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Safety and production: an integrated planning and control model

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A safety planning and control model (SPC) has been integrated into the production planning and control process. The model integrates safety into three hierarchical levels of production control. Safety long-term planning starts with the preliminary hazard analysis (PHA) of construction processes. These plans are detailed and updated at both medium- and short-term planning levels. The main performance measure adopted for safety evaluation at the short-term level is the Percentage of Safe Work Packages (PSW). It monitors the degree in which work packages are safely carried out. The model also proposes a participatory mechanism that allows workers to point out existing risks as well as to evaluate risk controls. This paper discusses two empirical studies in which the model was implemented in industrial construction projects.

Keywords: Safety, production planning and control, performance measurement, risk management

Introduction

Safety planning often appears as a core requirement in safety regulations and standards. OHSAS 18001 (Occupational Health and Safety Management Systems) safety planning requirements are limited to the establishment of a risk management cycle, involving continuous risk identification, evaluation and control. In Brazil, NR-18 (Work Conditions and Environment in the Construction Industry), the main safety regulation related to the construction industry, requires a health and safety plan named PCMAT (Plan of Conditions and Work Environment in the Construction Industry). However, most companies in Brazil produce a PCMAT only to avoid fines from governmental inspectors and do not effectively use it as a mechanism for managing site safety. PCMAT's main shortcomings are presented below (Saurin *et al.*, 2000):

- its 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;
- it is usually done by outside experts who do not work on a permanent basis for the company. Production managers, subcontractors or workers are not usually involved;
- it does not usually take into account the uncertainty involved in construction projects. A fairly detailed plan is produced at the beginning of the construction stage and it is not usually updated;
- formal control of PCMAT implementation is rarely carried out;
- it emphasizes physical protections, normally neglecting the necessary managerial actions (for instance, implementing proactive performance measures) that are needed to achieve a safe work environment; and
- it does not induce risk elimination through preventive measures at the design phase.

In Europe, Directive 92/57/CEE (Temporary and Mobile Construction Sites) requires a health and safety plan similar to PCMAT (Dias and Fonseca, 1996), which has some of the problems pointed out for PCMAT in Brazil (items *b*, *c* and *d*).

Such shortcomings in both conception and implementation of mandatory plans indicate that it is necessary to

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improve safety planning and control methods beyond what is required by regulations and standards. This statement is supported by some previous studies. Suraji *et al.* (2001) found that planning and control failures related both to safety and production itself were major contributing factors to accidents in construction sites in the UK. In the USA, Hinze (2002) and Liska *et al.* (1993) have consistently found that pre-project and pre-task safety planning are among the critical measures required to achieve a zero accident target. In fact, several authors (McCollum, 1995; Kartam, 1997; Hinze, 1998; Ciribini and Rigamonti, 1999) have suggested that safety planning and control (SPC) and production planning and control should be integrated. On one hand, typical production planning decisions – what will be done, when, how and by whom – are the basis to establish preventive measures. On the other hand, safety requirements must be taken into account in production planning. Otherwise, production plans may fail due to the lack of safety.

However, few studies have investigated the fully integration of safety into production planning. Ciribini and Rigamonti (1999) and Kartam (1997), for instance, discussed the introduction of safety measures into construction plans, using CPM or line of balance planning techniques. This approach tends to have little impact, since it has been accepted that planning should not be limited to the application of plan generating techniques, but be rather regarded as a broader multi-stage managerial process, including data collection, corrective action and information diffusion (Laufer and Tucker, 1987).

This paper presents an innovative safety planning and control (SPC) model that integrates safety management to the production planning and control process, based on concepts and principles that have been successfully used in production planning and control (Laufer and Tucker, 1987; Laufer *et al.*, 1994; Hopp and Spearman, 1996; Ballard, 2000). The aim was to adopt some of the main requirements for effective production planning and control, such as hierarchical decision making, co-operation, continuity and systemic view (Laufer *et al.*, 1994) for safety management. This study is focussed on the role of planning and control in safety management, and assumes that other methods and procedures (e.g. behaviour-based safety programmes) are needed to effectively improve safety performance in the construction industry.

Research method

Overview of the research project

Action research was the research strategy adopted in this study, because the aim was to devise and test a safety planning and control model in a real construction environment. Two empirical studies were carried out between January and November 2001 in two different

industrial building projects, carried out by a small sized construction company from Porto Alegre, south of Brazil. This company was chosen for two main reasons: it had a fairly well structured production planning and control system, and it was particularly interested in successfully implementing the SPC model. This interest was mainly due to demands from clients, since their plants had very strict safety requirements.

Empirical study A was carried out during the refurbishment of a steel mill building (site A). The duration of the project was approximately six months, while the development and implementation of the SPC model took place during the first four months. As in many industrial refurbishment projects, the steel mill activities were not interrupted.

Empirical study B was carried out during the construction of two labs in a petrochemical plant (sites B1 and B2). Site B1 consisted of a one-storey building (190 sq m), built in three months. Site B2 was a three-storeys building (2430 sq m), which was constructed in six months – the research study took place in the first four months of the project. Like in site A, high safety risks were primary factors in selecting those sites. All three sites had a full-time safety specialist.

Existing production planning and control process

The production planning and control systems adopted in both sites were very similar. They contained several elements of the Last Planner system of production control, proposed by Ballard (2000). There were four planning and control levels: one-day and one-week short-term commitment planning, three-week look-ahead medium-term planning, and long-term planning.

At the short-term level, work packages were initially assigned to different crews in weekly meetings. However, due to the high work environment variability, weekly plans needed to be re-evaluated in daily meetings. The PPC (percentage of plans completed) indicator, proposed by Ballard (2000), was collected both in a daily and weekly basis.

The main role of look-ahead planning was to support the removal of constraints related to work packages. A three-week plan was produced weekly, containing a list of constraints (e.g. space, materials, labour and equipment), and the deadlines for their removal. Finally, the master plan, produced at the beginning of the project for the whole construction stage, was updated in a monthly basis.

Overview of the SPC model

Figure 1 presents an overview of the SPC model. Integrated safety and production planning and control took place in three hierarchical levels. Long-term planning was developed before starting construction, being

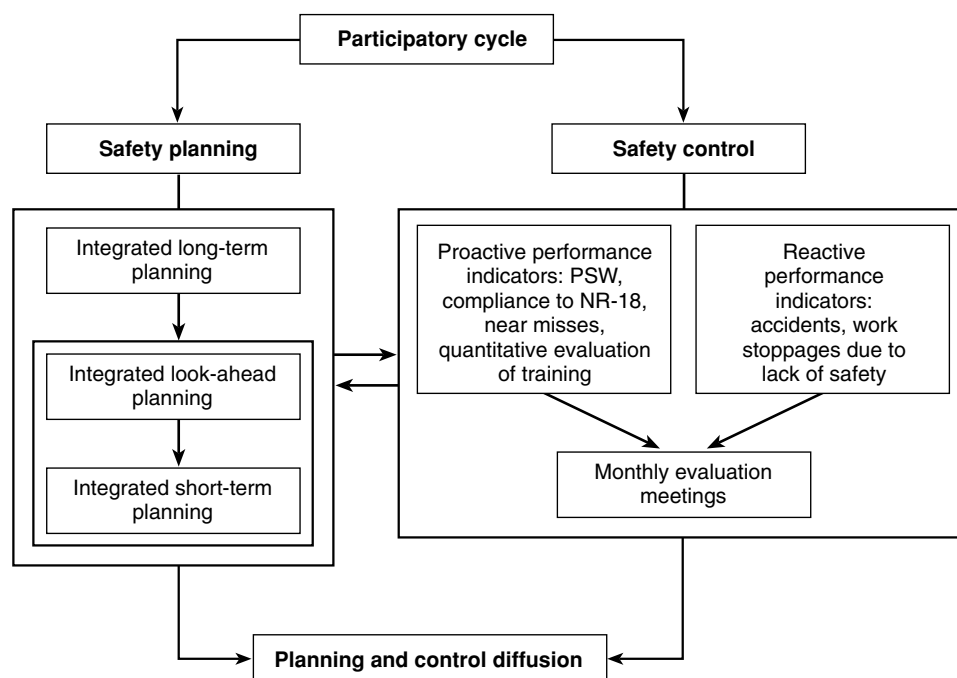


Figure 1 Overview of the SPC model

updated and detailed at both look-ahead and short-term levels. Safety control involved a set of proactive and reactive safety performance measures. The results were discussed in a monthly meeting in which a company director was involved.

Workers' opinions were taken into account through a risk identification and control participatory cycle. This cycle had an important role as a mechanism for designing the work system according to a macro-ergonomic perspective (Hendrick and Kleiner, 2001), based on the assumption that workers are prone to point out risks related to poor work organization, including ergonomic issues.

Safety planning diffusion was achieved mostly by training workers based on safety plans before they started carrying out their tasks. In addition to the monthly evaluation meetings, safety performance measures were also disseminated in weekly planning meetings. Moreover, this information was posted on bulletin boards all over the site.

Development of the empirical studies

Integration of long-term planning

In long-term safety planning, the construction phases established in the long-term production plans were considered as a starting point. For each construction phase (e.g. bricklaying) a plan was produced using the preliminary hazard analysis (PHA) technique (Kolluru

et al., 1996). In the SPC model, safety plans were categorized into two groups:

- the first group included activities whose risks cannot always be clearly associated to a specific work package. Six plans belonged to this group: temporary facilities, common circulation areas, equipment for materials hoisting, ironwork shop, formwork shop and mortar production mixer;
- the second group included activities whose risks can be clearly associated to specific work packages (e.g. painting, roofing). The majority of safety plans were included in this category. In this group, specific plans were produced for families of activities that took place in different construction stages. For instance, as welding activities were performed in different stages, it was easier to devise a single PHA for all of them, instead of producing several similar safety plans.

A member of the research team was assigned the responsibility of producing the first draft of the long-term safety plans. These were refined in meetings involving several project participants: the site manager, the safety specialist, some subcontractors and client representatives. The foremen also made contributions mostly when the plans were discussed in a NR-18 mandatory monthly safety meeting. The main steps for producing the safety plans are presented below:

- establish the necessary tasks to be undertaken: both conversion (for instance, laying bricks on the

wall) and flow activities (for instance, moving materials) should be considered, as suggested by Koskela (2000);

- identify existing risks: the effort to identify risks can be supported by tools such as checklists and brainstorming, as well as the technical literature or plans from past projects (Baker *et al.*, 1999). In order to establish a common language for all plans, it is also helpful to adopt a risk classification (e.g. caught in, stuck by) at this stage;
- define how each risk will be controlled: considering that safety control will be based on what has been written down in the plans, preventive measures should not be planned if they are not considered to be necessary or if there are not enough resources to carry them out. Although the aim should be to have no accidents, the contractor will always retain some residual risks, which must be kept within an acceptable level. Managers are the ones who must decide what is acceptable or not, following regulations as minimal requirements. In this study, no formal risk evaluation was carried out for establishing the magnitude of the safety measures and the extension by which residual risks were retained by contractor. This could be done, for instance, by estimating the degree of severity and the probability for each hazard and then decide whether the risks are acceptable or not. This procedure was not considered to be cost-effective at this stage, mostly due to the subjectivity involved in this activity (Tah, 1997).

Integration of look-ahead planning

Safety constraints were systematically included in the look-ahead constraint analysis, which was carried out weekly. Several stakeholders were also involved at this planning level: the production manager, the planning co-ordinator, the safety specialist, some subcontractors' representatives and a member of the research team.

In both studies, safety constraints were classified into five categories, according to the resources involved (Table 1). Such resources can be associated to one or more constraints. For example, the constraints related to safety signals might include both the manufacturing of the signal devices and their installation on site.

Safety constraints accounted for 41% of all constraints in empirical study A and 27% in study B. The former was higher mainly due to safety related space constraints, which were very common due to the interference of the steel mill operations in the construction-activities.

At the look-ahead planning meetings, construction methods had to be further detailed. This kind of discussion had to be introduced because production managers tend to neglect uncertainty related to methods and assume that

Table 1 Examples of safety-related resources

Category	Examples of resources
Training	Passing instructions to new workers, training videos
Safeguards	Handrails, safety signals, safety nets, fire extinguishers
PPE	Hard hats, safety shoes, harnesses, hearing protection
Design	Drawings to assemble scaffolds and handrails systems
Space	Areas for materials storage, released areas in the industrial building

teams will know how to carry out the work packages on site. In an attempt to make this discussion more effective, some questions were systematically introduced in the meetings, such as: how will workers access the workstation? How will safeguards be installed? Where will body harnesses be attached?

Because uncertainty is still high, construction methods are unlikely to be thoroughly defined at this planning level. Usually, two or three potentially safe alternatives procedures were considered and the final decision was made at the short-term planning meetings. On-site testing of alternatives was sometimes used to provide additional information for decision making.

Integration of short-term planning

At this planning level, safety measures were discussed in both daily and weekly planning meetings. The weekly meeting was the most important one in terms of decision making, since several key stakeholders were involved: the planning co-ordinator, the production manager, the safety specialist, client safety and production staff, and representatives from all subcontractors. Safety and production performance measures were routinely presented and discussed at these weekly meetings. In daily meetings, safety and production plans were re-evaluated and the client provided a work permit.

Even if formal daily planning meetings did not take place, the empirical studies indicated that some decisions regarding safeguards should be made on a daily basis. This was the case, for instance, of the selection of anchorage points for body harnesses during the replacement of the 300 m steel mill roof. Such anchorage points had to be relocated daily, according to crew work pace and existing constraints in the facility. If a new risk was identified or risk control measures were changed at short-term or look-ahead levels, this information was used to update the safety plans and to retrain workers. Such changes were documented in a specific form (see example in Figure 2), and copies were distributed to client representatives and subcontractors in the planning meetings.

Date	PHA n°	Risk	Control
29/03/01	PHA 06	Break energy cables during window demolition (the cables are inside the building)	Remove windows from inside to outside

Figure 2 Form used to register changes in safety plans

Site: Steel mill		Observer: Diego		Date: 10/05/01	
Observation period: 10h to 12h				Safe ?	
Gang	Work packages	PHA nº	Yes	No	Problem
BSF	Walls from column 25 to 28	PHA 2	X		
SH	Change roof from column 5 to 7	PHA 5		X	Body harness badly tied
	Activities not clearly associated to work packages				
BSF	Common circulation areas	PHA 8	X		
BSF	Formwork shop	PHA 6	X		

Figure 3 Example of the data collection form used for monitoring PSW

Short-term planning also provided an opportunity to apply one of the core techniques of the Last Planner System, shielding production. According to this technique, a work package must only be assigned if five quality requirements have been fulfilled: definition, soundness, sequence, size and learning (Ballard, 2000). In this study, safety was considered as part of the soundness requirement. Another core technique of the Last Planner System, planning a backlog of work packages, can also be extended to safety planning. Safety planning should also be conducted for this backlog, reducing the likelihood of implementing improvised safety measures.

Safety control

Percentage of safe work packages (PSW)

The percentage of safe work packages (PSW) – the main performance measure used to evaluate safety effectiveness – indicates the percentage of work packages that are safely carried out. It is fairly similar to PPC (percentage of plans completed). A work package is considered to be safe when (a) no failure in the conception of safety plans has been detected; (b) there has been no failure in their implementation; and (c) no accidents or near misses have been observed. The PSW assessment consists of checking the written safety plans against the actual work being performed – risks that are retained by the contractor are not taken into account in this assessment. The formulae for calculating PSW is presented below:

$$PSW = \frac{\sum \text{number of work packages safely carried out}}{\sum \text{total number of work packages}}$$

It must be also emphasized that a work package will be only considered as 100% safe after it has been completed. By definition, accidents are unplanned and uncertain events. Then, there is no guarantee that accidents will not happen, even though all planned safety measures have been implemented. However, once plans are followed, the likelihood of accidents to take place tends to decrease. Further implementation of the SPC model is needed to confirm this assumption.

Figure 3 schematically presents the form used for data collection in the empirical studies. Similarly to the Last Planner System, an analysis of the causes of safety planning failures must be conducted – a checklist for classifying such causes was developed to facilitate this task.

If possible, data must be collected on a daily rather than on a weekly basis, because some safety problems can be only identified through careful and frequent observation of site activities. The observer must walk around the construction site and identify where each work package is being carried out, and watch how each activity is being performed, checking whether the safety measures listed in the respective PHA are being implemented. It is necessary to pay attention to identify any other safety related event not specified in the PHA (for instance, a risk not identified in the PHA).

Probability	Severity				
	Very high	High	Moderated	Low	Minor
Extremely remote			9		
Remote	6.7				
Unlikely	1		10	4	
Likely					
Frequent					

 Risk not acceptable – controls must be improved (red zone)

 Residual risk is within an acceptable level (yellow zone)

 Residual risk is not significant (green zone)

Figure 4 Re-evaluation of controls after accidents or near misses

Notes:

The numbers in the cells correspond to the number of the accident or near miss.

If an activity not scheduled in the production plans is observed, it should be regarded as a new work package and included in the form. If there is a PHA for that activity, this is the basis to evaluate whether the work package is safe or not. Moreover, work packages that have not been initiated are not considered in PSW calculation, unless the cause for not carrying them out was the lack of safety. The form should only be completed at the end of the working day, since other safety failures can be detected after the observation period. The length of time dedicated to each observation varies according to a number of factors, such as the size of the crew, the complexity of the task and the work environment. In the empirical studies, it typically took fifteen minutes to observe a work package.

Other control measures

Besides PSW, other performance measures were also monitored. Two of them were related to the impact of the lack of safety: the number of accidents, and delays caused by safety failures. However, emphasis was given to proactive measures such as: (a) the degree of compliance to NR-18, evaluated through a checklist, and (b) the ratio between the number of man-hours of training and total number of man-hours.

The documentation and investigation of near misses was another important source of information. These were reported by safety specialists and by PSW observers. A review of safety controls took place after each near miss or accident. Such review was based on a subjective risk evaluation, adopting the risk zones presented in Figure 4. Although this is not a key element of the model, it helps to perform a systematic analysis of near misses and accidents, and helps to establish priorities in terms of corrective actions.

General safety performance was discussed in a monthly evaluation meeting. Four of those meetings took place in

each empirical study, involving a company director, the production manager, the safety specialist, the planning co-ordinator, an outside safety expert and a member of the research team. In each meeting, an action plan including both preventive and corrective safety measures was produced.

Workers participation

Besides the three hierarchical safety planning and control levels, a cycle of risk control based on workers perceptions was introduced in the model (Figure 5). This cycle starts by interviewing small groups of workers, typically eight people. The interviews are divided into two stages: (a) an open section, in which workers are encouraged to talk about good and bad aspects of the tasks performed by them and (b) an induced section in which workers are asked a number of questions, including the following topics: manual material handling, awkward postures, personal protective equipment, workload, relationship with colleagues and managers, food, tools, the most difficult tasks, knowledge of the environmental risks, emergency procedures and temporary facilities. When a

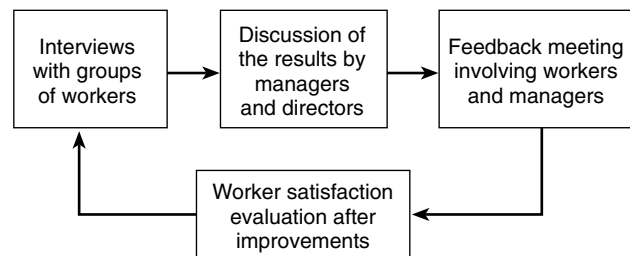


Figure 5 Risk identification and control cycle based on workers perceptions

problem is reported, workers are asked to suggest ways to solve it.

Based on the results of the interviews, a discussion is carried out in a meeting involving production managers and a company director. In this meeting, the first draft of an action plan to solve the problems reported by the workers is made. After that, another meeting is held, involving both workers and managers, in which this action plan is presented and discussed. Finally, an evaluation of workers' degree of satisfaction is performed after the improvements have taken place. This evaluation is based on another group interview, in which new risks can be identified and controls are re-evaluated. New interviews should be carried out whenever a substantial number of new crews come into the site.

Two risk identification and control cycles took place in each empirical study. The first round of interviews was carried out approximately three weeks after starting the work on site. The second round was undertaken around forty days after the first one.

Main results

Safety performance measures

Considering both empirical studies, two accidents resulting working days losses and 21 near misses were registered (11 in site A and 10 in sites B1 and B2). Taking both studies into account, this performance is equivalent to an OSHA recordable incidence rate (total number of recordable cases x 200,000/total site work-hours) of 6.7. This is better than the average performance of general contractors in the USA in 2001 (7.3), but it is well below the performance of Construction Industry Institute members, which was 1.02 (CII, 2003).

The PSW indicator was collected in all three sites. The percentage of the working days monitored in each

site was 40.5% on site A, 37% on site B1 and 39% on site B2. Table 2 presents PSW and PPC standard deviation and mean for all three sites. Figure 6 presents the evolution of PSW and PPC on site B1. In this example, two trends appear to exist after the project was 50% complete: both PPC and PSW increased, and there was a reduction on the variability in both of them. This reduction indicates that both production planning and safety planning became gradually more reliable. Both PSW and PPC were above 80% during a period of eight days, indicating that it seems feasible to achieve simultaneously good performance in both safety planning and production planning. However, no statistical correlation was found between PSW and PPC in this study (p -value = 0.7 on site A; 0.5 on site B1 and 0.8 on site B2).

The data also indicated that high PSW can be achieved even when PPC is low. This usually happens because the sources of uncertainty have a stronger effect on production planning than on safety planning. For instance, on site A, client interference contributed to 19.8% of safety planning failures and to 44.4% of production planning failures. Similarly, inclement weather was found to be a major reason for production plans failures in all sites studied, but did not have any effect in the implementation of safety plans. By contrast, PSW was positively affected by inclement weather, since fewer and less complex work packages were usually carried out in rainy days.

Table 2 PSW and PPC Standard Deviation (S.D.) and mean

	Site A (%)	Site B1 (%)	Site B2 (%)
PSW mean	74.8	76.1	68.8
PSW S.D.	16.5	20.9	14.5
PPC mean	65.4	76.5	72.5
PPC S.D.	33.8	29.0	23.2

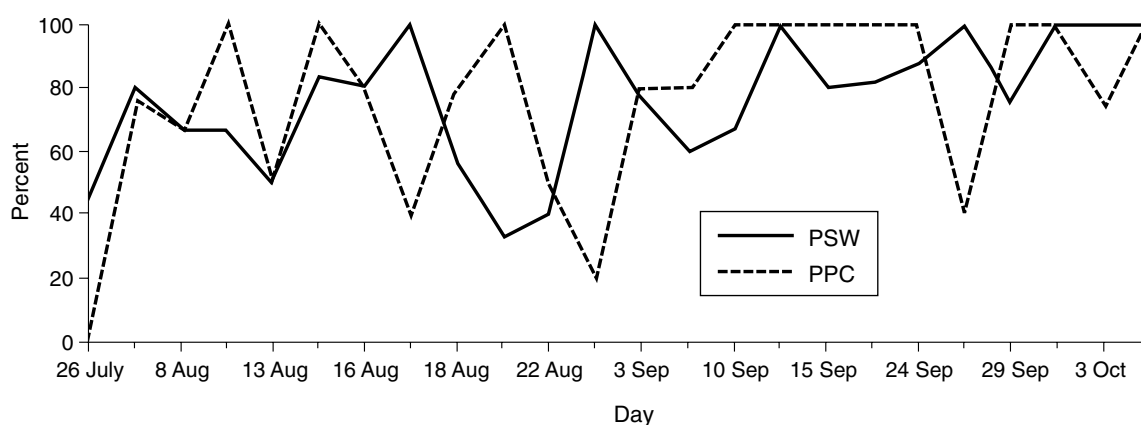


Figure 6 Illustration of PSW and PPC results (site B1)

Workers' perceptions on safety

As an example of workers' perceptions on safety, Table 3 presents the partial results of the first round of interviews in the empirical study A. All demands were classified according to five categories: work environment (WE), process and workstation design (PWD), human resources (HR), personal protective equipment (PPE) and training (TRA).

Based on workers' satisfaction evaluation, a new table was produced, indicating whether the complaints were totally solved, partially solved or not solved. The evaluation results considering both empirical studies were as follows: 44.8% totally solved, 20.7% partially solved and 34.5% not solved. Two main difficulties did not allow a better performance: (a) several complaints were concerned with the role of the client or third parties in the project (bad quality of food, for instance); (b) several complaints were closely related to poor safety awareness (untidy and dirty lodges, for instance) or training failures, which were difficult to be solved in a short-term basis.

Model evaluation

Two main criteria for evaluating the model were established: model effectiveness and ease of use. These criteria were further broken up into sub-criteria. On site observations, interviews with contractor staff and client representatives, and performance measures provided the main sources of evidence for evaluating the model according to each sub-criteria.

As the SPC model was devised and implemented in only two projects from the same contractor, it was not possible to fully evaluate the impact of this model in the reduction of accident rate. Therefore, further testing of

the model in different scenarios is necessary in the future.

Effectiveness

Contribution to risk identification and control

Integrated production and safety planning and control meetings contributed both to systematic risk identification and to improve understanding of existing risks among project participants. This was mainly because the methods and logistics were discussed for each work package. From the safety planning viewpoint, such discussions were even more important at the level of operations performed by workers. The risks identified at these meetings were mostly related to construction technology and site facilities.

The use of safety performance measures also contributed to risk identification, as well as to risk control. In general, the risks that were dealt with the support of performance measures had a similar nature of those identified in planning meetings. Forty-two new risks were identified during the production stage in studies A and B due to the use of performance measures and discussions at planning meetings.

By contrast, the risk identification and control participatory cycle pointed out problems which would be unlikely to be identified or perceived as relevant in planning meetings or through performance measurement. In fact, even if some of these problems can be identified in planning meetings or through performance measurement, they often require consultation to workers to be fully understood. Among the 59 workers' complaints, 27.1% corresponded to risks not addressed in safety plans, while 62.9% were related to ineffective controls.

The SPC model contribution for risk identification and control can also be evaluated based on the failure to identify existing risks. For example, unidentified risks were 7.7% of the safety planning failures in study A and 2.6% in study B. Although progress was made from study A to study B, it should be recognized that a greater effort in discussing potential risks is necessary at the long-term safety planning level. In fact, the most serious accident that took place during this study was caused by an unidentified risk.

The monthly evaluation meetings had an important role as a control mechanism, being the main opportunity to critically analyse the impact of the model being implemented. Some behavioural barriers to implement safety emerged from the discussions, indicating that production managers need to increase their commitment to safety management. Especially in the first empirical study, some participants tried to blame client interference or workers' unsafe acts as the main source of safety failures. In fact, a similar attitude is often found on PPC

Table 3 Main problems according to workers' perceptions (first round of interviews in the empirical study A)

Problems	Type
1. Widespread dust	WE
2. Lodges are untidy and dirty	HR
3. Body harnesses do not fit properly	PPE
4. Two cable body harnesses are necessary to work on scaffoldings	PPE
5. Poor quality rubber gloves	PPE
6. Workers were assembling scaffoldings without previous experience	TRA
7. Lack of knowledge on steel mill risk areas	TRA
8. Access to the steel mill bathroom is risky	TRA
9. Horizontal transportation distances are too long (layout problems)	PWD
10. Some tools are not well maintained	PWD
11. Bad quality of food	HR

analysis, when rain or other uncontrollable factors are blamed for production failures. Photographs of the site, pressure exerted by the company directors and recurring explanations that the objective of safety control is not to find 'who made the mistake' have contributed to gradually change this attitude in the second study.

It is worth emphasizing that ergonomic risks were addressed in the model in the same way as risks related to traumatic type injuries. It means that both types of risks should be identified in the PHA and be controlled in the safety planning and control cycle. Besides, the risk identification and control participatory cycle played also an important role in the investigation of ergonomic risks, since workers had the chance to report them to managers. However, preventive measures were not established based on quantitative data related to the physical demands of construction work, such as heart rate.

Contribution to compliance with client requirements and regulations

In both studies, the clients carried out audits in the existing safety management system. All sites had very positive assessments, and one of the clients considered that the implemented system should be considered as a benchmark among their contractors. The degree of satisfaction was also assessed in the interviews with client representatives. For instance, the steel mill safety manager reported that, compared to past projects conducted by the same contractor in the same steel mill facilities, this was the first time that he had seen a consistent safety management system, in which safety efforts are not limited to occasional safety awareness campaigns.

The degree of compliance to NR-18 was evaluated in both studies: 90% in site A and 77% in sites B1 and B2. These results are higher than the average degree of compliance of 55% found in a recent nation-wide survey of eighty construction sites (Saurin *et al.*, 2000). Moreover, the SPC model contains some practices that are more advanced than those required by Brazilian regulations, including proactive performance measures, procedures to update safety plans and systematic surveys of workers perceptions.

Integration of safety into production planning and control

This study indicated that long-term safety plans must be systematically updated, since several new risks were identified after starting the work on site. In spite of this, most safety procedures in long-term plans are likely to be the same whatever the site. Therefore, the set of long-term safety plans can be standardized to some extent, and be adjusted and completed for different projects.

Constraint analysis established an effective link between long-term and short-term safety planning. Several constraints were related to the procurement of resources defined in the long-term safety plans, such as scaffolds and handrails. The availability of these resources was a prerequisite to assigning work packages at the short-term level. In addition, look-ahead and short-term planning meetings were made more efficient, since it was not necessary to discuss basic preventive measures. These had already been established in the long-term safety plans. By contrast, the studies indicated that more time should be spent in the discussion of construction methods and logistics at both look-ahead and short-term levels.

Regarding the planning and control meetings, seven factors were identified as having a positive influence in safety planning: discussion of methods, participation of safety specialists, discussion of performance measures results, constraint analysis, site layout planning, analysis of the interference between construction and client operations, and stakeholders' commitment to site safety.

Ease of use

Implementation efficiency

According to the evaluation interviews, the inclusion of SPC model elements into existing managerial procedures made its implementation easier. Both production planning and control meetings and quality system maintenance ordinary meetings had their agenda extended to include the discussion of safety issues. Training sessions involved both production and safety procedures and instructions. Also, an existing monthly NR-18 mandatory safety meeting was used to review long-term safety plans – before the implementation of SPC model, this meeting was considered to be of little use to safety management. The implementation of the SPC model strongly involved safety specialists. They had to carry out a set of new activities. This change was considered to be positive by the company, since the work of safety specialists became more systematic and proactive.

The implementation efficiency was also evaluated by taking into account the resources and time required to implement the model. The person responsible for site observations must assign some time (between one and two hours a day) to walk around the site and observe all work-stations. In addition, this person must have time available to analyse data and produce reports (in this study, around five hours per month). The fact that data collection and processing is fairly time-consuming was considered to be one of the main drawbacks of the current version of the model.

Regarding the risk identification and control participatory cycle, a number of requirements must be considered in data collection: (a) the interviewer must have interviewing skills to be able to encourage people

to express their opinions; (b) someone must analyse and process data – in this study, such activities took around four hours for each round of interviews – and (c) the site should have an adequate place where the interviews can take place in privacy.

Understanding by stakeholders

In the interviews, all directors and employees of the construction company reported that the implementation of the SPC model contributed to develop their critical sense regarding accident prevention. Participants understood that, besides focusing on human errors, there must be a set of planning and control procedures that contribute to the prevention of accidents. The company planning co-ordinator stated that the SPC model look for causes of safety failures in the management system, instead of personal mistakes.

Another evidence indicating that the model was fairly well understood in the company was the fact that the SPC model was implemented in a third project without the support of the research team. Its implementation was led by the planning co-ordinator, who had the support of the safety specialists involved in the empirical studies. Moreover, in the evaluation interviews, everybody said that there was no major difficulty to understand the model, although they pointed out that it is necessary to provide basic training to clarify its underlying ideas.

Use of the model in future projects without the participation of the research team

Besides the implementation of the model in a third project, there were other evidences indicating that the company will continue to use the model. Firstly, the SPC model was internally disseminated in the company by inviting all production and safety staff to participate in monthly safety evaluation meetings. Secondly, directors stated in the interviews that they intended to extend the SPC model for all sites of the company.

Conclusions

This paper presented a safety planning and control model (SPC) that was developed through two action research empirical studies, carried out in industrial construction projects. Differently from previous proposals to integrate safety into planning, which focused mostly on the development of safety plans, the SPC model takes into account the control function and regards safety planning and control as a broader managerial process.

The results indicated that several concepts and methods successfully used in the Last Planner System (such as constraints analysis, shielding production and planning failure analysis) could be easily extended to safety management. In fact, the implementation of the SPC

model requires an existing production planning and control system that contains some key elements of the Last Planner System: hierarchical decision making levels (typically long-term, medium-term and short-term), constraint analysis, planning meetings on a regular basis and assignment of work packages based on quality criteria.

In addition, a hierarchical decision-making process on safety measures was established, involving client, managers, subcontractors and the workforce. The preliminary hazard analysis (PHA) technique was used for producing long-term safety plans, being continuously updated and detailed through the integration of safety into look-ahead and short-term planning levels. In this way, safety planning and control was systematic and continuously applied during the whole project.

A systemic approach to SPC was adopted, since the model involves a set of inter-related tools and procedures. The analysis of safety planning failures was also systemically approached, as the aim was to identify the underlying causes of unsafe acts and unsafe conditions. In this respect, planning and control failures were identified as major root causes of the lack of safety.

As a drawback, the implementation of the model was found to be time-consuming. It is necessary to devise means to reduce the effort to collect and process data in the future, for instance by using information technology. Besides, the model effectiveness is likely to be reduced if managers are not committed to safety management – they should give SPC a primary role in production management. This seems to be easier to achieve when the client establishes site safety as a priority.

As a potentially effective means to tackle other root causes of accidents, safety management should be systematically integrated into other core managerial processes, such as design, human resource management and cost management. The integration of safety into the design phase seems to be a natural follow up for this research project. Then, a broader SPC model could be developed encompassing both the design and production phases.

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