AN EFFICIENT HEURISTIC METHOD FOR THE HUMP YARD MANAGEMENT PROBLEM

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ABSTRACT

In this paper, we describe the hump yard management problem. The characteristics and particularities of French hump yard problem are discussed. An efficient heuristic procedure is outlined that first constructs an initial solution according to the characteristics of the problem and then try to improve it by a guided neighborhood search. Computational results show that our approach is capable of getting realistic and good solutions for large scale real instances within few minutes.

Keywords: hump yard, freight transport, sequencing, sorting, optimization, local search.

INTRODUCTION

Classification (or marshaling) yards is a main issue in railways where hundreds of vehicles arrive every day, are re-classified into new blocks, and routed toward their next destination. On average, a typical vehicle spends more time in a yard than traveling on rail lines. The classification yard is therefore an essential element in rail freight operations management where it can become a real a bottleneck if an efficient method or procedure is not applied. Improving the efficiency of yards will release the latent capacity of the yard and also increase the quality of service commitments. It is therefore necessary to use the best operational research's techniques to optimize this phase in the scheduling of freight transportation operations. The vehicles routing is done during a strategic phase upstream of our study; the railway yard goal is to increase the quality of service by minimizing the number of missed matches while ensuring resources constraints compliance and maximizing the utilization of resource.

A complete classification yard (cf. Figure 1) consists in a receiving yard, where incoming trains arrive, a sorting yard, where they are sorted, and a departure yard[1], where outgoing trains are formed.

[1] Some yards don't have departure yard. In this case all departure trains will be done from sorting yard.

There are two types of classification yards: hump yard and flat yard. The difference between both is that the first one uses a special lead track which consists in an artificial hill, called the *hump*. The hump uses gravity to propel the vehicles down the sorting yard tracks. The overall classification process can be shortly described as follows: inbound trains are collected in receiving tracks *(level 1)* where vehicles are separated from inbound trains and are inspected. When these steps are done, the whole set of vehicles is pushed over the hump *(level 2)* by a rail yard engine. At this point, due to gravity, the freight vehicles roll to a set of sorting yard tracks *(level 3)* according to a predetermined assignment. Then, the actual sorting process is performed to produce outbound trains, which are picked up by freight locomotives from the sorting yard and pulled into the departure yard *(level 4)*. Each level contains a set of activities involving the use of tracks, manpower and engine.

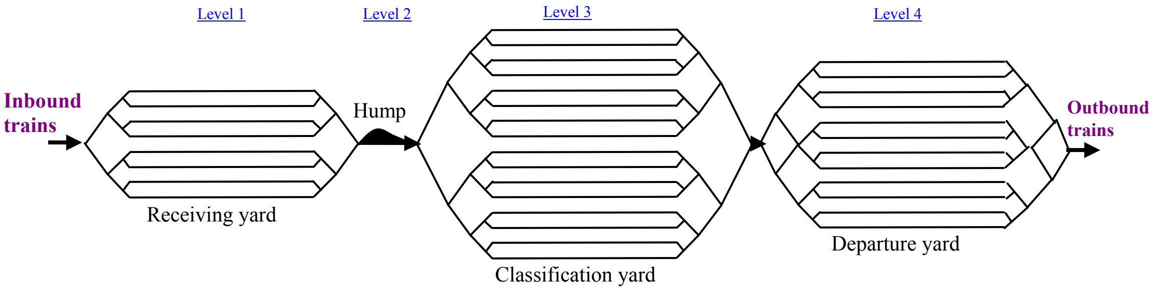

Figure 1. Description of a typical classification yard.

We pointed out the fact that on classification yard we have a specific number of tracks (called fridge tracks) that are dedicated to vehicles that can't be assigned to an available track when humped for their classification and for which the corresponding scheduled train departure time is too far in the future. These vehicles are stored on fridge tracks and are re-humped on the next service[2]

We distinguish two types of shunting railway yards: *single-stage* and *multistage* sorting [1]. The former is used for railway yards having a large volume of traffic (usually between classification railway yards); in this case, each track in the classification yard is dedicated to a specific destination and the freight vehicle sequences of the outbound trains are not imposed. The latter is used for railway yards with traffic directly going to its final destination and where the freight vehicle hump order of the outbound trains are imposed and must be respected. After the incoming trains have been pushed over the hump, a shunting engine repeatedly pulls the vehicles of a given sorting track on the hump's track. These vehicles are then pushed over the hump again, so that each vehicle can be independently routed through the ladder to any sorting track. This process, called re-humping, is iterated until all outgoing trains have been formed.

This paper is organized as follows. In the next section, we present the problem definition. In section 3, the literature review and problem solution are outlined. In section 4, the computational results are presented. In the last section we give a conclusion and future investigations.

[2] They are three services on day.

PROBLEM DEFINITION

We describe the hump yard problem through its input data, constraints, criteria, output data and a degree of freedom.

Input data

We are given:

- Timetable :
  - Period (horizon) of study (one week)
  - Timetable of trains arrivals and departures
- Infrastructure :
  - Number of tracks at each level and characteristics (length, direction, …)
  - Tracks and paths dedicated to specific vehicles
  - Availability of the tracks (e.g. for maintenance)
- Trains and vehicles :
  - Set of trains arrivals and their attached vehicles
  - Connections between vehicles arrival and trains departure. Each vehicle has a set of three possible connections
  - Set of trains departures
  - Static and dynamic rules for vehicles priorities
  - Vehicles that cannot use a hump
- Yard operations :
  - Description of the set of operations at each level
  - Capacity at each level in term of number of operations per period (for instance an hour). This capacity pilots the engine and crew resources

Constraints

The constraints can be classified into two categories, hard and soft constraints. The hard constraints must be respected and soft constraints must be respected as far as possible.

- Vehicles and trains :
  - Connection between vehicles from inbound trains and outbound train
  - Vehicles priorities
  - Maximal length and ton of train
  - Rules to manage the multi-stages classification
- Resources :
  - Maximal capacity that can be used at each step
  - Minimal duration at each step
  - Minimal operation between two consecutive operations
- Infrastructure :
  - Tracks availability
  - Compatibility between trains and tracks in term, of track length and track direction
  - Maximal number of fridge tracks (hard constraint)
  - Tracks that are dedicated for northbound and southbound
- Timetable (hard constraint):
  - arrival time for inbound trains
  - departure time for outbound trains

Criteria

The addressed problem is a multi criteria problem:

- Minimize the number of missed outbound connections (quality of service)
- Minimize the idle time of the vehicles in the yard

- Minimize the set of vehicles in fridge tracks
- Minimize the utilization of receiving, hump, sorting and departure capacities

We pointed out that behind the first criterion we include the delay or the weighted delay by cost.

Output data

- Humping sequence
- Gantt chart to describe tracks assignment to trains at each level
- Key results (criterion value, number of missed connections, the number of vehicles humped over the number of trains departing, Idle time, working time, …)

These outputs will help the user to analyze and to evaluate the process cycle time of the yard.

Degrees of freedom

- Humping sequence or hump speed
- Inspection duration
- Maintenance period of the tracks
- Increase/decrease capacity at each level
- Number of fridge tracks used, …

These degrees of freedom allow the user to define scenarios and to guide the optimization engine towards a realistic and good solution.

Reached decisions

To understand the objective for solving this problem, we first need to understand that yard operations involve several decisions involving scheduling of activities and allocation of corresponding resources to these activities. The Figure 2

Figure 2 gives the most important decisions that are associated to the hump yard management problem defined above.

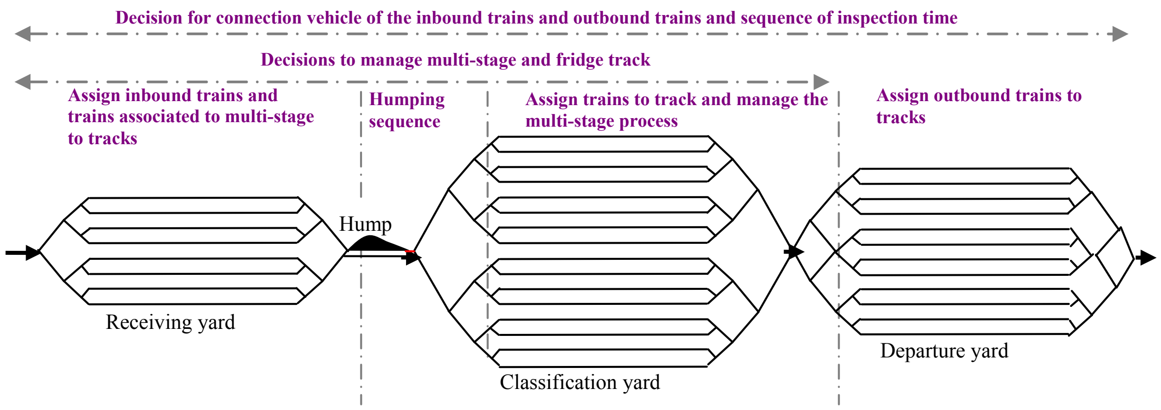

Figure 2. Decisions that are associated to the hump yard management problem.

PROBLEM SOLUTION

Before describing a problem solution we will give a brief review of the proposed methods in the literature. The yard management problem is well known to be NP-Hard and little research has been done on it. One can categorize the realized studies in two groups: The first group is focused on the analysis of the performances of the different operations of the yard by lean or six sigma method for instance. The yard is considered as a production system [2,3] and one can therefore apply the different techniques of production management to improve its performances and to analyze each step of the process. On [2] we can see a good analysis (working time and idle time) of the process cycle time at each step from train arrival to train departure. The second group is concentrating on the operational research techniques. Almost all the methods of proposed optimizations in this group are approximate methods: simulation based rules [4], heuristic [5,6], dynamic programming with problem decomposition for the train-shunting problem. The mathematical programming was proposed on [4,7,8]. For a detailed literature review we refer to paper [4]. All these methods do not approach the freight French problem by taking all the required functionalities: humping order, manage the fridge track, multi-stage sorting and tracks assignment.

Our first investigation is focused on a MIP (Mixed Integer Model) of the hump yard problem with resources and temporal constraints. This approach does not allow us to model the whole problem especially the multi-stage process and to solve a real life problem with reasonable computational time. After that, we decided to direct our research towards a heuristic approach. We have developed a heuristic approach based on two modules: the first one proposes a humping order for the inbound trains and the second one minimizes the number of missed matches with a succession of local optimizations. The first module uses the response of the second one to modify its humping sequence. This process, is iterated until the first module cannot propose a better humping sequence. The proposed solution method is divided in sequential and iterative steps.

Algorithm

Step 0: *"Pre-processing"*

- We load the whole data: infrastructure, material and parameters

- According to the arrival and departure time of the trains we define a restricted dataset by using a feasible and realistic connection between arrival vehicles and outbound trains and defining a realistic time for inspection, humping, etc..

Step 1: *"Construct the first hump sequence"*

- According to the characteristics of the problem we define a first hump sequence

Step 2: *"Construct and repair the solution"*

- According to the current hump sequence:

- *We determine tracks assignment to trains for each level of the process (receiving, sorting and departure track)*
- *We determine the location of the inspection time for the trains at each level*
- *At each decision we propagate the information for the whole system and repair the partial solution if it improves the considered criteria.*

Step 3*: "Guided neighbor hump sequence"*

<u>If</u> the computational time limit is reached <u>then</u> go to step 4

<u>Else</u> We analyze the key results according to the number of missed connections between inbound vehicles and departure trains and define a new hump order.

Step 4: *"Output" It determines the Gantt chart for the track assignment and calculates key results*

The step 2 is the principle and important stage of our approach.

COMPUTATIONAL RESULTS

To validate our approach computationally we have obtained ten real cases. We believe our real tests cases are large enough to indicate that our approach is viable in terms of solution quality and in terms of computational time. In table 1, we illustrate the characteristics of the

tested cases and the corresponding CPU time for our approach without neighborhood search (step 3). Table 1 only shows the important criterion of service quality (measured by the number of missed connections).
The obtained results on the real dataset show that we can find quickly a very good solution in comparison with the manual solution that can be obtained in a few days with a hard work. The proposed method will help the planner to adapt his plan very quickly.

Table 1. Results on real life hump yard instances.

	Dataset for two classification yards	Nb. Of vehicles[b]	Nb. of Inbound trains	Nb. Of outbound trains	Nb. of missing connections	CPU time in seconds[c]
Yard 1	*dataSet1*	6451	236	184	**1**	14.72
	dataSet2	6262	214	201	**329**	60.82
	dataSet3	6110	428	406	**0**	4.21
	dataSet4	7710	300	233	**162**	96.25
	dataSet5	7262	353	338	**155**	26.56
Yard 2	*dataSet6*	7366	403	372	**0**	5.23
	dataSet7	7582	228	219	**156**	10.54
	dataSet8	8032	262	287	**172**	7.85
	dataSet9	8705	272	274	**190**	11.45
	dataSet10	9273	403	372	**154**	9.58

[a] The average number of tracks was between 7 and 15 for receiving yard, one hump, between 30 and 44 tracks for sorting and between 17 and 23 tracks for departure yard.
[b] The study period was a week. To avoid the edge effect we took two days before and two days after the considered week.
[c] The numerical experiments have been performed on a 2.33GHz AMD Athlon PC with the memory of 2Go and running windows XP. The CPU time corresponds to the data reading, the optimization and the output generation. 1/3 of this time is for the optimization.

We also remark that when the size of the problem grows there is no impact on the cpu time. And by introducing the guided neighborhood search (step 3), table 2, the average improvement of the solutions in terms of criteria is very important.

We can see that in table 2, we reach the optimal solution for the third and the last example. If we look into details, for the second example we have 48 missing connections with a total of 6262 wagons in inbound trains; these 48 missing connections are linked with only 6 inbound trains (with a total of 214 inbound trains). For the fifth example, we have 21 missing connections with a total of 7710 wagons in inbound trains; these 21 missing connections are linked with only 5 inbound trains (with a total of 300 inbound trains).

Table 2. Results on real life hump yard instances.

Dataset for two classification yards		Without step 3		With step 3	
		Nb. of missing connections	**CPU time in seconds(c)**	**Nb. of missing connections**	**CPU time in seconds(c)**
Yard 1	*dataSet1*	1	14.72	1	105
	dataSet2	329	60.82	48	115
	dataSet3	0	4.21	0	138
	dataSet4	162	96.25	21	107
	dataSet5	155	26.56	5	123
Yard 2	*dataSet6*	0	5.23	0	131
	dataSet7	156	10.54	42	105
	dataSet8	172	7.85	0	101
	dataSet9	190	11.45	12	97
	dataSet10	154	9.58	17	151

The algorithm developed has been used on MS Excel where we exploit their power with VBA code. The figure 3 gives the architecture of the decision support prototype.

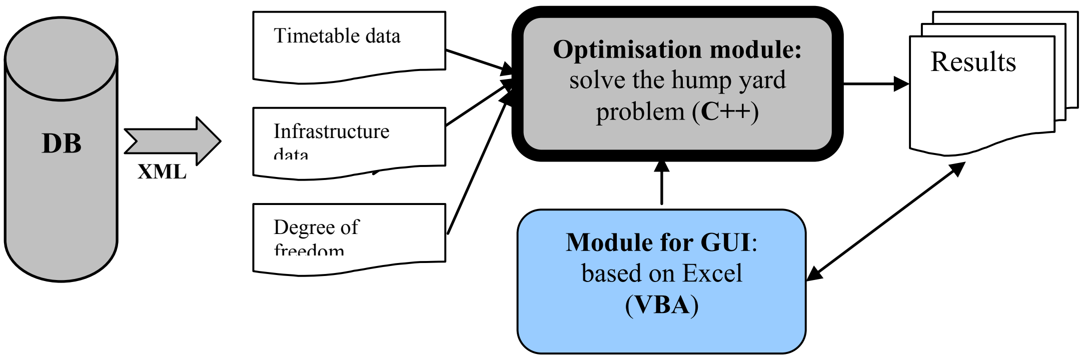

Figure 3. Architecture of the decision support prototype.

The results of a run of the algorithm can be shown by the decision support prototype in Excel sheet, by tabular format or in graphical format in the form of a Gantt chart. An example of such a Gantt is shown in figure 4 which represents assignment of tracks to trains in sorting. The colors represent the different operations: inspection time, waiting time, transfer time from one level to the next level.

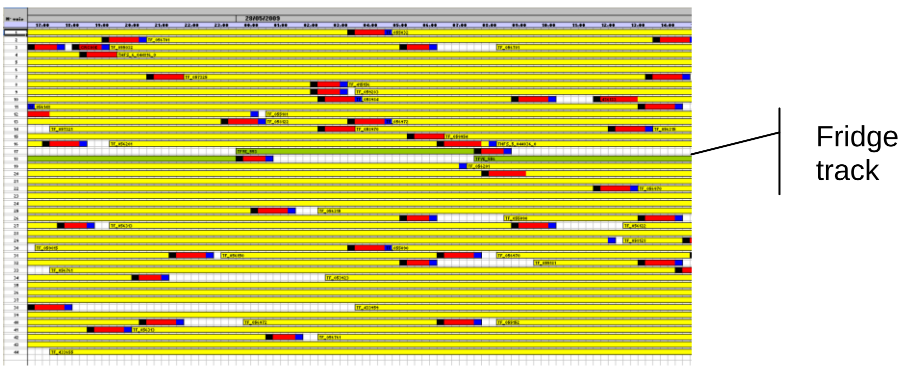

Figure 4. Gantt chart for tracks assignment in sorting.

The figure 5 represents the different capacities that are associated to the obtained solution: the maximal capacity, the capacity provided and the capacity used.

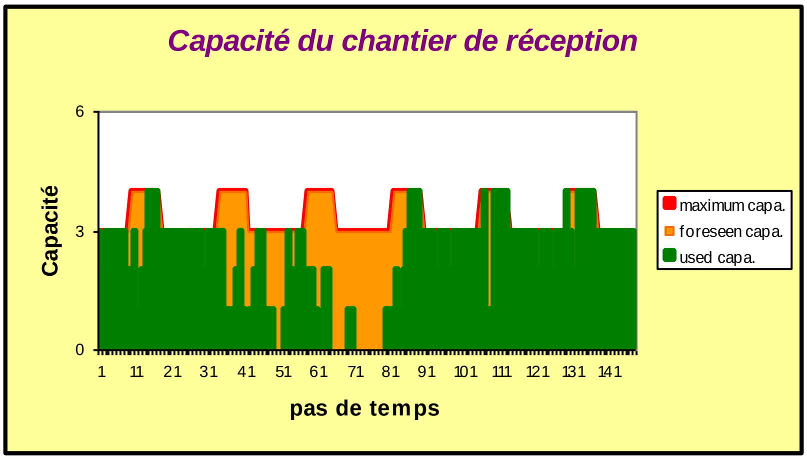

Figure 5. Resource consumption in a receiving yard.

The experimentation of our approach on large scale real datasets, proposed by our customer, has shown, on the one hand, the efficiency of the solution techniques proposed, and on the other hand, the flexibility of the proposed heuristic to model any type of constraint. We have also shown and evaluate the influence of each parameter on the solution quality and the corresponding cost. The decision support prototype will be used as a system of "*what if analysis" by studying the impact of each resource: +/- capacity, +/- tracks..*.

CONCLUSION AND FUTURE WORK

In this paper, we addressed the hump yard problem and their characteristics and variants. And we outlined the proposed approach that allows us to solve the hump yard management problem in a realistic way. The proposed method is based on two steps: the first step is to construct a hopefully good solution by taking into account characteristics of the problem and then try to shake the solution in order to improve the optimized criteria.

The obtained results are very promising and we show with real data that the proposed method is well oriented to propose quickly a solution that maximizes the service quality and that optimizes the resources used. The proposed system is intended s a strategic decision making tool. It will help our organization in charge of the yard management plan to reduce the throughput time of the planning process. Meanwhile, it allows the organization to increase the flexibility and react faster to changes in the environment in particular in the context of freight. Further recognized advantages of the proposed tool are the fact that the organization becomes less dependent on the experience and the craftsmanship of the planner.

Future research on the hump yard problem could aim, on the one hand, at the integration of robustness criteria in our approach, and on the other hand, at the adaptation of our approach to the operational context.

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