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Materials Handling and Site Layout Control

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Abstract

Construction field operations are markedly inefficient in terms of where and how materials get stored and handled. This is often due uncertainty at the time of advance planning, the difficulties associated with achieving real-time coordination, and the lack of control in the field, as materials get delivered and used by many different people throughout the construction process. At any given point in time, key questions asked by field personnel are "Where are the materials we need and when will they get here?" and conversely, "Who needs these materials, when are they needed, and where?" The described research presents a new layout planning and control system to address these questions. This model, named MoveCapPlan, integrates the MovePlan system, that aids in creating sequences of layouts corresponding to an activity schedule, with the CAPSY™ one-person surveying station, that aids in identifying positions of materials in real time. MovePlan's graphical display of the site layout, from which a daily printout can be made, informs suppliers of where materials ought to be unloaded on site, and informs workers of where materials can be found. CAPSY™'s spatial positioning data creates actual layouts that can be compared against those planned. Accordingly, control decisions—assessing desirability and feasibility of rehandling materials, determining the availability of rehandling means, or reassigning laydown space—can be made. Example uses illustrate the capabilities of this novel integrated system for planning and controlling on-site materials handling.

1. INTRODUCTION

Construction field operations are markedly inefficient in terms of where and how materials get stored and handled. This is due to the highly dynamic nature of site operations, the limited extent to which advance layout planning can be done, and the inability of existing tools to collect and use updating information and reflect change in a layout plan as construction progresses.

Not all situations can be anticipated during advance planning, so site managers tend to create layout plans that show only larger and more static resources (such as laydown and staging areas, access ways, trailers, parking, and major equipment) that will remain in place for major phases of construction. These plans are of limited value for field personnel as they do not show layout detail on a day-to-day basis. Moreover, as work progresses, materials get delivered and used by many different people, which invariably gives rise to changes and situations that could not have been anticipated. When actual layouts gradually get to differ more from what was planned, the plan becomes obsolete. Deviations from the layout plan will arise because of many reasons, including:

- Uncertainty of the timing of deliveries, handling, and use of materials.
- Lack of communication of layout data throughout construction.
- Discrepancies between estimated, delivered, and needed quantities.
- Order lead times, material availability, and availability of substitutes.
- Material characteristics (e.g., unit size, weight, bulkiness, packaging), imposing specific handling, protection, and management requirements.
- Damage to and loss of materials.
- Inadequacy of available space (e.g., total area, shape, access, proximity).

In order to gauge the importance of such deviations, to study the actual vs. the planned flow of materials, and to decide on taking remedial actions, one needs to develop a system for data collection and manipulation. This has been achieved in the MoveCapPlan system, which is presented here. MoveCapPlan integrates surveying technology and interactive computer graphics to form a comprehensive unit for layout planning and control. Example uses illustrate the capabilities of this novel integrated system.

2. RELATED WORK

Few tools exist to model construction material flow as opposed to activity-based construction work. Discrete-event simulation for process modeling has enjoyed a steady interest for more than 20 years, but until recently, it was the only construction management tool in use to explicitly represent resource flow.

Materials management practices, inherently dealing with resource flow, have been critiqued for not using the best of existing tools and techniques [3]. This led to systematic studies of existing systems (e.g., [2]). Thomas et al. [10] also conducted a case study demonstrating a benefit/cost ratio of 5.7, favoring greater attention to materials management. Riley and Sanvido [8] are now working towards a more general model for improving materials management practice.

Several researchers have visited the concept of material flow in the process of modeling space as a construction resource. Their work relates to walk-through-like graphical simulation and site layout modeling. Tommelein et al. [13] summarized the state of the art of layout tools used in construction throughout the 70s and 80s. Muehlhausen [7] and Lundberg and Béliveau [6] described the need for planning and controlling the use of construction site space over time. Thabet and Béliveau [9] showed how work space availability could constrain a construction schedule. Tommelein and Zouein [14] developed a model to create a sequence of layouts related to the construction schedule, showing site changes over time. They are now developing heuristic procedures to automate the dynamic layout construction task [15]. All this work has been greatly enhanced by the wide availability of computers with graphical interfaces, which are so essential to providing people with cognitive, spatial reasoning support. Advances in real-time positioning technology is also opening up new possibilities [1, 4].

Koskela's [5] most interesting study describes how production philosophies that proved successful in manufacturing apply to construction. A key premise in this work is that processes comprise conversion and flow. While conversion is value-adding, flow is non-value-adding. Thus, time and effort spent on the flow of materials on site should be minimized. Traditionally, too much attention has been devoted to improving construction operations by introducing technological change to enhance conversion and ignoring flow. Great process improvements are therefore expected from modeling and improving flow, i.e., cutting out waste. This idea is consistent with much of the aforementioned research, in which material laydown and handling practices were critiqued and models were proposed to improve upon them.

3. MATERIALS HANDLING AND LAYOUT CHARACTERIZATION

An impediment to modeling flow is that construction operations are highly dynamic; flow and conversion processes could take place anywhere on site and are likely to change location as work progresses. It is a sequence of positions and the amount of time a material spends in each position, that characterizes flow.

A space-time characterization of construction materials and equipment was presented in [12]. The modeling of material flow is revisited and further refined here. Figure 1 depicts my subjective assessment of the desirability of flow between different on- and off-site locations. Each circle describes a function that can be fulfilled by any given area on site, depending on how long materials tend to be in that area and on the conversion process that takes place at that location. Space and time are only implicitly represented in this figure.

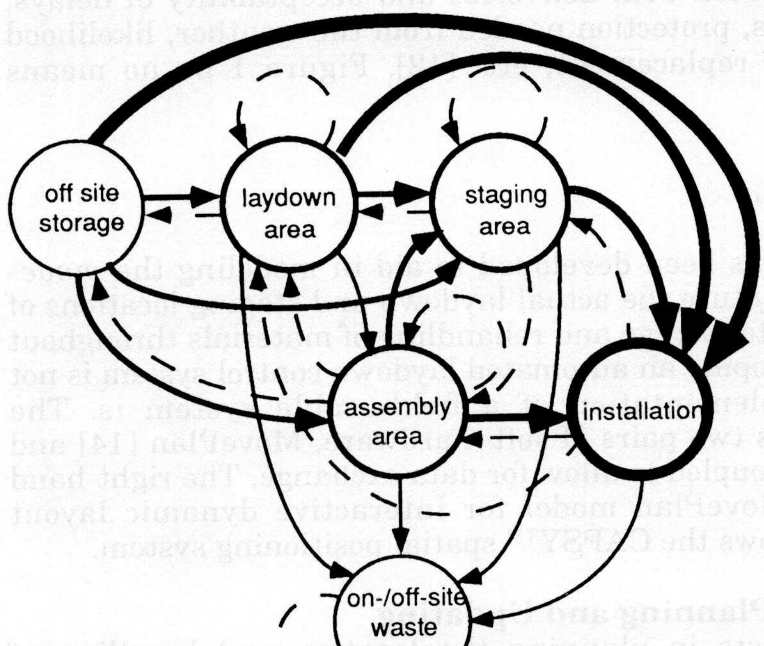

Figure 1. Preferred Materials Flow

A *laydown area* is allocated for long-term use and materials remain there for a long time relative to the duration of the project. Each laydown area tends to be controlled by a single entity (e.g., a specific sub-contractor). In contrast, a *staging* *area* is assigned for short term use only and many entities will need to coordinate its use. At each of these locations, some conversion process takes place, the most simple one being a change in packaging (e.g., take materials one at a time off the pallet). In an *assembly area*, units get put together to form larger ones. Materials can be brought from off-site, or from a laydown-, staging-, or assembly area to be installed in their final location (*installation*). Conversion processes at each of these functional locations may create waste which must subsequently be disposed of (*on-/off-site waste area*).

Any given location can fulfill several functions. However, this intuitively appears to be undesirable from a flow-optimization viewpoint: one does not want materials lying around for a long time if there is a lot of traffic caused by short-term handling.

The arrows in figure 1 represent flow from one functional area to another. Heavier arrows emanating from a circle indicate preferred flow over the lighter arrows, assuming that one tries to minimize overall flow. Dashed arrows are the least preferred of all. For example, materials ideally get delivered from off-site storage to be installed right away. Alternatively, they may get moved to an assembly area, or, if need be, to long-term laydown.

Also, materials can flow from one area with a given function to another area with the same function (dashed loops in figure 1). At a first glance, this appears to be needless, particularly when no conversion takes place in one of these areas. However, it is conceivable that due to a shortage of space at a given time, such rehandling cannot be avoided.

Other factors play a role in determining the quality of a flow. They relate to site access, uncertainty associated with deliveries and acceptability of delays, difficulty of handling materials, protection needed from the weather, likelihood of incurring damage, ease of replacement, etc. [12]. Figure 1 by no means represents all of these factors.

4. MOVECAPPLAN MODEL

The MoveCapPlan model has been developed to aid in modeling the *move*-ment of materials on site, to *cap*ture the actual laydown and staging locations of materials, and to *plan* for on-site storage and rehandling of materials throughout construction. This idea of developing an automated laydown control system is not new [6], but the actual implementation of a field-usable system is. The MoveCapPlan model comprises two pairs of soft-/hardware, MovePlan [14] and CAPSY™ [4], that are loosely coupled to allow for data exchange. The right-hand side of figure 2 shows the MovePlan model for interactive dynamic layout planning; the left-hand side shows the CAPSY™ spatial positioning system.

4.1 MovePlan for Layout Planning and Updating

The MovePlan model assists in planning the location and handling of materials on site [14]. This model extends CPM scheduling with a 2-dimensional graphical interface to represent the use of space over time. MovePlan runs on a lap-top computer so that it can easily be taken into the field.

The MovePlan user must input a CPM schedule of activities and the resources (e.g., materials, equipment, laydown areas, trenches, trees, existing buildings) that will be needed to perform those activities or that are otherwise present on site. The user must also specify how much space each resource occupies or is to occupy on site.

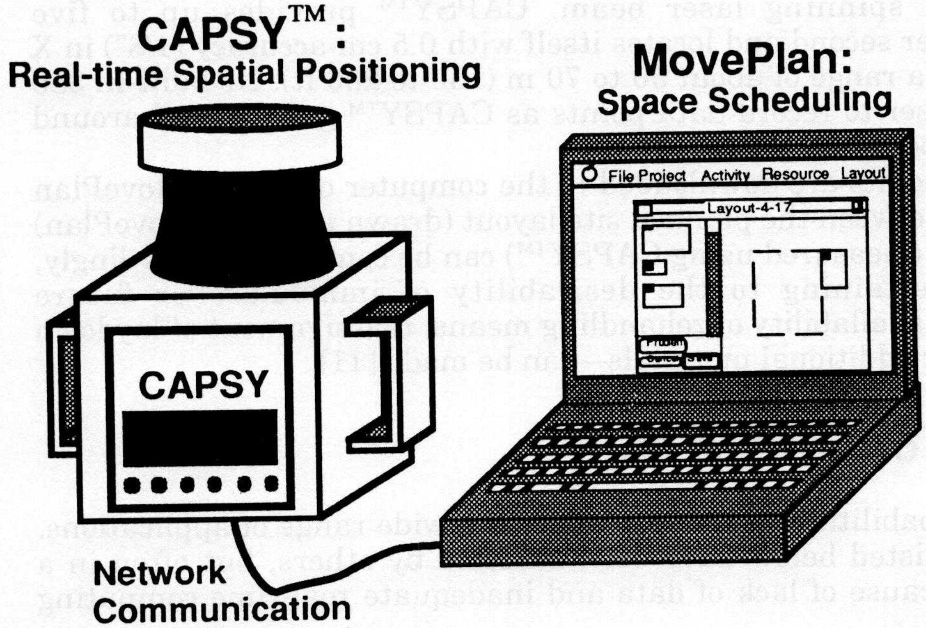

Figure 2. MoveCapPlan Layout Planning and Control System

When the user selects a time interval over which to construct a layout, MovePlan displays the current site arrangement with resources already in place and templates representing resources yet to be positioned corresponding to the schedule of activities (Fig. 2). The templates tagged with a black box can interactively be moved around until a satisfactory layout is obtained. The untagged ones cannot be moved as they either were defined by the user to have a fixed position or were positioned in a layout that includes or overlaps in time with the current time interval. MovePlan thus helps a user develop sequential or hierarchical layouts that are forcibly consistent (i.e., a resource can only have one position at any one time). A play-back of a layout sequence shows how the site evolves over time (it is therefore termed a "dynamic layout") and supports the assessment of flow efficiency.

A methodology for layout planning must be complemented by one to monitor and control. Even when people know where materials should be unloaded, not much effort can be wasted on determining designated locations and exact positioning (except, of course, in the case of final installation). Especially in highly dynamic environments, site arrangements therefore become obsolete all too quickly. The solution to the layout monitoring problem is to use the appropriate real-time spatial positioning equipment so that actual layout maps can be created in a timely fashion.

4.2 CAPSY™ for Site Layout Control

The CAPSY™ [4] real-time positioning system has been integrated with and complements MovePlan. Used by a single person, CAPSY™ makes it possible to quickly log positions of materials on site and trace worker pathways or equipment trajectories, i.e., to map material flow.

After initial calibration, CAPSY™ uses triangulation to compute its position relative to a dozen or so reflective and bar-coded beacons that have been set up around the site. These beacons can be at random locations but must be within range of CAPSY™'s spinning laser beam. CAPSY™ provides up to five coordinate readings per second and locates itself with 0.5 cm-accuracy (1/8") in X and Y directions over a range of about 50 to 70 m (150 to 200 ft). Its built-in 386 processor allow the user to record data points as CAPSY™ gets carried around the site to record the positions of resources.

When these data points are downloaded to the computer on which MovePlan runs, the differences between the planned site layout (drawn up using MovePlan) and actual site layout (measured using CAPSY™) can be computed. Accordingly, control decisions—pertaining to the desirability of immediate or future rehandling materials, availability of rehandling means, reassignment of laydown space, or need to order additional materials—can be made [11].

5. EXAMPLE USES OF MOVECAPPLAN

MoveCapPlan's capabilities enable it to address a wide range of applications. Several applications listed below have been modeled by others, but often in a simplified manner because of lack of data and inadequate real-time computing support.

5.1 Developing and Communicating Dynamic Layout Information

MovePlan aids in scheduling the use of site space over time and thus lies at the heart of on-site materials management. Using MovePlan, spatial information can easily be disseminated (either in hard copy or in electronic form) to negotiate the use of common work areas and to coordinate and locate shared resources. A daily printout of MovePlan's graphical display informs suppliers of where materials ought to be delivered and workers of where materials can be found.

MovePlan's display is interactive, so that its users can take their lap-top into the field, double-click on layout templates, and find out what materials should be stored at the corresponding location. By means of visual inspection, they can determine whether materials are missing or misplaced, and they can use the graphical interface to update the model.

5.2 Lost and Found: Controlling Materials on Site

CAPSY™ makes it possible to collect data to update the layout plan on a regular basis. For example, a person can walk around the site each morning and identify changes relative to the previous day's layout. When this data collection is integrated with an inventory control system, it becomes easy to check which materials will be in short supply so that orders can be placed in a timely fashion. The updated plan can also be tied to the procurement schedule and used to locate material deliveries that are scheduled for that day or identify those that must be moved out of the way or removed from the site.

In contrast to the updating mode, CAPSY™ can also be used in a guiding mode. Its PointMan feature enables a user to upload the coordinates of known positions on site. PointMan then depicts the user's current position relative to the uploaded points and gives the direction and distance in which the user must travel to get to each, one at a time. This makes finding materials easy and less error prone.

5.3 Where to Go To: Promoting Feasible and Safe Site Conditions

MovePlan's rectangles are implemented as objects that can be programmed to have behavior. For example, an underground-utilities object could determine whether or not an above-ground object can overlap with it: laydown areas may be acceptable, but heavy equipment may not. A crane object could determine which loads (objects themselves) lie within its reach and lifting capacity; it could determine its own location relative to its load, their destinations, and obstacles. Conversely, loads could determine within which crane's reach they are or assess the proximity of other appropriate handling means. Open trenches could warn that they must be fenced off. That MovePlan's spatial representation is only 2-dimensional does not mean that the third dimension cannot be recorded if needed to perform the aforementioned calculations. The MovePlan model is currently being extended to accommodate these behavioral capabilities.

5.4 How to Get There: Modeling Material Flow

Possibly the most important use of MoveCapPlan is modeling the flow of materials on site. Figure 1 depicted a subjective assessment of the desirability of flow. It is clear that resource positions in MoveCapPlan can be labeled as laydown, staging, assembly, installation, and waste, and when this is done, each individual resource's flow can be critiqued. By repeating this process for alternative layouts, one can thus express preferences and make trade-offs. On-going research at the University of Michigan is taking these ideas further.

Besides representing positions of physical entities, nothing prevents the MovePlan user from introducing symbols for abstract entities, such as pieces of information to be communicated between people on site. Thus, MoveCapPlan can also model information flow.

5.5 Determining Space Needs

Finally, the MoveCapPlan system can be used for data collection, e.g., to learn how much space is practically needed to lay down materials on site. Only rough rules-of-thumb exist in people's minds and few have been published in industry guidelines, e.g., a 100 MW fossil power plant will need about 0.8 ha (2 acres) of parking and twice that amount of laydown space for the duration of construction. Using CAPSY™, one can actually start measuring space occupied, e.g., by a truck load of reinforcing bars or steel beams, to articulate heuristics for estimating needed laydown, arrangement, access, and possibly stacking configurations [12] on a smaller scale of time and space.

6. CONCLUSION

The efficiency with which materials get handled on site and flow from one location to the next is key to improving productivity. This paper described how the MoveCapPlan system, with its layout display and real-time positioning capabilities, aids in capturing changing uses of site space. This makes it possible to effectively plan how materials will be handled and moved about a site, to disseminate such dynamic layout information in a timely fashion, and to exert control by comparing actual to planned layouts before interference problem arise. Field tests with MoveCapPlan are currently under way. Pertinent questions pertaining to the nature and frequency of collecting layout data and updating layout plans, remain to be answered.

7. ACKNOWLEDGMENTS

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