Scheduling and Rostering of Flexible Labour at Container Port Terminals using Metaheuristic Algorithms

Ali Rais Shaghahi 1*, Tom Corkhill2 and Abdellah Salhi1

1. Department of Mathematical Sciences, University of Essex, Colchester, United Kingdom
   * Corresponding author: arais@essex.ac.uk

2. Operations Development, Hutchison Ports (UK), Felixstowe, United Kingdom

Abstract: The rise in container shipments causes higher demands on the container terminals, container logistics and management, as well as on physical equipment. This results in increased competition between container ports, especially between geographically close ones. The competitiveness of a container port depends on a number of factors, in particular the time taken to complete discharge and loading operations, operational efficiency and the resulting contractual rates offered to customers. Therefore, a competitive edge may be gained if containers were to be quickly and efficiently processed within the port by matching resource levels to varying customer demands. Many of the operations at the container ports are carried out by a skilled labour force. Efficient deployment and allocation of it is therefore of great importance as the cost related to labour is relatively high. In this paper we will introduce an optimisation model combined with a metaheuristic algorithm to efficiently deploy flexible employees with multiple skills. The key objectives are to maximise utilisation, reduce cost and provide good working conditions for employees. Our method provides good quality schedules for employees whilst reducing associated costs to labour deployment.

Keywords: workforce, labour, combinatorial optimisation, metaheuristics, scheduling, container port.

1 Introduction

In this ever-increasing competitive market in container port operations, port operators are looking at improving service level whilst reducing costs. Balancing cost and performance is a major challenge in this line of business. Ensuring best service levels whilst reducing associated cost requires efficient management of resources. As many of the port operators are moving towards bringing more automation in to operations, labour is still one of the highest cost resources that port operators struggle to minimise.

Container terminal operators serve a number of shipping lines by discharging and loading their periodically arriving container vessels according to an agreed timetable, [4]. Deviations of vessels’ travel times lead to stochastic arrivals in the port around the scheduled arrival time.

This variability in service levels leads to the requirement of variable staffing at various stages, thus requiring a flexible labour schedule to match the service demand. Ensuring high customer satisfaction and cost efficient operations. In some container ports the labour cost is the largest contributor to the cost of sales. Any reduction in the cost associated with labour deployment would have significant positive effect on a container port’s business profitability. Whilst cost reduction is always of great interest, it is crucial to ensure that any plan that might lead to cost reduction will not have negative impact on service level. In order to match this variability the labour planning process is carried out in two stages. Firstly the labour demand is determined and secondly based on the demand requirements appropriate labour will be rostered and scheduled. Usually the staff scheduling and deployment is carried manually by labour planners, which often takes quite long time to be completed. In this paper we will provide an optimisation framework that will deal with complex rostering of container port labour. The rostering of the labour follows complex rules and constraints related to operational, legal and work condition requirements.

Our optimisation framework will produce solutions that will reduce the cost of labour deployment and will satisfy various constraints. We present the optimisation model formulation and will use a metaheuristic method to solve the problem to near optimality. The optimisation framework could act as a decision support system in order to guide the labour planning team to effectively utilise available labour. The rest of this paper is as follows, in Section 2 the related literature presented. Section 3 describes the general specifications of the labour scheduling model. In Section 4 we specifically represent the flexible labour scheduling model. Moreover in
2 Related Work

Similar scheduling problems are studied under the term of staff scheduling and rostering. In [1] it is described as the process of constructing work timetables for staff so that an organisation can satisfy the demand for its goods or services. Key elements related to staff scheduling and rostering are categorised in these groups, [1]:

- Demand modelling: how many staff are needed over a planning period
- Shift scheduling: what shifts are to be worked, together with an assignment of the number of employees to each shift, in order to meet demand
- Line of work construction: which are sometimes referred to as work schedules or roster lines, spanning the planning horizon, for each staff member.
- Task assignment: It may be necessary to assign one or more tasks to be carried out during each shift. These tasks may require particular staff skills or levels of seniority and must therefore be associated with particular lines of work.
- Staff assignment: the assignment of individual staff to the lines of work

It is often difficult and computationally infeasible to solve the problems related to all these elements. Scheduling problems often have to be solved piecemeal while considering all related elements.

The staff scheduling problem could also be categorised in regards to its application to various industries. For example industries such as call centres, health care systems (commonly known as nurse rostering), protection and emergency services, civil services and utilities, venue management, financial services, hospitality and tourism, retail and manufacturing require use of staff scheduling mechanisms to efficiently manage their workforce. One of the most active research fields is related to nurse rostering, [2], and [3].

Apart from the modelling aspect that relates to staff scheduling, an appropriate solving method should be picked to efficiently solve the scheduling problem. These algorithms are categorised as below.

Demand modelling: demand modelling is a complex process that requires detailed information related to various operational aspects of the business. Forecasting, modelling and statistical techniques are used to provide accurate and efficient demand model to match the business requirements.

Artificial Intelligence (AI) approaches: techniques such as constraint programming and studies related to fuzzy systems often are the most prominent use cases of AI in the staff scheduling field. Most of such systems act as decision support systems in cases where a human interaction with the software is necessary.

Constraint Programming (CP): CP provides a powerful tool for finding feasible solutions to rostering problems. This technique is particularly useful when the problem is highly constrained and/or when any feasible solution will suffice even if it is not optimal.

Metaheuristics: form an important class of methods that solve hard, and usually, combinatorial/discrete optimisation problems. Typically, these methods are used to solve problems that cannot be solved by traditional approaches such as steepest descent or greedy local search. There is a growing interest in using such algorithms for various optimisation problems,[6], [7], and [8].

Mathematical programming approaches: In mathematical programming approaches, scheduling and rostering problems are formulated as linear integer programs, or general mathematical programs. Exact mathematical programming approaches solve scheduling problems to optimality when their size is manageable. They, however often, fail to solve instances with large search space which is typically the case in high dimensions.

3 Labour Optimisation Problem

The Labour Scheduling Problem at container terminals consists of planning the shifts for the employees, and minimising costs associated to the workforce. While minimising the labour costs the optimisation model should
optimise other desired targets such as requirements of demand, establishing acceptable working conditions and minimising risks associated to some uncertainty on the availability of the workforce (e.g. overtime availability over weekend). For this, various factors such as company, employees demand requirements and legislation has to be considered and it is necessary to achieve a balance between these factors.

There are several key elements that directly affect the schedule and could from the basis for the objectives in the optimisation model, these include:

i) Overtime deployment cost: There are variable pay rates for overtime workers based on the type of the shift. These rates are typically higher for night and weekend shifts. Therefore in periods that the demand is not matched by contract employees, while considering other constraints, a good plan (lower cost) would reduce the allocation of overtime employees to shifts that attract higher pay rates.

ii) Uncertainty in demand and supply information: Due to some operational aspects and human elements, it is frequently not possible to have accurate demand data. The longer the forecast period is the more uncertainty arises in the demand data. For example when planning the future shifts, a good plan should consider a balanced allocation of overtime and flexible employees.

iii) Licences/competencies: Employees often hold a combination of licences/competencies they also have a primary role. Employees could be allocated to different jobs whilst following certain contractual rules and the fact that they hold the appropriate license. This flexibility allows the labour planner to provide a balanced match to the demand. In addition to meeting demand, it is also desirable to provide frequent and balanced deployment exposure for employees to the various licenses they hold. This is because if a license is not used for certain amount of time it will become dormant, and the employee will require retraining before the license can be used again.

### 3.1 Scheduling Model

The aim of labour planning is to supply sufficient labour to cover the labour resource demand. Most of this demand is covered via deploying basic contract employees. These are employees with a fixed shift pattern. For example a fixed contract employee knows that he/she has to be present at work place every Monday morning to complete a 12-hour shift as crane driver. Any additional labour will be covered via two main sources that are: Flexible Terminal Operatives (FTOs) and staff volunteering for overtime work. FTOs are employees with flexible shift patterns. These employees do not have a fixed shift pattern and are deployed as required.

The combination of employee information, demand data and other related operational, legal and business requirements are the building blocks of the scheduling model. Figure 1 is the overall view of the model with key inputs and outputs illustrated by the arrows.

---

**Figure 1: Labour Scheduling Problem**
4 Optimised Flexible Staff Deployment

As described in previous section, in order to match the demand requirements in cases where contractual labour is not sufficient to match this demand, FTO and overtime labour is deployed. As a result of relatively high pay rate of deploying overtime labour especially during night and weekend shifts, efficient deployment of FTO labour could potentially reduce to total labour deployment cost. Potentially an optimised FTO deployment could lead to these benefits:

- Reduction in overtime pay rate as result of reducing rate B (night, weekend) payments.
- Better planning in order to balance the deployment of floaters in planning period
- Analysis of various deployment scenarios by altering objectives and constraints
- Introducing some additional preferences to improve working conditions for flexible workforce

4.1 Problem Description and Scope

The process of matching workforce demand could be described in two sections. Firstly it is allocating fixed contract employees and secondly matching any additional requirement with employees on flexible contract and the ones willing to do overtime.

In this paper we assume that the fixed contract employees have already been allocated to cover part of the labour demand. The resource demand requirement should be available for all the shifts that require workforce assignment. For example if for an specific shift there is a requirement of 24 crane drivers and the fixed contract workforce can provide 20 crane drivers, the excess resource demand requirement for that shift would be 4 drivers. Allocation of flexible workforce and overtime will cover the excess of 4 drivers for that particular shift.

In this paper the optimisation will focus on deployment of FTOs. The deployment cost will be controlled via calculating the cost of overtime employees for each shift with appropriate shift rate. Basically, these are the shifts that are not covered by flexible staff.

4.2 Planning Horizon

There is a trade-off between planning for longer and shorter time horizons, there is significant advantage to be able to plan for several days, even weeks in advance, however there are some uncertainties in the elements defining the demand forecast. The general idea is that if we plan for longer time horizons we are able to utilise the workforce more efficiently. However, there are two down sides with this, firstly planning for longer periods is computationally intensive task which might take hours to be completed by even fast computers, and secondly the demand forecast information becomes less reliable for longer periods. Therefore in order to balance these criteria a careful selection of planning horizon is important.

4.3 Flexible Labour Optimisation Criteria

An optimal allocation process requires detailed definition of goals and targets and also constraints. The allocation constraints could be categorised into two groups; hard and soft constraints. Hard constraints are sets of criteria that have to be satisfied in order to have a feasible plan. Violation of any hard constraints would result in an unfeasible plan. Soft constraints are a set of constraints that could be violated and they act as set of preferences but violating these constraints will not cause any problem to the feasibility of the schedule solution. In cases where there are several feasible solutions, i.e. all hard constraints are satisfied, then the aim is to find an optimal solution with regards to maximising or minimising some objectives. For example one of the main objectives is to minimise the associated cost with each deployment and at the same time balancing the availability of flexible workforce in time where there is less possibility to deploy overtime workers.\(^1\) Examples of some of the constraints and targets that can be considered are listed below in Table 1.

---

\(^1\) The availability of overtime workers is reduced during weekend and holiday seasons.
### Hard Constraints

- Employee availability (Holiday, sickness)
- Collective Agreement and regulatory

### Soft Constraints

- Employee working shifts preference
- Maintaining staff skill exposure

### Objectives (Max and Min)

- Minimising cost of deployment
- Maximising assigning of flexible workers to times where overtime availability is scarce

#### Table 1: Flexible Labour Optimisation Criteria

4.4 Constraints

Hard constraints related to flexible staff scheduling are as follows:

- **HC-1**: Deployment in each shift, skill license should not exceed the demand.
- **HC-2**: For each day, an employee may start at most one shift.
- **HC-3**: Maximum number of working days is $7 \times 12$ hour shift over a reference period of two weeks.
- **HC-4**: One complete weekend off in any rolling 4 week period.
- **HC-5**: Maximum 4 night shifts in 2 week reference period.
- **HC-6**: Maximum 4 consecutive working days (12 hour shifts).

4.5 Optimisation Algorithm

In order to solve the optimisation problem we need to utilise an optimisation algorithm to solve the scheduling problem. Because of the size of this problem, mathematical optimisation algorithms e.g. mixed integer programming are not always able to produce solutions in reasonable time. However metaheuristic algorithms tend to produce near optimal results in a relatively short period of time. In this paper we have modelled the optimisation problem into an open source optimisation framework called Optaplanner (see [5]). This framework enabled the scheduling model to be programmed into the framework. Appropriate algorithms could also be plugged in to solve the problem.

In this paper we utilise a Tabu search metaheuristic to solve the scheduling problem. A Tabu search method works on a basis of local search technique that searches the neighbourhood of a candidate solution. More specifically Tabu search uses a memory structure in order to avoid previously visited solutions with inferior objective results.

5 Experimental Setup and Results

In this section we present the experimental results of the optimisation software for the purpose of deployment of flexible labour. The challenges involved in the evaluation of the optimisation framework relates to these three categories:

- **Creating feasible staff schedules**: this means that all of the hard constraints have to be fully satisfied.
- **Handling problems with large numbers of employees**: due to the combinatorial nature of this type of application, an explosion in the size of the problem is often observed, making the problem potentially truly intractable.
- **Optimising key objectives**: the optimisation process must achieve near optimality on all relevant objectives.

5.1 Experimental setup

We will evaluate the effectiveness of the optimisation framework for two scenarios.

**Scenario 1**

In this scenario demand is equal for each day of the two-week period. Shifts only represent day or night. Also all shifts have the same type of skill requirement. The objective is to only maximise the number of day shifts covered. This means our preference is to cover more day shifts rather than night shifts.
The results presented in Figure 2 indicate that the optimisation software is able to achieve the objective successfully while satisfying all related constraints. For example each employee works no more that 7 days in a two week time horizon and no more than 4 working days consecutively. Also as objective function indicates the number of day shift cover is maximised.

<table>
<thead>
<tr>
<th>Shifts</th>
<th>Fri</th>
<th>Sat</th>
<th>Sun</th>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTG Driver Day</td>
<td>18</td>
<td>10</td>
<td>15</td>
<td>14</td>
<td>10</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>RTG Driver Night</td>
<td>7</td>
<td>8</td>
<td>15</td>
<td>14</td>
<td>12</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>IMV Driver Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>IMV Driver Night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crane Coordinator Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Crane Coordinator Night</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berth Operator Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

This experimental problem is a relatively large problem with 360 decision variables, which each of them can hold 90 different values. This creates a problem with $90^{360}$ permutations. It is clear that all permutations (candidate solutions) of the problem create a very large search space.

The key objective in this scenario is to maximise the workload of Flexible staff for night and weekend shifts. This is due to the fact that any weekend or night shift that is not covered by the Flexible staff have to be covered by overtime employees. The weekend and night shift overtime rate is 50% more than any normal overtime rate, therefore the cost associated to the total employee roster will be higher if overtime staffs are deployed for night and weekend shifts.

The optimisation results show that the software is able to produce feasible rosters, schedules that satisfy major constraints, and at the same time reduce the cost associated with labour deployment.
Figure 4 represents the portion of the shifts that are not covered by the employees, the four empty areas relate to weekends. As it can be seen the number of night shifts that are not covered are zero and also there no uncovered shift for weekend period. This emphasises the effectiveness of the optimisation framework to maximise cover during weekend and night shifts. A solution with these characteristics reduces cost requirements for night and weekend overtime covers which is known to be more expensive than normal shifts.

Figure 4: Scenario 2 ‘not resourced’ shifts

6 Conclusion

The increasing competition arising in container port business requires efficient delivery of operations at all levels. Efficient use of labour resources is key to successful delivery of operations and increasing the quality of customer service.

In this paper we presented an optimisation framework to schedule and roster flexible labour in order to maximise efficiency and reduce associated costs. The optimisation model captures all the operational, legal and work related constraints that must be satisfied in order to have an acceptable work schedule whilst reducing costs related to deployment. The unique structure of these types of scheduling problems conveys the need to use metaheuristic optimisation algorithms to solve these scheduling problems in a reasonable time and provide near optimal solutions. Exact methods are often of no use.

Further extension to this work includes a more extensive model to include all employees in all sections. The key challenge is the increase in the size of the problem. It may well be necessary to adopt a decomposition approach in order to handle large instances of the problem.

References


