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PRACTICAL IMPLICATIONS OF LOCATION-BASED SCHEDULING

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The traditional method for planning, scheduling and controlling activities and resources in construction projects is the CPM-scheduling, which has been the predominant scheduling method since its introduction in the late 1950s. Over the years, CPM has proven to be a very powerful technique for planning, scheduling and controlling projects. However, criticism has been raised on the CPM method, specifically in the case of construction projects, for deficient management of construction work and discontinuous flow of resources. Alternative scheduling techniques, often called repetitive or linear scheduling methods, have proven to be well suited for projects of a repetitive nature, such as building projects. As the repetitive or linear scheduling methods may include locations or places, they are also referred to by the comprehensive term of location-based scheduling (LBS), which is the concept that will be used in this study. LBS is a scheduling method that rests upon the theories of line-of-balance and which uses the graphic representation of a flow-line chart. As such, LBS is adapted for planning and management of workflows and, thus, may provide a solution to the identified shortcomings of CPM. Even though LBS has a long history and is well grounded theoretically, it has gained generally little attention in the construction industry. Besides the theoretical research available on LBS, some studies report on the application of LBS, but empirical data on the practical implications of LBS is limited. This study rests upon three case studies of residential projects carried out in Denmark in 2006. The purpose is to test and evaluate the practical implications of LBS when applied on site. The study concludes, with emphasis from the site management involved, that improved schedule overview, establishment of workflows and improved project control constitute the three most important implications of LBS.

Keywords: critical path method, line of balance, location-based scheduling, scheduling, workflow.

INTRODUCTION

The coordination of activities and resources in order to establish an effective work flow is central to the management of construction projects. The Critical Path Method (CPM) constitutes the predominant technique for planning and scheduling of construction projects, since it was introduced in the late 1950s. Together with Gantt charts, the universal graphical representation of schedules, which was introduced by Gantt and Taylor in the early 1900, CPM provides the common corner stone in the vast number of scheduling software tools that have been developed (Kenley 2004).

CPM has proven to be a very powerful technique for planning, scheduling and controlling projects, especially for complex and non-repetitive work (Arditi *et al.* 2002). However, despite the dominance of the CPM-method, there is criticism raised on the method for the management of construction work. The criticism of CPM refers

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to the inability to manage and monitor resource limitations in a way that corresponds to the reality of construction, i.e. work that to a large extent is characterized by repetition (Kenley 2006). Repetitive activities are often characterized by imbalanced production rates (Arditi *et al.* 2002), which might lead to unforeseen work stoppages and, consequently, inefficient resource usage. The activities, and their logical connections, are the principal focus of the CPM-method, whereas resources are given minor attention as the CPM-method assumes there are unlimited resources available for executing the work. Consequently, CPM-based schedules, graphically represented by Gantt charts, may result in discontinuous resource usage that in turn will lead to interruptions in the production where each trade suffers from recurrent starts and stops during the project process. It is difficult to monitor the planned resource usage from a Gantt chart, as the different amounts of work and different pace of each trade is concealed in the bars of the activities.

As construction work is generally characterized by continuous or repetitive work, where the same activities are executed at various locations of a building or construction, construction scheduling appears to be more closely aligned to repetitive scheduling methods (Russell 2004) such as “Line-of-balance”, “Time-location Matrix Model”, “Construction Planning Technique”, “Time Space Scheduling method” (Harris and Ioannou 1998), “Flow-Line” (Kenley 2004, referring to Mohr 1991) and similar methods. Arditi *et al*. (2002) refer to those alternative scheduling techniques, developed over the last 30 years, by the generic term of “linear scheduling methods” and claim that those methods have proven to be well suited for projects of a repetitive nature. Harris and Ioannou (1998) suggest the generic term of “repetitive scheduling method” as those methods involve repetitive activities. Kenley (2004) points out that the linear or repetitive scheduling methods strongly suggest locations or places and, consequently, he introduces the comprehensive term of “location-based scheduling” (LBS).

However, despite the long history and a promising potential of these repetitive, linear or location-based scheduling methods, they have gained little attention among the practitioners of the construction industry. Finland, however, constitutes an exception. As a result of two decades of research and development, a comprehensive line-of-balance-based planning, scheduling and control system, has been developed and implemented among the main contractors in Finland (Seppänen and Aalto 2005). The conception of a system does, in this case, refer to a set of planning and scheduling functions such as a risk simulation module based on the Monte Carlo technique, a bill of quantities collecting the building materials of the project that are distributed among the activities, a procurement module for the supply of building material, a national database with building productivity data etc. The various functions of this planning, scheduling and control system are integrated in a commercial software package, originally named DynaProject™ and later versions called Control™, which empowers the Finnish line-of-balance based system. It has now become the prevailing planning methodology among the large contractors in Finland (Kankainen and Seppänen 2003). The Finnish scheduling system is based on a modified line-of-balance method, in which the y-axis of the flow-line chart is represented by the locations of the project, i.e. the y-axis consists of a hierarchical structure of the physical locations of the building or construction. This line-of-balance method, in this study, will be referred to by the term of location-based scheduling, a conception originally coined by Kenley (2004).

Figure 1 presents an example of a location-based schedule developed in Control™ in which the hierarchic location structure is presented along the y-axis and four activities repeat in the different locations of the building.

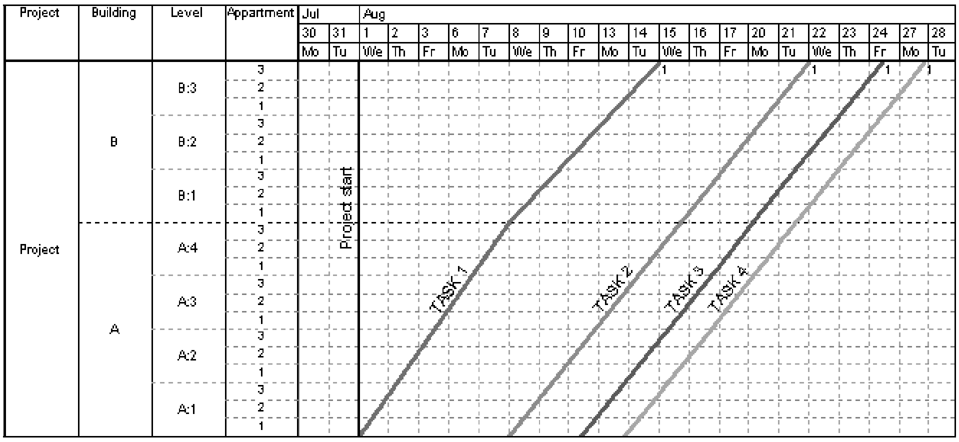

Figure 1: The graphical presentation of a location-based schedule in a flow-line chart

The flow-line chart of an LBS schedule, as seen in Figure 1, is adapted to planning and management of continuous work-flows, i.e. where resource groups can perform their work without interruptions caused by other resource groups working with other activities at the same location at the same time. Thus, LBS supports the establishment of continuous activities and a resource usage with limited waiting time and avoidance of work disturbance, and as such, LBS promotes the efficient use of resources and the delimitation of waste which corresponds to some of the principal elements of Lean construction. Kankainen and Seppänen (2003) describe the connections between LBS and lean construction, referring to the common focus on efficient resource usage and waste avoidance. Kenley (2004) explains that the application of lean construction requires a new approach to production planning and suggests LBS as a key to improve the selection of lean construction techniques. This argument rests upon the difficulties of identifying continuous workflows in a traditional CPM-based schedule, which consists of discrete activities.

Problem statement and delimitations

The argument for this study rests upon the identified shortcomings of the traditional planning and scheduling technique of CPM in the context of construction, the current attention given to the implementation of lean construction and thereby an increased focus on flow-management and, finally, the fact that there is a LBS planning and scheduling software package recently developed.

The purpose is to identify and review the main practical implications of LBS when applied on a building project in conjunction with the management on site. The research area of the study relates to the subject fields of construction management and logistics, where planning, scheduling and control are in focus. It is not within the scope of the study to develop either the scheduling method of LBS or the software tool.

Research method

The study focuses on the production phase of construction, i.e. the planning and scheduling of the activities that take place on site. Three building cases that represent typical Danish residential building projects constituted the empirical input to the study. Case 1 is a new residential building project with an 11-storied house, 144 apartments, and a total living space of 13,500m^2. Case 2 is a renovation project that includes the modernization of bathrooms, façades, windows, roofing etc. It includes 10 separate building blocks, including 385 apartments, and has a total budget of fully 40 million EUR. Case 3 is another new residential building project with 225 apartments, a living space of 20,000m^2 and a total budget of about 30 million EUR. The three largest Danish contractors were assigned as general contractors in each of the three cases. The building cases, according to the plan, will be delivered between mid 2007 and 2008.

The research in all three cases was designed as practical tests of LBS in close collaboration and dialogue with the management on the sites. The schedules that were established by the site management in each case provided the starting point for the test of LBS. Thus, the initial step was to transform the original CPM-based schedules that were developed for each case into LBS versions. For Case 1, this step is exemplified in Figure 2. In the next step, the established LBS-copies of the original schedules were worked up and were adapted to an LBS configuration. Figure 3 shows the optimized schedule for Case 1. The findings from the analysis of the three cases corresponded basically, which is why the schedules from only one of the cases are presented. All the empirical results have continuously been discussed and evaluated in dialogue with the construction managers and other relevant staff members of each case.

All schedules were developed using the scheduling software of Control™ 2005 or the later version Control™ 2007, developed by Graphisoft. An early version of the software, named DynaProject™, is referred to in the text. Graphisoft has facilitated the study with professional support regarding the application of the software.

The empirical data collection was carried out in 2006, from September to December.

ABOUT LOCATION-BASED SCHEDULING

The literature on LBS, or other repetitive scheduling methods, includes a theoretical direction, which is the greater part, and a field that reports on the application of LBS in practice. The theoretical direction typically deals with simulations or algorithms and heuristics, e.g. for optimization of resource continuity to achieve duration cuts and to model learning curves (e.g. Kang *et al.* 2001). An underlying presumption in this type of work is that LBS mainly is a tool for highly repetitive work (e.g. multi-storey buildings or road constructions) and, consequently, is not suitable for non-repetitive work. The theoretical work provides a solid foundation to the LBS-method, but it does not reveal whether LBS meets the demands of planning, scheduling and control on site and in different kinds of projects (Soini *et al.* 2004).

As indicated earlier in the text, there is a discussion going on about the argumentation that LBS has the potential to support a greater acceptance of lean construction. Kenley (2004), for example, claims that LBS allows the management of projects according to Lean concepts, including work flow, production reliability, supply chain management and just-in-time delivery. Mendez and Heineck (1998) describe a production preplanning process in which interdependent tasks are lumped together into main activities for which the number of crews that must be allocated to each task is calculated in order to achieve a balanced production pace. Kankainen and Seppänen (2003) add to the discussion about how interdependent tasks are merged together in summary activities on a master schedule level, where the activities are balanced in relation to production rate, locations and continuity, and where the summary activities are divided into delimited tasks at a detailed schedule level in order to achieve the desired level of schedule accuracy. Kankainen and Seppänen (2003) support the argument that LBS promotes the philosophy of Lean.

Kenley (2004) as well as Kankainen and Seppänen (2003) and other Finnish authors have contributed to the understanding of adopting LBS in practice and report on the experiences of using the DynaProject™ software as a practical tool to help control the project on site. However, one should be conscious about that some of the Finnish authors that report on the benefits of LBS and the advantages of using DynaProject™ (or later versions) are connected to the development of the commercial software tool.

PRACTICAL IMPLICATIONS OF LBS

The practical examination of LBS took its starting point in the existing schedules that were prepared by the site management for each of the three cases of the study. All the original schedules were prepared without any consideration of the study and it is therefore likely to believe that the schedules represent typical examples of production schedules in Danish construction projects of today. The site management in all cases used the traditional activity-based scheduling method of CPM, where the schedules typically were developed in MS Project and represented in a Gantt chart. The original schedules covered the production phase of each project, i.e. they represented the so-called production or master schedules of the respective projects. A review of the original schedules in the three cases maintained that they were generally characterized by:

- An extensive number of activities.
- Activities were organized in a WBS-structure.
- Interdependencies between activities were normally, but not always, appointed.
- Resources were delimited to labour, i.e. building materials or equipment/machinery were not considered.
- Resources were allocated solely to “own” activities, i.e. subcontracted work were not resource allocated.

As the original schedules were translated into LBS-copies, as shown in Figure 2, some common remarks were identified and reviewed together with the site managers. For example, the number of activities in the original CPM-schedules were substantially reduced in the LBS-version and consequently, made it possible to overview the whole schedule. It was also observed in the original schedules that the planned work flow of activities through the different locations of the building was frequently discontinuous, i.e. the production was typically characterized by frequent starts and stops for the various working crews.

Further, parallel activities were not always properly balanced in respect of their production pace. In some cases, this led to overlapping activities, which meant that two or more activities were planned to take place at the same location at the same time. The LBS-versions of the original schedules also revealed that there were a number of unused areas in each case, which also can be a consequence of unbalanced activities. An unused area signifies one or more locations where no work takes place during a period of time and, consequently, it indicates that the project can be scheduled in a more appropriate way.

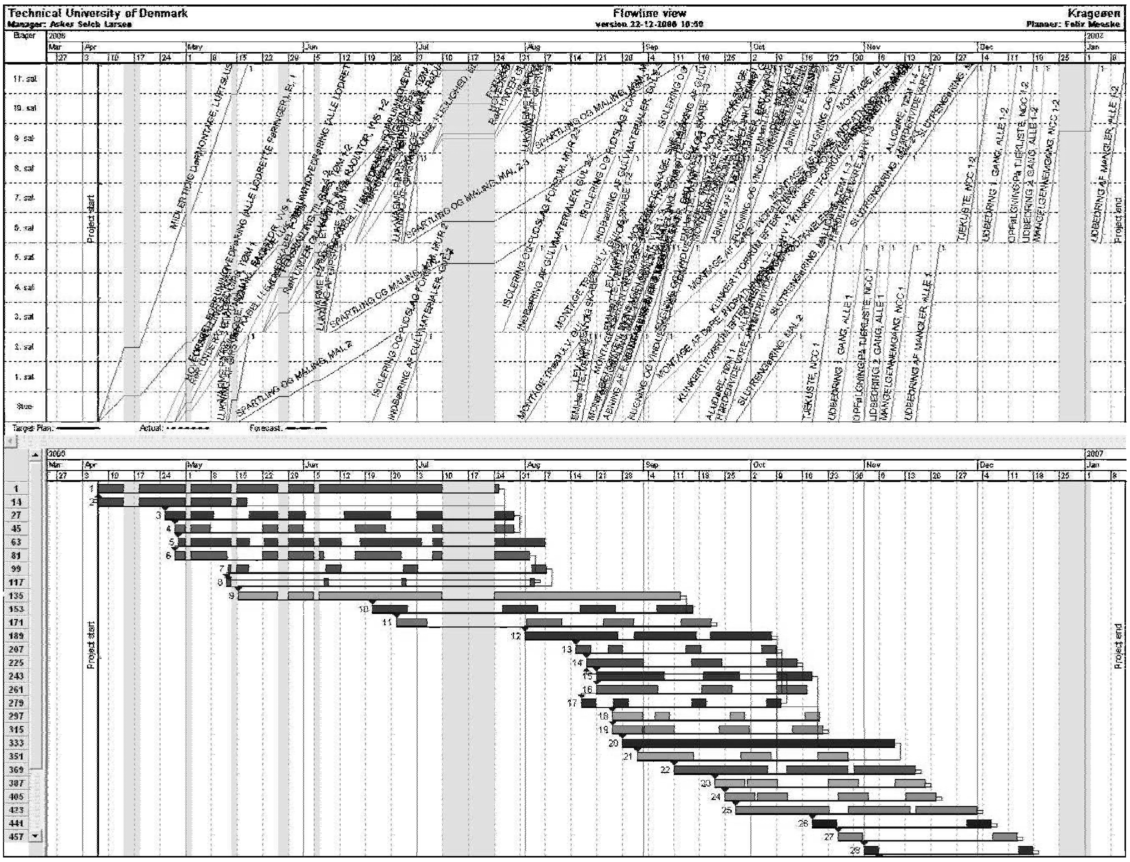

Figure 2: LBS-copy of the original schedule for Case 1 showed in a combined flow-line and Gantt-chart view. (Source: Larsen and Meeske 2007)

Based on the review of the original LBS-versions of the schedules, improvements were made in order to optimize the production planning. Figure 3 shows the optimized version of the LBS-schedule for Case 1 shown in Figure 2, which makes it possible to compare the two versions of the schedule. The analysis of the other two cases showed similar results as in Case 1, which is why the schedules from only one of the cases are displayed.

The processing of the LBS schedules revealed three major constructive implications of LBS, emphasized by the site management, namely improved schedule overview, establishment of work-flows and enhanced project control.

Improved schedule overview

The most immediate comment on the flow-line view, valued by the site managers, was the improved possibility to get an overview of the project and to actually see the activities repeating in various quantities through the multiple locations of the project. This simple implication of LBS and the flow-line view was considered a key aspect of LBS, and it constitutes a prerequisite for the establishment of work-flow and the enhanced project control.

Communication with subcontractors and other parties involved in the project is an aspect that gained from the LBS schedules as they were easier to understand and, consequently, easier to implement. This aspect of LBS is also expressed by Kenley (2004) who states that traditional project scheduling is frequently failing when it comes to communicating the management of a project from the management level down to the general site personnel.

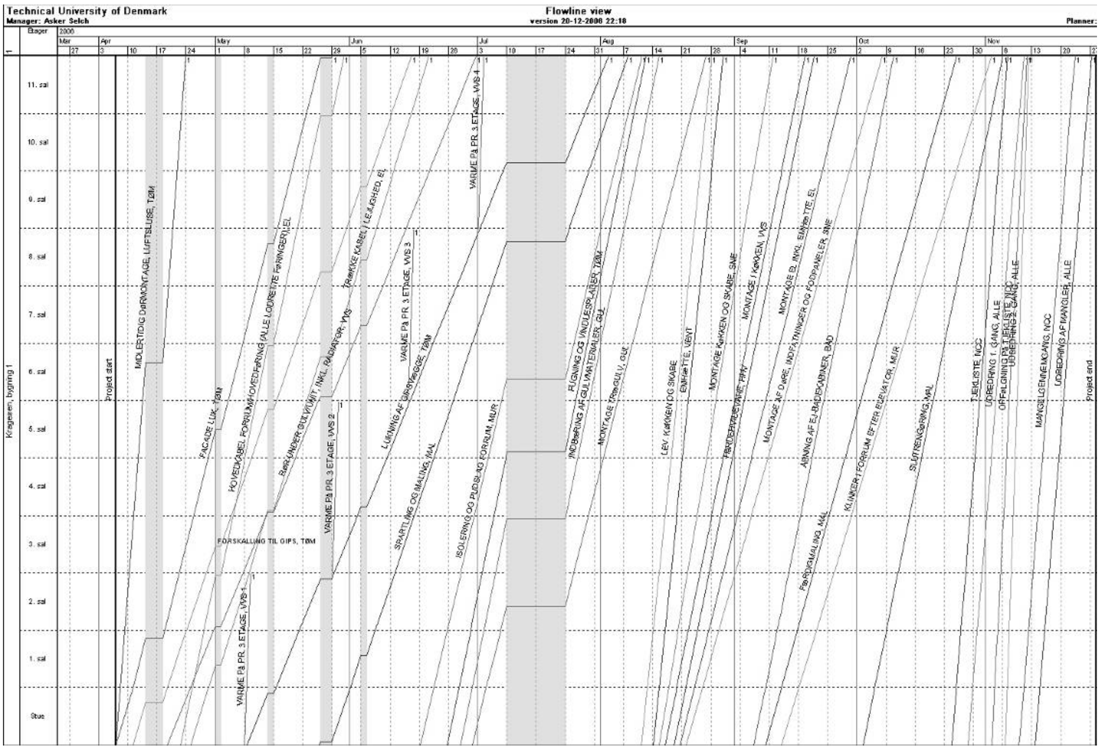

Figure 3: Improved LBS schedule for one of the three cases shown in a flow-line view (Source: Larsen and Meeske 2007)

Establishment of workflow

As indicated in the review of the original schedules developed for the three cases, it is difficult to ensure continuous workflows from a Gantt chart. The LBS schedules, however, provide information about the location of work and allocated work crews, which enables planning of continuous workflows (flow of resources through locations), avoidance of overlapping work (two or more crews working at the same location at the same time) and, possibly, avoidance of unused locations. Further, the graphical visualization of the production pace of the activities makes it possible to balance parallel activities, i.e. to adjust the resource units allocated in order to establish a sufficient production rhythm in a group of parallel activities.

LBS allows for simulations of different completion orders of the workflows following the defined locations of the project. This implication of LBS follows from an additional type of dependencies, i.e. location-dependencies, that comes with LBS. By changing the place completion order of an activity, for example from floor 1-2-3-4 to 4-3-2-1, the most sufficient completion order can be evaluated. This was of particular interest in one of the three cases where the installations originally were planned to commence at the top level of the building and continue down to the ground floor, but where a simulation in the processed LBS schedule showed that it was beneficial to commence the installations at the ground floor.

Figure 3 shows the processed LBS-version of the original schedule shown in Figure 2. It is manifested that the revised schedule includes continuous workflows that are balanced without overlaps at any time and that the empty locations are reduced.

Enhanced project control

The simple fact that an LBS schedule provides information about the planned location for each resource crew at a given time supports and simplifies project control of the work performed at each location, besides, it is generally valuable for the site management to know the precise location of a specific resource crew. In that respect, it is worth mentioning that a fundamental principle in LBS is that an activity should be fully completed in one location before the crew moves on to the next location. This principle involves a change in the current situation of planning and management of subcontracted work where the subcontractors more or less are indulged to consider their scheduled activities as a time-limit during which they are allowed to carry out the work as they whish, without respect to a specific location succession (see, for example, Conlin and Retik 1997 for more details on this subject). The insufficient consideration of the subcontractors' resources in the original schedules of the three cases, reveal that the planning and scheduling of subcontracted work can be improved. Kankainen and Seppänen (2003) suggest that agreements on payments should be connected to the work completion of locations in order to compel the subcontractor to conclude their work in the planned succession.

Seppänen and Aalto (2005) point out that improved schedule control, besides the possibility to examine how deviations from weekly plans influence the master schedule, is a significant benefit of LBS. An interesting point in this connection, presented by Kankainen and Seppänen (2003), is that the master schedule never should be updated even when the weekly schedules indicate deviations from the plan. They explain that this is because updating the master schedule will not solve the deviation problems, but rather transfer the problems towards the end of the project where they will accumulate. This is, however, an implication of LBS that is not tested or confirmed in this study.

Experienced difficulties in the application of LBS

The site management of the tree cases had none or limited experience from LBS when the study was initiated and even though the results describe LBS in generally positive terms, the study also experienced difficulties in relation to LBS. Some difficulties were directly connected to the application of LBS or the LBS-software that was used, while other problems were of a more general nature.

LBS implies a new, or preferably unfamiliar, scheduling method which requires a new approach to scheduling and it involves new conceptions. For example, LBS requires the definitions of locations and there are different more or less appropriate ways of dividing the project into locations. One aspect is about finding a sufficient level of details required for the planning, scheduling and control of the project. It is possible, but very inconvenient, to change the level of detail once the scheduling has commenced. Another difficulty experienced in one of the cases concerned the definition of different kinds of locations, e.g. how to handle ground works in relation to the locations that are connected to the actual building. The study found no guidelines for the proper approach to defining locations.

Well-known concepts of the CPM-method become irrelevant besides the introduction of new terms. For example, the concepts of critical chain and float fail as LBS principally concern the management of workflows where resource constraints become a central aspect. In connection to this, the new concepts of synchronized and paced activities become relevant. Synchronized activities imply that crews are sized in order for activities to proceed at the same pace, and paced means that crews proceed continuously through locations. Instead of the traditional total and free float, LBS includes buffers that somehow replace the conception of free float. Another difference from the traditional scheduling method is location dependencies, which caused some initial problems in the cases. Activities in LBS are location dependent on a certain hierarchy level or location independent, and it is for the manager to decide on the appropriate hierarchy level for each activity.

Besides the LBS specific difficulties, some general problems that cannot be directly connected to the specific application of LBS were identified. For instance, it became an apprehension among the site managers that the LBS software requires a significant amount of input information in the initial stage of the planning process. This is a consequence of the design of the LBS software, which uses a bill-of-quantity as the starting point for definition of activities. Thus, the LBS software calculates activity durations from a selection of the bill-of-quantity allocated to a specific activity together with the resources that are allocated and information on productivity for the specific type of work. The site management in this study experienced, which ought to be typical in a Danish context, that they did not have access to a coherent bill-of-quantity for their respective projects. Thus, activity durations were generally valued on basis of the site managements' individual experiences rather than extracted from bill-of-quantities, documented productivity data or specified numbers of resource units.

This study argues, however, that this is not a problem associated with LBS as such, but rather a consequence of the lack of a coherent and standardized information structure in the Danish context. In Finland, a productivity database with information on construction activity data has been developed by a joint effort of the construction industry, which of course facilitates the information management. Finally, it is worth mentioning that it is not a definite requirement for neither LBS scheduling in general nor the specific LBS software to use a bill-of-quantity.

CONCLUSION

The evaluation of LBS for the on-site management of building projects revealed, emphasized by the site management involved in the study, three major beneficial practical implications of location-based scheduling. First, the improved overview of the project schedule from the flow-line view of LBS supports, not only the understanding of the schedule, but also the communication with subcontractors and other involved parties and thereby it facilitates the implementation of the schedule. Second, LBS schedules support planning of continuous workflows of resources through locations, avoidance of overlapping work on the same location at the same time and avoidance of unused locations. Third, LBS supports improved project control as LBS provides information about the planned location for each resource crew at a given time, which facilitates the monitoring of work performed at each location.

Thus, it is confirmed from the three cases that LBS provides some practical implications beneficial for the on site management of building projects. This conclusion principally concurs with the findings reported in previous studies, e.g. Kenley (2004), Seppänen and Aalto (2005) and others.

The identified difficulties with the application of LBS were either LBS-specific or of a more contextual nature. The application of LBS requires basic knowledge about the LBS method and it implies the introduction of new software tools that, all together, involve new conceptions and a new approach to scheduling, which initially will challenge the site management. Another experienced difficulty was related to the general lack of a coherent and standardized information system that would facilitate the application of the LBS software. However, it is concluded in this study that a bill-of-quantities is not a definite requirement in the application of LBS or the specific

LBS software that has been used. This is rather to be considered a possibility to further develop the applicability of LBS, as a bill-of-quantity would allow for, e.g., coordinated procurement planning, material delivery schedules and on-site logistics.

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