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Review

Survey of quantitative methods in construction

Dirk Briskorn[1], Michael Dienstknecht[1,*]

Bergische Universität Wuppertal Lehrstuhl für BWL, insbesondere Produktion und Logistik Rainer-Gruenter-Str. 21, Wuppertal, 42119 Germany

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ABSTRACT

Quantitative methods and techniques from operations research (OR) are well-accepted in many industries, e.g. the manufacturing industry or the transportation industry. Similarly, numerous applications in the field of construction can be found in the academic literature. This paper gives an extensive overview on a number of popular fields where OR methods are applied in the construction industry. These fields comprise layout and location planning for construction facilities, scheduling of construction projects and problems related to construction cranes. While the first two topics relate to traditional problems in the field of OR, the latter one is motivated mainly by the construction industry. In either case, this review presents a survey of papers in the scientific literature. Each paper is categorized and problem setting as well as techniques applied are briefly described.

1. Introduction

In 1960, Heiman (1960) wondered whether operations research (OR) could be applied to construction in order to increase efficiency compared to planning by gut feeling or experience. It has been stated that OR had proven to be helpful in other disciplines and, thus, could support planning in construction projects. Since then, a vast amount of OR-related literature tackling planning problems in construction by different means has been published.

Several review papers have appeared in the past. Goh (2008) analyzes the application of quantitative techniques based on publications in two particular journals – *Construction Management and Economics* and *Journal of Construction Engineering and Management* – from 1983 to 2006. The survey distinguishes conventional techniques (regression models, time series analysis, probability functions, simulations) and AI techniques (artificial neural networks, genetic algorithms (GAs), fuzzy techniques, case-based reasoning, expert systems). These are applied to problems in construction economics (bid estimation, cost estimation, demand forecasting) and construction management (resource allocation, equipment selection, layout planning, scheduling). It is found that there is a positive trend in employing AI techniques to construction management. AbouRizk et al. (2011) give a review on existing simulation tools such as CYCLONE and COSYE and their application. They argue that simulation with its ability to reflect uncertainties as well as complex interdependencies is particularly suitable and allows for analyzing different scenarios. Regarding the aspects of uncertainties and planning complexity, Chan et al. (2009) promote the use of fuzzy techniques and give examples for their employment (e.g. contractor selection, scheduling, layout planning, risk assessment, productivity estimation) in eight construction-oriented journals from 1996 to 2005. Liao et al. (2011) focus on the use of metaheuristics such as tabu search, GAs and simulated annealing for various problems during the construction life cycle. Similarly, Sarker et al. (2012) give an overview on the application of quantitative techniques such as heuristics, mathematical programming or simulation in construction projects. Finally, Jato-Espino et al. (2014) review more than 20 techniques for multi-criteria decision making in construction environments and name cases of application in the period from 1992 to 2013.

In contrast to most of the above mentioned reviews, this paper is not structured according to the OR techniques applied, but according to the field of application. It gives an extensive overview on literature covering a selection of planning problems that arise in construction management. This selection is limited to the three fields that are most comprehensively considered in our opinion.

This paper's contribution is twofold. Naturally, it first summarizes existing literature with focus on the problem variants being tackled. Methods applied are briefly stated, as well. We categorize the problems tackled according to their structure rather than real-world concepts being represented. This is due to the fact that the problems' structure often is identical although different concepts are represented. By focussing on the structure we, thus, reveal similarities or even equivalences between problem variants devel-

* Corresponding author.
E-mail addresses: briskorn@uni-wuppertal.de (D. Briskorn), dienstknecht@uni-wuppertal.de (M. Dienstknecht).
[1] http://prodlog.wiwi.uni-wuppertal.de .

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oped independently. This enables researchers to re-apply methods to seemingly different problem variants that, in fact, just differ in their verbal descriptions. Secondly, for each type of planning problem we identify generic OR models which can be found at the core of many more involved problem variants. This relates the problem variants discussed to classical OR problems and points to basic approaches to tackle them.

The remainder of the paper is organized as follows: the following two sections are dedicated to two well-known optimization problems with applications in the field of construction, i.e. Section 2 and Section 3 summarize literature on construction site layout planning and construction project scheduling, respectively. In Section 4, research regarding construction cranes – i.e. rather construction-specific problems – is studied. Finally, Section 5 concludes the paper with a short summary and an outlook on possible aspects for future research.

2. Construction site layout planning

Sadeghpour and Andayesh (2015) have reviewed papers on construction site layout planning with a rather application-oriented perspective. We, contrastingly, take a rather abstract, methodological perspective with a focus on structural problem aspects and will only briefly discuss common constraints and objectives from a practical point of view at the end of this section's introductory part. Thus, we start by defining general terms that will be used while reviewing the literature. Layout planning on a construction site – as in other fields of application – is concerned with assigning positions to objects. Usually, a set of objects to be positioned is given and restrictions regarding the positioning have to be considered, e.g. objects must not overlap and must be placed within a given area. It should be emphasized that this section only covers research concerned with placing objects *within* the boundaries of a single construction site. Note that some authors employ concepts for facility location planning in order to tackle such problems. These approaches, consequently, are summarized in the section at hand, as well. Often an objective function is given implying that not only a feasible positioning but an optimal one or at least a good one is desired.

In the literature different objective functions have been proposed in order to evaluate a given assignment. Two common ones are instantiated by the quadratic assignment problem (AP) and the linear AP, respectively.

- The quadratic AP employs distances between positions, amount of material to be transported between objects, and – potentially – a cost factor. The effort for transport from one object to another equals the amount to be transported times the distance between the assigned locations times the cost factor. The objective of the quadratic AP is to minimize total effort for transport. The quadratic AP is NP-hard, that is it is hard to solve, and it cannot even be approximated within a constant factor in polynomial time (see Burkard, 1984 for details). Nevertheless, since it is one of the most intensively analyzed optimization problems there are many solution methods available in the literature, see Loiola et al. (2007).
  In construction engineering there is a variety of concepts regarding the objective above. Most of them rely on the distance between two objects as a first factor. The distance is multiplied by a second factor depending on the pair of objects. The interpretation of this second factor varies among different papers. It may represent, e.g., amount of material transported, safety factors, preferences, or simply be an abstract value. Sometimes, a third factor, mostly reflecting variable costs is employed. Note that all these different interpretations do not influence the objective function's structure. In order to emphasize these structural commonalities and unify the phrasing we refer to this component of objective functions as *total weighted proximity cost* (TWPC).
- The linear AP employs assignment costs for each object and each position. A layout is then evaluated by the total cost of chosen assignments. Again, various interpretations can be found, e.g. set-up costs, associated risk or utility when installing a facility in a certain position. We refer to this component of objective functions as *total assignment cost* (TAC). As opposed to the quadratic AP, the linear AP can be solved in polynomial time and is, therefore, used either as a simplifying problem capturing the main characteristics or as subproblem in order to tackle problems in numerous applications.

Most often the objects to be positioned are any kind of construction facilities, but some papers are dedicated to a specific type of facility, e.g. storage areas. In the following, the general term *facility* is used and it is specified more accurately whenever necessary. Regarding the term *position*, it can be broadly distinguished between discrete approaches where a predefined finite set of available locations is given and continuous approaches where any point on the construction site that is not occupied by any existing structure is available for placing an object. More precisely, we refer to a model or an approach as continuous if there are two different locations available so that each location in between these two is available, as well. It should be noted that most researchers discretize a continuous space by laying a grid over the site. Hence, we differentiate with respect to the original problem description rather than to the model and categorize papers according to their problem description rather than the model and solution procedure developed. If a paper considers a truly continuous solution space, this will be explicitly stated. Another distinction can be made with respect to time. In static approaches, a single layout is planned and considered to be valid throughout the planning horizon. A dynamic approach, in contrast, respects requirements changing over time. For example, a storage place for bricks is needed maybe prior to and definitely during building the walls, but afterwards it can be removed from the site and its position is free for other equipment. Most of these dynamic approaches respect the time dimension by subdividing the whole construction life cycle into periods or phases that are planned successively. Andayesh and Sadeghpour (2014) correctly point out, that this is more of a phased perspective rather than a dynamic one. However, this type of approach is considered dynamic in this review, since the dynamic nature of the problem has been recognized and is reflected.

Most of the reviewed papers are classified in dynamic and static as well as discrete and continuous approaches. According to this classification, they are listed in Table 1 and are presented in more detail in the corresponding Sections 2.1–2.4. Additionally, within these categories, we distinguish single-objective and multi-objective problems. The modelling variety in discrete approaches is much smaller than in continuous approaches. We therefore lay the emphasis on outlining structural commonalities when discussing these in Sections 2.1 and 2.2. When reviewing continuous approaches in Sections 2.3 and 2.4 we provide more details about the model and the actual application.

There are papers that are rather related to classic facility location problems (FLPs); see Klose and Drexl (2005) for a detailed review and categorization. These are presented in Section 2.5. Similar to the layout problems from Sections 2.1 to 2.4, FLPs can be categorized into discrete and continuous and static and dynamic problem variants, as well. While the categorization with respect to time does not differ from the one for layout problems, we briefly outline the difference between discrete and continuous FLPs in the following.