HUMAN RESOURCES DAILY ALLOCATION IN A TRANSHIPMENT CONTAINER TERMINAL

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ABSTRACT
In this paper we present a mathematical model for optimal human resources daily allocation in a transhipment container terminal.
The aim is to support planners in finding the minimum cost choice fulfilling different customers' needs and priorities.
Problem formulation is mainly based and validated on the direct observation of the real complex decision processes at Cagliari International Container Terminal.
The testing phase is performed by an open source code: GLPK (Gnu Linear Programming Kit) up to a problem size of 12.144 variables and 1032 constraints in less then 2 seconds.

Keywords: human resources, resource allocation, operation planning, terminal container, optimisation,

1. INTRODUCTION

Operations Planning has an important role in order to improve container terminal's efficiency and advanced support systems are absolutely needed to offer high quality services and improve port competitiveness (Steenken et al., 2004, Vis and Koster, 2003).

Taking in consideration terminal planners needs we focused the research on daily planning level, where the main target is the allocation of resources (human resources and equipment), in order to improve productivity and reduce costs of operations. At this planning level information about vessel arrival time is greatly affected by uncertainty. Even if line operators send the ETA (Estimated Time of Arrivals) 24 hours before vessel arrivals, lot of delays occurs. For this reason, resources are planned with a certain flexibility that involves high costs.

A forecasting model, predicting vessel delays, could give planners more certainty knowing in advance demand size in any daily work shift, in order to consecutively allocate resources minimising costs and maximising productivity.

2. SURVEY OF THE LITERATURE

The problem of planning resources on daily level in terminal containers is studied in literature with different approaches.

Complexity of daily planning is described by Dell'Olmo and Lulli (2004). They present both human resources and equipment in the same way, taking into consideration the possibility to share resources in different points of work. The problem is then formalized by a "generalized" scheduling model. Even if having a unique model both for equipment and human resources can reduce complexity, on the other hand a generic model could imply less support for final users, which would do better with their experience.

The scheduling approach (Kim et al., 2004; Hartmann, 2004) implies a precise sequence of jobs assigned to specific resources, programming time and location of every ring of the jobs chain. Observing real operations we found that they are characterized by frequent presence of fortuitous circumstances (like damages, lack of documentation etc.) that could imply the reformulation of the scheduling problem many times. This can be not compatible with model solving computational time.

The resource allocation approach (Gambardella, 2001; Legato and Monaco, 2004; Zaffalon et al 1998) allows describing the general problem, without giving a precise schedule of jobs but considering volumes to perform.

In this paper we focus on the problem of human resources allocation in terminal containers at daily planning level (Gaudioso et al. 1999, Legato and Monaco 2004), including different peculiarities of human resources allocation, traced on direct observation of planning processes.

3. PROBLEM DESCRIPTION

Operational process related to daily human resources allocation can be described as follows.

A work day is divided in 4 shifts, of 6 hours each, in which any operator can perform only one task. Available operators come from the monthly planning and are divided in two groups: those who are already allocated to a precise work shift and those who are "flexible", e.g. available in the planning day but not yet assigned to a precise work shift.

In addition to standard workers, the operations manager can assign additional external workers only for the lower skill task (Truck-Trailer driving task), Tasks can be classified in driving tasks (on lift cranes and horizontal transport equipment) and ground tasks (checker, deck man, raiser). In our model we consider only driving tasks. Any operator has a main task, that represents his higher skill level and determines his salary, but he can also perform lower level tasks if is needed, conserving his main task salary, while the contrary is not allowed.

Operators are grouped in so called gangs (teams), each of them is generally employed to serve one quay crane. Quay cranes operational speed (Gross Crane Productivity) determines terminal productivity (Ferraro, 2006) that is the most important parameter for client's satisfaction. Quay crane productivity depends on many factors such as: equipment performances, operator's skill, gang performances, operational conditions (congestion), vessel typology (mother, feeder, hold structure), containers yard location.

Gangs can perform two kinds of work: vessel loading/unloading works (vessel to/from yard) and housekeeping works (yard to yard). Housekeeping works don't need any quay crane operator.

Works have to be performed for different "clients" (groups of containers are related to trade lines, vessels), having different contract agreements, that means different productivity constraints and priorities.

Historical values of any operator task performances (productivity in moves/hour) are stored on a data base and considered before allocation in order to assign higher performance operators to high priority works, building a high performance gang.

4. THE MATHEMATICAL MODEL

Let N be the total set of nt available workers in the planning day. As a result of the monthly planning, set N consists of the following subsets: Tj, set of na workers assigned to each period j of the planning day; F, set of $nt\text{-}na$ workers on flexible duty for the planning day. So

$$N = U^4_{j=1} Tj \ \ U F$$

$$Tj \cap F = 0 \ \ for\ j=1,...,4.$$

Let J be the set $\{1,2,3,4\}$ of 4 workshifts, of six hours each, in which is divided the planning day.

Let K be the set of driving tasks $\{qc,rt,ra\}$ where qc states for quay crane operator task ,rt denotes yard crane operator task and ra indicates the truck trailer driver.

Let Z be the complete set of works to be performed during the planning day. The set is constituted by the set Na of nv vessel works (ship to/from yard) and the set H of $l\text{-}nv$ housekeeping works (yard to yard). As a consequence the following relationships hold:

$$Z = U^4_{j=1} Na \ \ U H$$

$$Z \cap H = 0 \ \ \text{for}\ j=1,...,4\ .$$

We adopt the following notation:

DATA

$nm_{j,k}$ denotes the average number of workers performing task k in a vessel gang on workshift j

$$\forall j \in J,\ \forall k \in K$$

$nh_{j,k}$ denotes the average number of workers performing task k in a housekeeping gang on workshift j

$$\forall j \in J,\ \forall k \in K$$

$r_{j,z}$ denotes the number of vessel gangs needed on period j

$$\forall j \in J, \forall z \in Na$$

$h_{j,z}$ denotes the number of housekeeping gangs needed on period j

$$\forall j \in J,\ \forall z \in H$$

$p_{i,k}$ priority of task k for worker i

$$\forall i \in N,\ \forall k \in K$$

cmp_i salary of worker i for his main task

cma_k salary of assigned task k

b salary of external worker

d fictitious salary of $u_{\ j,k,z}$ workers needed to perform on shift j, task k and work z

$prod_{i,k}$ average historical productivity of worker i on task k

$0<=a_z<=2$ coefficient for reduction/increase average gang productivity in different operational state of work z

$$\forall z \in Z$$

$$yt_{i,j} = \begin{cases} 1 \text{ if worker i is assigned, by monthly planning, to workshift j} \\ 0 \text{ otherwise} \end{cases}$$

$$\forall i \in Tj,\ \forall j \in J$$

VARIABLES

$$x_{i,j,k,z} = \begin{cases} 1 \text{ if worker i is assigned to workshift j, task k, work z} \\ 0 \text{ otherwise} \end{cases}$$

$$\forall i \in N,\ \forall j \in J,\ \forall k \in K,\ \forall z \in Z$$

$$y_{i,j} = \begin{cases} 1 \text{ if worker i is assigned to workshift j} \\ 0 \text{ otherwise} \end{cases}$$

$\forall i \in N, \ \forall j \in J$

$v_{j,k,z}$ denotes the number of external workers needed on workshift j, work z, only for task ra (truck-trailer operator)

for $k=ra, \ \forall j \in J, \ \forall z \in Z$

$u_{j,k,z}$ denotes the lack of human resources (number of operators) on workshift j, task k, work z

$\forall k \in K, \ \forall j \in J, \ \forall z \in Z$

In order to enforce the assignment, to each worker, of tasks consistent with his own skill, we adopt the same rules of Legato and Monaco (2004), relating costs to the priorities $p_{i,k}$ (ranging from 1 to 3, if finite).

They define the unitary (i.e. related to a single shift) cost for the worker i performing task k (assigned by the model) as follows:

$$c_{i,k} = \begin{cases} cmp_i & \text{if } p_{i,k}=1 \ (k \text{ is the main task of the worker i}) \\ cma_K + (cmp_i - cma_k) & \text{if } 1 < p_{i,k} < \infty \\ M & \text{if } p_{i,k} = \infty \end{cases}$$

Where M is large enough with respect to all real costs involved in the function.

Note that an employee with a high skill level (crane-operator: $p_{i,qc}=1$) could perform any other lower level task (with priorities $p_{i,rt}=2$; $p_{i,ra}=3$), while the contrary is not allowed.

In order to enforce the assignment of higher skill operators (with higher average historical productivity) to works that need higher priorities and performances, we define a monetary coefficient g_z that represents, for each work $z \in Z$, different profits/moves for different clients (trade lines, vessels related to each work). In this way, if a client has high priority to be served, more moves gang can perform (higher productivity gang) more profit the terminal gains. So, we define: g_z as the profit for each move (unit/container move) performed in work z.

We can now formulate the problem as follows

$$MIN \ \Sigma_{i=1,nt} \Sigma_{j=1,4} \ \Sigma_{k=qc,rt,ra} \ \Sigma_{z=1,l} \ (c_{i,k} - ((a_z \ (prod_{i,qc} + \\ +prod_{i,rt} + prod_{i,ra}) \ / \ 3) \ g_z) \ x_{i,j,k,z} \ )+ \\ + \Sigma_{j=1,4} \ \Sigma_{k=qc,rt,ra} \ \Sigma_{z=1,l} (b \ \ v_{j,k,z}) + \\ + \Sigma_{j=1,4} \ \Sigma_{k=qc,rt,ra} \ \Sigma_{z=1,l} (d \ \ u_{j,k,z})$$

SUBJECT TO

$$\Sigma_{i=1,nt} \, x_{i,j,k,z} + u_{j,k,z} + v_{j,k,z} = nm_{j,k} * r_{j,z} \quad (1)$$

$\forall z \in Na, \ \forall j \in J, \ \forall k \in K$

$$\Sigma_{i=1,nt} \, x_{i,j,k,z} + u_{j,k,z} + v_{j,k,z} = nh_{j,k} * h_{j,z} \quad (2)$$

$\forall z \in H, \ \forall j \in J, \ \forall k \in K$

$$y_{i,j} = yt_{i,j} \quad (3)$$

$\forall i \in Tj$

$$\Sigma_{k=qc,rt,ra} \, \Sigma_{z=1,l} \ x_{i,j,k,z} = y_{i,j} \quad (4)$$

$\forall i \in N, \ \forall j \in J$

$$\Sigma_{j=1,4} \ \Sigma_{k=qc,rt,ra} \, \Sigma_{z=1,l} \ x_{i,j,k,z} = 1 \quad (5)$$

$\forall i \in N$

$$v_{j,k,z} >= 0 \text{ integer} \quad (6)$$

$\forall j \in J, \ \forall k \in K, \ \forall z \in Z$

$$u_{j,k,z} >= 0 \text{ integer} \quad (7)$$

$\forall j \in J, \ \forall k \in K, \ \forall z \in Z$

In the objective function we specify two main allocation criteria, taking into account:

1. human resources versatility, minimising costs that could come from a lower skill operator allocation ($c_{i,k}$);
   the need to allocate high performance gangs to works with more priorities, maximising gang productivity for works having more priority. More precisely we introduce in the objective function the quantity

   (prodi,qc + prodi,rt + prodi,ra) / 3)

   in order to estimate gang productivity.
   More precisely, $prod_{i,k}$ represents the average historical productivity of worker i on task k. This quantity can be corrected by a coefficient a_z, reducing or increasing gang performance, taking in consideration the operational state of work z (terminal congestion, vessel structure etc.). We assume that a_z is a real value between 0 and 2.
   This deterministic expression must be taken with care because the gang productivity is an indefinite parameter, influenced by many factors.

The monetary coefficient g_z ensures that more moves gang performs more profit terminal gains.

Then we associate the “cost”

$$(c_{i,k} - ((a_z(prod_{i,qc} + prod_{i,rt} + prod_{i,ra})/ 3)g_z)$$

to the Boolean variable $x_{i,j,k,z}$ equal to *1* if worker *i* is assigned to workshift *j*, task *k*, work *z* , *0* otherwise.

Moreover the objective function requires to minimize the total cost charged by external workers (second term) and the lack of human resources (third term).

Constraints (1) and (2) ensure, respectively, manpower demand satisfaction, for vessel works and housekeeping works while maintaining the correct composition, in number and skill-mix, of gangs.

Constraint (3) imposes the monthly allocation to workers just assigned to workshifts.

Constraint (4) imposes the logical link between variables x and y: if i will work on period j, exactly one task must be assigned to him for that period, otherwise none.

Constraint (5) ensure that only one worker can be assigned to only one workshift, task and work in the planning day.

5. RESULTS

The problem was formulated and solved with GLPK (Gnu Linear Programming Kit) an open sources code which contains a tool for problem formulation which uses a comprehensive language (Gnu MathProg), a solver (GLPsol), which automatically generate instances and solves the problem.

First instance was built considering 48 available operators 3 vessel works and 2 housekeeping works to be performed during all 4 workshifts, up to 3.192 variables and 516 constraints. The solver finds a feasible solution in less then 1 second. The problem with 96 available operators for 6 vessel works and 4 housekeeping works, up to 12.144 variables and 516 constraints, was solved in less than 2 seconds.

6. CONCLUSIONS

Container terminal operations are characterised by complexity and high costs, that’s the reason why, finding optimal solutions in short time means a great support for planning.

In this work we describe the real decision process related to human resource daily allocation observed at Cagliari Container Terminal, representing the “trade off" between costs and client satisfaction involved.

Formalising the problem some simplifications are adopted because of problem complexity and some parameters are found to be not simply “monetized”.

For this reason a more careful cost-profit analysis could be the next step of our study.

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