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A Decision Support System Approach for the Postal Delivery Operations

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***Abstract*— The research aims at developing a Decision Support System (DSS) devoted to manage Postal Delivery Systems (PDSs). In particular, the complex structure of the PDS is analyzed by the Unified Modeling Language diagrams and the main decisions necessary to manage the system are enlightened. Moreover, we focus on the operations of the Postal Automation Centers that are the core of the PDS and have charge the distribution of the outgoing mail to the borough Postal Delivery Centers. Among the decision problems of the Postal Automation Center we focus on the vehicle routing problem. An integer programming formulation is proposed and a real case study of the Italian postal network is solved by a heuristic algorithm.**

I. Introduction

The Postal Delivery Systems (PDSs) are huge and complex networks that present many types of challenging problems faced by logistics or express service decision makers. Indeed, a large number of nodes, long distances, large areas, complex flow directions and flow quantities make the regional postal network very complex and its management is of crucial importance.

The Italian PDS adopts regional Post Automation Centers (PACs), Postal Delivery Centers (PDCs) and post offices. The PACs are central offices of a postal regional zone that collects the incoming mail, sorts the scattered mail into packages according to the delivery destinations and delivers the packages to the PDCs. Moreover, the PDCs are the centers responsible for the mail delivery and distribution to the post offices. Hence, the PAC is the heart of the logistic supply chain since it involves the borough postal transportation network that is the foundation of the national PDS.

The management of the PDS involves a lot of problems, such as vehicle routing, location routing, network design and crew assignment [9]. Thus modeling and optimizing the PDS decision problems involves complex tasks and NP hard combinatorial optimization problems [11]. The basic models of such problems are largely addressed in the related literature [1].

In the context of the postal delivery transportation and management, we recall the paper [10] that proposes a hybrid method for route generation based on the automatic developing of the delivery scheduling system. The method combines experts' know-how and various optimization and heuristic algorithms such as Genetic Algorithms. In addition, Dong and Xiang [5] address the vehicle routing problem in the mail delivery context. They propose a hybrid algorithm that combines the Ant Colony Optimization meta-heuristics with two local optimization heuristics. Song et al. [8] consider the problem of borough postal transportation and propose the corresponding lexicographic order linear programming model to minimize transportation costs based on the minimization of fixed costs. An optimal solution is derived using a genetic algorithm [8]. In a successive work [9], the authors construct a postal express mail network that can realize the fastest transfer of mails with the lowest cost. The problem is solved by a swarm intelligent scheme. In [7] the sequence sorting, moving, delivery and additional work environments and mail types for postal delivery operation are addressed. However, such approaches deal with just one problem of the management of the PDS and do not consider the complete process.

Due to the complexity of the complete process, the system needs support during the decision making procedure. For this reason, in this paper we address the complex problem of the PDS management using a Decision Support System (DSS) approach, in fact DSS monitors the network, detects the events occurring and sends the related information to the system. DSS are computer-based systems that support individual or organizational decision-making activities [4]. In [6] the authors implement a spatial DSS that enables the decision makers from small and medium intercity delivery companies to make a successful decision. However, it does not consider the vehicle resources in the decision, as it performs the routing selection only. In this paper we analyze the PDS and single out the main decisions necessary to manage the system. More in detail, we describe the PDS by the diagrams of the Unified Modeling Language (UML) [2]: a graphic and textual modeling language intended to understand and describe systems from various viewpoints. Moreover, the UML is a standardized visual modeling language that is suitable to describe and specify software engineering.

Furthermore, we present the structure of the DSS devoted to manage the processes and the workflows of the PDS in

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order to optimize the resources and to plan the routes. In particular, we focus on the PDCs operations and specify one of the main modules of the DSS: the optimization of the routing and the determination of the daily fleet size for transport.

The routing problem is modeled as a *capacitated arc routing problem* [1] and is formulated as an Integer Programming (IP) problem. However, the exponential number of the constraints of this formulation makes the direct use of the IP problem impractical in the real system applications. Hence we solve the problem by a heuristic augment-insert algorithm [1]. The efficiency of the algorithm is verified by the application to a real case study of an Italian Postal network constituted by a PAC and the borough PDSs that it has to serve.

The paper is organized as follows. Section II describes the Italian PDS by the UML diagrams. Section III presents the DSS architecture and section IV specifies the vehicle routing module. Finally, Section V discusses the conclusions.

II. The Postal Delivery System Description

We consider the Italian Postal Delivery System (PDS) devoted to the daily pick up and delivery of the mail. The PDS serves the Country and daily reaches all the destination nodes through the postal transportation network. More precisely, the PDS is constituted by two types of centers: i) the regional Post Automation Center (PAC) is the central office of a region that collects and sorts the mail and dispatches letters and packages to the borough Postal Delivery Centers (PDCs); ii) the PDC is the center responsible of the distribution to the city post offices.
The mail delivery process can be divided in six phases as shown in Fig. 1 and described in the following.
1) *Acceptance phase.* In this first step of the process, the mail is collected by means of the mailboxes, the postal offices and the express special services.
2) *Incoming mail collection and outgoing mail sorting.* In this phase, the PAC office deals with the incoming mail, sorts the scattered mail into packages according to the delivery destinations and dispatches it to the other PACs.
3) *Transportation.* During the third phase the mail is transported through the transportation network by trucks, trains, airplanes; the mail distribution plan is determined on the basis of the year period and the amount of products.
4) *Incoming mail sorting and PDC distribution.* During the fourth phase, the correspondence arrives to the PACs from the other PACs: it is sorted and again dispatched to the borough PDCs.
The PAC is the heart of the logistic supply chain and performs the following main operations:

- *sorting* of the incoming mail;
- *packing* of the mail to be dispatched to the borough PDCs,
- *dispatching* of the mail packages to the borough PDCs.

This phase involves the borough postal transportation network and is the foundation of the national PDS. The large number of nodes, long stances, large areas, complex flow directions and flow quantities make this postal network very complex and its management of crucial importance.
5) *Delivery.* This is the last phase of the PDS. During this phase the mail arrived to the PDCs is delivered to the postal offices and to final users by a widespread distribution.

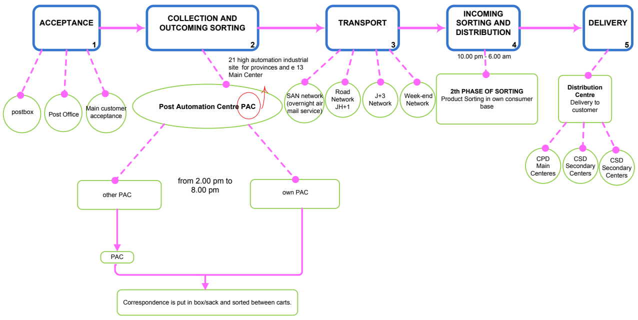

Figure 1. The Postal Delivery System.

This complete process allows the postal service to answer the user requests and to ensure the service five days a week.
In order to better understand the complexity of the PDS, in the following subsections we present the top down procedure that addresses the PDS structural model by using the UML package diagrams and class diagrams [3].
From the structural point of view, a system is made up of a collection of pieces often referred to as objects and described by classes. Hence, in the UML environment, the system structure is described by class diagrams that illustrate the different types of objects that the system can have and their relationships. Each class is represented by a rectangular box divided into compartments. The first compartment holds the class name, the second holds attributes, and the last holds operations. Moreover, classes can exhibit relationships that are represented by different graphic connections
Class diagrams can be collected into logically related groups that in UML are modeled with packages. In particular, package diagrams are often used to view dependencies among packages that are represented by complex nodes composed of other generic communicating objects. Hence, arrows show the cases in which a class in one package needs to use a class in another package and causes a dependency between packages.

A. The PDS Package Diagram

The first step to describe the PDS consists of identifying the main subsystems composing it. Indeed, the PDS can be divided into the following structural subsystems: the Management System, the PACs, the PDCs (that includes the post offices), the Information and Communication System (ICS) and the infrastructures connecting the subsystems (streets, stations, airports). They represent the generic concepts used within the modeling framework and are modeled by the UML package diagram of Fig. 2. The arrows show the dependence between packages and exhibit that the ICS is updated on the basis of data obtained in real-time using Information and Communication Technology (ICT) tools. We assume that each package includes an information class representing the informative structure devoted to manage the considered subsystem.

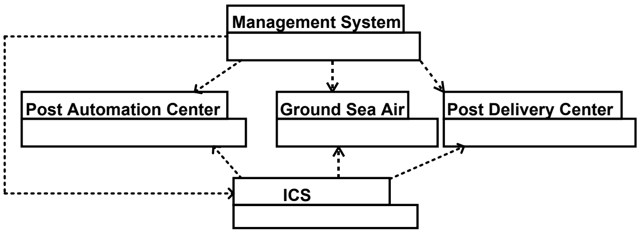

Figure 2. The package diagram of the PDS.

B. *The PDS and PAC Class Diagrams*

The next step of the structural modeling procedure consists of setting up the class diagrams related to particular packages. Figs. 3 and 4 show the class diagrams of two packages that are depicted in Fig. 2, namely the PAC and the Management System.

The Management System is the subsystem that has the task of managing and coordinating vehicles, routes and requests. The Management System is in charge of managing and coordinating vehicles, routing and requests. It can control the interactions between the database and the infrastructures, by receiving data from the PACs, the PDCs and the transportation network. The Management System class is composed by a Database class collecting data to be used during the decision process. Moreover, the Management System class is composed by the Optimization System 1 (OPT1) class and the Optimization System 2 (OPT2) class. In particular OPT1 considers the optimization problems that refer to generic routing and delivery problems that are involved in the PDS. This class is specialized in three lower level classes:

- the Transportation On Demand (TOD) class that considers the problem of the exceptional and urgent deliveries such as telegrams;
- the Urban Courier Service Problem (UCSP) class that optimizes the mail delivery to the final users;
- the estimated path class that optimizes the paths of tracks, post man etc. in the different phases of the PDS.

On the other hands, the OPT2 class considers the following management problems:

- optimization of the packing,
- warehouse management,
- scheduling and shipping of the orders,
- dimensioning and scheduling of the means of transport fleets.

Figure 4 reports the PAC class diagram and shows the different relationships among the classes of the PAC. In particular, the PAC class is composed of three main sub-classes:

- Mail class, composed by the tracked and ordinary mail;
- Employees class, that includes the staff and the resources available in the PAC;
- Means of Transport class, that includes different kinds of transportation means, e.g. cars, vans, lorries and trucks.

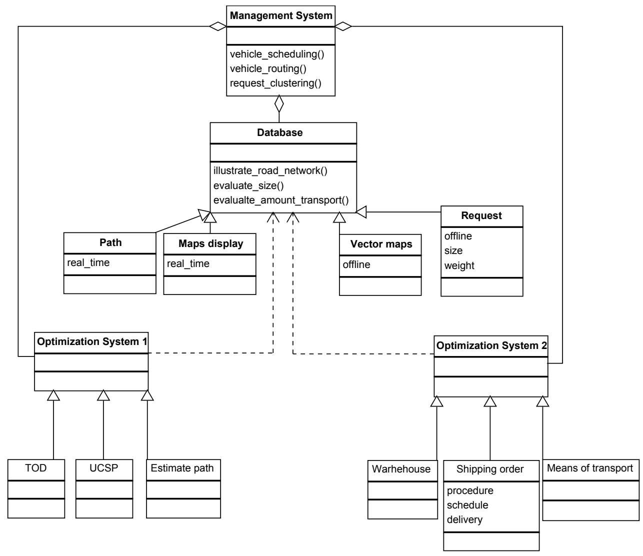

Figure 3. The Management System class diagram.

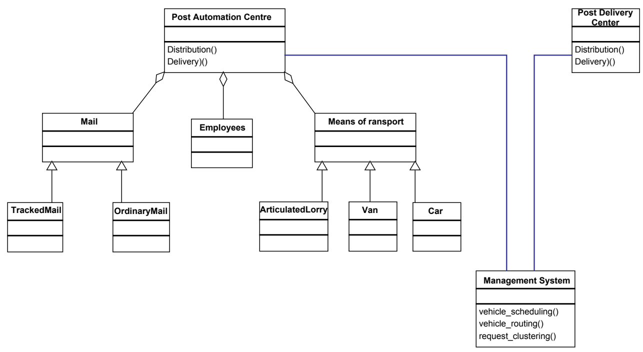

Figure 4. The Post Automation Centre class diagram.

III. THE DECISION SUPPORT SYSTEM ARCHITECTURE

In this section we describe the structure of the DSS devoted to manage the routing, packing, sorting and delivering operations that are performed in a PAC.

The DSS helps the decision makers to use communication technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions. The main distinctive features of the DSS are handling a large amount of data from different sources, providing report and presentation flexibility, offering both textual and graphical orientation.

Typically, a DSS consists of three components: the Data Component (DC), the Model Component (MC) and the User Interface Component (UIC) [4]. Figure 5 concisely shows the main elements of the architecture of the proposed DSS and their connections.

The DC stores all information needed for the DSS to operate. We distinguish three types of data. The first and second kinds of data are stored in the DC: the internal data and the external data. The internal data represent all data necessary to describe the internal procedures, e.g. the time required for each activity, the number of available resources, historical data etc. On the other hand, the external data are information coming in real time from the system: the police data, the conditions of the roads, the accidents, the road maintenance works, the weather conditions, etc. The third kind of data are the internal data used by the MC: the input and output data managed by the decision module, the queue of the requests to be sent to the different modules, the state of each request and the results of the decision and optimization modules.

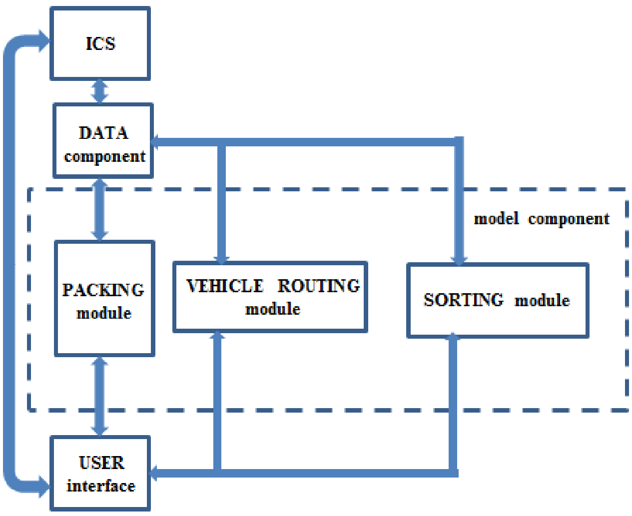

Figure 5. The DSS Structure.

The MC contains all the models, algorithms, rules and knowledge needed to provide decision support for the user. This component consists of different modules, each one dedicated to the management of a particular activity performed in a PAC: vehicle routing, packing and sorting modules. In the presented DSS, we specify the main module: the Vehicle Routing (VR) module.

The UIC allows the effective interaction of the user with the system. This module is the part of the DSS that is responsible of the communication and interaction of the system with the MC. Such a component is very important and the accuracy of the model is based on this interface. Indeed, the UIC communicates and interacts with the real system by the ICS and maintains the consistency between the stored data and the real system.

IV. The Vehicle Routing Module

This section specifies the vehicle routing module of the proposed DSS in order to optimize the routes starting from the PAC and necessary to dispatch all the postal issues to the PDCs. Moreover, the vehicle routing module determines the number of trucks necessary to the daily delivering operations.

A. *The Model Formulation*

We model the vehicle routing problem as a *capacitated arc routing problem* that is analogue of the classical vehicle routing problem in that it places an explicit capacity restriction on the tour associated with each vehicle [1]. We model the problem by an IP formulation.

The postal transportation network is modelled by a directed graph $G = (V, E)$, where $V = \{0,1,2,\ldots,V\}$ is the set of nodes and E is the set of edges. Moreover, the edges $e_{ij} \in E$ represent the streets that the vehicles can go trough. Node 0 is reserved for the starting node that here represents the PAC and we denote by $N(i)$ the nodes adjacent to i in G. In addition, a weight $c_{ij} \in R$ is associated to each edge $e_{ij} \in E$ and represents the distance between node i and node j. Furthermore, a demand $q_{ij} \geq 0$ is associated with each edge $e_{ij} \in E$ and expresses the amount of mail that has to be delivered to the PDC that is located in edge $e_{ij} \in E$. Edges with positive demand (hence the edges that include a PDC) are called required arc and are collected in the set $R=\{e_{ij} | q_{ij} > 0\}$. K identical vehicles (trucks) of capacity $Q \geq q_{ij}$ are available.

In order to model the problem, we introduce two sets of variables: $x_{ij}^k = 1$ if vehicle k traverses e_{ij} from i to j; $l_{ij}^k = 1$ if vehicle k serves e_{ij} while traversing it from i to j.

The mathematical formulation is the following:

$$min \sum_{k=1}^{K} \sum_{(i,j)} c_{ij} x_{ij}^k \quad (1)$$

Subject to

$$x_{ij}^k \geq l_{ij}^k \quad \text{for all } (i,j) \text{ and all } k \quad (2)$$

$$\sum_{k=1}^{K} (l_{ij}^k + l_{ji}^k) = 1 \quad (3)$$

$$\sum_i \sum_j l_{ij}^k q_{ij} \leq Q \quad \text{for all } k \quad (4)$$

$$\sum_{j \in N(i)} (x_{ji}^k - x_{ij}^k) = 0 \quad \text{for all } i \text{ in } V, k=1,\ldots,K \quad (5)$$

$$x_{ij}^k, l_{ij}^k \in \{0,1\} \text{ for all } e_{ij} \in E, k=1,\ldots,K. \quad (6)$$

Constraint (3) forces all required arcs to be served; (2) states that the served edges must be traversed. The explicit capacity constraint (4) applies to each vehicle. Constraint (5) ensures route continuity for each vehicle. Moreover, it is necessary to add an exponential number of constraints in order to eliminate disconnected sub-tours and to allow tours that include two or more closed cycles. This formulation makes its direct use impractical.

Hence, we use in this paper the *Augment-insert algorithm* [1] that is designed to perform well on relatively sparse graphs with large edge demands.

The input of the algorithm are: the defined graph G, the weights $c_{ij} \in R$ associated to each edge $e_{ij} \in E$; the demand $q_{ij} > 0$ associated with each edge in R (the PDCs to be visited), the number K of vehicles and the capacity Q. Moreover, it is necessary to use an input parameter CLIM that controls the length of the cycles: a large value of CLIM creates long cycles with long detours.

As a result, the algorithm provides a set of cyclic paths starting from the PAC and ending to the PAC. The complete set of the paths includes all the PDCs to be served. Each path is performed by one vehicle. Moreover, on the basis of the cost (the path length) associated to each cycle, it is possible to obtain the delivery time of each vehicle. Therefore, the algorithm determines the number of necessary transport means to complete the daily delivery.

B. *A Case Study*

In this section, we consider a case study constituted by an Italian PAC and the connected borough PDCs. The postal network is described by the directed graph shown in Fig. 6. It is composed by 48 nodes that represents the 48 PDCs of the considered Italian region. The node 0 is the PAC. In Fig. 6 the edges in R are indicated by solid lines and the arrows indicate the sense in which the arc can be traversed.

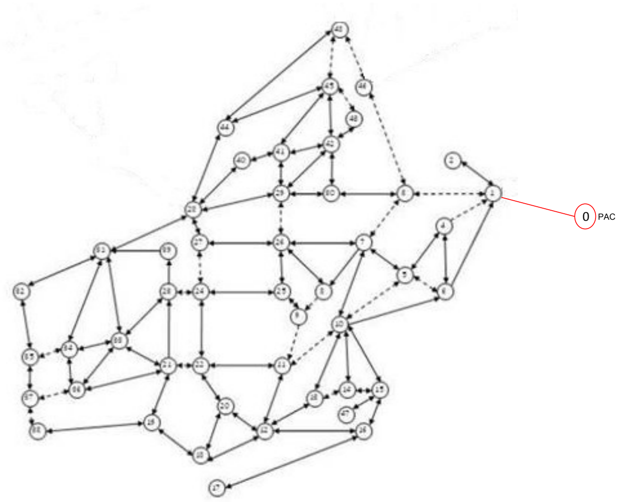

Figure 6. Graph PAC-DC network.

For the sake of brevity, here we do not report the weight $c_{ij} \in R$ (in km) associated to each edge $e_{ij} \in E$ and the demand $q_{ij} \geq 0$ (in kg) associated with each edge $e_{ij} \in R$. Moreover, the truck capacity is denoted by Q=550 kg and the variable CLIM is assumed equal to 10 km.

The algorithm has been implemented in C++ 9-2 on a 3.33 GHz Intel i7 980X with 24 GB of memory.

Table I reports all the paths determined by the algorithm. In particular the first column identifies the path, the second one indicates the time necessary to go through the complete path: such data are determined by considering the length of the path, the average speed of the trucks of 80 km/h and the average time to unload the trucks of about 15 minutes. The third column indicates the amount of mail delivered by a vehicle during the path and the last column indicates the path length. All the paths come from the PAC and return to the PAC.

It is evident that 5 paths (indicated by 1, 2, 4, 6, 8) use the whole vehicle capacity and are the longest ones. The remaining paths (3, 5, 7, and 9) are shorter and deliver smaller amount of mail. In the presented case study the maximum working time for each vehicle is 8 hours, then in order to satisfy the complete demand in one day it is necessary a fleet of at least 7 trucks.

TABLE I. THE PATHS GENERATED BY THE ALGORITHM.

Path	**Time (min)**	**Quantity (kg)**	**Length (km)**
1	311.9	550.0	207.9
2	464.3	550.0	340.5
3	365.5	525.0	249.7
4	374.1	550.0	259.0
5	166.7	100.0	148.1
6	225.0	550.0	195.0
7	289.1	325.0	199.5
8	433.6	550.0	307.2
9	279.3	200.0	205.1

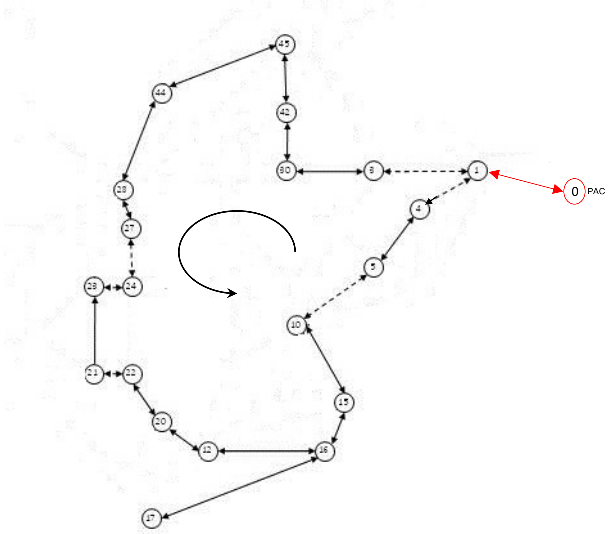

Figure 7. The path n.4 generated by the algorithm.

Moreover, Fig. 7 shows one of the paths provided by the algorithm: path 4. It comes from node 0 and arrives to node 17 that is the farthest node from the PAC of this path. Since tere is not an edge $e_{16,17}$ in the graph, the truck has to come back to node 16 to continue its tour. Successively, the truck finishes its tour and goes back to node 0. During this path the vehicle serves 22 PDCs in 374 minutes (including 15 minutes per node for unloading procedures).

V. CONCLUSION

This paper addresses the complex problem of the Postal Delivery System (PDS) management by using a Decision Support System (DSS) approach. To this aim, we analyze the PDS by the class and package diagrams of the Unified Modeling Language (UML). Moreover, we present the structure of the DSS devoted to manage the process and the workflow of the PDS in order to optimize the resources and the delivery routes. In particular, we focus on the operations of the PACs and optimize the routing to serve the PDCs and of the daily fleet size for transport.

The problem is modeled as a *capacitated arc routing problem* and is solved by a heuristic algorithm. Moreover, a case study that considers an Italian Postal network constituted by a PAC and the borough PDSs is solved.

Future works will investigate on the following issues: considering real time traffic restrictions and congestion information for determining the path and route scheduling and rescheduling; investigating and comparing new heuristic algorithms for the different management problems to be addressed in the DSS design. Furthermore, we will compare this method with other existing methods to highlight the performance of the results.

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