02	
40.124.48	Inf New	Install baseboard	Houses 163/165	Block N	JAM team1	2013-11-28	2013-12-02	
40.122.48	Inf New	Install baseboard	Houses 159/161	Block N	JAM team1	2013-11-28	2013-12-02	

Figure 3: Spreadsheet for integrated production and quality control

ID	Making-do	Category	Cause	Photo
M01	truck access on the gutter	access/movement	materials and components	
M02	lack of water facility	temporary facilities	workstation infrastructure	
M03	storage of materials outside the warehouse	storage	space	
M04	worker supporting himself on the concrete wall formwor	access/movement	equipment	
M05	inadequately shored formwork	adjustment of components	materials and components	
M06	inadequate pipes for the wiring	adjustment of components	materials and components	

Figure 4: Spreadsheet for monitoring making-do waste

PRELIMINARY RESULTS

This section presents the preliminary results obtained in the first stage of the pilot study. Through the application of the integrated control model, it was possible to identify the informal packages executed on the construction site, the waste making-do waste that occurred during the running of the work packages, as well as the difficulties encountered when performing the production control and checking of the quality of the work.

During this stage of the pilot study, on average, 34% of the packages executed on the building site were informal. Figure 5 shows the percentage of informal packages identified on ten different occasions. Out of all the informal packages observed, 69% were new packages and 31% were unfinished work. The last category includes both small finishing tasks and rework packages.

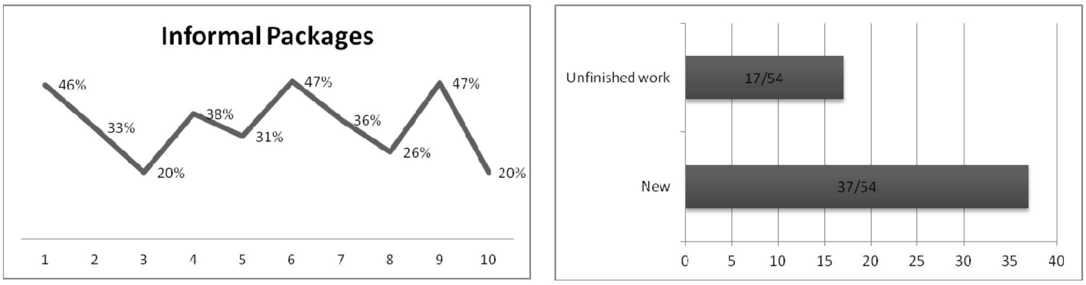

Figure 5: Informal packages: total percentage (left) and
types of informal package (right)

The causes of the informal packages were also identified from direct observations in workstations and participant observation in weekly short-term meetings. A major cause of informal work packages was the lack of communication between people involved in the process. The crews were often unaware of the planned work packages and, consequently, performed tasks in workstations that were not included in the short-term plan, changing the production order. Informal rework packages were mostly due to the fact that quality checks are conducted informally. The person responsible for checking quality listed the necessary rework tasks and passed them directly to the subcontractors. Those rework packages were included in the short-term plan only when there was resistance on the part of the subcontractors to undertake those tasks. Moreover, new crews may arrive at the building site during the week, which had not been considered at the short-term meeting. Then, the engineer authorises the execution of new work packages without including them formally in the plan.

The application of the integrated control model also produced data on making-do events that occur during the execution of work packages. The most frequent types of making-do observed during the study, according to the classification proposed by Formoso et al. (2011), are those related to the categories access/mobility and adjustment of components (Figure 6). Jointly, those categories represented over 50% of the making-do waste identified during this study. With regards to the nature of the waste, the unavailability of the following inputs should be highlighted: equipment and tools, and material and components. Regarding the impact of the waste observed, rework and reduced safety are consequences worth mentioning. It was also observed that over 50% of the waste is recurrent.

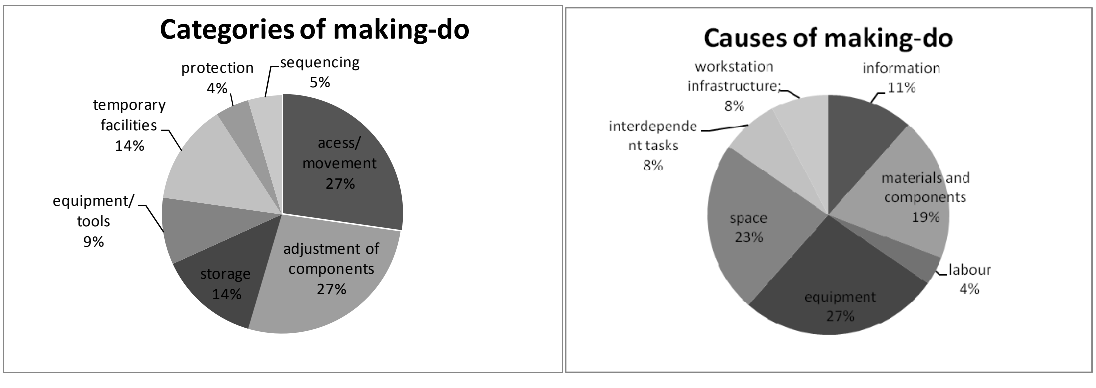

Figure 6: Making-do waste: Categories and Causes

Figure 7 illustrates two recurrent types of making-do waste on the building site. On the left, the absence of support equipment adequate for the assembly of the concrete wall formwork, forcing the worker to find support on the formwork themselves in order to reach their upper part. On the right, there is an illustration of the improvisation occurred during the installation of the electrical wiring of the raft foundation. Orange pipes, which are more resistant and, hence, more appropriate to the ends, should be used; however, in the absence of that material, yellow pipes were used. The impact caused by these two making-do events are, respectively, reduced safety and rework.

Figure 7: – Examples of improvisation: worker supporting himself on the concrete wall formwork (left) and inadequate electricity pipes in the raft foundations (right)

The first stage of the pilot study also allowed identification of the benefits and shortcomings of the implementation of the integrated control model on the building site. The first difficulty was in quality assessment. The procedure adopted by the company to check the quality of the work is the manual filling out of quality assessment inspection forms. However, as that involves using a lot of paper, it is difficult to fill out the spreadsheets on the building site. Therefore, the information is collected on site by using notepads and clipboards, and it is subsequently transcribed to the inspection forms. As filling out those forms is a lengthy process that demands concentration, this activity is usually postponed until the release of another task, functioning as a pre-task check. Hence, the work packages carried out during the week could not be quality assessed.

Despite its shortcomings, the implementation of the integrated control model supported by information technology is considered beneficial for management systems. Among the benefits worth mentioning are better organization and dissemination of information.

CONCLUSIONS

The literature review has pointed to the integration between production and quality control as a way to improve the production management system as a whole and to reduce making-do waste, which causes other waste, such as reduced safety, rework, reduced quality and material loss. However, due to the amount of data that has to be processed by the same person and the need to synchronise some controls, it is necessary to use information technology to facilitate integration.

This paper presents a proposal for an integrated production and quality control model connected with the Last Planner System, which uses information technology as support for data collection on the building site, the processing of that data and the management of information. The first application of the control model on a building site allowed the identification of informal packages executed on the site, the most frequent making-do waste, and difficulties found during the quality assessment of the work packages. Based on a preliminary evaluation, improvements are being made on the control model and new applications of the model for testing and validation are being implemented.

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