INTEGRATING SAFETY INTO PRODUCTION PLANNING AND CONTROL PROCESS: AN EXPLORATORY STUDY

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ABSTRACT

This paper presents partial results of an ongoing research project that aims to develop a safety planning and control (SPC) model, integrated to the production planning and control process. A pilot study aiming to evaluate the feasibility of the integration was carried out at the site of a small sized building company. Safety planning was introduced in an existing planning and control cycle.

One of the main conclusions of the study is that some lean production concepts and methods that have been used for production planning and control (such as the Last Planner Method, for instance) can be easily extended to safety planning. For instance, a performance indicator named PSW (Percentage of Safe Work Packages), similar to PPC, is potentially effective for safety control. Based on the overall analysis of the case study, some guidelines for further improvements in the SPC model are proposed.

KEY WORDS

Safety, production management, planning and control, macroergonomics.

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1. INTRODUCTION

In spite of the high costs of work accidents (Hinze, 1991), many construction companies in Brazil adopt as their only safety management strategy to be in compliance with safety regulations. However, as regulations do not require formal and comprehensive safety management structures, even the total compliance with them may not be sufficient to eliminate work accidents. This is the case of the NR-18 (Work Conditions and Environment in the Construction Industry) standard in Brazil and similar regulations in other countries, in which the most important proactive requirement is the elaboration of a health and safety plan before starting construction. In Brazil, the plan required by NR-18 is named PCMAT (Plan of Conditions and Work Environment in the Construction Industry), which is mandatory only on sites where there are more than twenty workers.

Since it was created in 1995, most companies produce the PCMAT only to avoid fines from governmental inspectors and do not effectively use it as a mechanism for managing site safety. Its main shortcomings are presented below:

a) PCMAT implementation is usually regarded as an extra activity to managers, since it is not integrated to routine production management activities. NR-18 does not require its integration to other plans, except for site layout planning;

b) Safety experts (usually external from the company) produce it and normally there is no involvement of production managers, representatives of subcontractors or workers;

c) PCMAT does not usually take into account the uncertainty of construction projects. A fairly detail plan is produced at the beginning of the construction stage. This plan is not updated during the production stage, and there is no formal control of its implementation;

d) PCMAT focuses on physical protections, normally neglecting the necessary managerial actions for achieving a safe work environment;

e) PCMAT does not induce risk elimination through preventive measures at the design stage.

In Europe, Directive 92/57/CEE (Implementation of Minimum Safety and Health Requirements at Temporary or Mobile Construction Sites) also requires a health and safety plan similar to PCMAT (Dias and Fonseca, 1996), and it has similar problems pointed out for PCMAT in Brazil (items *a* to *c*). Regarding items *d* and *e*, although the European regulation requires safety considerations in design, there is not enough knowledge available on how to implement this practice. This gap has recently encouraged several research initiatives (MacKenzie et al.; 2000; Coble e Blatter, 1999; Hinze e Gambatese, 1996).

Such shortcomings in both conception and implementation of mandatory plans indicate that it is necessary to improve safety planning and control (SPC) methods beyond what is required by the regulations. Some studies that have investigated causes of accidents and good practices to avoid them support this statement. Suraji and Duff (2000), for example, based on the analysis of approximately five hundred accidents in the UK, found that planning and control failures contributed in 48 % of the accidents. Coherently with these findings, a study carried out at the Construction Industry Institute (Liska et al., 1993) found that, among several preventive actions that were used by the industry, detailed safety planning was the most effective one towards achieving the zero accident target. However, that study did not provide details on how safety planning worked in the companies that were investigated.

There seems to be an opportunity for improving SPC methods, based on concepts and principles that have been successfully used in production planning and control, according to the literature (Hopp and Spearman, 1996; Laufer et al., 1994; Laufer and Tucker, 1987). In this respect, it must be stressed that some of the main requirements for effective production planning and control, such as hierarchical decision making, cooperation, continuity and systemic view (Laufer et al., 1994), are also requirements for safety management, indicating that there are several similarities between those two processes. Although literature suggests that the integration between safety and production planning is a good practice (Leijten et al, 1997; Laufer et al., 1994), there is no evidence so far that the construction industry have followed this recommendation.

The integration of safety into planning has been studied by authors such as Ciribini and Rigamonti (1999) and Kartam (1997). However, these research studies have been limited to the introduction of safety measures into construction plans, using CPM or line of balance planning techniques. This approach tends to have not much impact, since it has been accepted that planning should not be limited to the application of techniques for generating plans (Laufer and Tucker, 1987). Conversely, planning should be treated as a broader managerial process composed by several stages, including data collection, implementing corrective actions, and information diffusion (Faniran et al., 1997; Laufer and Tucker, 1987). Taking this context into account, this paper presents the results of an exploratory case study, which aimed to investigate the integration between safety management and production planning and control. A set of guidelines for performing safety planning and control is proposed.

2. DESCRIPTION OF THE EXPLORATORY STUDY

The case study was carried out in a small sized building company, which was involved in the construction of four six-floor residential buildings. There were approximately one hundred workers on site and 90 % of them were hired from ten different subcontractors. The site organization was fairly poor. An evaluation of compliance with the NR-18 standard indicated that only 35 % of its requirements were been followed.

As it was an exploratory case study, there was no intention to implement substantial changes in the production system. The main objective was to study the feasibility of integrating production and safety planning and control, as well as to refine the research questions to be investigated in this research project.

2.1 RISK CLASSIFICATION

In the first planning and control cycles, the researcher observed that risks could be organised into two groups: *i)* risks which could be associated to one or several work packages, *ii)* risks that could be associated to all work packages. The former category of risks can be subdivided into two subgroups:

a) Risks related to value adding activities, such as fall from scaffoldings (plastering activity, for instance) or caughting hands (formwork removal activity, for instance). Some risks related to some conversion activities, such as production of mortar, could be associated to several work packages at the same time;

b) Risks related to not value adding activities (e.g. storage and transportation of materials) can usually be clearly associated to work packages, since some activity that use those materials has been planned in that week. Risks related to loading mortar on lifts, for instance, can be associated to wall plastering and bricklaying work packages. Likewise mortar production, load lift risks also can be associated to many work packages in the same week.

Risks that can be associated to all work packages can also be classified into two subgroups. Both of them are related to non value adding activities:

a) Risks related to horizontal and vertical flows of people, such as, for example, the fall from the permanent stairs and fall into the elevator well. Any person (worker, client or manager) who is walking around the site could have an accident in those places. Another example was the risk of fall in a well that was opened to drain rainwater. Such well was placed in a common circulation area and any person could be a victim;

b) Risks related to materials delivery and storage, in case some materials are kept in storage during several weeks without being used. If the materials were used in the same week that they are delivered, storage and receiving risks should be associated to a particular work package. Some examples of this kind of risk were identified in the case study: risk of collapse of the pipes shelf, which was badly maintained; risk of collapse of brick inventories; and risk of fire in flammable materials stored in the warehouse.

It must be pointed out that three categories, out of the four listed above, are related to non value adding activities. This is not surprising since processes and operations that do not add value usually spend a major share of resources in construction sites (Koskela, 2000). As a consequence, accidents are probably more prone to take place during these processes and operations. Thus, an effective SPC model should make explicit these not add value activities, making it easier to identify their risks and their respective safety measures. However, it does not mean that the SPC model shall be strictly linked to the classification presented in this section. Traditional safety risk classifications (such as ″struck by″ and ″caught between″) may also be useful for classifying accidents and inducing risk identification.

2.2 PLANNING MEETINGS

Planning was carried out at three hierarchical levels: short-term commitment planning, in which the planning horizon was one week; look-ahead planning, in which the planning horizon was five weeks; and long-term planning, which took the whole construction stage into consideration. Weekly meetings took place to elaborate commitment planning and update look-ahead planning. These meetings involved the production manager, the foreman and subcontractors representatives.

Safety planning was included in the already existing weekly planning meeting. From one hand, this approach was positive, because decisions related to sequencing, interference between teams, and availability of labour and equipment could be evaluated taking into consideration both safety and production points of view. On the other hand, the inclusion of safety issues in the same meeting increased its duration. In order to overcome the lack of time for discussion, two measures were proposed:

a) It is necessary to have a checklist of the site potential risks. This makes it easier to identify risks related to specific situations. This checklist was based on a literature review, observation of the site and interviews with workers. It is worth remembering that risk identification is a critical task, since if a risk is not identified it can not be controlled;

b) Detailed safety planning should take place before the meetings, involving at least the safety staff and the production manager. It is believed that the best alternative to make available this detailed planning is through the elaboration of preliminary risk analysis (PRA) of each stage of the construction, as established in the master plan. PRA is further discussed at item 2.3.1.

The most important safety planning activities were both the risk identification and the definition of the necessary preventive actions. If it is not possible to eliminate risks at the origin, the preventive measures should involve actions to reduce risks, such as materials or methods substitution, training or physical protections. In the SPC model to be proposed, each activity must have its safety measures introduced in production planning, as much detailed as possible, considering the information available. Risks and preventive measures should be established from the analysis of work content, through the study of sequencing, labour, equipment, layout, tools and materials involved. Thus, the detailed design of each process is a fundamental requirement for safety planning.

2.3 HIERARCHICAL LEVELS OF PLANNING

2.3.1 Long-term planning

Preliminary risk analysis (PRA), a widely used tool in risk management (Kolluru et al., 1996), can be used as a basis to prepare the first draft of safety plans for each activity. PRA might be seen as a long-term safety planning activity, allowing an effective procurement of safety resources before starting construction.

A PRA must be produced for each construction stage, as defined in the master plan. Several people must be involved in this process, such as the production manager, the foreman, subcontractors representatives and safety staff, so that production requirements are properly considered in the PRA. Basically, PRA content should consider all steps that are necessary for each activity, the risks in each step must be identified, and the necessary preventive actions must be established. A further benefit of PRA is that it induces the planning of methods, which is a subject normally neglected in production planning and control process (Laufer and Tucker, 1987).

The only safety plan available in the exploratory study was PCMAT, which was not very useful to safety management. It seems that plans similar to PRA should be the core of mandatory safety plans such as PCMAT. If PRA were available in the case study, they could be continuosly updated and detailed during production stage, through their integration with look-ahead and short-term planning. New versions of PRA would be produced whenever work methods and/or risk controls had changed. In such a situation, PRA integration with long-term safety planning would already have taken place during its first elaboration.

2.3.2 Look-ahead planning

The main role of look-ahead safety planning was to plan the purchase of safety resources that were required by the work packages. In the case study, safety resources were divided into four groups: personal protective equipment (PPE), collective protections, training and safety facilities design. The greatest difficulty at this level was to update plans in a weekly basis, as this task was very time consuming (around thirty work packages were considered in each planning cycle). Both look-ahead and short-term safety planning were based on the risk classification presented in item 2.1. An example of look-ahead safety plan is shown in table 1 below.

Table 1: Example of look-ahead safety planning: risks associated to one or more work packages.

				Resource				
Workp. / Team	**Start**	**Rem. of Constr.**	**Risks**	**PPE**	**Collective protections**	**Training**	**Design**	**Other**
plastering			- fall of people	PVC gloves	scaffolds and load lifts	prepare training (this is a new	detailing of scaffolds	

facade 3 (Zé Gomes)	08/08	05/08	and materials - cement	(3 pairs), safety belts (3)	according to NR-18	task for this team)	(dimensions, materials)	

2.3.3 Short-term planning

Weekly safety planning had two main roles: to assign resources defined by the look-ahead safety plan and to establish corrective actions (repairs in a handrail, for instance). In the exploratory study, short-term planning had a strong reactive role, since the majority of safety facilities had already been installed when the study began. Short-term plans can also be used as a basis for training workers, before starting each planned activity. This training should be seen as the last opportunity to discuss safety measures with workers, contributing to prevent accidents. Obviously, a wider training program is required.

The weekly safety plans were written down in a form, which is similar to the one used in the Last Planner Method of Production Control (Ballard and Howell, 1997). An example is presented in table 2. The work packages are exactly the same ones that were defined at the weekly production plans.

Table 2: Example of short-term safety plan: risks clearly associated to one or more work packages.

Work package / Team	Risks	Existing prevention	Planned prevention	PPE*	100 % safe ?	Problem
bricklaying walls 5 and 6 (João)	- fall of people and materials from wall 5 (through the boundaries) - contact with cement	___	- safety nets around the boundaries of the floor	- safety belts (2) - PVC gloves (2 pairs)	Yes	
plastering facade 3 (Zé Gomes)	- fall of people and materials from the scaffolds - fall of people while entering or leaving scaffolds - contact with cement	___	- training (does not come or leave scaffolds without belt, inspect work area) - repairs in the handrails - isolate area below the scaffolds	safety belts (3) and PVC gloves (3 pairs)	No	repairs in handrails were not carried out due to lack of labour planning

* Consider that hard hat and safety shoes are obligatory for any task.

At the end of the week, an evaluation of the safety plans must be undertaken. A performance indicator similar to PPC (percentage of plans completed) proposed by Ballard and Howell (1997) was used. It was named **PSW (percentage of safe work packages),** indicating the percentage of work packages that were carried out 100 % safe. A work package is considered 100 % safe when it took place with all preventive measures implemented and without any accident, near miss or other unforeseen event. The formula to calculate PSW is presented below:

$$PSW = \frac{\sum \text{work packages 100 \% safe}}{\sum \text{all work packages}}$$

In table 2, PSW is 50 %, since only one work package, out of two, was carried out with all the necessary preventive measures and without any unforeseen event. PSW has an important role as a proactive control tool, since it indicates safety problems that can cause accidents in the future. Calculate PSW can be a difficult task, since some problems can only be identified through the observation of all activities during all the time. However, a more realistic way to collect the data to PSW calculation is through direct observations of all activities, if possible on a daily basis. It is important that observations are carried out by a person who is not directly involved in the site routine, in order to avoid bias. Also, workers can be trained and stimulated to report safety problems, helping to collect information to calculate PSW.

The PSW target should be higher than the one pursued in PPC, since lack of safety can lead to an accident, while a delay in the schedule does not have such a serious consequence. A hypothesis - which shall be evaluated in future studies - is that the PSW average in a "zero accident" construction should be between 90 % and 100 % of safe work packages. As a result, it is more important to carry out the activity within an acceptable level of risk (planning will define what level of risk is acceptable or not) than to follow the schedule overseeing safety. In order to get a good performance both in time and safety, time planning must take into account the safety measures which will be adopted. A realistic time planning must consider, for instance, time to implement safety facilities such as handrails or stairways.

Finally, table 3 presents the form that was used in the case study for safety planning related to the risks that can be associated to all work packages. The calculation of total weekly PSW might consider that the two subgroups in table 3 are two work packages. Thus, considering tables 2 and 3 together, the total weekly PSW is 25 %. Among four work packages, only one of them was carried out completely safe.

Table 3: Example of safety planning in short-term: risks that cannot be clearly associated to any work package.

	Risks	**Existing prevention**	**Planned prevention**	**100 % safe ?**	**Problem**
horizontal and vertical flows of people	- falls of people (into the elevator well, from the stairs, in the drainage well) - struck by materials thrown from higher floors	- handrails in the well of the elevator and in the stairs (all floors)	- training (all materials must be transported through the load lift) - signs in the well of drainage	No	near miss (see the investiga-tion report)
materials delivery and storage	- collapse of stock of bricks - overexertion to take off elevators from the dump		- reduce the height of bricks stock (< 1,40 m) - use the crane to take off the elevators	No	crane was not available. Planning failure

Besides PSW, another important control tool for safety management is the investigation of all accidents, whatever its consequences. This is mandatory by the existing regulations. However, a more preventive control measure is to investigate also near misses, as they indicate potential sources of accidents.

2.4 PARTICIPATION OF WORKERS

As workers are the main customers of safety planning, they must take an active role in the planning process. One way to allow them to get effectively involved is to identify their perceptions about the risks and problems in their work environment. Besides getting their involvement, such strategy can make explicit macroergonomic risks, which have not been addressed by the planning approach previously discussed. The macroergonomic approach (Hendrick, 2001) is not limited to traditional microergonomic concerns, such as to fit workstations dimensions or to reduce manual materials handling. The assumption of macroergonomics is that there are organisational variables, such as job enrichment, workload and rhythm, which together have a strong influence on safety, health and productivity performance.

The perceptions and suggestions from workers were obtained through individual interviews, made with a sample of 20 % (twenty-one people) of the workforce. The interviews were divided in two stages: *i)* an open section, in which workers were encouraged to talk about their work (talk about both good and bad aspects of the work as a whole, not only about their tasks), *ii)* an induced section in which workers were asked to talk about specific issues such as the relationship with managers and colleagues, the most difficult task, transportation of loads, postures, noise, PPE, and risks around the site. Tables 4 and 5 below present the main results of the interviews:

Table 4: General needs.

Problem	Frequency
arguments among workers	3
lack of providing PPE	3
throwing materials from high floors	3
no use of PPE	2
lack of physical barriers in the elevator	1
poor relationship between workers and managers	1

Table 5: Specific needs for some tasks.

Problem	Frequency
levelling of mortar in coatings (fall of mortar on the face, tool is heavy)	4
lack of safety in the load lift	3
working under the rain	2
put mortar on the ceiling (awkward postures, work above shoulders line)	2
manual transportation of cement bags (too heavy, weight of 50 kg)	2

Based on these tables, a questionnaire was applied aiming to establish a ranking of problems according to their relative importance. The questionnaire also included questions about problems identified by the researcher (e.g. the lack of a refectory). A good practice is to present the results of the survey to the workers and managers in a meeting, in order to establish guidelines to solve the problems. Besides, this meeting provide an opportunity to solve communication gaps between workers and managers. However, this strategy only will be effective if both contractor and subcontractors are committed enough to implement changes in the workplace.

3. SCOPE AND CHARACTERISTICS OF SPC MODEL

Based on this case study the main functions of the SPC model were identified. In general terms, the model must perform four essential functions:

a) To anticipate safety resources which are necessary to control risks;

b) To identify and control risks originated in production planning decisions - for instance, to identify conflicts between activities;

c) To evaluate safety performance based on both, proactive and reactive indicators;

d) To provide an opportunity for workers to identify risks and make suggestions to control them, according to their perceptions.

In order to follow efficiently these functions, the SPC model should have some key features:

a) To be participatory: as safety planning requires knowledge on technologies and methods, it is critical the involvement of production managers and workers representatives. Thus, plans elaborated exclusively by safety experts are not effective;

b) To be transparent: plans should be disseminated to workers through training and visual devices. In addition, performance indicators should point out weak points of safety management, driving preventive actions;

c) To be proactive: the anticipation of risks should be a major characteristic of the model. The aim must be to eliminate the risks at the origin through interventions both at the product and process design;

d) To have a macroergonomic approach: it is fundamental to identify risks in a wider scenario, instead of being limited to traditional and most visible risks;

e) To follow regulations: safety is a subject ruled by mandatory regulations. Therefore, the SPC model cannot ignore their requirements. Conversely, the SPC should optimise the application of regulations in terms of safety performance, and complement it if necessary;

f) To be easy to apply: the model must be easy to understand and apply, and do not take too much time from people involved in planning and control. Regarding this requirement, the integration to production planning and mandatory monthly safety meetings seems to be a good practice;

g) To follow planning good practices: safety planning must also follow good planning practices, such as use of hierarchical levels, continuity, participation, systemic view and control in real time;

h) To follow risk management cycle: as safety planning and control involves the risk management activities - identification, evaluation, response and monitoring (Baker et al., 1999), their tools and guidelines can be considered useful for this process.

4. FINAL CONSIDERATIONS

This paper presented the results of an exploratory study on the integration of safety into production planning and control process. The results of the study suggested that existing concepts and methods that have been successfully used in production planning and control, such as the Last Planner Method, can be adapted to safety planning. For instance, a performance indicator similar to PPC is potentially workable for safety control.

Based on the study, the main features of a safety planning and control (SPC) model were proposed. Among the safety management improvements introduced by the model, one of the most important ones is the simplification of the safety planning procedures. The aim is that safety planning and control does not make normal planning meetings very time consuming. The integration should not be dependent on the use of any specific production planning model. It should only require a formal planning system - which is characterised by planning hierarchy, continuity and participation.

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