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SUPPLY CHAIN ROUTING SCHEDULING SUB-MODEL DESIGN: CASE OF EXPORT BULK PORTS

S. Mallah*, ** & A. Aloullal*
*ILO – University Mohammed 6 Polytechnic (UM6P), Bengueir, Morocco
**LTI – National School of Applied Sciences – Abdelmalek Essaadi University (AEU), Tangier, Morocco
sara.mallah@um6p.ma/sara.mallah@etu.uae.ac.ma, afaf.aloullal@um6p.ma

O. Kamach*, **, M. Masmoudi***, N. Najid****, K. Kouiss******, L. Deshayes*
***University Jean-Monnet, France
****Mechanical and Productive Engineering Department, University of Nantes, France
******SIL – Blaise-Pascal, university of Clermont Ferrand, Aubière, France
oulaid.kamach@um6p.ma, malem.asmoudi@univ-st-etienne.fr,

ABSTRACT: The integration of planning and scheduling decisions of loading, stacking/scraping, routing and production making up an integrated optimization plan without contradictory goals is vital for an efficient use of the four aforementioned bulk port operations. Usually, the optimization of these decisions is approached in an integrated fashion in one mathematical model. In this paper, we discuss another integration approach using a real case as an illustration. The proposed approach can improve the design phase in optimization problems and avoid the cons of the classical methodology. It can also come up with a number of pros which can be summed up mainly in the ability to design the optimization problems, in such a way to reflect the real aspects of the industrial settings.

KEYWORDS: shipping operations, optimization, transport problem, conveyor paths, problems integration.

1 INTRODUCTION

In order for an export bulk terminal to deliver the right product, with good quality, to the right customer, in the right place and at the right time, an optimization of its logistics process is essential to set up. The case study in this work deals with an optimization which aims to return, in a reasonable planning time, an integrated operations plan maximizing the loading capacities over a planning horizon of tactical level. Where each of the four sub-problems (loading, stock, routing and production) making up the overall port optimization problem must maximize the loading capacities taking into account the other logistics operations which may have contradictory goals.

An alternative to planning and scheduling the port operations in an integrated approach, considering the four sub-problems in one mathematical model is to integrate the planning sub-problems as separated sub-systems interacting with each other in a smart fashion. The rational behind this alternative is because the integrated approach may lead to an optimization result which does not include all the specifications reflecting reality or that does not converge. Similarly, the option of treating each of these sub-problems separately has raised two very important questions:

- How to manage the interactions between the four sub-models so that the planning system converges in a reasonable response time and avoids quasi infinite interaction loops between the three sub-models?
- What are the decision variables, the objective functions and the constraints of each sub-model, provided that consistency and avoidance of redundancy between the four sub-models are maintained?

A discussion about how a coupling strategy can allow to answer the questions above is presented along with how the routing model can be designed considering the real industrial settings. The paper is structured as follows: related works concerning the planning and scheduling of bulk port problems are provided in section 2. Section 3 will describe the problem at hand. Section 4 comprise the discussion about the coupling strategy and the routing problem. Finally, a conclusion and perspectives are given in section 5.

2 LITERATURE REVIEW

The belt-conveyors routing scheduling problem in bulk port has just been studied recently [2]. In fact, enormous efforts have been rather made toward optimizing transportation problems in container port terminals, which implies without having the belt-conveyors routes as a means of transportation [3, 4, 5, 6]. The authors of [3] tackled transportation systems for container port logistics by focusing mainly on task assignments problems or routing problems for automated guided vehicles, while the authors of [4] solved multi-trailer transportation routing problem and in [5], the authors solved the routing problem for a fleet of trucks with different capacities. The authors of [6], on the other hand, worked on the container allocation and the straddle-carrier routing problem. Apart from container ports, the transportation
optimization was studied in a general context in [7] which studies the vehicle routing and truck driver scheduling problem where routes and schedules must comply with hours of service regulations for truck drivers. Therefore, as bulk ports started to receive a growing interest conveyors-belt based transportation optimization is strongly demanded. In this paper, we are focused on the belt-conveyors routing scheduling problem, in bulk ports, in such a way to comply with the other operations planning and scheduling decisions, namely: stock management and reclaiming problem and berth allocation problem.

From the earliest work, we can find the work of [8] where the authors dealt with the belt-conveyor routing transportation routing problem along with the storage allocation problem where requests are given in real time. They provided a formulation of the problem using a mixed integer programming approach and proposed a Lagrangian decomposition to solve it and compared it with the hierarchical planning method.

In the same perspective, the authors of [2] dealt with the conveyor-belt transportation routing optimization along with stockyard optimization in an integrated fashion, while calling the integrated problem as the Product Flow Planning and Scheduling Problem. But they also considered more constraining aspects, compared to [8], such as route allocation constraints, product scheduling constraints and equipment capacity constraints.

In fact, instead of considering one mathematical model that would lead to uncontrollable complexity, or to an optimization result that miss real industrial use cases, and that wouldn’t converge, we actually proposed to integrate the planning and scheduling sub-problems as separated sub-systems interacting with each other without falling in quasi-infinite interaction loops. And to the best of our knowledge, there is no optimization work in the literature that takes the interactions between subsystems into account before moving to the optimization of each subsystem, although these interactions cannot be neglected in a real case, otherwise, the returned solution of each subsystem will be biased. Besides, since the integration approach proposed in [1] managed to maintain consistency and avoidance of redundancy between the sub-models in terms of decisions, thus in terms of decision variables, constraints and objective functions. Then, as a result, the routing sub-model, has its constraints relaxed given that all the dynamic aspects of a real industrial setting are considered including the real conveyors paths matrix structure. In this paper, we are going to propose the model of the routing scheduling sub-problem.

3 PROBLEM DESCRIPTION

The problem investigated in this paper is motivated by a real case dealing with the planning and scheduling of an export bulk port. In order to fulfill its mission which is to supply the end customer (trucks / ships) with the requested product, the terminal possesses several types of equipment: stacker for stocking products, scrapers to scrape or destock the products, belt conveyors to transport products from a source to a destination, and gantry cranes to load ships. The trucks are loaded directly by pouring the product, contained within the belt conveyor, into the truck. The products moved through the port concern fertilizers and phosphates whose qualities differ in their chemical and physical characteristics such as granularity. Thus, for fertilizers and phosphates, there is a whole host of ranges or families of products and each of these ranges includes a whole set of qualities amounting to about 40 qualities.

The port platform is made up of four subsystems (figure 1) which are: the fertilizer and phosphate production lines, the storage sheds where the two operations of stocking and scraping are carried out, the set of conveyor routes for the transport and finally the loading stations, be it the berths for loading ships or the loading stations for trucks.

The production subsystem consists of several sets of production lines. In our case, these are four sets of production lines. Each set of production lines is connected to a unique set of the storage subsystem. Given that each set of the storage subsystem is composed of several hangars where different qualities of the products are stored.

The storage subsystem automatically includes four storage sets: A, B, C for the storage of fertilizers, and D for the storage of phosphates. All storage subsystems are supplied with products from their own factories. The stock subsystem B, in particular, can also receive products from the storage set: A.

The loading subsystem includes a trucks loading stations set and a vessels loading set. The trucks loading set consists of loading stations where each station manages to load a truck with product from the storage sets A and B only. While the vessels loading set is made up of several berths each housing a set of gantry cranes for loading vessels with products from all the storage sets: A, B, C, and D.

The routes subsystem is a combination of routes defining several path options through which products can be routed between the different subsystems. Many routes share common conveyors, so if products of different demands are to be transported at overlapping time intervals, they must be assigned to routes that do not overlap. Each route has a predefined capacity which must be respected. Figure 1 shows a general schematic about the four sub-
systems of: production, storage, loading and routes without representing the extreme degree of complexity of each of them. For instance, the conveyor routes combination whose each line illustrated in figure 1 refers to a whole combined set of paths.

In this paper, as already mentioned, the interest is focused on the routing sub-problem in particular. In addition, the port of the case study does not raise any need for optimization involving transport from the production lines since each storage shed has a production plant which supplies it with product. The need for optimization lies in the network between the storage and loading subsystems. In fact, the sets of the storage subsystem are not of the same kind, thus constituting six sources instead of the four already mentioned: A, B, C, D. To detail this further, each set of \{A, C, D\} is a homogeneous set. Which means that all the hangars of the same set have the same characteristics. Conversely though, the set B consists of hangars which do not have the same characteristics, thus generating three subsets of the set B.

More precisely, each of \{A, C, D\} is a set of hangars:

- Where each hangar has only one entrance or input, making it one destination at a time.
- Where each hangar has only one exit or output, making it one source at a time.
- The maximum output capacity is the same for all hangars in the same set: capacity C1 for sources in set A, and capacity C2 for sources in sets C and D.

Given that C2 is greater than C1.

While set B is special in all aspects. It consists of hangars:

- Where each hangar has only one entrance, making it one destination at a time.
- The maximum entry capacity is the same for all hangars, which is C3.
- Where a subset of hangars B is at a single outlet making each of them a single source at a time with a maximum capacity C2.
- Whereas another subset of hangars B has two exits, making each of them two sources which, in turn, are not homogeneous. Because the two sources are at a maximum capacity C1 and C2 respectively.

The loading subsystem is made up of destinations with different maximum capacities: C4 for trucks loading stations and C1 and C2 for berths gantry cranes.

The routing sub-model is intended to transport the products between the sets of the storage subsystem and between the storage and loading subsystems. This refers to transporting the products from six sets of sources: \{A, B (including its three subsets), C, D\} whose capacity belongs to the set of capacities \{C1, C2\} to the set of destinations \{B, trucks loading set, vessels loading set\} whose capacity belongs to the set of capacities \{C1, C2, C3, C4\} Given that: C3 <C4 <C1 <C2. Thus, making a combinational game of very complicated conveyor. To fully understand the matrix of conveyor routes, we have classified the routes into ten types. Each type composes a set of routes with the same source set, the same destination set and whose maximum capacity is equal to the minimum capacity of the source and the destination. This will contribute in reducing the complexity while generating the routing plan. All of these ten routes classes (figure 2) include:
• **Rx**: the routes formed from the exits of the hangars of set A, to the entrances of set B with a capacity C3.

• **Rs**: the routes formed from the exits of the hangars of set A, to trucks stations with a C4 capacity.

• **Ry**: the routes formed from the exits of the hangars of set A, to the berths gantry cranes with C1 capacity.

• **Rt**: the routes formed from the exits of the hangars of set B (the three sub-sets of B included), to trucks stations with C4 capacity.

• **Rzsmall**: the routes formed from the exits of the hangars of set B (the three subsets of B included), to the berths gantry cranes with capacity C1. The term "small" refers to the fact that loading of ships is possible on two capacities: C1 and C2. Except that C1 is smaller than C2.

• **Rzbig**: the routes formed from the exits of the hangars from set B (only two subsets of B included: hangars with only one exit with capacity C2, and hangars with 2 exits and precisely from exits whose capacity is C2), up to ship berths gantry cranes with capacity C2. The term "big" refers to the fact that loading of ships is possible on two capacities: C1 and C2. And C2 is the maximum capacity.

• **Rvsmall**: the routes formed from the exits of the hangars of set C to the berths gantry cranes of ships with a capacity of C1.

• **Rvbig**: the routes formed from the exits of the hangars from set C to the berths gantry cranes with C2 capacity.

The combination of these paths has of course given possible overlaps within each type of routes and between different types. The possible overlaps between routes of different types are illustrated in table 1.
Table 1: Overlaps between routes

<table>
<thead>
<tr>
<th>Routes type</th>
<th>Itinerary</th>
<th>Overlap with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routes S (R_s)</td>
<td>A – Trucks loading stations</td>
<td>( R_s, R_T, R_x, R_y, R_{m,small} ) and ( R_{big} )</td>
</tr>
<tr>
<td>Routes T (R_t)</td>
<td>B – Trucks loading stations</td>
<td>( R_T, R_s, R_{m,small}, R_{big} )</td>
</tr>
<tr>
<td>Routes X (R_x)</td>
<td>A – B</td>
<td>( R_x, R_T, R_s )</td>
</tr>
<tr>
<td>Routes Y (R_y)</td>
<td>A – Loading berths with capacity C1</td>
<td>( R_T, R_s, R_x, R_{m,small}, R_{big}, R_{m,small}, R_{big} )</td>
</tr>
<tr>
<td>Routes Z</td>
<td>( Z_{small} (R_{m,small}) )</td>
<td>B – Loading berths with capacity C1</td>
</tr>
<tr>
<td>Routes V</td>
<td>( V_{small} (R_{m,small}) )</td>
<td>C – Loading berths with capacity C1</td>
</tr>
<tr>
<td>Routes W</td>
<td>( W_{small} (R_{m,small}) )</td>
<td>D – Loading berths with capacity C1</td>
</tr>
</tbody>
</table>

4 INTEGRATION APPROACH AND ROUTING OPTIMIZATION DISCUSSION

In this paper, we report that optimization problems especially those that comprise a number of sub-problems, could be approached otherwise than in classical methodology. The latter consists of formulating the subproblems into one mathematical model, which will yield to many complications we will bother to resolve afterwards, such as: getting optimal results in enormous response time or may be no optimal results at all. Even if they are gathered in one mathematical model, we may not be exhaustive in terms of real-world use cases. In either case, there will be massive work to put in while designing a resolution method. We suggest that we can approach such optimization problems by considering sub-problems of the global problem and formulate each sub-problem into one mathematical model. Each one will be bound to give optimal plans feasible for other sub-models. However, there is an urge for a coupling strategy to consider between the sub-problems in order to avoid quasi-infinite interaction loops. An important word of caution, the decision variables, objective functions and constraints of each sub-model should not be redundant with those of the other sub-models. As the matter of fact, they should be consistent between each other. For instance, in our case, the global objective is to maximize the loading volume. Therefore, the loading sub-model will first generate optimal loading plans in such a way to maximize the loading volume. The stocking/reclaiming and routing sub-models on the other hand should have objective functions that lead to maximizing the loading volume.

Furthermore, the routing sub-model could not generate optimal plans given only the loading plans which advise the routing sub-model on the destination i.e., to which transport the product, but it also needs to get the stocking/reclaiming plans as input to know the source from which the routing sub-model can take the product. So, the routing problem comes the last one on the decision process which can save the routing problem for many decisions. The decisions of the routing problem will be broken down into a small number of constraints. In fact, this will allow the routing problem to focus on real aspects of a routing problem, namely the sophisticated conveyor-routes matrix and the configurations of the qualities to be loaded. For example, to serve a demand whose qualities can be loaded at the same time or successively. So, the routing sub-model would receive the planning demands from the loading and stocking sub-systems, where each demand is characterized by a list of qualities (products) that should be transported to a destination. The time window of each demand is known, as well as the source and destination of each quality that make us define the subset of routes \( R_k (R_s, R_T, R_x, R_y, R_{m,small}, R_{big}, R_{m,small}, R_{big}, R_{m,small}, R_{big}) \) rather than the whole set \( R \). The routing sub-optimizer aims to find for all demands, the routes that minimize the sum of tardiness penalties and waiting costs. Hence, for each logistics operation, the optimal path can be selected from a subset of routes instead of all of the routes set. We hypothesize that selecting routes from smaller sets will accelerate the response time.
In this paper, we presented the spirit of the integration approach of bulk port operations planning and scheduling decisions. The integration approach implies that the global port optimization problem is decomposed into four sub-problems, then the four resulted planning sub-systems interact with each other in a way that retains coherence between the sub-optimizers and avoids any eventual decision redundancy between them. Thanks to this approach, many constraints can be relaxed in the routing model. In the literature review, some authors studied the integrated routing-stock problem, which makes the formulation more complex. However, in our case, the extra decisions related to the stock nor those of the loading do not need to be modeled, because these decisions are already dealt with by the stock and the loading sub-optimizers respectively. The idea is to get each sub-problem deal with its own decisions; first the loading sub-optimizer handles many decisions, then comes the stock sub-optimizer that has other decisions left. As a result, the routing sub-optimizer has less decisions to do and focuses only on the significant complexity of a real industrial belt-conveyor paths matrix with routes conflicts included. The future work, we will propose a mathematical model formulation of the routing problem to verify the hypotheses we talked about in the discussion.

REFERENCES


