A Hybrid Bin-Packing algorithm for solving the yard optimization problem.

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Abstract. Maritime container terminals are facilities where cargo containers are transshipped between ships or between ships and land vehicles (tucks or trains). They can be automated; semi-automated or static ones depend on the type of the equipments that they contain. There are crucial resources at container terminals; the yard, cranes and the vehicles. The yard refers to the temporary storage area where inbound, outbound containers can be stored. While we have two kinds of cranes depending on the type of the yard we are working on: yard crane and quay crane. Vehicles are used to transfer the container between the seaside and yard side (the external trucks XTs are not considerable in our study).

The decision of the container stacking position is the most important operational task for the incoming containers which affects not only the productivity of the stacking but also for the later retrieval and also to avoid the unproductive moves to access to the requested containers stored in the stack. Our aim is to define a new approach to design the container stacking problem using an approach of optimization and simulation. Thus in this paper we will define a new MIP which has as objective the minimization of the number of the stacks used to store a given number of inbound containers, and to define afterwards a simulation model using a simulation software (Arena) which has as input the result of the optimization model. So we will try first to define a relocation model using the standard (FCFS) then the Best fit decrease (BFD) from the bin packing algorithm to store and maintain the storage area and to avoid unproductive moves and reshuffles to find out the requested container sequence.

The main inputs are high, weight, destination and the delivery time of each container. Our objective is to have, based on heuristics, a guide to the planner to obtain an optimized stacking / reshuffling plan, given a stacking state and a container demand. We will try to minimize the number of reshuffles as well as the number of stacks used and obtaining a conclusion about possible yard configurations.

Keywords : Containers terminals; optimized plan; reshuffle; container stacking problem; heuristics; optimization; simulation.

1. Introduction:

Maritime transportation has increased remarkably over the last few decades according to Steenken et al. (2004) **[1]**, the use of containers reduces the amount of the product packaging and the possibility of damage.

A container terminal is an interim storage area, where container vessels dock on berths to unload inbound containers during the import operations and load outbound containers for the export operations. To be more competitive containers has been standardized in the world wide, an ISO standardized metal box, so the most famous ones are: 20feet, 40feet (TEU : twenty feet equivalent units) . They can be stacked then on top of each other following a 'last-in, first-out' (LIFO) strategy. Once the container will be transferred from the seaside to the yard side via internal vehicles, the yard crane will store this container in a specific location based on a certain criterions: destination, estimated departure, weight, size and destination. Figure 1 illustrates the complete process of typical operations and equipment in container terminals, including quay cranes for loading and unloading containers from vessel, internal vehicles for carrying containers within the terminal area and RTGC (Rubber Tyred Gantry Crane) for stacking containers in the storage yard.

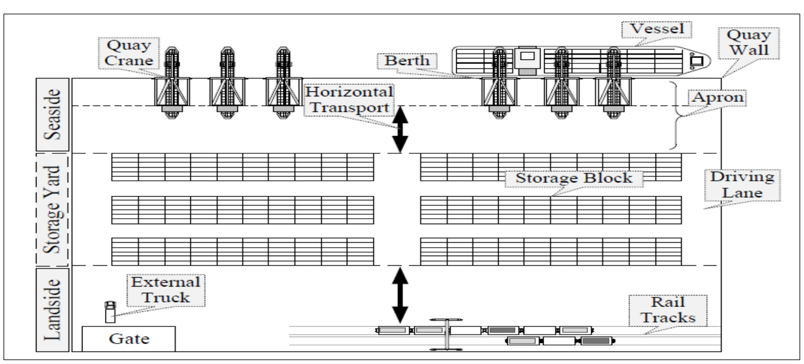

Fig.1. Container Terminal Main Area

In order to access a container which is not at the top of its stack, those above it must be relocated. It occurs since other ships have been unloaded later or containers have been stacked in the wrong order due to lack of accurate information. This reduces the productivity of the cranes. Maximizing the efficiency of the current process leads to several requirements:
1. Each incoming container should be allocated a location in the stack which should be free and supported at the time of arrival. This location can be identified either by the worker or by the state of the stack before each planning horizon.
2. Each outgoing container should be easily accessible, and preferably close to its unloading position, at the time of its departure. This process can be also optimized by storing containers of the same vessel in the same yard bay for example.

The number of containers handled by the container terminals is growing then the competition between containers terminals is increasing. The using of the scientific methods and operational research tools became crucial in container ports.

According to Stahlbok and Voss (2008) **[2]** activities in a containers terminal are conducted in two main areas: the quay and the yard area. In the quay area, we can found various optimization problems discussed in the literature such as:

- Berth allocation problem (BAP);
- Container storage;
- Quay crane scheduling;

Others one in are interested to the yard area:

- Yard crane scheduling;
- Storage Yard Planning;
- Container truck scheduling;

Based on this, Rashidi and Tsang (2013) **[3]** divided the operations in container terminals into 5 operations as in Figure 2 that effect the efficiency of the problems in container terminals:

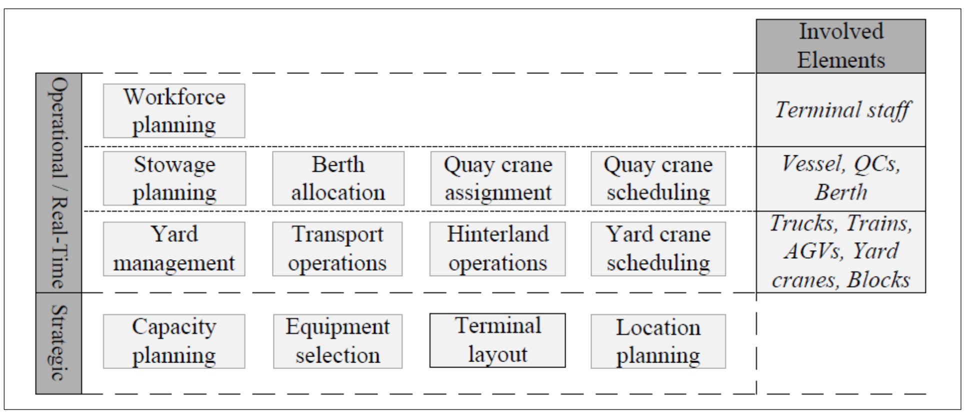

Fig.2. Decision problems in container terminals **[4]**

The majority of decision containers terminal can be divided into three levels of planning and control: 1) strategic, 2) Tactical and 3) operational. Strategic decisions are long-term decisions that include the structure of the terminal, handling equipment and handling procedures. Tactical decisions are medium-term decisions that are interested in determining the number of quay cranes, yard cranes, straddles, etc. And finally operational decisions are short-term decisions and include the process to be followed by the quay cranes, the yard cranes, straddles, etc. In this paper we will focus on the operational operations, so the objective is to have storage containers planning to be flowed by gantry cranes in non automated container terminals for the inbound containers by minimizing the total distance and the reshuffles number in the yard area.

The rest of this paper is organized as follows: Section 2 presents a literature review, section 3 defines the problem and section 4 presents the solving methods to our MIP. The results of numerical simulations and a comparative study are presented in Section5. Finally Section 6 is devoted to conclusion.

2. Literature review:

In this paper we focus on the storage space assignment already presented in the previous section and study the existing research for container stacking positions for import operations in automated containers terminal. Each yard area had a specific level to store containers; containers on the top of the stacks must leave earlier to avoid unproductive movements (reshuffles). These moves have a negative effect on the operational efficiency of the container terminal. Therefore, while determining the stacking positions of the containers, the objective of the problem is defined to minimize the global distance between the sea side and the yard area and also to reduce the number of the reshuffles.

The factors involved in determining the stacking plan are: stack level, stacking strategies for storage and retrieval containers for import, weight of containers, size and EDT. In our study to stack containers, the RTGC will be used to pick up the container from the internal vehicle to deliver it in the stacking position**.**

According to Steenken et al. (2004) and the extended study of Stahlbock and Voss (2008) the main logistics operations at container terminals can be classified as follow: Berth allocation, stowage planning, crane scheduling, terminal transport optimization, and storage and stacking logistics. There are static and stochastic cases of containers. In the static storage, the location of each container in the storage yard was allocated and reserved before the vessel arrival. The reservation for containers could be based on discharge port, container type and container weight, depending on the stacking strategy. On the other hand, stochastic case, container's location was not determined before the vessel's arrival. Instead, the storage location was determined in real time and after the vessel berthed. The EDT and the container destination are not taking into account for the inbound containers in this study.

According to Carlo et al. (2014) **[5]** the containers stacking problems can be divided into three types: storage of individual containers, of group of containers and the storage space assignment in relation with the other yard process. we will introduce under each type the related researches.

2.1 Storage space assignment of individual containers:

The main idea of this type of research is to first assign containers to blocks and secondly to specific locations within the selected block. Guldogan et al. (2010) **[6]** considers an integrated policy that takes into account the work balance, number of used trucks and the travel distances, the aim of the new strategy is to define clusters which group containers according to their departure dates, weight and type of the stored containers are not considered also the number of reshuffles can grow with the big instances. Park et al. (2011) **[7]** first select blocks to balance the GC's workload, and secondly, select the specific storage location based on a weighted function of space and GC utilization so departure dates of containers are not considered which will cause additional unproductive moves. Chen and Lu (2012) **[8]** aim to avoid rehandles in their approach to assign outbound containers, but workload balance of GC's are not considered. Ng et al. (2010) **[9]** used a new heuristic for the problem with import containers on ports with cyclical calling patterns, weight of containers are not considered.

2.2 Storage space assignment of groups of containers:

The main idea of the related research to this part is to propose methods to assign groups of containers to storage locations, where groups are, for example, based on the destination vessel, departure time, and type of containers. The heuristic's performance is assessed for variations in type of berth allocation, the transfer vehicle travel times, and loading/unloading times. An SA-based heuristic for this problem is proposed by Huang and Ren (2011) **[10]** that require enumerating all possible assignment permutations for the three container groups of import containers, result is not compared with existing storage policies. Jeong et al. (2012) **[11]** define a method to decide for each block how many import containers will be stored there, the consigned strategy take into account only the destination of containers the EDT is not considered. Nishimura et al. (2009) **[12]** propose a new MIP, and they use a new heuristic to minimize the weighted total container handling time no additional constraint for the destination type of the stored containers.

2.3 Storage space assignment in relation to other yard processes:

The aim of this part is to study the interaction between several marine operations in a containers terminal, each operation is a related to another adjacent operation so they can be optimized together. Here we will highlight papers that address more integrated decision making.

Murty (2007) **[13]** proposes a storage space assignment policy for a terminal using a consignment strategy. The policy is an adaptation of the best fit on-line heuristic for the bin packing problem, this is a limited MIP we will extend the proposed model by adding additional constraints and using the bin packing approach. Lee et al. (2006) **[14]** study storage space assignment to minimize the total number of GC shifts required to assign a group of containers to a set of blocks the workload can be reduced but the number of reshuffles can grow as we don't have a limitation of the EDT of the stored containers. Laik et al. (2008) **[15]** use the consignment strategy and the gantry crane dispatching problem their objective is to minimize the total handling and storage cost over a planning horizon, and to balance the workload between blocks the limitation of the proposed model the consignment strategy take into account only the inbound and outbound containers and the authors didn't define a container category to distinguish between export and import containers this may cause additional reshuffles in the storage area.

3. Problem definition : Container Stacking Problem (CSP)

Container terminals are divided into automated and non automated ports. The automated ports (AP) use the RMGC (Rail Mounted Gantry Crane), the AGV (Automated Guided Vehicles), the ALF (Automated lifting vehicles…Therefore non-automated ones (NAP), use the RTGC and the internal vehicles to transfer the containers from the berth to the storage space. So the AP needs a higher investment cost comparing with the NAP, but they have a lower operational cost, a faster crane speed and have more storage area. After the study of Lee et al. (2013) **[16]** 63.2% of the container terminals studied are non automated so they use the RTGC and the internal truck. So, this is the reason why we will focus on the NAP in this paper.

After the vessel's berth, quay cranes are assigned to each arrived docked vessel. Inbounded containers are unloaded by quay cranes (QCs) during the import operation. Then, containers are transported from berths to the storage area by trucks or other vehicles, the assignment of trucks to the storage area must verify the model's constraints and also starting by the containers which will have the smaller EDT and store them as close as possible to the transfer point. Once a container arrives at its stacking yard bay in the storage area, the stacking crane lifts the container from the truck and stacks it to the storage position. Afterwards GC can re-stack containers according to their EDT and destinations.

A container's position in the yard is then denoted by its block, bay, row and tier identifiers. A block is defined by its bays (length: basically [20, 30] per block) and rows (width: basically 6 per block, one is reserved to the internal truck) and the tiers (4levels per yard bay). Stacking yards are usually divided into multiple blocks, each consisting of a number of bays. A bay is composed of several stacks (row and tiers) of a certain size, and holds containers of the same size. This problem is called as the Container Stacking Problem (CSP), which is one of the most common and important problems at container terminals. Figure 3 show a schematic overview of container terminal, the theatrical container capacity of the yard is: 15 x 30 x 5 x 4 = 9000 TEUs (twenty-feet-equivalent units), which correspond to 9000 standard 20-feet containers.

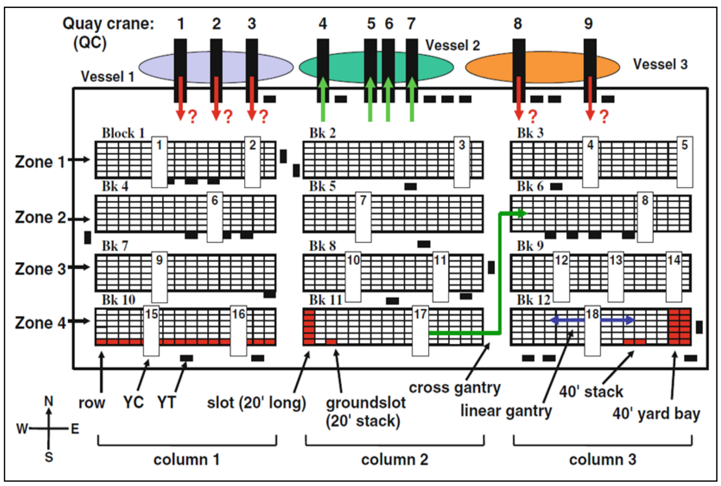

Fig.3. Schematic overview of the container terminal **[17]**.

3.1 Mathematical formulation

In a single stack, we can stores only containers of the same size, destination. The proposed stacking strategy is used to decide where to store newly arrived containers. The incoming containers belong to one of two types, namely 20-feet and 40-feet. A 20-feet container occupies 1 TEU in the storage area, while a 40-feet container occupies 2 TEUs. However, yard bay can only accommodate containers with the same size this is a physical restrictions to prevent possible damage. Therefore, the containers terminal assigns each position in the yard bay to a type of containers before the beginning of each planning horizon; this is done automatically, even for empty stacks.

Let R = (K, B) be a graph where K = {1, ..,N} is the containers set and B = {1, …, Nb} is the sub blocks set. The distance matrix cost is denoted by C_k^b. It represents the shortest way between the position of the block b and the ship of container k. The number of empty position of each block is denoted by B.

We propose a new mathematical model that reflects reality and takes into account most of the constraints imposed by port authorities. This model treats the following hypotheses:

1 We do not mix on the same block and in the same period the loading and the unloading containers.

2 Before the beginning of each period, we know the state of the storage area. For each block, we know: the number of container stored, the departure time of each container and the type of the block (dimension of stored containers).

3 For each stack, containers must be stored in the decreasing order of their departure time.

4 Containers are stored by respecting the constraint of dimension compatibility. All containers stored in the same block have the same dimension.
The CSP is formulated as a new and original mathematical programming model. This model is applied on each period in order to determine an optimal storage strategy.

3.2 Model Parameters

The proposed model is applied to each period of the working day in a containers terminal. The planning horizon is consisting of several shifts (3shift per day). In our study we will suppose that the range of shifts will be [1, 10].

Our objective is to minimize the global distance for the unloading containers from the berth to the storage space and then to balance the workload between the adjacent yard bays. The model parameters are defined as follow:
k: Container index.
b: Yard-bay index.
r: Index of row in the yard bay b.
e: Index of the level (tier) in the bay-row.
N: Total number of containers to be stored during the planning horizon.
B: Total number of yard-bays that may contain the containers during the planning horizon.
$\mathbf{w_k}$: The weight of the container k.
$\mathbf{C_b}$: The free storage space in the yard-bay b (free storage positions).
$\mathbf{r_b}$: Type of the yard-bay b (Three types: 20, 40).
$\mathbf{R_k}$: Type of container k.
$\mathbf{D_k}$: Destination of container k.
$\mathbf{D_b}$: Destination of yard-bay b.
$\mathbf{t_k}$: Estimated departure time of container k.
$\mathrm{C_k^b}$**:** The assigned cost to choose / store a container k in the corresponding yard-bay b in the yard area.

Decisions Variables:

$$\mathbf{X_{bk}^{re}} = \begin{cases} \mathbf{1} & \text{if k is assigned to the bay b, row r and tier e.} \\ \mathbf{0} & \text{otherwise.} \end{cases}$$

$$Min \sum_{k=1}^{N}\sum_{b=1}^{B}\sum_{r=1}^{R}\sum_{e=1}^{E} C_k^{\mathrm{b}} X_{bk}^{\mathrm{re}}$$

$$\sum_{k=1}^{N}\sum_{r=1}^{R}\sum_{e=1}^{E} X_{bk}^{re} \leq C_b \; ; b \in \{1, .., B\} \qquad (1)$$

$$\sum_{b=1}^{B}\sum_{r=1}^{R}\sum_{e=1}^{E} X_{bk}^{re} = 1 \;\; ; \; k \in \{1, .., N\} \qquad (2)$$

$$\sum_{k=1}^{N}\sum_{r=1}^{R}\sum_{e=1}^{E} (R_k - r_b) X_{bk}^{re} = 0 \;\; ; b \in \{1, .., B\} \qquad (3)$$

$$\sum_{k=1}^{N}\sum_{r=1}^{R}\sum_{e=1}^{E} (D_k - D_b) X_{bk}^{re} = 0 \;\; ; b \in \{1, .., B\} \qquad (4)$$

$$\sum_{k=1}^{N} X_{bk}^{re} = 1; \; b \in \{1, .., B\}, r \in \{1, .., R\}, e \in \{1, .., E\} \qquad (5)$$

$$(w_k - w_{k'})(X_{bk}^{re\prime} - \sum_{e=e'+1}^{E} X_{bk'}^{re}) \leq 0, b \in \{1, .., B\}, \forall r, \forall e, k\#k' \qquad (6)$$

$$(t_k - t_{k'})(X_{bk}^{re\prime} - \sum_{e=e'+1}^{E} X_{bk'}^{re}) \leq 0, b \in \{1, .., B\}, \forall r, \forall e, k\#k' \qquad (7)$$

$$\mathrm{X_{bk}^{re}} \in (0,1) \qquad (8)$$

3.3 Model explanation :

In order to simplify our model, the related cost of the assignment of a specific container to the yard bay will be equal to distance between the berthing location and the final position in the yard bay. The reason behind this choice is to have a reference to which we can compare the obtained result. In the presented problem, only one vessel will be taken into account in each planning horizon, the planning horizon is defined before the ETA of vessel. It will be based on the vessel length and the number of containers to be stored.

The objective function aim to minimize the global distance for the total inbound containers to be stored during the planning horizon. This horizontal distance is calculated by adding all the distance of the stored containers between the berth location and the storage area (the assigned yard bay to each container). In the constraint (1) we define a total free positions per each yard bay, so the total number of the assigned containers must not exceed the numbers of free positions (this number is known at the beginning of the planning horizon).Constraint (2) ensures that each container is stored in a unique bay during the planning horizon. Constraint (3), (4) ensure that the size and the destination of the bay and the stored container are the same in each planning horizon, the aim of those constraints is to allow the proposed method to define a clustering of the available containers based on their destination and type, then we can allocate in the storage area a specific space to the those containers (consignment strategy). Each free position in the storage space can have only one container stored at the same time, this is what the constraint (5) present. The constraint of weight between the stored containers is defined in the next step (6) so the container on the top must have a weight less than the one stored in the previous level (this data is known for each inbound container). The estimated departure time is also known per each inbound container we will take it into account during the containers storage in the stacking area constraint (7).

4. Container stacking strategy :

Container stacking strategies are solution algorithms used to determine the storage position of each individual container, considering several operational constraints. In other words, stacking strategies are used to decide where to store newly arrived containers. We can find several studies in the literature which are interested in the container stacking problem study, Genetic algorithm (GA), Ant Colony (AC), Simulated annealing (SA) and hybrid between them are already applied to the CSP. No study was interested on the application of other heuristics such as: Bin Packing (BFD) to the CSP by defining a cluster with a set of containers taking into account the defined constraints this is what justifies the choice of this resolution strategy.

In this strategy, we consider several attributes of the containers while determining a stacking position. The first attribute is the expected departure time (EDT), which is defined as the time when a container will be removed from the stack. Secondly, the category of each container is considered the destination of each container and the weight.

The algorithm of the proposed strategy inspired from the bin packing (BFD) heuristic is defined as follow:

1. Get the relevant information of the container: Container type, weight, EDT and container destination.
2. Check each bay of matching container type in order, in ascending order and check whether selected bay is empty or not.
- **a**. If empty, place the arriving container to the first tier of the first stack in ascending order.
- **b**. If not empty, check each stack in order in ascending order of the selected bay for empty positions.
  - **i.** If stack empty, place the arriving container in this stack.
  - **ii**. If not empty, check whether category of the arriving container is the same as the category of the containers in the stack, or not.
    - **1**. If category is same, check if the Destination of the topmost container of the stack is equal to the destination of the incoming container.
      - **a**. If yes, check for the weight constraint
        - **i.** If satisfied.
          - **a.**If the ETD is less than the ETD of the topmost container of the stack, then stack the container.
          - **b.**If not return to the step 2.b
        - **ii**. If violated, return Step 2.b to check another stack of the selected bay.
      - **b**. If no, return Step 2.b.
    - **2**. If category is not same, return to Step 2.b

C L U S T R I N G

C O N S I G N M E N T

The aim of the proposed algorithm is to define an optimized plan to store the incoming containers by minimizing the global distance and reducing the number of reshuffles. As a summary, we will try to take into account to the below assumptions:

- Concentrate on the import operation to locate, store containers in the yard side.
- Use the available terminal equipments: QC, IT (trailer), YC and the straddle carrier to carry and handle the containers between the yard side and the gate.
- The productivity of the QC is known at the beginning of the unloading operation.
- The objective is to minimize the global distance between the yard side and the storage location.
- Reduce the number of reshuffles and avoid the housekeeping operation.
- The key factors of the terminal containers management: ETA (expected time of arrival), ETB (expected time of berthing), and ETD (expected time of departure).
- The assignment of the containers to the blocks will be performed using: the destination, the ETD, the size of the containers.
- A container can be stored in the vessel after the berthing [0,18h] before the unloading operation by the QCO. And during the transfer operation the container can stay in the IT [0, 1h]. And in the yard area between [1,5days].

5. Results:

Our problem interested in the deterministic state of the container stacking problem, the input is supposed to be known beforehand: State on the storage area and also the number of the containers to be stored in a specific planning horizon. The used instances verify the below technical constraints which are related to our port of study. Several instances have been tested using the bellow data:

- There are two types of containers (20 feet, 40 feet).
- We will consider a maximum number of 8QCs.
- Each stack can contain a maximum of four containers.
- Expected Departure date of containers to be stored is randomly chosen between [2h, 96h].
- Each container can wait [0,18h] for unloading from the vessel.
- The productivity of the quay crane is [30, 50] moves per hour.
- Planning Horizon: [0, 36h], Destination Type: 6
- The productivity of one QC which can perform 30moves per hour can be explained by: 5IT + 2.5 YC.
- The available IT in the port: [5, 25] depending on the type of the operation.
- During the transfer by IT, the move time between the seaside and the landside can be [0, 1h].

The model is coded with the Java programming language on Eclipse Standard Edition. The developed program is executed on a Core i5 2,7 GHz Win7 PC with 8-GB memory.

EDT Destination	**10**	**20**	**40**	**50**	**60**	**80**
1	50	40	40	25	24	-
2	20	35	11	-	64	25
3	45	75	56	35	60	45
4	50	50	60	64	-	0
5	50	-	50	24	30	30
6	30	30	30	-	-	15

Fig.4. Dispatching of arrived containers based on the destinations and the EDT.

In order to be able to compare with other results existing in the literature, we tried first to solve the model with an exact method using ILOG cplex, the proposed method (Branch & Cut) provide relevant result only for the small and medium instances. For the big ones, we tried to relax some constraints (10) & (13) to be able to compare with the result provided by Moussi et al (2015) **[18]** in his paper using the HAC/SA (Hybrid Ant Colony / Simulated Annealing).

In fact the initial model proposed by Moussi et al (2011) **[19]**, exclude the incoming containers with a residence time more than the one of all containers stored in the stacks. And also the author didn't take into account the destination and the type of the stored and adjacent sub blocks. So the proposed method has to be adjusted in order to be aligned with what we have in the literature.

The exact method (Branch & Cut) was tested and confirmed for the instances with small and medium parameters. In fact, this exact method can only used to verify the performance of our proposed method for this kind on instances.

The utilization is defined as the ratio of the total storage space occupied by all the unloading containers to the total storage space in the storage yard.

Utilization	Computation Time (s)	Results	Objective Value	Branch & Cut	HAC/SA
0.05	1	Optimal	15350	15350	15350
0.1	1	Optimal	10500	10500	10500
0.15	1	Optimal	17350	17350	17860
0.2	1	--	12004	19980	19980
0.25	1	Optimal	21345	21345	21558
0.3	274	--	21700	20065	20065
0.35	340	Optimal	31500	31500	31500
0.4	1	Optimal	31100	31100	32899
0.45	34,196.03	Out of memory	17564 (gap=12,18%)	33004	30345
0.5	3,833	Optimal	20399	20399	20399
0.55	110	Optimal	21344	21344	21344
0.6	13,304	Optimal	25345	--	25867
0.65	114	Optimal	27234	--	27445
0.7	6	Optimal	32897	--	32988
0.75	11,602	Optimal	39456	--	40156
0.8	6	Optimal	30231	--	--
0.85	32	Optimal	45676	--	47809
0.9	16	Optimal	50769	--	52344

The obtained result for the proposed method is relevant for the majority of the instances mentioned above. This means that the proposed method is more efficient than the one proposed in the study already mentioned above. For the future researches, this method can be combined with a local research method as an hybrid algorithm.

The new developed algorithm will be known as: Constraint satisfaction for minimizing stack numbers (CSMSN)[18]. The idea of CSMSN can be described as: Firstly, value selection rule to stack goods into an available stack location tentatively. Secondly, the domain of the remaining variables is changed through applying Best Fit Decreasing (BFD) and the look-ahead strategy of constraint propagation technology.

After performing the previous experimental evaluation and demonstrated that the effectiveness and feasibility of our approach compared with the best previous approach BFD. The decision maker was able to routinely solve the large & small scale discrete combinatorial optimization problems.

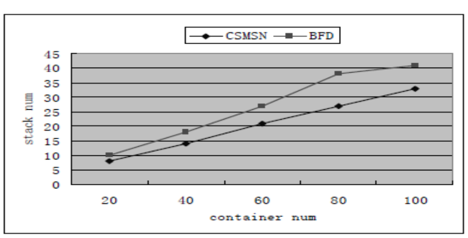

Fig.5. Comparison in stack numbers.

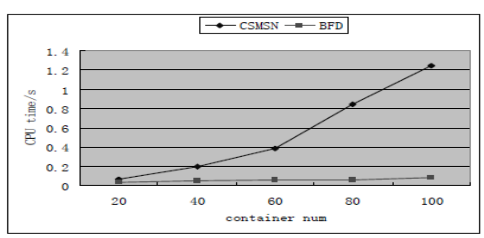

Fig.6. Comparison in CPU time.

6. Conclusion

In this paper we tried to introduce the containers terminal by introducing his structure and also the related researches to each component. Then we proposed a new mathematical formulation of the CSP with new constraints and objective function.

The proposed strategy defines a new method for unloading containers by using the bin packing heuristic as approach of resolution. The obtained result mentions a good performance for the small and medium instances. While it blocked for the big instances.

Future researches can add additional attributes such as the closest transfer point, which requires selecting an empty position closest to the transfer points from which the container will leave the stack, for instance import containers should be stacked as close to the transfer point landside as possible to decrease the traffic caused by external trucks. And also work with several vessels at the same time and also for export and transit in parallel to import operation. Finally the workload between adjacent bays in a storage block can be evaluated after the storage period.

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