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Building up business operations and their
logic

Shaping materials and technologies

Edited by
Arto Saari
Pekka Huovinen



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Safety Constructability Improvement Adding Spatial Dimension and Workers' Safety in the Critical Path Method

Rana Alzayd,

Dipartimento di Ingegneria Civile e Ambientale, University of Florence
rana.alzayd@dicea.unifi.it

Vito Getuli,

Dipartimento di Ingegneria Civile e Ambientale, University of Florence
vito.getuli@dicea.unifi.it

Tommaso Giusti,

Dipartimento di Ingegneria Civile e Ambientale, University of Florence
tommaso.giusti@unifi.it

Pietro Capone,

Dipartimento di Ingegneria Civile e Ambientale, University of Florence
pietro.capone@unifi.it

Abstract

In this contribution, at first an approach to analyse safety in the construction process is proposed. This approach includes Building Design for Safety (BDS), a specific method to check both constructability and workers' safety of the critical phases in construction process. Safety management in design and construction phases is one of the essential components that can influence the actual achievement of the constructability goal. Compliance with costs and time, necessarily passes through the risk mitigation of the critical activities, this must be done in order to safeguard the quality of the building. Prefiguring the construction process from the design phase, allows us to manage both safety and constructability. We operate within a framework that has to be used in design phase. In the framework, making use of the construction management instruments, we can identify critical activities for the workers' safety during the future construction process. For critical activities characterized by overlapping of time and physical space of construction, the BDS tool is proposed. BDS makes a check both of constructability and safety of the critical construction activities in order to suggest technical and management solutions to mitigate risks. The tool allows the user to identify measures and procedures for risk prevention and protection, with respect to the constructability. BDS has to be performed during the design phase, in order to prefigure the construction process. This way, risk mitigation can be performed according to the constructability goal, safeguarding the building correspondence to the needs of the design. So far, the results achieved concern the BDS application in many real case studies. Future issue are related to the development of the instrument in BIM technology.

Keywords: Constructability, safety, design

1. Introduction

It is within the last fifty years that quantitative methods for project analysis and scheduling have been developed and documented, and particularly those supported with computerization.

Critical Path Method (CPM) has ever since been the dominant methodology for scheduling construction. (Baldwin, 2014)

In this paper a new approach based on the analysis of construction scheduling supported by a construction simulation is proposed and used in order to increase safety constructability in the phase of activities planning.

Such an approach provides a new tool for extending basic activity-based CPM logic adding workers' dimension and optimizing basic scheduling in function of workers' safety. Traditional CPM uses a single layer of logic which operates only between any two activities. Production occurring inside an activity is described only by duration, and there is no recognition of the worker's position in terms of working areas.

Until now the approach of Location-based management assumes that there is value in breaking a project down into smaller locations and using these to plan, analyze and control work as it flows through these locations.

The location-based planning system takes into account activities and tasks, where a task is made up of a sequence of activities in differing locations. Then it uses CPM external logic to define the logic or connection between different activities within locations wherever they occur. However, unlike CPM, the planning system also considers a task's own internal logic, by calculating durations based on quantities and allowing the planner to plan the location sequence and production rate to achieve continuous production.

Starting to carry out a review of the current practice in the field of Location Based Management Systems (LBMS) a new approach is proposed which generates a logical relationship between working areas and activities and automatically, first, integrates this relationship in the CPM and then manages overlapping activities in terms of risk workers' risk reduction.

This approach comes from the consideration that in construction management, the health and safety is one of the most important element able to influence the entire process-management.

In this perspective it could be useful to remember the close relationship between safety and design (Capone et al., 2015). In safety management, EU Communications refer to architectural, technical and/or organizational choice in order to minimize professional risks. Such choices underline the cooperation needed between designer and safety coordinator at design stage: actually the main issue is related to the effectiveness in reaching the constructability goal.

2. Constructability, design and safety

As referenced by Capone et al. (2015), in the theoretical approach to Constructability the difficulty of designers to lead the construction phases during design phases was straight from the beginning. This opened up to a discussion about the aim to link design phase and construction phase: the results of building's quality are strictly related to the separation/integration between design and construction.

Together with Constructability the development of methods and tools aimed to manage this complex relationship, known as "Constructability", is a strategic resource for the field of Construction management and the progression of this concept shows that the aims could change throughout time depending on many factors such as incidental, environmental, social and economic (Gambatese 2007). According to Russel (1994), the construction time and cost could be depending on the way of running of the relationship between design and workers Healthy and Safety. The aim of directing such factor, according to the Constructability theories, means to find new design tools that aim to manage H&S during the design phase (Gambatese, 2009) (Creaser, 2008) (Taiebat, 2001).

The research line about Constructability has been carried out at two levels of analysis: one is overview level which focuses on the broad picture of Constructability and the other is the practical level, which investigates new tools, created ad hoc, to reach the research objectives. From the relationship between design and safety, the Building Design for Safety (BDS) method has been proposed by Capone (2014). This tool, better explained in Section 4 of the presented paper developed a construction simulation based by starting the activity simulation from the shop drawings. A 2D representation was used to visualize construction operations but the integration of this approach with a construction scheduling tools was not proposed. The presented work first develops a new tool for an automatic re-scheduling of CPM in function of workers' safety and when the tool is not enough proposes BDS as design solution in order to consider safety reasons before construction process starts.

3. Location Based Management System

Location-based management considers there is value in breaking a project down into smaller locations and using these to plan, analyse and control work as it flows through these locations. The location provides a container for project data at a scale which is easy to analyse.

Location-based planning is, in turn, concerned with the process of planning for work to protect production efficiency as work moves through locations. Specifically, the emphasis in location-based planning is to plan for productivity.

Location based methods extend basic activity-based CPM logic to yield an easy-to-use system which possesses the underlying analytic properties of CPM but specifically includes production estimation. This is reached by layered logic which is a simple process of automating the creation of a critical path network by using locations. Traditional CPM uses a single layer of logic while

Location-based planning introduces new layers of logic which add more detail to both the internal task production of the location-based task, and to the external links between tasks.

In this case all the analytic features of CPM are preserved when examining the logic between activities within locations, as activity sequencing is driven by normal CPM algorithms with familiar concepts such as precedence and lags.

In parallel, Location-based control assumes that planning has maximised productivity, found an optimal balance between risk and duration and is feasible to implement.

At least this approach aims to reach a better productivity level without considering how site and workers' conditions change due to overlapping activities and how safety risks increase in construction site.

For this reason the proposed WSiCPM framework, which is explained in section 6, aims to propose a novel approach which consider the integration of CPM with locations but assumes the planning as function of potential hazards which has been calculated using equations depending on different parameters. WSiCPM framework is integrated in a wider framework of design phase as explained in section 5.

4. The method Building Design for Safety (BDS)

The starting point is the idea that the visual simulation is not only a "passive" image of contents, but it is an "active" control in terms of built result. The aim was then to improve the contents of the representation to accentuate its "dynamism", implied in the project. The approach tends to re-elaborate project drawings to clearly express those construction processes implied in the drawings of the constructive details. The approach is to entrust to the design the role of harmonizing different parties. The chosen way is to assess "workers' safety" as the parameter to implement a new tool in order to obtain a safety realizable project. Starting from the representation of construction details, according to Building Design for Safety (BDS), it is possible to simulate the construction of them using the CAD 2D as graphical tool. This can be done through progressive drawings that express the breakdown in construction phases –one phase for each new building product-, chronologically processed and logically related. In these specific drawings are depicted all site facilities (temporary works, machineries and manpower) in order to simulate and verify the real conditions in which it will be the realization. BDS allows both the detailed assessment of safety conditions –by using a traditional risk analysis- for the realization of the item and the Constructability verify of the element itself. It is important that this happen before construction stage, when it is still possible to intervene, where appropriate, with amendments on the project itself. It is possible to find more details on the BDS method in (Capone et al. 2014). The picture below (Figure 2) shows the visual representation of the method.

5. Safety management approach for critical construction phases

In BDS method have been proposed and tested a simulation process of the construction operations, with the specific aim to correct and optimise shopping drawings in order to have a better performance of the building (Capone et al. 2015). After a lot of applications in different case studies, the necessity to consider the “time variable” has appeared, above all in managing interfering activities.

The question should be how to insert BDS method in a wider processual and operative framework, in order to make BDS free from the theoretical, episodic, uneconomical and unrealistic aspect that could have been attributed to it.

To reach this goal the first step was to define an approach that, using the construction management tools, could individuate the critical construction activities in the safety point of view. In professional practice, regarding interfering activities, the Health and Safety (H&S) Coordinator usually gives operative prescriptions to stagger in space and/or in time the interfering activities and gives the instructions to control the efficacy of such prescriptions.

If interfering risks still remain, the H&S Coordinator must determine preventive and protective measures in order to minimise risks.

Nevertheless there are a lot of situations in which is difficult to stagger in space and/or in time the interfering activities preserving together the workers’ safety and the Constructability requirements.

Usually the individuation of critical phases is performed by means of the classical construction management tools; with BDS method we have a closer analysis of the critical phases (Figure 2).

Searching for the applications in which the BDS method could be more effective, we investigated different theories linked with construction management and safety (Baldwin and Bordoli 2014).

The link between design and safety suggested us to improve and optimize visual representation of construction site issues, taking distances from the traditional site layouts in order to improve information and make designer tools more effective.

According to the aforesaid traditional theories, planning techniques such as critical path method (CPM) are useful for analyzing the logic of construction activities, identifying critical activities and producing a model form which it is possible to produce schedules for activities and identify milestone/completion events. From the literature review emerged that CPM helps to clearly identify key contractual dates for the start of the activities on site and completion of construction work. CPM confirms production deadlines and contractual obligation. However,

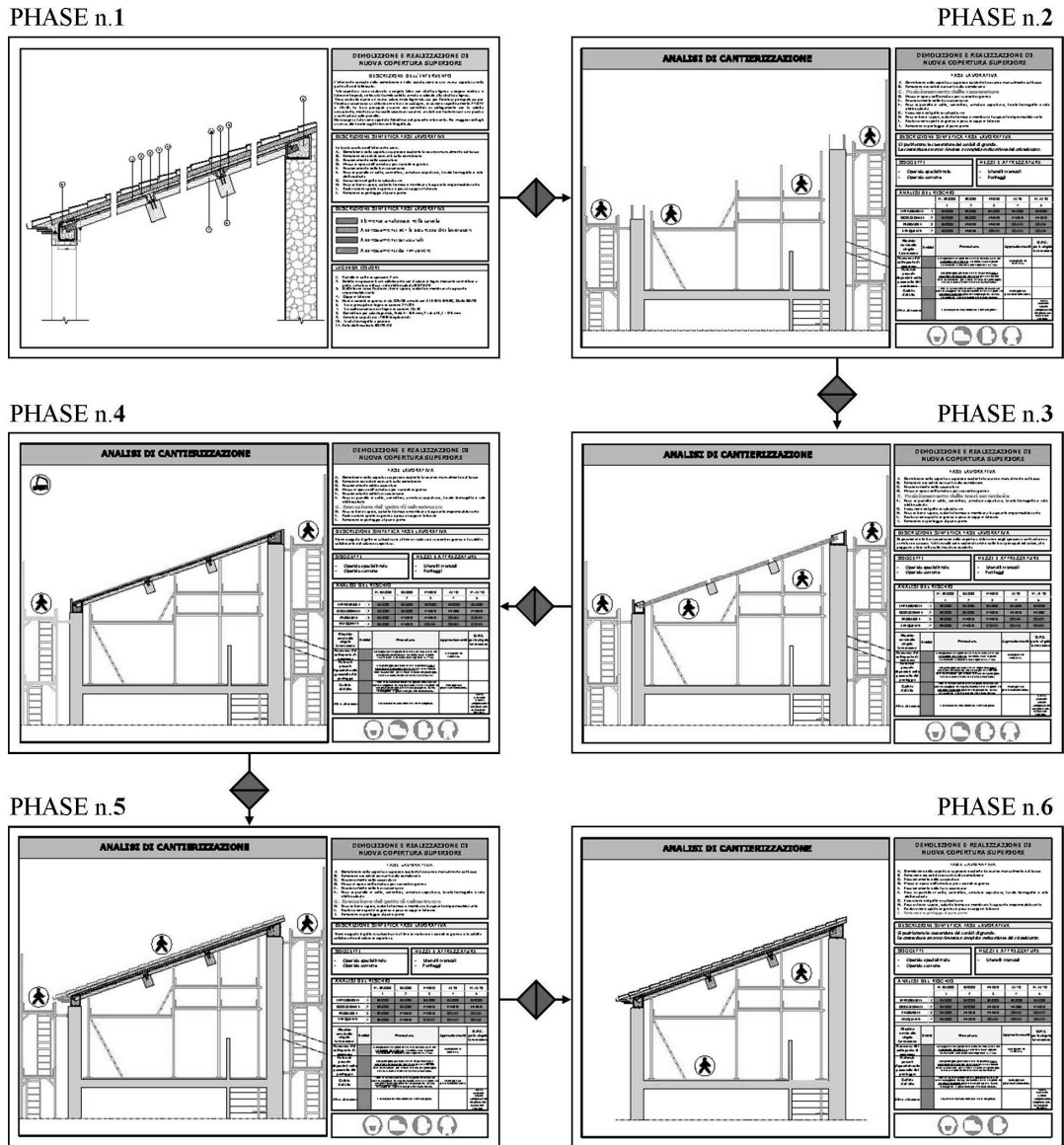


Figure 1: Operative Framework of the BDS procedure for a roof redevelopment (Capone et al. 2014)

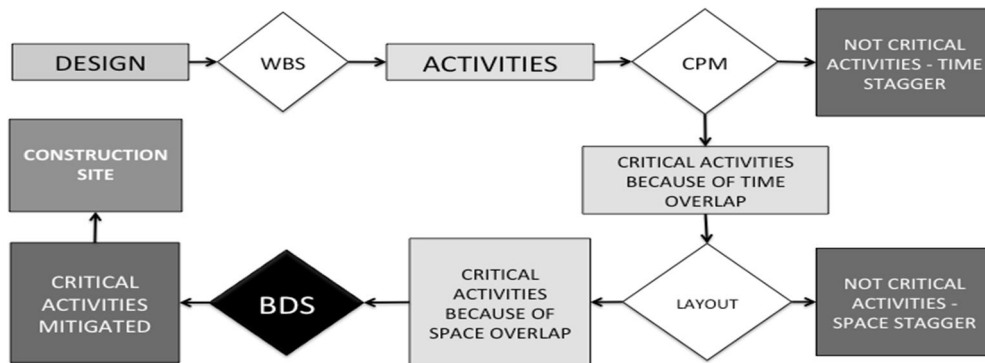


Figure 2: Graphical representation of the approach to safety management of critical construction phases (Capone et al. 2015)

CPM is not the best tools to direct production on site. The great deficiency is the lack of a direct connection between scheduling approach, used for the baseline schedule, and the real site condition. Only introducing the spatial dimension and workers' dimension, considered by BDS method as well, in the traditional construction tools and in CPM planning in this particular case, it could be possible to effectively manage the site conditions.

A step in this direction can be the WSiCPM framework, as in the following it is described.

6. The WSiCPM framework

6.1 The methodology of the WSiCPM framework

An attempt to create a methodology able to incorporate the workers' safety and the spatial dimension into the critical path method (CPM) has been done. Such methodology can be used as a supplemented tool in planning and design phases to identify and remove early the risk of accidents by means of BDS method. The methodology called WSiCPM (Workers Safety into CPM) has been developed to detect time-space-conflicts of activities in order to help health and safety risk assessment in construction management. In WSiCPM framework, a method for qualitative and quantitative risk assessment was programmed and implemented. Probability of potential hazards has been calculated using equations depending on parameters such as: overlapping duration, overlapping working area, number of workers in the observed pair of interfering activities and type of hazard. The severity of the hazard has been estimated analogously, with the compensation of a casualty by insurance companies (through this, the risk can be modified into a monetary value representing the predicted accident cost). Additionally, the framework proposes possible solutions for each pair of interfering activities. BDS has been linked with WSiCPM as a method useful to analyse and resolve health and safety risks in space-time conflicts activities. In figure 3 WSiCPM framework is depicted.

In the following steps the methodology is described using the information from a case study which includes a set of nine different site activities.

6.2 Step 1: Definition of the Overlapping Matrix

This step of the analysis sets out an overlapping matrix which is able to identify and control the *time-overlapping activities* in order to achieve the following aims:

- Organize the analysis of interference activities by way of a pairwise comparison, in order to discuss their interaction;
- To apply the mathematical concept of non-analogue relationship between the two activities of each pair;
- Calculate the overlapping duration of each pair of interfering activities.

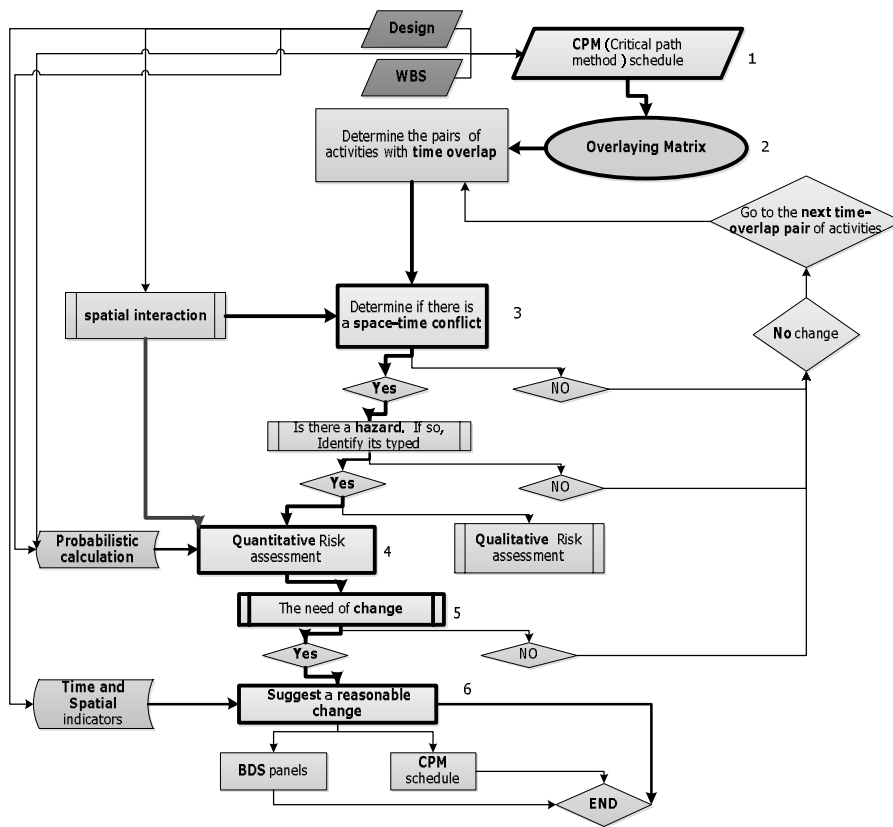


Figure 3: WSiCPM workflow

This is carried out exporting information about the activities' properties (name, duration, finish, dependencies, cost, ...) from the baseline schedule CPM (Fig. 4), practically using MS Project Software, to a pre-set database, practically implemented in MS Access Software.

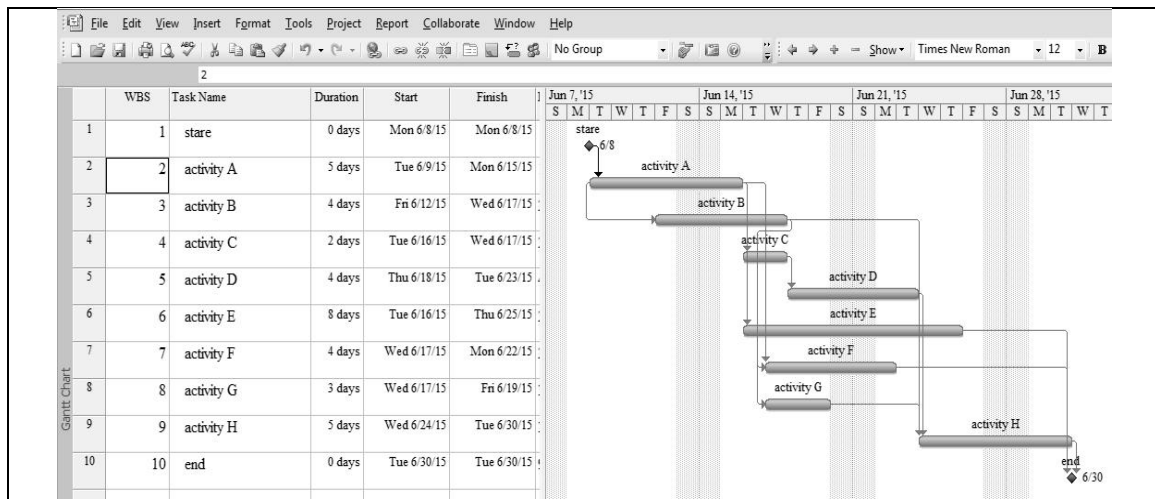


Figure 4: Example of the baseline schedule –CPM- taking into account nine activities by using MS PROJECT

The method automatically fills the matrix in using two type of overlapping scenario: “No conflict”, “Time interference”. The figure 5 shows the matrix for the proposed case study. After this analysis it’s possible to pull the pairs of activities with a time overlap out from the aforesaid matrix.

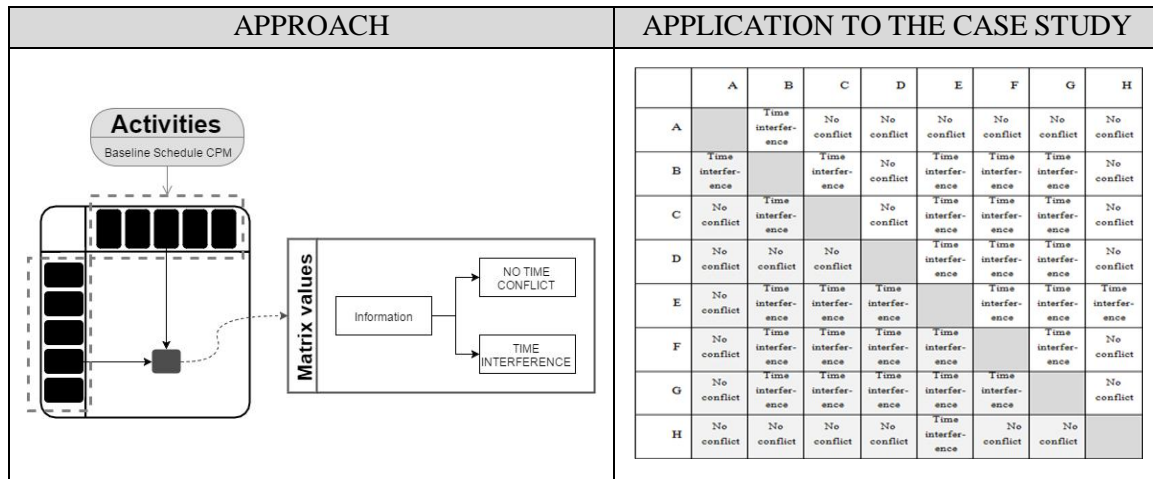


Figure 5: Example of matrix of overlapping

6.3 Step 2: Determination of the space-time-conflicts

According to the framework, after determining the activities with a time overlap, each activity pairs should be processed in order to achieve a double-check: time interaction (as described in the step 1) and spatial interaction as described below, locate the “space-time conflicts”.

This double-check aims to locate the “space-time-conflicts” which mean that there is a spatial interaction between the two activities, even if they are run in separated spaces, since the conflict could be present not only in the activity’s work area but also in in the areas connected to each activities. For this reason, referring back to the designer, the method considers four different kind of areas related to each activity and check their interaction as shown in the Figure 6.

If the two activities run in different places without space interface, then space-time-conflict has not occurred as the Figure 6 shows.

6.4 Step 3: Determine the type of hazard and risk assessment

After determining the space-time-conflicts, it is important to know whether a hazard has been created by each space-time-conflict pair of activities. If so, once hazard has been identified, it is necessary to calculate the associated risk.

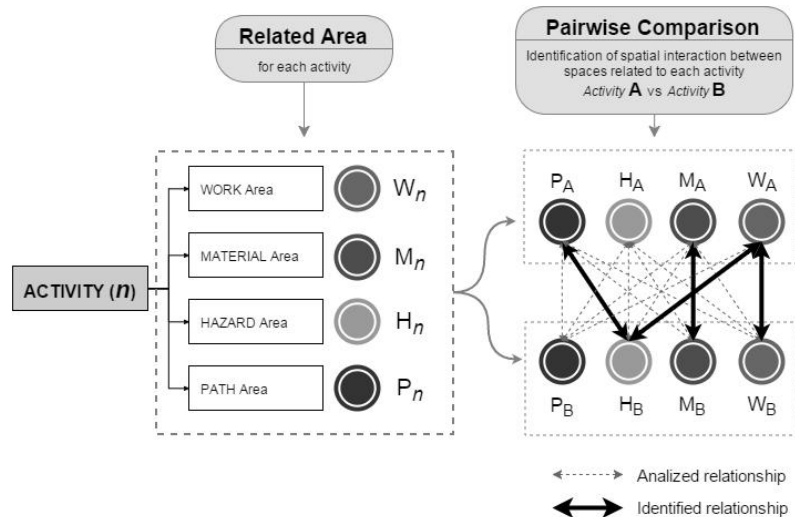


Figure 6: Example of space-time conflicts determination

In WSiCPM a specific quantitative risk assessment has been developed and the risk evaluation is generated by the framework. Inside WSiCPM the probability has been estimated with probabilistic calculation of the time and space probability with respect to the space overlapping areas and the number of workers. The severity of the accidents has been expressed using a method deriving from insurance (monetary quantification of the damage).

6.5 Step 4: Risk response and change request

The WSiCPM framework works like an expert system: the outputs of the quantitative risk assessment, in addition to spatial information and time information from CPM, are the input in this operation. For each space-time hazard conflict pair, the framework suggests a solution.

The framework provides four different kinds of suggestions in order to mitigate risks, helping the decision maker in resolving the conflict.

BDS will be used in WSiCPM to solve the risk situations that cannot be mitigated just with scheduling actions. BDS will be used in case if it would be necessary to have a deep H&S and constructability analysis, coming until the possibility to solve critical situation even by changing the design.

The solutions automatically proposed by WSiCPM are listed as follows.

1- Changing the path

This suggestion is given if there is interference between the hazard area of an activity and the path area of another.

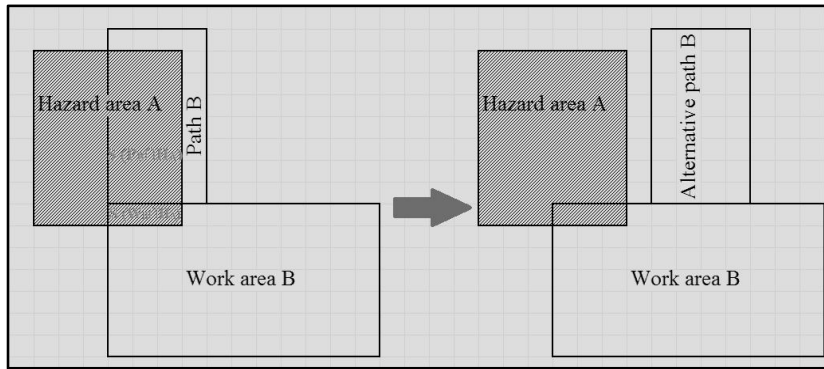


Figure 7: Example of path changing

2- Dividing the areas

This suggestion considers the interference of the hazard area of an activity with the work area of another activity. If this interference is minor with respect to the work area itself and the overlap time is less than the duration of the last activity, taking into account the ability of the last activity to be divided, then the framework will suggest to subdivide it.

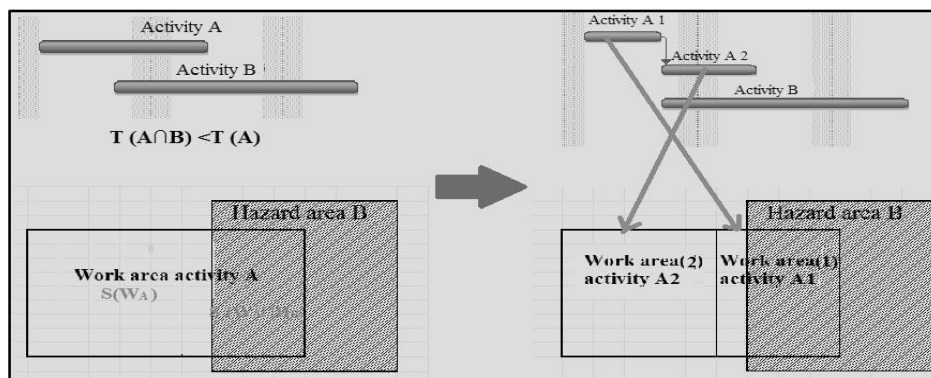


Figure 8: Example of dividing areas

2- Splitting the activity

This suggestion considers that, if the overlap-time is small in comparison with the duration of one of the activities, which can be achieved in two phases and it is not critical, the framework proposes to divide the workload. Thus, the work in the long activity is halted and later continues after the end of the hazard (time dividing).

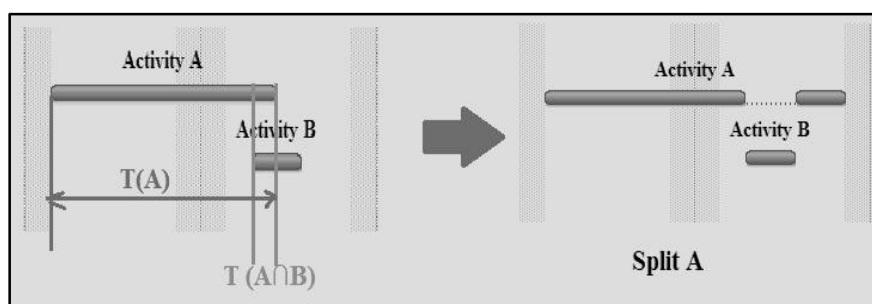


Figure 9: Example of splitting

2- Rescheduling

This suggestion considers that, when the risk is high and the interference of the space is substantial (the two activities take place almost in the same place), and the time overlap is equal to the duration of one of the two activities; re-scheduling the non-critical activities would be the main solution proposed by the framework.

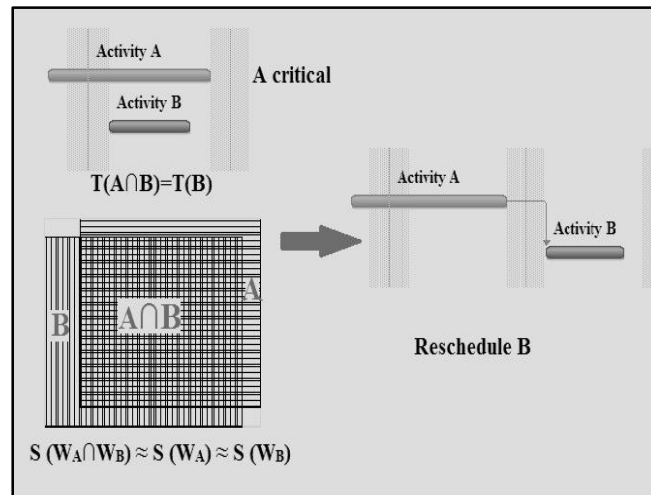


Figure 10: Example of re-scheduling

7. Conclusions

An attempt to propose a framework to analyse, evaluate and solve space-time conflicts with respect to health and safety risk mitigation has been made. If the automate solutions given by the WSiCPM are not suitable for the specific situation, BDS is suggested as the best method to solve the constructability issue mitigating health and safety risk for workers. This way, we tried to individuate acceptance criteria for critical activities overlapping, both in space and in time and then to quantify workers' safety risks.

The analysis, the assessment and the management of health and safety for workers in complex risky activities by using BDS, seems to push future developments in the direction of Building Information Modeling (BIM). In this perspective the research group is working on the implementation of site-analysis in a BIM-environment.

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