INTEGRATING SAFETY ANALYSES IN PRODUCTION PLANNING AND CONTROL – A PROPOSAL

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ABSTRACT

This paper proposes a model to integrate safety analyses as part of performing production planning and control in construction projects. The model takes a system view of accidents, implying that hazardous situations occur due to characteristics of the construction production system. In the model, a joint effort is described to prevent accidents in which safety risk analyses are carried out as part of dealing with short term operative and longer term strategic production planning.

In the case company, which is one of the major Scandinavian construction and real estate development companies, Last Planner has successfully been applied to handle the work flow on the construction site. At the same time, the company has put forward an objective to remove four out of five injuries by the end of 2015, including all subcontractors and hired workers. To fulfill this objective, knowledge and insights are needed on a number of levels to develop and implement adequate interventions.

In this paper, we look at safety performance at the sharp end. Statistics are used on injuries collected from all construction projects in the company, to gain clear insight into the types of injuries occurring on the construction site, the factors affecting the likelihood of injuries and the frequency of injuries among different groups of workers. To diminish the effects of hazardous situations and reduce the emergence of injuries on the construction site, a model is proposed to integrate safety analyses with systematic planning of production progress.

KEYWORDS

Safety and quality, production planning and control

INTRODUCTION

The construction site is a risky work place. Last year, one out of five of all work fatalities in Norway took place in the construction industry. In the same year, one out of ten of all construction workers was injured on the job. The Norwegian construction industry is subject to a comprehensive health and safety regulatory framework. A substantial effort is made by labor unions and employer organizations, as well as by

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different governmental institutions, to monitor and attract attention to the problem. Considerable research and development is carried out to explore the phenomenon. Among big construction companies, the health and safety of workers is at the top of their priorities. In spite of all the initiatives taken, regulations applied and knowledge gained, people on the construction site continue to get injured. What could possibly work to solve this seemingly enduring problem?

In the case company, the development in accidents and injuries has stagnated after some years with a positive, falling trend. A health and safety strategy has been developed. It approaches the existence of accidents and injuries as a multi-level problem. On the one hand, the strategy is directed towards those who are involved ahead of projects, and on the other it addresses the project stage including those who are directly involved with construction. Ahead of projects, of primary concern is to make sure that each project is provided with the best possible conditions regarding health and safety, in particular when it comes to competence and team compositions, communication and learning, and systems and routines. In the project stage, the main aim is to ensure a significant reduction in the level of risk involved in all activities through a high level of involvement of workers, extreme tidiness on the construction site, a system of risk evaluation and collaborative planning, systematic deviation analyses, the availability and consequent usage of safety equipment, and a proper safety behavior.

This paper explains the efforts made by the case company in the project stage. On the construction site, three concrete efforts are prioritized: 1) Usage of safety equipment (hard hat, protective glasses and gloves), 2) Risk evaluation and analyses, and 3) Extreme tidiness. The combination of these efforts, in conjunction with a clear and demanding leadership as well as a focus on worker-to-worker relationships, a consistent follow-up, and tight and binding co-operation between management and union representatives, is believed to bring the company a significant step forward and closer to the goal of eliminating four out of five injuries. In the paper, we hold that the Last Planner system can represent a powerful tool in this struggle. The obvious reason is that accidents and injuries on the construction site are expected to be deeply intertwined with the workflow that the planning system seeks to control. A less apparent although equally important reason is that Last Planner, due to the way it includes systematic interaction between techniques and humans, is anticipated to open for the use of frequent communication, negotiation and intuition also in the matter of construction health and safety.

THEORETICAL BACKGROUND

For more than a decade, papers to the IGLC conferences have contributed to the system view of accidents in the construction industry. At the 10th IGLC conference in 2002 in Gramado, Brazil, a significant contribution was made by Howell et al. (2002) in the form of proposing a new approach to construction safety beyond root cause analyses of accidents performed around more or less worker or human centered causation models. The paper is deeply inspired by the work of Rasmussen et al. (1994), which in turn is based on the fundamental recognition that people adapt to circumstances and that helping them develop and apply their judgment would be more successful than just making them follow rules. Rasmussen et al. (1994) identify three zones related to safety – the safe zone, at the edge and over the edge – and discuss what people may do according to which zone they are in. Based on this way of thinking around hazards, Howell et al. (2002) suggest that improved safety and organizational performance in the construction industry can be achieved by learning to work close to the loss of control boundaries in order to better cope near the edge.

The principle of learning to cope with hazards near the edge was followed up in the subsequent year by Mitropoulos et al. (2003) in a paper to the IGLC conference in Virginia, USA. In the paper, error management based on "simulation" training from aviation is introduced to increase workers' ability to work safely in the hazard zone. Mitropoulos et al. (2005) contribute further to the understanding of the system view of accidents in an article in the Journal of Construction Engineering and Management. In the article, a system model of construction accident causation is introduced, in which reducing task unpredictability together with improving error management capabilities is held to be decisive for accident prevention. The same line of argument reappears in Mitropoulos' (2012) paper to the 20^{th} IGLC conference in San Diego, USA, where he suggests production control and safety management as project safety determinants. Mitropoulos (op.cit) moreover argues that improving the effectiveness of the production control system should be a key strategy for safety improvement. In the same breath, he pinpoints the need for initiatives that include a closer and more integrated effort between production and safety efforts.

From a more practical point of view, a study from Denmark (Thomassen et al. 2003) found that crews using the Last Planner System of production control showed a 45 per cent lower accident rate than crews who did not use it. In the view of Mitropoulos et al. (2005), this has very much to do with the system's aptitude to produce high quality work assignments. As a result, the working conditions are stabilized and task unpredictability – causing hazardous situations, interruptions and short term production pressures – is reduced. Nevertheless, reducing task unpredictability is only one step on the way to a safer construction site. Also important is error management, or enabling the crew to successfully recognize, cope with and recover from hazardous situations and errors (op.cit). One remaining question is how to integrate the function of error or safety management into production control.

Construction workers are workers at the edge, who tend to operate in the hazard zone and who are inclined to trust their own judgment more than just following rules. In other words, construction workers are likely to respond to danger in informal ways. At the same time, a study carried out on a Danish construction site indicates that safety practices evolve in the complex relationship between the individual, the pair and gang (Baarts 2009). It concludes that both individualist and collectivist preferences influence the amount of risk the individual worker will assume and expose workmates to, and that aspects such as self-regulation, self-confidence and independence are acceptable values only to the extent that they do not pose a threat to the solidarity of the community or safety of other workers (op.cit). Safety in the construction industry thus seems to be predominantly a social and collective effort.

If safety is considered a product of human behavior it is not a property of any system. Rather, it is something a system or organization *does* (Hollnagel et al. 2006). Safety is thus not something placed into a system through rules and standards that will remain in place. Instead, safety is a reflection of how a system performs (Schafer et al. 2008). A resilient safety system has the ability to recover from infrequent and unexpected perturbations and disruptions to expected working conditions (Hollnagel et al. 2006), but not simply by using more procedures, guidelines, personal protective equipment and barriers. Rather, system resilience is achieved through continuous monitoring of system performance and "how things are done" (Schafer et al. 2008). Just like a resilient safety system, Last Planner has the capability to handle disruptions and variations that fall outside of planned events. Incorporated in this multilevel planning of production is frequent communication and negotiation about tasks and thereby also adaptability to perturbations. Instead of the workers being controlled, they come together on a regular basis to interact in the process of planning in different time horizons. It is as if the whole design process of this production planning system, although this is nowhere spelt out in its description, is based on the fundamental notion that humans are superior in scheduling techniques – with respect to e.g. flexibility, adaptability and learning, and communication and negotiation.

Subsequently, how can a resilient safety system gain from being merged with or integrated in such a system of production planning and control? Mitropoulos et al. (2005) describe error management as a set of strategies that enables the workers to detect and correct errors before the onset of consequences. In so far as Last Planner helps in detecting potential disruptions and variations in activities, it can also help workers better detect where hazards might be released and minimize the effects if loss of control is irreversible. Furthermore, whenever deviations occur between planned activities and actual production progress, they are systematically followed up by analyses identifying root causes for non-completion. In much the same way, a resilient safety system can be designed to analyze safety deviations and near-accidents in order to learn from situations where there are risks involved. In addition, a well-functioning production planning system is also sensitive to actions that have the potential to move production from the normal working realm where adaptability is anticipated to an area that stretches the ability to adapt. In this perspective, Rasmussen et al. (1994) propose accident prevention efforts focusing on error-tolerant work systems that make the boundary of loss of control visible and reversible. Capacity utility could here work as a safety indicator, together with for instance the extent of overtime work. Likewise, the prevalence of sick leave can indicate the level of work load and stress in the work force, together with tidiness at the construction site. Whenever production demands impinge upon safety, the functioning of a resilient safety system can then make sure that interventions are made to allow workers to stay out of dangerous working situations by being better prepared and not surprised by perturbations to the system.

INJURIES IN THE CASE COMPANY

A DECENTRALIZED COMPANY

The case company is divided into four regions, and each region is made up of five to six smaller districts where the districts represent the business units. It is a decentralized organization. In turn, the freedom to operate leads to a pressure on units – and not least projects – to come up with local, effective solutions. In the matter of safety, the overall goal is clearly defined and the main tools to achieve it have been pointed out by the company. However, given the decentralized organization and the complexity of projects, monitoring and controlling the safety of workers becomes first and foremost a project concern.

Experiences so far show considerable variation in the implementation of the health and safety strategy. Especially, small projects fail to meet the new demands. Likewise, projects with a substantial number of hired workers struggle to keep up with the new standards. Particularly when many of these are foreign language speaking, involvement and knowledge transfer become a challenge.

When it comes to Last Planner, or Collaborative Planning which is a company adapted version of the Last Planner system, it has for several years been the company's approach to production planning and control in projects. For much the same reasons as seen in the implementation of safety efforts, there is substantial variation between projects in how the system is adopted. Among other factors, project size and type, and the competence of the project team, play an important role for whether and to what extent the system is used.

INJURIES IN THE COMPANY

In the previous year, just above 250 persons were injured at one of the company's work places. By the end of 2015, the goal is to reduce this number to 50. As Table 1 indicates, 112 of the company's own employees were injured on the job that year. For 33 of these or in around 30% of the incidents, the damage was so severe that it resulted in absence from the job. When hired personnel and workers from subcontractors are included in the statistics, the number of injuries increases considerably. In fact a comparison reveals that two out of every three injuries with absence involves either a hired or subcontracted person. Besides, as the table also shows, there were two work fatalities last year, where one of these involved a hired person and the other a worker employed by a subcontractor. Thus, to succeed in the ambition to eliminate 80% of all injuries over a three-year period, to include the hired and subcontracted persons in the health and safety efforts is fundamental.

Table 1 Injuries and accidents in the company

2012	Employed in company	Hired personnel	Employed by subcontractor	Total
Fatalities	0	1	1	2
Injuries with absence	33	14	51	98
Injuries without absence	79	21	54	154
Total	112	36	106	254

Including these other workers is even more important with regard to injuries, because the propensity to get injured is considerably higher among subcontracted workers than among the company's own employees. In Table 2 below, safety indexes H1 and H2 for respectively own employees and subcontracted workers are presented; H1 is based on the number of injuries with absence per million work hours while H2 includes all injuries per million work hours. As the table shows, subcontracted workers have twice the probability to get seriously injured and 1.5 times the possibility to get injured than the company's own employees. To date, we do not have corresponding indexes developed for the hired workers in particular; however, rough estimates indicate that these are even higher than for subcontracted workers.

Table 2 Safety indexes among groups of workers in company projects

2012	Employed in company	Employed by subcontractor
H-1	3.9	12.2
H-2	17.1	27.0

TYPES OF INJURIES

Our statistics show that fingers, hands and arms are most exposed to injuries, thereafter foot and ankle, back and ribs, and eyes, head and neck. The same material reveals that injuries due to falling are the most important incident, followed by being hit by an item or wounded by a sharp item, and being crushed and torsional injuries. These were the most frequent injury causes as stated in the statistics. From the way injuries are categorized in the data base, which we assume is quite similar to how this is done in other construction companies as well as industry-wide, one might get the impression that accidents in construction most often occur during direct work. We decided to investigate this further, by arranging all serious injuries (injuries with absence) into the following three categories; injuries during direct work, injuries during rigging, and injuries during transportation (including walking). The categorization was performed manually, based on complementary information from a data base concerning each of the serious incidents. We find the results of this analysis, which are presented in Table 3, quite intriguing. It shows that only just above one third of the accidents happen under direct work, whereas nearly two thirds happen either under rigging or transportation.

Table 3 Serious injuries divided by job situation

Job situation	2012
Injuries under direct work	38.6
Injuries under rigging	33.7
Injuries under transportation	27.7

The findings led us further to explore the serious injuries divided according to winter and summer season and time during the working day. Given that most of them take place out of operations, we expected that other conditions – such as the weather – could influence the probability for accidents to occur due to thin ice, snowfall, etc. First, we divided the year into two, where April-September was defined as the summer season whereas October-March was categorized as the winter season. Indeed, while injuries tend to occur more frequently during the winter season, we found the difference to be less significant than one would expect considering that the summer season also includes more days off than the winter season. Neither does there seem to be any distinct injury pattern depending on the time of day, as accidents are relatively evenly spread over the working day. Above all, what these findings may tell us is that safety precautions on construction sites are equally important no matter what time of year or day.

INTEGRATING SAFETY ANALYSES IN PRODUCTION PLANNING AND CONTROL – A MODEL

Table 4 Integrating safety analyses in production planning and control – a model

Level			Common	Process	Time scheduling		Risk analyses		Person(s) in charge
No.	Name		Principles	Work form	Purpose	Document	Purpose	Document	
1	Master plan	Project	-Include client in preparing H&S plan	-Start-up meeting	-Plan total project, including milestones	-Rough plan, part of contract	-Mapping of hazards in building and process	-Health and safety plan (H&S plan)	Project leader
2	Phase plan	Phase	-Prepare rigging plan (dynamic) including H&S aspects -Develop manning plan based on production calculation	-Post It-planning	-Decide main direction of activities -Time scheduling -Capacity planning	-One plan for each phase	-Identify Safety Job Analyses (SJA) needed -Highlight SJAs in plan	-Phase plan including safety warning signs	Site manager
3	Look Ahead plan	Activity	-Make sure same level of detailing in all activities in plan	-Work break-down structu-ring	-Define individual activities -Execute constraints analysis (information, materials, equipment, labor)	-5-9-week plan	-Execute SJA -Evaluate risks within and between operations -Follow up SJAs with relevant interventions	-SJA scheme identifying risky operations, hazards and possible interventions	Site manager
4	Weekly work plan	Week	-Design jobs based on competence and capacity available in work force	-Job definition	-Decide final direction and duration of activities - Execute constraints analysis (place, other conditions)	-2-4-week plan	-Make SJAs operative -Evaluate if extra efforts needed	-Safety Job, detailed description	Foreman
5	Team plan	Week (current)	-Point out weekly organizer in charge of tidiness in his area -When controlling progress at end of week, check on safety indicators (capacity utility, overtime work, etc.)	-Daily pep-talk (on site)	-Division of jobs between operators in the team	-1 week plan	-Check on near misses from yesterday's work -Briefly go through work of today, with safety in mind	-White board, describing safe operations	Supervisor/ team of operators

The starting point of the model presented in the table above is that one can eliminate many of the risks or hazards connected with construction work through designated safety risk analyses, performed as part of systematic planning of the production progress. An underlying notion is that the risk one is willing to take on a personal level is in fact fundamental for construction health and safety. Therefore, the most effective way to reduce it is likely to be to let risks and hazards become an everyday and not least collective matter among the workers, when they make plans, discuss and negotiate about short and longer term production progress. This may be particularly important considering that many accidents occur out of operations, since planning production progress is very much an exercise in how to reduce time loss due to indirect work. In the following, we propose certain principles we suspect to be crucial in reducing risk on a construction site, where these principles are adjusted to different plan horizons and relevant risk analyses to be carried out.

1. Master plan/project level: The master plan comprises the total project. It is, at least in projects where the case company is the main contractor, usually developed by the project leader together with the site manager. Our main principle here concerns the fact that clients should be included in the effort to achieve fewer accidents and injuries on the construction site. This is because we believe that decisions made early in the project have fundamental safety implications for the later construction process, such as in relation to e.g. technical solutions, choice of materials and use of prefabrication. A construction client is by governmental regulations obliged to prepare a health and safety plan that envisages how a proper working environment will be provided for in the project. To ensure that this plan is not separated from the project we would suggest performing a general mapping of hazards at this point concerning the entire building and production process.

2. Phase plan/Phase level: The phase plan details the content of what should be done in each project phase, and a separate planning process is normally devoted to each phase by the site manager. A key principle here is that since most injuries happen out of operations, the physical layout of the whole construction area should be included in the production planning. Additionally, different phases in the project, such as groundwork and foundations, erection of the building, and fixtures and technical work, are likely to be associated with specific hazards. We therefore suggest that the layout of the production area must be dynamic since the character of the production process changes. As part of producing the phase plan, we include the development of a rigging plan. A rigging plan concerns how to establish a functional design of the whole construction area, including the use of the area, the location of cabins, cranes, electricity, etc. For obvious reasons a rigging plan should also include health and safety concerns, as many injuries tend to occur under circumstances of transportation and rigging. Otherwise, since the level of detail at this point includes making decisions about the activities to be accomplished, safety job analyses – wherever needed for particular jobs – should be identified and highlighted in the plan. Finally, we recommend a manning plan to be carried out for each phase based on a review of the production calculation, in order to be able to foresee if and where the production can be moved out of its normal working realm.

3. Look-ahead plan/Activity level: The look-ahead plan is where each phase is broken down into smaller planning periods or windows, where each window usually includes all activities to be conducted in 5-9 weeks time. The main principle implies that since unsafe activities and hidden hazards tend to reappear on the construction site, extra consideration should be devoted to the process of work breakdown structuring. This is the level where, in collaborative planning, constraint analyses are conducted to make sure that only those activities where information, materials, equipment and labor are in place are transferred to the production foremen. Concerning the making of the look-ahead plan, the site manager who is normally in charge of this process must pay particular attention to the work breakdown structuring, so that every activity included in the plan has the same level of detailing. If this is not taken into consideration, one might end up with poorly defined, unsafe activities that also include hidden hazards. As part of the look-ahead plan process one should moreover conduct safety job analyses for all the risks identified – both within operations and between operations – to make sure that risks are followed up with relevant interventions before they are handed over to the foremen.

4. Weekly work plan/week level: The weekly work plan comprises activities to be conducted in 2-4 weeks' time. The main principle is that there is a close relationship between job design and the level of safety, so that the designing of jobs should happen in accordance with the competence and capacity available in the work force. Normally, at this level of planning, dates for start-up and completion are set by the foremen for all activities. A constraint analysis should ideally also be carried out for each activity including space and previous work in addition to other conditions to make sure that all prerequisites are in place before an activity is transmitted to week number 2, which is the next week in line for operation. We here advise that safety job analyses should be made operative by the foremen to evaluate whether extra efforts are needed to secure an activity even more, depending on capacity in the work force and on which workers will be involved in the job and their competence.

5. Team plan/current week: In many of the company's projects, the weekly work plan is supplemented with a so-called team plan for each type of work. The team plan involves the planning and division of work in the current week between workers of each team. The main principle here concerns how tidiness can help to ensure a safer construction site. We generally believe there are physical, social and symbolic sides to tidiness when practiced in the work place. A tidier work area makes it easier and safer to conduct operations more effectively; it raises the workers' well-being, and also gives them the opportunity to show off a disciplined, neatly arranged work place. When producing the team plan, we suggest that for each on-site area where activities are going on an organizer should be pointed out on a weekly basis to take the overall responsibility for tidiness in his area. We further propose a daily pep-talk for each team to check on any near misses from yesterday's work and briefly go through today's work – with safety in mind. Finally, when controlling progress at the end of the week, using PPC or otherwise, safety indicators should be included, such as capacity utility, overtime work, etc. to guarantee a safe and healthy balance between safety and production progress in all activities.

CONCLUSIONS

In this paper we have argued that planning of production progress can be useful for safety reasons, and that the planning of production and safety could go hand in hand. A model was proposed, providing details about how this could be done in practice all the way from a total project perspective and down to the daily pep-talk on the shop floor. This is basically by introducing certain principles attached to each of the planning levels in the system of collaborative planning, the principles being related to the following factors: the inclusion of the client in safety planning; the incorporation of a concern for the physical layout of the construction site as part of planning for safety; an extra consideration towards work breakdown structuring to avoid hidden hazards; the designing of jobs in accordance with the competence and capacity available in the work force and lastly; by letting tidiness become an everyday and collective matter within each team of operators.

To conclude, we believe that joint, systematic planning of production progress and safety can enhance every project by reducing the emergence of dangerous misses, accidents and injuries on the construction site. At the same time, we believe that a full implementation of the model can be achieved through guided training and support on the project level. In the case company, a new improvement strategy named "Start-up Assistance" has just been formulated and adopted, which is aimed to support every project with competence and tools to improve their performance in certain prioritized areas, where health and safety and production planning are two such areas. Finally, we believe that to develop safe work practices in the construction industry there is a need for fuller insight into the factors that create safe individual and organizational behavior at the operative level. In the case company, a PhD has just been initiated to explore amongst other how to improve systems for incident reporting and deviation control, how to balance between compliance to requirements and resilience in work operations.

REFERENCES

Baarts, C. (2009): Collective individualism: the informal and emergent dynamics of practicing safety in a high-risk work environment. In *Construction Management and Economics*, 27, 949-57.

Ballard, G., Howell, G. A. (1998): Shielding production: An essential step in production control. In *J Constr Eng M ASCE*, 124 (1), 11-17.

Hollnagel, E., Woods, D. D., Leveson, N. (2006): *Resilience Engineering; Concepts and Precepts*. Farnham, UK: Ashgate.

Howell, G. A., Ballard, G., Abdelhamid, T. S., Mitropoulos, P. (2002): *Working near the edge: a new approach to construction safety*. Paper to the 10th IGLC conference in Gramado, Brazil.

Mitropoulos, P. (2012): *Production control and safety management as project safety determinants*. Paper to the 20th IGLC conference in San Diego, USA.

Mitropoulos, P., Abdelhamid, T., Howell, G. A. (2005): Systems Model of Construction Accident Causation. In *J Constr Eng M ASCE*, 131 (7), 816-825.

Mitropoulos, P., Howell, G. A. and Reiser, P. (2003): *Workers at the edge: hazard recognition and action*. Paper to the 11th IGLC conference in Virgina, USA.

Schafer, D., Abdelhamid, T. S., Mitropoulos, P., Howell, G. A. (2008): Resilience Engineering: a New Paradigm for Safety in Lean Construction Systems. In *IGLC 16 Proceedings*, 723-33.

Rasmussen, J., Pejtersen, A. M., Goodstein, L. P. (1994): *Cognitive System Engineering*. John Wiley Sons, Inc. New York, NY.

Thomassen, M. A., Sander, D., Barnes, K. A., Nielsen, A. (2003): Experience and results from implementing Lean Construction in a large Danish contracting firm. Paper to the 11th IGLC conference in Virgina, USA.