



Implementation of a Computerized System Based on the Recursive Core Heuristic (RCH) Algorithm for Optimal Filling of Tankers

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2021/v27i1230477

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/63937>

Original Research Article

Received 15 October 2020
Accepted 22 December 2020
Published 21 December 2021

ABSTRACT

The paper focuses on the implementation of a computerized dispatching system for petroleum products in service stations for the company SEPCONGO. The objective is to achieve a software allowing to automate the optimal planning of filling of tanker trucks by using the tools proposed by Operational Research, more precisely of the combinatorial optimization resolution methods for the multiple backpack problem. In this contribution we propose the design and realization of a computerized system for optimal filling and dispatching of tank trucks through the service stations of the City of Kinshasa based on a mathematical optimization problem, with making an optimal good decision. Knowing the trajectory of vehicles is important for a company because it saves time and capital. In this article, we clearly show that with a backpack algorithm we can easily solve the dispatching problem. However, we are proposing a system that will allow SEPCONGO to optimize the delivery of products through the city of Kinshasa in particular and those of the Democratic Republic of Congo.

Keywords: RCH; MKP; multiple knapsack problems; heuristic; dynamic; programming; operational research.

1. INTRODUCTION

It is increasingly clear that companies can no longer operate efficiently without automating their IT infrastructure. Operational Research, through its tools, can help the decision-maker when he is confronted with a problem such as a combinatorial type, i.e. includes a large number of admissible solutions among which a solution is sought. optimal or close to the optimum. And this by using algorithmic processes making it possible to optimize the solution of the problem posed while respecting its constraints [1]. This is how the algorithms, like those of the backpack problem, which are part of these Operational Research tools make it possible to solve combinatorial type problems in practical areas of daily life within companies such as in logistics such as the loading of planes, boats or even trucks, Faced with the increase in data to be managed within companies, automation has become a key issue in them [2-5]. Aware of this reality, SEP / CONGO, more particularly its Dispatching service, wishes to carry out the development of the planning of tanker truck loads in an automatic way using a computer application. Indeed, the difficulty of developing tanker truck loading planning lies in having to decide on: when faced with a set of controls and a tank truck set, which controls should be loaded into a truck of a certain capacity [6-9]. Given the tankers intended to deliver the products. Knowing about the different orders, what combination of products should be loaded into the trucks in order to maximize loading at 100%; and How to carry out this loading .while wanting to minimize the cost of transport? These are the questions the dispatching service seeks to answer, as it has been a difficult task to perform until then. Of course, we are stuck with a decision problem that may have a large number of admissible solutions among which we are looking for an optimal solution or close to the optimum, in order to solve it. We thus propose to design an application implementing a combinatorial optimization algorithm while modeling the problem in the form of a multiple backpack problem [10-12]. This will allow the dispatching service: to considerably increase its potential for scalability and capacity by guaranteeing constant and controlled quality of services; reduce the arduousness of the tasks for the dispatching manager. By freeing the dispatching manager from tedious and iterative tasks, we will give them time to optimize the management of the production line: Anticipate, optimize, while making him able to opt for better

solutions. And also, we will help him meet the customer's needs while controlling costs.

2. PRELIMINARIES

2.1 Mathematical Optimization

2.1.1 Definition

Optimization is a branch of mathematics seeking to model, analyze and solve analytically or numerically the problems which consist in minimizing or maximizing a function on a set. The function to be optimized is called economic function or criterion or objective-function or quite simply objective [R. FAURE, 2009.]. Optimization plays an important role in Operations Research in applied mathematics and in analysis and other areas of applied mathematics [13].

2.1.2 Methods of solving optimization problems

The resolution of different kinds of problems encountered in every day has prompted researchers to come up with resolution methods and to make great efforts to improve their performance in terms of the computing time required and / or the quality of the proposed solution. The exact methods, the approximate methods. metaheuristic methods. Metaheuristics can be classified into two categories: single solution-based methods and population-based methods of solutions. The single solution-based methods are generally based on a local search (search by neighborhood), unfortunately most of these methods suffer from the fact that they allow to escape the problem of the local optimum and to determine the overall optimum [14].

2.1.3 Fields of application

We have several fields of application, notably in optimization of a route, a sale price, a chemical reaction, air traffic control, the efficiency of a device, the operation of an engine, the management of railway lines. , the choice of the economy of the investments, the construction of a ship, in the development of databases, for the search engines, for the code etc.

2.1.4 Uses

The problems of the dynamics of indeformable solids (especially the dynamics of articulated rigid bodies) often need mathematical optimization techniques, since we can see the

dynamics of rigid bodies as solving an ordinary differential equation on a constrained manifold, the constraints are various nonlinear geometric constraints such as "these two points must always coincide", or "this point must always be on this curve".

2.2 Backpack Problem

In algorithmic and optimization, the backpack problem, also noted KP (in English, Knapsack problem) is a combinatorial optimization problem whose statement is presented as follows: "Given several objects each having a weight and a value and given a maximum weight for the bag, what items should be put in the bag in order to maximize the total value without exceeding the maximum allowable weight for the bag?" The Multiple Knapsack Problem (MKP) is a generalisation of the standard 0-1 Knapsack Problem where instead of considering only one knapsack, one tries to fill m knapsacks of different capacities. Let $N = \{1, \dots, n\}$ be the set of items where each item j has a corresponding profit p_j and weight w_j . We consider m knapsacks of capacity c_i , $i \in \{1, \dots, m\}$, then the MKP consists in filling all knapsacks so that the total profit is maximised and the sum of weights in each knapsack i does not exceed the capacity c_i . We denote the binary decision variables by x_{ij} which take value: 1 if item j is assigned to knapsack i and 0 otherwise. The MKP is formulated as the following 0-1 integer programming problem:

maximise :

$$\sum_{i=1}^m \sum_{j=1}^n p_j x_{ij} \quad (1)$$

$$S.t \sum_{j=1}^n w_j x_{ij} \leq c_i, i \in \{1 \dots m\} \quad (2)$$

$$\sum_{j=1}^n x_{ij} \leq 1, j \in \{1 \dots m\} \quad (3)$$

$x_{ij} \in \{0, 1\}$, $i \in \{1, \dots, m\}$, $j \in \{1, \dots, n\}$; where p_j , c_i and w_j are positive integers and constraints (2) and (3), respectively, ensure that the filling of knapsack i does not exceed its corresponding capacity c_i and every selected item is assigned only to one knapsack, respectively. In order to avoid any trivial case, we make the following assumptions.

- All items have a chance to be packed (at least in the largest knapsack):

$$\max_{j \in N} w_j \leq \min_{i \in \{1, \dots, m\}} c_i \quad (4)$$

- The smallest knapsack can be filled at least by the smallest item:

$$\min_{i \in \{1, \dots, m\}} c_i \leq \min_{i \in N} w_j \quad (5)$$

- There is no knapsack which can be filled with all items of N :

$$\sum_{k=0}^n w_j \leq c_i, \forall i \in \{1 \dots m\} \quad (6)$$

We assume also that the items and the knapsacks are sorted as follows:

$$\frac{p_1}{w_1} \geq \frac{p_2}{w_2} \geq \dots \geq \frac{p_n}{w_n} \quad (7)$$

$$c_1 \leq c_2 \leq \dots \leq c_m. \quad (8)$$

Cargo loading is a real world application of the MKP, [see Eilon and Christofides (1971)]. The problem is to choose some containers in a set of n containers to be loaded in m vessels with different loading capacities for the shipment of the containers. Other industrial applications are the loading of n tanks with m liquids that cannot be mixed, [see Martello and Toth (1980),] vehicle loading, [see Hifi (2009)], task assignment and multiprocessor scheduling, [see Labbé et al. (2003)]. The MKP problem is strongly NP-complete and the need for algorithms that give a good heuristic solution is justified by the computational complexity of this problem. Reference is made to Hung and Fisk (1978), Martello and Toth (1990) and Kellerer et al. (2004) for contributions to this problem. In this paper, we present a heuristic which yields a feasible solution within a reasonable computing time, this is done by exploiting efficiently the core of each knapsack. To the best of our knowledge, this paper is the first paper to deal with a heuristic since Martello and Toth (1980). Section 2 deals with principle of the Martello and Toth heuristic. The proposed method is presented in Section 3. The Section 4 is devoted to the presentation and analysis of computational results on randomly generated instances. Finally, in Section 5, we give some conclusions and perspectives of our work.

2.2.1 Martello and toth heuristic

In Martello and Toth (1980), the so-called MTHM heuristic is given for the MKP. This algorithm consists of three phases. The details are available on pages 179–181 in (Martello and Toth, 1990, pp. 179–181). The first phase of MTHM obtains an initial feasible solution by applying the Greedy algorithm (Procedure 1) to the first knapsack; a set of remaining items is obtained, then the same procedure is applied for the second knapsack; this is continued till the

m th knapsack. The second phase tries to improve the initial solution by swapping every pairs of items assigned to different knapsacks and trying to insert a new item so that the total profit is increased. The last phase tries to exclude in turn each selected item if it is possible to replace it by one or more remaining items so that the total profit sum is increased. The advantage of the MTHM heuristic is that some items can be exchanged from a knapsack to another or excluded from the solution set so that total profit increases. This can lead to an efficient and fast solution when the solution given by the first phase is good. The main drawback of MTHM heuristic is that it considers only the exchanges between a pairs of items instead of combinations of items.

2.2.2 RCH, a recursive core heuristic for the MKP

The proposed heuristic called RCH, is a recursive method that performs computation on the core of knapsacks. The RCH heuristic is compared with the MTHM heuristic of Martello and Toth. Computational results on randomly generated instances show that the proposed approach gives better gap and smaller restitution times. The aim of the proposed approach consists in packing the maximum number of 'best' items with regards to relation (4) in a small computation time. For that purpose, an efficient lower bound z of the MKP is built as follows. We consider the series of knapsack problems:

$$(KP_i) \left\{ \left\{ \max \sum_{j \in N_i} p_j x_j \mid \sum_{j \in N_i} w_j x_j \leq c_i, x_j \in \{0,1\} \right\}, \in \right. \\ \left. N_i, i=1, \dots, m \right. \quad (9)$$

With $N_1 = N$, $N_i = N_{i-1} - \{I \in N_{i-1} \mid x_I = 1\}$ and z_i the lower bound of (KP_i) such that $z = \sum x$

$\sum_{j \in N_i} p_j$. Then, a lower bound of MKP is given as follows. $z = \sum_{i=1}^m z_i$

In order to simplify notation and without loss of generality, we consider that the elements of N_i are indexed from 1 to $Card(N_i) = n_i$, i.e., $N_i = \{1, \dots, n_i\}$.

Procédure RCH

Entrée: $N, (p_j), (w_j), (x_j), c_i$

Sortie: Z ;

$Z=0$;

//Traitement des $m-1$ premiers sac à dos//

For $i := 1$ to $m-1$ do ;

$Z_i = 0, c_i = c_i$

Procédure 1 sur c_i ;

If $c_i > 0$ then

Définir le noyau C_i de c_i ;

Procédure 2 sur SPP

End if

Mise à jours de N ;

$Z=Z+Z_i$;

End for

//Traitement du dernier sac à doc//

Procédure 1 sur c_m ;

If $C_i > 0$ then

Définir le noyau C_m de c_m ;

Procédure 3 sur KPC_m ;

End if

$Z=Z+Z_m$

end

3. MATERIALS AND METHODS

3.1 Presentation of the Tools Used

For our study, we used the following tools:

3.1.1 Google maps

This is an online mapping service created by Google allowing from the scale of a country, to zoom to the scale of a street.

3.1.2 Netbeans

Integrated development environment supporting various programming languages such as the one we used for the implementation of our application: Java [15].

3.1.3 Wampserveur

Windows-based web development platform for dynamic web applications using the Apache2 server, PHP scripting language, and a MySQL database. It also has PHPMyAdmin to more easily manage databases. We used it especially for its MySQL database [15].

3.1.4 EDraw max

EDraw Max is a software solution for making professional diagrams, graphics and drawings for many needs.

3.2 Methods

As far as we are concerned, we used the automatic processing method based on the creation of suitable software using the Java programming language and the MySQL DBMS. The following techniques were used: interview techniques which is verbal communication for gathering information through qualified people. The documentary technique which consists of consulting different works documentation,

scientific publications, websites as well as related lecture notes. We present to you some orders from service stations across the city of Kinshasa to collect using Google Map software and GPS to process with a LENOVO DualCore Computer with a 500 Giga hard disk, 2 Giga Ram memory which also served us as implement our computerized system [15].

3.3 Collection of Filling Station Orders

We have orders for the product from petrol pump service stations located in the municipalities of Gombe and Lingwala:

3.4 Collection of Information from Tankers

We have harvested the following tankers:

4. DESCRIPTION OF RESULT AND DISCUSSION

4.1 Computer Modeling of the Application

For the modeling of our application, we opted for the Unified modeling language approach [16]. Indeed, the UML language makes it possible to realize a software system by representing it, by specifying it, by building it and by documenting it beforehand.

4.1.1 Identification of actors

With regard to the product delivery process, we were able to identify the following players: The dispatching manager; the customer; the marketer; the Operations Department and the Loading Order Service.

Table 1. List of stations collected

| N° | Localization | Title | Quantity | Distance in (m ³) |
|-----|---|-----------|----------|-------------------------------|
| 1. | Gombe: Proche de la maison communale | Engen1 | 2 | 6 |
| 2. | Gombe: Proche du rond-point Forescom | Engen 2 | 10 | 8 |
| 3. | Gombe: Proche de l'hôtel de ville | Engen 3 | 12 | 11 |
| 4. | Gombe : Proche de la maison Schengen, Avenue de la libération | Engen 4 | 4 | 3 |
| 5. | Gombe : 1 Avenue de la Justice, réf : En face de la cours suprême de la justice | Engen 5 | 12 | 5 |
| 6. | Gombe : Crois Avenue du Tombalbaye et Bakongo. Rondpoint Kin Mazière | Engen 6 | 7 | 13 |
| 7. | Gombe : Avenue colonel EBEYA | Engen 7 | 15 | 10 |
| 8. | Gombe : Croisement Kasai et Haut-Congo | Sudoil 1 | 11 | 14 |
| 9. | Gombe : Proche de l'avenue KASAVUBU Avenue Haut Congo | Cobil 1 | 12 | 12 |
| 10. | Gombe : Avenue colonel EBEYA, réf : DG Airtel | Cobil 2 | 12 | 9 |
| 11. | Gombe : Avenue LUKUSA, réf : Entre Vodasquaire et Rond Point Forescom | Cobil 3 | 11 | 7 |
| 12. | Gombe : Avenu de la liberation, ref : Alimentation JIJ | Total 1 | 15 | 4 |
| 13. | Lingwala : Avenue de la liberation, ref :RTNC | Total 2 | 8 | 2 |
| 14. | Lingwala : Crois. Avenue huillerie et Boulevard Triomphale | Cohydro 1 | 4 | 1 |

Table 2. Tank trucks

| No | Tank trucks | Capacity (m ³) |
|----|-------------|----------------------------|
| 1. | K02 | 20 |
| 2. | K03 | 25 |
| 3. | K04 | 25 |

4.1.2 Identification of use cases

The following use cases have been identified: Ordering; Generation of BLs and Delivery Program; BLs compliance test and Delivery program; Conversion of BLs and delivery program into OC; Consult the availability of

vehicles; Elaborate the rounds of tankers and establish the roadmaps

4.1.3 Presentation of the use case diagram

Based on the use cases and actors listed above we can build the use case diagram as follows:

4.1.4 Class diagram

4.1.4.1 Identification of classes

4.1.4.2 Identification of relationships / association

For our work, we have identified the following relationships:

4.1.4.3 Presentation of the class diagram

Starting from the elements listed above, we can represent our class diagram as follows:

4.1.4.4 Transition from the class diagram to the logical pseudo-data model

To enable us to design our application database, we propose to design a logical pseudo model of the data starting from our class diagram using the rules for passing from the conceptual model to the relational model.

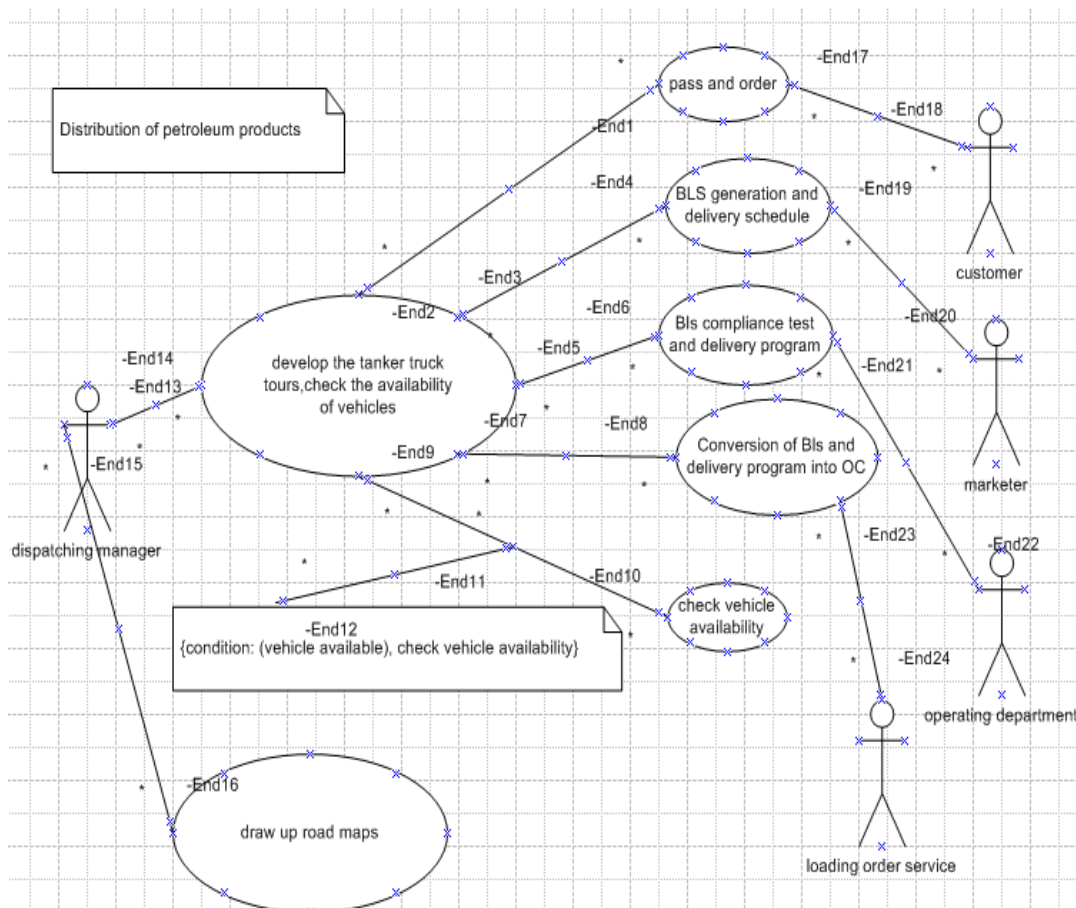


Fig. 1. Use case diagram

Table 3. Identification of classes

| Classroom | Attributes | Attribute types | Methods |
|-----------------|---|--|---|
| Station-service | - id_station - nom_stat - commune_stat - quartier_stat - avenue_stat - numero_stat | chaîne chaîne chaîne chaîne chaîne chaîne | Enregistrer () :void Supprimer () :void |
| Commande | - id_cmde - produit - quantité_cmde: - date_cmde | chaîne chaîne entier date | EnregistrerCmde () :void SupprimerCmde () : void |
| Camion-citerne | - id_cc: - num_plaque - capacité_cc | chaîne chaîne entier | EnregistrerCC() :void SupprimerCC() :void |
| ChargerCamionC | - id_chargerCC - quantite_chargeCC | chaîne entier | EnregistrerCCC() :void AnnulerCCC() :void ModifierCCC() : void Pourcentage_charg() :void |
| Course | - id_course:chaîne - libellé_course:chaîne - date_course: date | chaîne chaîne date | EnregistrerCourse () : void |

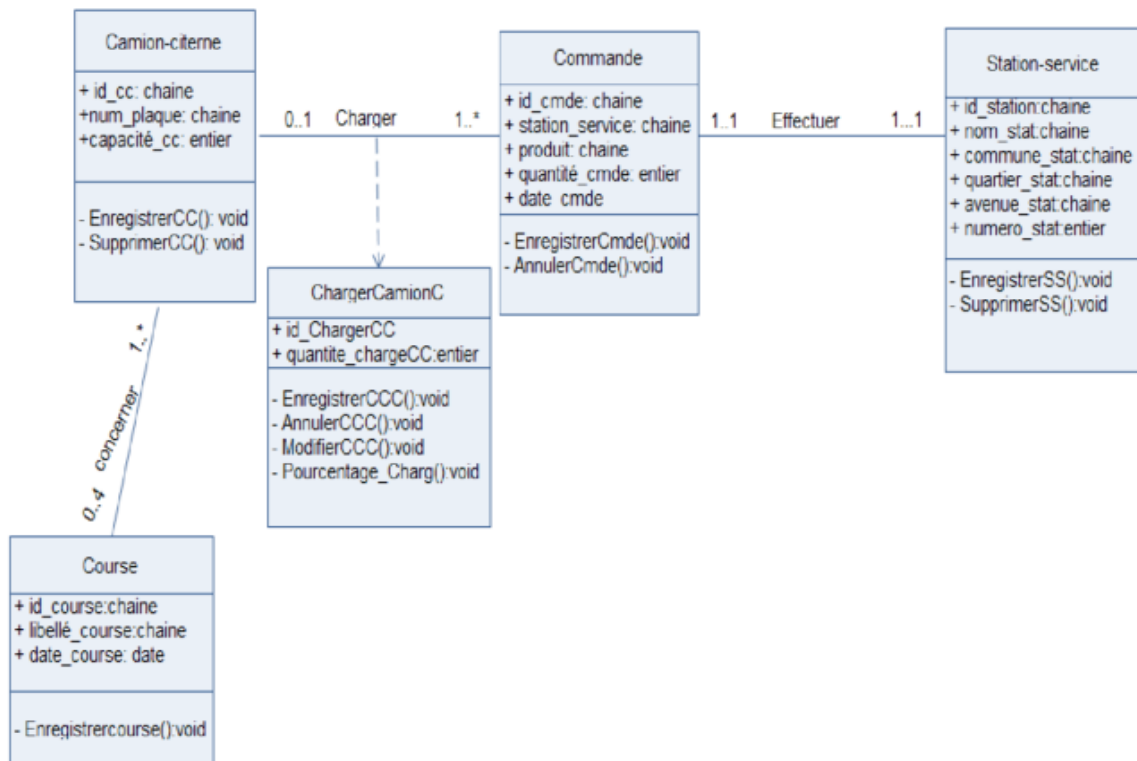


Fig. 2. Class diagram

4.1.4.5 Physical model of the data

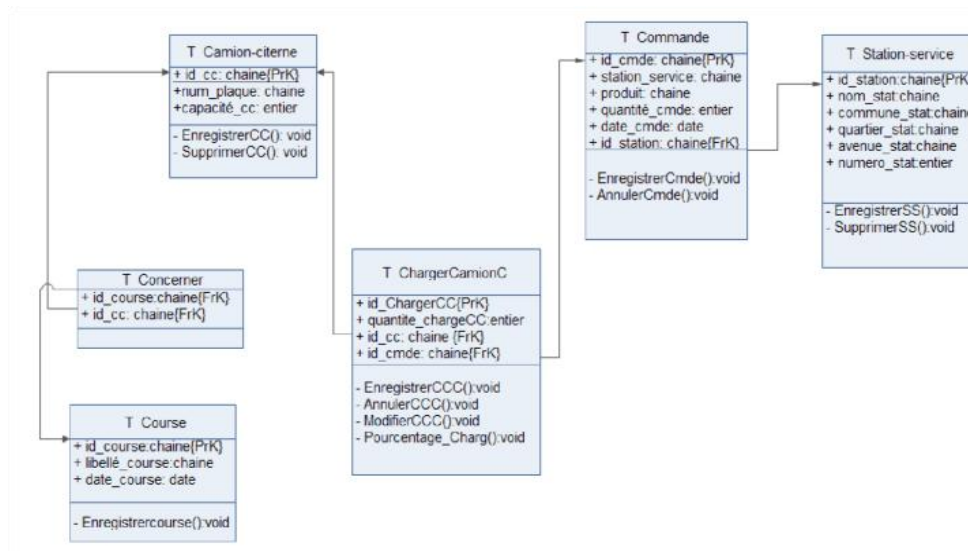
The physical data model obtained from the logical data pseudo model looks like this:

4.1.5 Application interfaces

When we start our application, we have the following interface:

Table 4. Relationship identifier

| Name of the relationship | Type of relationship | Related classes | Multiplicities |
|--------------------------|----------------------|-----------------------------|----------------|
| Effectuer | Association | Station-service et Commande | 1...1 et 1...1 |
| Charger | Association | Camion-citerne et Commande | 1...* et 1...1 |
| ChargerCamionC | Dépendance | Camion-citerne et Commande | |
| Concerne | Association | Course et Camion-citerne | 1...* et 1...* |

**Fig. 3. Pseudo logical data model****Table 5. Physical model of the data**

| Class | Attributes | Types | Size |
|------------------------|-------------------------|-----------|---------|
| Station-service | - id_station | Varchar | 4 |
| | - nom_stat | Varchar | 8 |
| | - commune_stat | Varchar | 20 |
| | - quartier_stat | Varchar | 20 |
| | - avenue_stat | Varchar | 20 |
| | - numero_stat | Varchar | 10 |
| | Commande | - id_cmde | Varchar |
| - quantité_cmde: | Int | 2 | |
| - date_cmde | DateTime | 15 | |
| - produit | Varchar | 6 | |
| - id_station | Varchar | 10 | |
| Camion-citerne | - id_cc: | Varchar | 5 |
| | - libelle_cc | Varchar | 3 |
| | - num_plaque | Varchar | 10 |
| | - capacité_cc | Int | 2 |
| ChargerCamionC | - id_chargerCC | Varchar | 5 |
| | - camion_Chrgt | Varchar | 3 |
| | - cmde_chrgt | Varchar | 8 |
| | - quantite_chargeCC | int | 2 |
| | - Date_chrgt | DateTime | 15 |
| Course | - id_course:chaîne | Varchar | 3 |
| | - libellé_course:chaîne | Varchar | 9 |
| | - date_course: date | DateTime | 15 |
| Concerner | -id_course | Varchar | 3 |
| | -id_cc | Varchar | 5 |



Fig. 4. Authentication interface

It allows you to manage access to the application. Only dispatching officers are authorized to do so. After the user (the dispatching manager) has authenticated himself and clicked on the OK button, the Authentication window closes and then opens the main window of our application. It looks like this:

As you can see, this is a tabbed window. The default tab (Status tab) is displayed with two tables (order table and tanker table) initially empty. But after clicking on the "View" button,

the stored data is loaded onto the tables. Indeed, this is the data received in the dispatching service to carry out the loading planning of the day. This planning is carried out in our second tab (Loading tab) which looks like this: Indeed, it is simply by clicking on the "Load" button that our application solves the loading problem. And display the results as follows:

4.2 Results Obtained

Let's take the results found above:

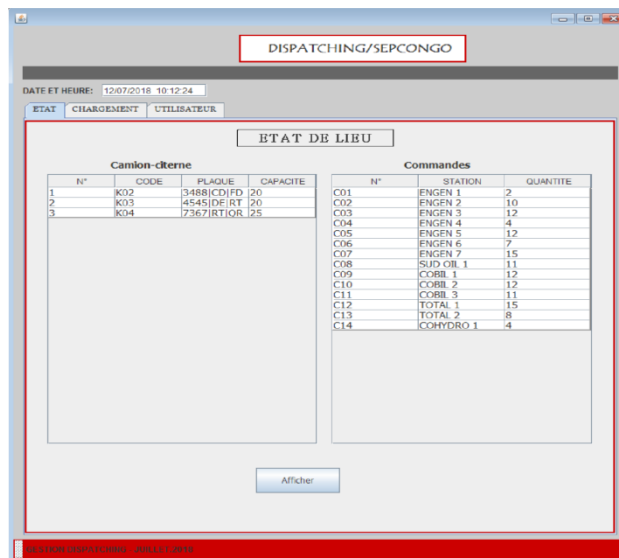


Fig. 5. Main window

Table 6. Table of results

| No | Truck | Ordered | Amount | Date |
|----|-------|---------|--------|------------|
| 1 | K01 | Engen 1 | 2 | 12/07/2018 |
| 2 | K01 | Engen 6 | 7 | 12/07/2018 |
| 3 | K01 | Sudoil | 11 | 12/07/2018 |
| 4 | K02 | Cobil 1 | 12 | 12/07/2018 |
| 5 | K02 | Engen 4 | 4 | 12/07/2018 |
| 6 | K02 | Cohydro | 4 | 12/07/2018 |
| 7 | K03 | Engen 3 | 12 | 12/07/2018 |
| 8 | K03 | Cobil 2 | 12 | 12/07/2018 |

DISPATCHING/SEP/CONGO

DATE ET HEURE: 12/07/2018 11:06:09

ETAT CHARGEMENT UTILISATEUR

CHARGEMENT

| N° | CAMION | COMMANDE | QUANTITE | DATE |
|----|--------|----------|----------|------------|
| 1 | K01 | ENGEN 1 | 2 | 12/07/2018 |
| 2 | K01 | ENGEN 5 | 7 | 12/07/2018 |
| 3 | K01 | SUDOIL | 11 | 12/07/2018 |
| 4 | K02 | COBL 1 | 12 | 12/07/2018 |
| 5 | K02 | ENGEN 4 | 4 | 12/07/2018 |
| 6 | K02 | COHYDRO | 4 | 12/07/2018 |
| 7 | K03 | ENGEN 3 | 12 | 12/07/2018 |
| 8 | K03 | COBL 2 | 12 | 12/07/2018 |

Pourcentage de Chargement par camion

| CAMION | POURCENTAGE |
|--------|-------------|
| K01 | 100.0 |
| K02 | 100.0 |
| K03 | 96.0 |

Pourcentage de Chargement par course

98,46%

Fig. 6. Loading results

We obtained these results thanks to the RCH multiple backpack problem solving method having for: (w_j) the quantity ordered by the station and (p_j) the distance between the station and the SEP / CONGO depot at the head office such that the nearest station has the greatest (p_j) and (c_i) the capacities of tank trucks. Indeed, we can see that our planning using our app gave us a total load percentage of 98.46%. That is to say, for a total capacity of our 3 trucks of 65 m³, we managed to load the station orders for a total quantity equivalent to 64 m³. The orders not chosen will serve as the loading of the second race. These results are satisfactory for us and allow us to be reassured about the quality of our application, especially since they are obtained through an optimization process. We have limited ourselves to stations in the communes of Gombe and Lingwala, but in the real case, this is station for the whole city of Kinshasa. Certainly, for the dispatching manager it is difficult to carry out this planning and especially in an optimal way. Of course, he will be able to achieve even 100% schedules, but it will remain to be seen whether they are optimal. This is where our app comes in to optimize its decisions.

5. PROSPECT

As an extension of our research work, we will consider a possibility to explore: the evolution of our work concerns the application aspect of the proposal detailed in this document. Indeed, this

work has been proposed in the context of handling large volumes of data. We lacked data especially of delivery of petroleum products in all provinces of the Democratic Republic of Congo to broaden our research. Therefore, our wish is that research can continue in this direction.

6. CONCLUSION

At the end of this study, We have implemented the tanker truck filling and dispatching system of tankers: Case of SEP / CONGO. The objective was to realize a software allowing to automate the planning of optimal filling of tanker trucks by using the tools proposed by the Operational Research, more precisely of the combinatorial optimization resolution methods for the backpack problem. multiple: Recursive core heuristic (RCH). To do this, we started from a base on mathematical optimization in general, and combinatorial optimization in particular, while presenting the different methods of solving optimization problems. Then backpack problems by presenting its variant of the multiple backpack and its different resolution methods and by highlighting the RCH heuristic to understand how it works, before implementing our application while taking into account the prior analysis. The implementation of our application was done with the Java programming language under the Netbeans environment with the MySQL database under the WampServeur platform. The results obtained by our application being satisfactory, we are very happy to realize that our objectives set from the start have been

achieved. However, as it is said in economics: "the satisfaction of one need creates another need", the automatic realization of the loading of products has created other automation needs which we classify in perspective under the improvement. of our application such as: after loading, manage to automate the rounds of these trucks for the delivery of its orders to service stations leaving from a depot while minimizing the cost of transport, why not leaving from several depots,.... This can lead to other optimization problems, in this case: the transport problem, the traveling salesman problem and the vehicle routing problem.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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