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An optimization model for the short-term manpower planning problem in transhipment container terminals

Massimo Di Francesco *, Nuria Díaz-Maroto Llorente, Simone Zanda, Paola Zuddas

Department of Mathematics and Computer Science, University of Cagliari, Italy

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ABSTRACT

This paper investigates the short-term manpower planning problem regarding transhipment container terminals. It consists of determining shifts, tasks and activities of the manpower working in these terminals in order to serve vessels in time intervals, which typically do not overlap with personnel shifts. This complex problem is modelled by an integer linear programming formulation. The optimal solutions of the model are compared with the decisions made in accordance with the manpower policy adopted by a real transhipment container terminal. The experimentation sheds light on when its policy is effective or when there is room for optimisation. The computational tests indicate that the model can be optimally solved even in the case of huge transhipment container terminals.

1. Introduction

Transhipment container terminals (TCTs) play crucial role in the shipping industry. In fact, the hub-and-spoke topology of maritime networks results in the consolidation of flows among them. Unlike origin and destination ports, TCTs are under heavy competitive pressure, as shipping liners have high bargaining power in re-designing their maritime routes if they are not satisfied with the services of TCTs. In order to be competitive in the shipping industry, TCTs must accurately plan the management of their resources in order to meet the requests of shipping liners. Since few ports adopt fully automated systems, currently the manpower is still a key resource for TCTs, particularly for those with high labour costs. Moreover, it represents a relevant cost item and its management is a crucial topic for TCTs.

The workload in TCTs is typically organised in shifts providing 24/7 coverage. Owing to union and work rules, personnel shifts must be planned several months in advance. However, when shifts are planned in advance, there is little or no knowledge regarding the final manpower demand, because maritime logistics is affected by uncertainty owing to congestion at terminals, natural causes (wind, etc.), equipment failures as well as geopolitical factors. These sources of uncertainty result in frequent priority changes for TCTs, which must adjust their internal processes in accordance with these external changes in order to remain competitive in the shipping industry.

The manpower management can be separated into the following two planning stages:

- *The long-term manpower planning problem* is a sequence of workdays and days off, which spans several months. The long-term plan denotes a worker as *fixed* in a shift if he must be on-duty during that shift, whereas he is denoted as *flexible* in a day if he must be on-duty during that day, but his shift will be determined in the next planning stage, when there will be more precise knowledge regarding the final workload. This inaccurate information prevents determining at this stage what each worker is required to do and results in the risk of personnel over-manning and under-manning. The long-term plan is made in accordance with the following work rules, which are independent of the final and uncertain workload: the right frequency of rest days, the minimum time interval between two consecutive duties in fixed shifts and a rotation policy in order to avoid the repetition of unattractive shifts as well as the recurrence of the same shift for several consecutive days. The long-term plan is generated from a basis sequence of work and rest periods, which is feasible with respect to previous work rules. Some shifting techniques are adopted in the basis sequence for determining the feasible sequences for all workers (i.e. the long-term plan). See Legato and Monaco (2004) for additional details.
- *The short-term manpower planning problem* is faced every day before the beginning of a planning horizon spanning several days, wherein the workload is almost certain. This problem is required to inherit the separation between fixed and flexible

* Corresponding author.

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workers from the long-term plan, determine the shifts of flexible workers, decide the activities of all workers (i.e. what each worker is required to do) as well as their tasks (or roles) in these activities. Moreover, at this stage, TCTs must compute personnel over-manning or under-manning and make an appropriate decision regarding how many external workers have to be hired.

This paper investigates the short-term manpower planning problem. Despite the availability of vast literature regarding manpower management in several fields (De Bruecker, Van den Bergh, Beliën, & Demeulemeester, 2015), little attention has been devoted so far to the specific context of container terminals (Carlo, Vis, & Roodbergen, 2014; Stahlbock & Voss, 2008). Some studies investigated the scheduling of preselected workers for handling activities, whereas our problem setting is different, as it aims to select which workers will be employed by TCT. Kim, Kim, Hwang, and Ko (2004) studied the worker-scheduling problem, in which each preselected worker is assigned time slots of handling equipment. Lim, Rodrigues, and Song (2004) investigated an allocation problem, wherein pre-selected servicemen are dispatched to locations in the yard, while minimising the number of servicemen, distances, travel and waiting times. Hartmann (2005) presented a model for scheduling and assigning a set of jobs on reefer containers for pre-selected workers. A closer study was conducted by Legato and Monaco (2004), who investigated both the short-term and long-term manpower planning problems, but they did not call for which activities must be carried out. This additional attribute was introduced in Di Francesco, Fancello, Serra, and Zuddas (2015), but they assumed that activities perfectly overlap with the shifts of workers. This assumption is relaxed in this paper.

The limited research regarding the manpower planning problem has resulted in a few tools to support decision-making processes, which are typically based on hunch and experience. In this paper, we cover this gap by the proposal of an optimisation model minimising the assignment costs of workers to shifts, tasks and activities in a planning horizon of several days, when the workload demand is almost certain, while penalising personnel under-manning and over-manning. The optimal solutions of the model are used to evaluate the manpower policy of a real TCT.

This paper is organised as follows. In Section 2, the short-term manpower planning problem is described and a real case study is presented. The optimisation model is formulated in Section 3. In Section 4, we will compare the optimal solutions of the model to manpower policy adopted in this case study. Moreover, we will also show that the model can be optimally solved even in the case of huge TCTs. Finally, Section 5 will present a summary of conclusions and future research perspectives will be described at the end.

2. The short-term manpower plan

2.1. Problem description

Over-manning and under-manning are the main issues of the short-term manpower problem. Since the number of internal and external workers is limited, workforce under-manning may occur. As TCTs cannot afford to pay penalties for delays caused on vessels, it is crucial to detect and correct the possible occurrence of workforce under-manning. It is mainly addressed by the overtime of internal workers, if they are on a day off according to the long-term plan. However, overtime costs are quite high and, thus, they should be paid only if necessary.

Personnel over-manning may also occur because the long-term plan is made when the workload is not yet known. Over-manning must be avoided, as TCTs cannot pay workers for doing nothing. It is faced by swapping a workday with a day off in the long-term plan: a day off is added to unnecessary workers, who were on duty according to the long-term plan and a future day off is changed into a workday in the long-term plan.

Two types of activities are performed in maritime TCTs: vessel activities and housekeeping activities. A vessel activity is a sequence of handling operations, wherein containers are loaded onto and discharged from a vessel. A housekeeping activity is a sequence of container transfers along the yard, occurring when the areas of the incoming and outgoing vessel activities differ. Generally speaking, vessel activities are much more important, because shipping liners request them, whereas housekeeping must be unavoidably performed to be in the position of properly performing future vessel operations.

Each activity is performed by a team (or gang) of workers, each of which is in charge of one task (or role). For example, in each vessel gang, a person is charged of the so-called QC task, which consists of driving a Quay Crane to pick up and drop containers in vessels. Generally speaking, tasks depend on the specific terminal configuration and have a tight hierarchy: workers cannot be assigned to upper level tasks and can be employed in lower-level tasks, even if each worker is paid according to the top task he can do.

The objective of the short-term manpower planning problem is to assign internal and external workers to shifts, tasks and activities at the lowest possible cost, as well as to minimise personnel under-manning as well as over-manning. The planning problem must enforce the satisfaction of the workforce demand, which is defined as number of workers requested to perform each task in each activity and shift. Moreover, sufficient rest times must be guaranteed after a duty. Generally speaking, it is recommended to assign the most skilled workers to the most important activities. Therefore, the costs of internal workers depend on the individual ability of each worker to perform tasks and activities in different shifts.

Unlike internal workers, the costs of external workers do not have individual attributes, because TCTs do not have a priori knowledge of which external person will be hired. Nevertheless, they must be paid according to tasks, activities and work times.

2.2. A case study

This section presents a case study on the short-term manpower problem in a real TCT, where each workday of internal workers is divided into three consecutive shifts of 8 h each. Moreover, vessel services are typically provided to shipping liners in time intervals multiple of 6 h. External workers could also be hired to overcome under-manning in vessel services and they must be on-duty for 6 h a day whenever they are hired. If all vessel services are 6 h long, all time intervals can be represented as shown in Table 1 in the case of available information regarding vessel arrival and departure times for the next two days.

This example indicates that several criticalities take place because of the different durations of internal workers' shifts and vessel services. For example, some vessels may berth at the end of the 6th hour of the planning horizon and internal workers must be assigned to these new activities during their shift. The same problem occurs at the end of the 12th, 18th, 30th, 36th and 42nd hour of the planning horizon. In addition, vessel services must be interrupted at the end of the 8th, 16th, 32th and 40th hour of the planning horizon owing to shift change.

Although many tasks are performed in this case study, only the most important are investigated: the Quay Crane (QC) driver, who picks up and drops of containers from vessels, the Rubber Typed Gantry crane (RTG) driver, who stores containers in the yard and the driver of Internal Transfer Vehicles (ITV), which are low-cost tractors providing horizontal transport. The QC is the top-level task, in fact QC workers can also perform any other task; RTG