Home health care logistics management problems: a critical review of models and methods

Gestión logística de sistemas de hospitalización domiciliaria: una revisión crítica de modelos y métodos

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Abstract

Home Health Care (HHC) services are based on a delivery network in which patients are hospitalized at their homes and health care providers must deliver coordinated medical care to patients. Demand for HHC services is rapidly growing and governments and health care providers face the challenge to make a set of complex decisions in a medical service business that has an important component of logistics problems. The objective of this paper is to provide a critical review of models and methods used to support logistics decisions in HHC. For this purpose, a reference framework is proposed first in order to identify research perspectives in the field. Based on this framework, a literature review is presented and research gaps are identified. In particular, the literature review reveals that more emphasizes is needed to develop and implement more integrated methodologies to support decisions at tactical and strategic planning levels and to consider key features from real systems.

---------- *Keywords*: Home health care, health care, logistics management

Resumen

Los servicios de Hospitalización Domiciliaria (HD) se basan en una red de distribución, en la cual los pacientes son hospitalizados en sus casas y

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los prestadores de servicios de salud deben entregar cuidados médicos coordinados a los pacientes. La demanda de estos servicios está creciendo rápidamente y los gobiernos y proveedores de servicios de salud enfrentan el reto de tomar un conjunto de decisiones complejas en un sector con un componente logístico importante. En este artículo se presenta una revisión crítica de los modelos y métodos utilizados para darle soporte a las decisiones logísticas en HD. Para esto se presenta primero un marco de referencia, con el objetivo de identificar las oportunidades de investigación en el campo. Con base en dicho marco, se presenta la revisión de la literatura y la identificación de brechas en la investigación. En particular, se hace énfasis en la necesidad de desarrollar e implementar metodologías más integradas para dar soporte a las decisiones estratégicas y tácticas y de considerar puntos clave de los sistemas reales.

---------- *Palabras clave*: Sistemas de hospitalización domiciliaria, sistemas de salud, gestión logística

Introduction

Home Health Care (HHC) services appeared around 1950 as an alternative to reduce overall costs of health care systems, to improve the utilization of scarce resources and to improve patients life quality [1]. These services are a growing sector in the medical service business due to social and economic factors that have accelerated their expansion. On one hand, the increase on life expectancy and the ageing of the population have influenced on the demand for health care [2]. On the other hand, resources for health care are limited and health care providers face the challenge to design and operate more efficient health care delivery systems [3]. Having a patient receiving medical care at home instead of a hospital, results in a lower general cost for the health system [4, 5] and HHC services allow to improve life quality of patients and to reduce recovery periods [6].

According to the U.S. Home Health Services Industry [7], the industry of HHC services comprises establishments primarily engaged in providing skilled nursing or medical care at home, under supervision of a physician. A HHC system can be viewed as a health services network that includes the patient; the person who asks for the home care (the patient, his family, the hospital or the physician); the people involved in the logistics implementation (coordinator in charge of the evaluation of material and human needs, pharmacy) or in the financial aspect of home care (health insurance); and the home care team (nurses, physicians, therapists, among others) [8]. The coordination of this health services network is a complex task and managers have to face many logistics decisions when designing, planning, and operating the system.

Most research found in the literature dedicated to HHC services refers to studies based on developed countries for operational decisions. Brailsford and Vissers [9] show the increase on the development of Operations Research techniques in health care in Europe, where HHC services have become a central element in the health policies. Despite these achievements, no scientific study focused on the design, planning, or operation of HHC has been carried out in developing countries. The majority of developing countries face severe health care crisis and the dilemma of very restrictive budget limitations for health care expenditures with a growing population [10, 11]. Health care systems vary among countries and the current state of the art on HHC cannot be generalized due to differences on health policies and funding structures. This suggests that models and methods for logistics management need to be studied and developed in order to reach more efficient HHC delivery networks.

The objective of this paper is to provide a critical review of models and methods used to support logistics decisions in HHC. For doing so, a reference framework is proposed first in order to identify research perspectives in the field. Then, a review of the existent literature of models and methods used to support logistics decisions based on the proposed framework is presented. Based on the state of the art identified, a critical analysis of the review is provided, pointing out important features that have received little attention in the literature. Finally, conclusions are presented and research perspectives are identified.

Home health care framework

In order to provide a framework, three different dimensions from which HHC logistics management can be viewed are presented (see figure 1). First, the *planning horizon* is identified according to the duration and impact of the planning decisions. Second, logistics functions are differentiated by groups of *management decisions*. Finally, *services processes* are defined as the set of steps performed when the HHC service is delivered to a patient.

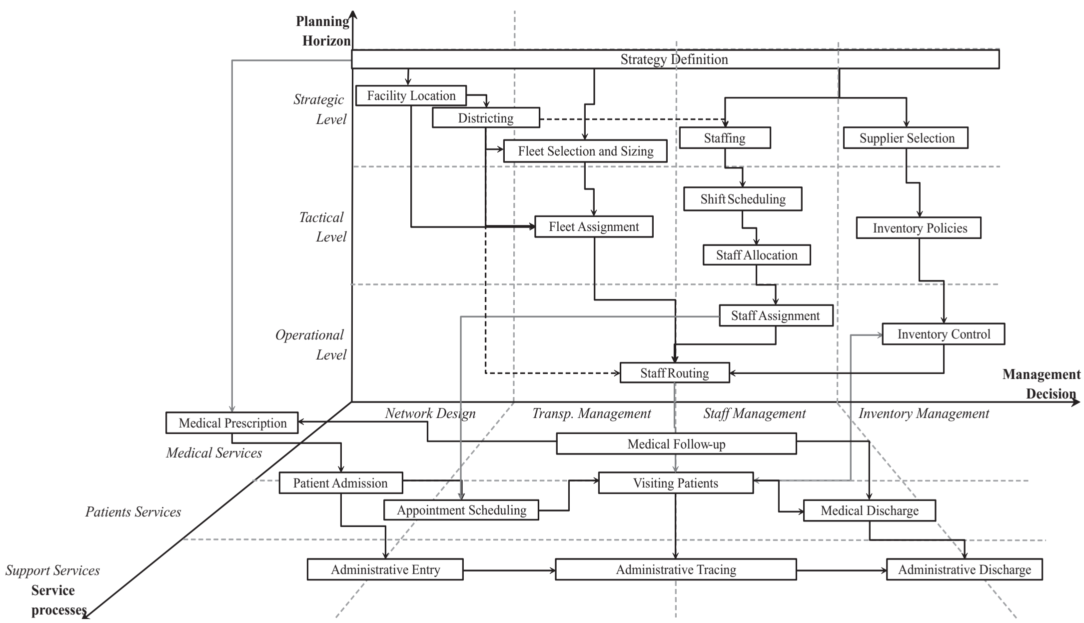

Figure 1 Home health care logistics management framework

In HHC logistics management three levels of planning can be distinguished depending on the time horizon, namely *strategic*, *tactical* and *operational* [12]. The *strategic level* considers time horizons of more than one year and includes the design and allocation of long-lasting resources over long periods. Decisions at this level include the location and allocation of HHC central facilities, urban districting, fleet size and selection, staffing levels, and supplier selection. The *tactical level* involves medium term decisions that are usually made for a year. The fleet assignment to urban districts, shift scheduling and staff allocation, and the definition of inventory policies are considered as tactical. The *operational level* is related to short term decisions that need to be made daily. These decisions include staff assignment and routing as well as inventory control. A fourth planning level has been recently recognized as the *real-time level*, and it refers to decision making situations in which operations must be undertaken or altered in a short time, according to the actual execution of the service processes of the system. A detailed definition of each of the *management decisions* and the *service processes* is provided in [13].

For each of the logistics functions, the abovementioned levels define a hierarchy among management decisions that impose constraints in lower planning levels and influence the performance of the HHC delivery network. For example, in transportation management, the size and selection of the fleet used by medical staff to visit patients is a long-term decision that influences the way the fleet is then assigned to patients' districts at the medium-term. Equivalently, the fleet assignment to districts influences staff routing decisions at the short-term. This hierarchy suggests that models and methods used to support logistics decisions at the operational level will not have a significant impact on the system performance, if decisions made at upper levels are not based on proper methods to design the network and to assign resources.

Literature review

This section presents an overview of the existent literature of models and methods used to support logistics decisions in HHC. For doing so, the classification of logistics problems is followed according to the planning horizon. Thereby, the strategic level corresponds to *design and planning decisions*, the tactical level corresponds to *resource planning and allocation*, and the operational level corresponds to *services scheduling*.

This literature review is not intended to be exhaustive but rather it is directed towards identifying the key aspects to consider when designing and implementing a model or a method to support logistics decisions in HHC. The main contribution of this review is the classification of the logistics problems according to the proposed framework and the identification of the characteristics of the models and methods, including the *authors*, the *problem type*, the *problem characteristics*, the *objective(s)*, the *model structure*, and the *solution methods*.

Design and planning decisions

In the context of *Network Design* decisions, few researches study facility location and districting problems in HHC. As stated by Daskin and Dean [14], these problems are critical in health care and their impact goes beyond cost and customer service considerations. However, despite the large number of publications dedicated to the facility location problem in health care, no published works that study this problem in HHC were found. Referring to the districting problem, the majority of the works that study this decision problem is found in the context of health care [15-20] but not in home health care.

The literature review shows that the first published work that study the districting problem in HHC is presented in [21]. The authors solved a practical districting problem in the management of public HHC services for a local community health clinics center in a province of Canada. They modeled the situation as a multi-criteria optimization problem which was solved with a Tabu Search heuristic. Two criteria were considered in the objective function: the mobility of visiting staff and the workload equilibrium among districts. Authors reported an improvement of the districting configuration after two years of implementation of the solution. The improvement was measured in terms of the standard deviation of the number of annual visits assigned to the set of districts. Later on, authors in [22] analyzed the territorial approach to deliver homecare services in the same context. Based on a historical comparison of patients visits, the authors concluded that the districting problem must be solved in a more frequent periodicity due to the changes in the patients census over the time.

The work presented in [23] studied a home health nurse districting problem through a set partitioning model, which was solved by a column generation heuristic that integrated ideas from optimization and local search. In the model, districts demand, districts cost and districts workload feasibility are formally defined and included in the mathematical formulation. The solution procedure included a heuristic to obtain an initial solution that might be unfeasible. Then, local search was used to attain feasibility and to improve initial solutions. Based on computational experiments performed with instances of a real home health care agency, the author reported that the column generation heuristic is effective when improving initial solutions.

More recently, the same author [24] described the home health nurse districting problem as a tactical decision, and identified formulations and solution methods for this problem. The author presented a survey of the relevant literature of the problem and found that the works presented in [21, 23] and [25] are the three studies published that present computational results for the districting problem in HHC. According to the author, two formulations are appropriate for the districting problem in HHC, the *location-allocation* and the *set partitioning*. In the first type of formulation the decisions include selecting which district centers must be opened, and the assignment of each basic unit to one district center. The second formulation does not require a fixed set of districts center and a large set of possible combinations of basic units is evaluated.

Resources planning and allocation

Related to tactical level decisions, the resource planning and allocation models published have focused on the definition of patient admission policies and on the staff allocation problem. The *staff allocation* decision refers to the need to employ temporary staff or to use float staff to handle unexpected large patient demands or staff shortages, during particular shifts and to assign individual staff to patients' districts [26].

Despite the impact of *Staff Management* and *Inventory Management* at this level, only few works study decisions such as *staffing*, *shift scheduling* and *inventory policies* for HHC services. On one hand, concern about *Staff Management*, the *staffing* decision is usually made between the strategic and the tactical level, and it involves determining the number of personnel of the required qualification in order to meet estimated patients demand [27-29]. This is a complex problem given the factors to consider such as organizational structure and characteristics, personnel recruitment, skill classes of the staff, working preferences and patient needs [30]. At the tactical level, *shift scheduling* deals with the problem of selecting, from a potentially large pool of candidates, what shifts are to be worked, together with an assignment of the number of employees to each shift.

On the other hand, for *Inventory management*, *inventory policies* determine when the inventory levels of each reference of medicines, supplies and devices (MSD) should be reviewed, how much to order from the supplier and when to do so [31]. Investments in inventory are substantial and the control of capital associated with MSD represent an improvement opportunity for the HHC network, in which scientific methods can give a significant competitive advantage [32]. To the best of our knowledge, the work presented in [33] is the first published paper that tackles the inventory problem in a HCC network. They studied the planning of operations related to chemotherapy at home, focusing on the anti-cancer drug supply chain. The problem is solved by an optimization model that seeks to minimize the production and delivery costs of medicines. The model also considers production scheduling and nurse routing decisions simultaneously and it is solved by an exact method.

The work presented in [34] dealt with the problem of allocating resources to the home care service provided to AIDS patients in the city of Rome, Italy. The author developed a linear programming model for solving the problem for single organizations and for providing assistance to public health authorities, in order to evaluate the results of tentative budgets assigned to home care. The model produces an optimal schedule for admitting new patients to the HHC system for a 12-week period, with the objective to maximize the total number of patients admitted, subject to constraints on available resources.

In [35] a waiting list model for residential care for mentally disabled patients in The Netherlands was developed. The model is a linear stock-flow model and distributes the mentally disabled patients over different living situations. It explicitly includes institutional and semi-institutional care, and it implicitly considers ambulatory and other types of care. Four scenarios were also simulated with the objective to include the differences in the mortality rate of mentally disabled patients, the supply and use of ambulatory care, and the possible effect of uncertainty in the data.

Authors in [36] studied the client demands and the allocation of home care in The Netherlands, through a multinomial logit model of client types, care needs and referrals. The purpose of the model was to facilitate policy decisions by offering simulations of intended policy measures. The model represents a section of an overall route followed by the person seeking help from a home care service. The model was estimated on the basis of more than 7,000 requests for home care in the northern area of the Netherlands. Results showed that elderly chronically ill applicants have a greater chance of being referred for domestic help only, while applicants with psychosocial disorders are more liable to be offered packages that include social support.

The work presented in [25] considered the problem of assigning patients to nurses for HHC services, in the context of the local community health clinics center in Montreal, Canada, in order to improve the workload assignment achieved by the districting configuration defined in [21]. For doing so, they proposed a mixed integer programming model which was solved with a Tabu Search heuristic and compared with solutions obtained by CPLEX. The objective function was a weighted quadratic relation that included three measures of the workload: the average number of visits, the average number of cases, and the travel load. A first formulation of the model resulted in a *multi-resource generalized assignment problem* (MRGAP), which is known as an NP-hard problem and it could easily result in unfeasible solutions. The authors then developed a non-linear model that minimizes the deviations from the ideal average of the three measures considered. The model was tested in three different instances and computational experiments demonstrated the effectiveness of the Tabu Search algorithm. No further detail is provided about the implementation of the model in the real system in Montreal.

Services scheduling

In the study of *Transportation* and *Staff Management*, the *staff routing* decision is directly related to the vehicle routing problem which consists on designing optimal delivery routes from a central location to a set of geographically distributed patients subject to various constraints [37]. In HHC, this problem is also related to the *staff assignment* decision which is concerned with the assignment of visits among a given medical staff. In the staff scheduling literature, the problem is known as task assignment and it is often studied when working shifts have already been determined but tasks have not yet been allocated to individual medical staff [38].

The first application of this problem in HHC is due to authors of [39] who studied a manpower decision problem in order to schedule the available nurses to visit patients in a defined route. The objective was to develop schedules that minimize non value-added travel time and that balance workload requirements among all nurses. They developed a mixed integer programming model for a five-day weekly scheduling problem. The model was formulated as a single-depot, single-period multiple travel salesman problem (m-TSP). To solve the problem, the authors implemented the well-known *Clarke and Wright* savings-type route-building heuristics [40] and the sweeping algorithm [41]. To improve the routs, they used the insertion procedures proposed [42] and the edge-exchange procedures [43].

Authors of [44] worked on the home health care routing and scheduling problem. The problem was treated as a *vehicle routing problem with time windows* (VRPTW) and *multi-depots*. Although the formulation did not include differentiation among staff skills, feasible matches were defined in terms of staff and patients. Staff over-time is also included. The objective was to find an optimal schedule such that each nurse that is scheduled to work leaves from her home, visit a set of feasible patients within their time window, takes a lunch break and returns home. To solve it, the authors developed a two-phase algorithm. In the first phase they implemented a parallel tour-building procedure and in the second one, attempts are made to improve the resulting tours.

The work presented in [45] studied a dynamic stochastic vehicle routing problem in HHC scheduling in the context of the Senior Care Department of the Sinclair School of Nursing at the University of Missouri in the US. The author developed a *cluster-first route-second* heuristic, three solution strategies to solve the problem, and a pure dynamic discrete event simulation model to study the dynamic scheduling and routing aspects of the problem. The solution method was tested on a real instance with four staff members and 24 patients.

Authors of [46] considered the integration of staff rostering and routing decisions in the context of a project for the development of a software called PARAP. The development includes a single-depot, single-period configuration with time windows, heterogeneous skills and shift guidelines. The model was formulated as an assignment problem, such that the overall assignment cost is minimized and the patients and staff preferences are maximized. Patients' preferences include the accomplishment of time windows. Staff preferences include the nurses' preference for certain patients, the experience for certain jobs, and factors that guide a fair distribution of difficult jobs. All preferences are modeled as soft constraints and penalized in the objective function. To solve the problem, the authors developed a hybrid solution method that uses linear programming, constraint programming and metaheuristics.

The work proposed in [47] presented the development of a decision support system called LAPS CARE for the staff planning in home care. The objective of the support system is to develop visiting schedules for care providers that incorporate soft constraints. The system includes time windows, required skills, staff breaks and working areas. These conditions, as well as customer preferences, were modeled as soft constraints. The model was based on a VRPTW scheme with a single depot and a single period. The authors used a set partitioning approach to solve the model. Authors of [48] dealt with the scheduling problem of home care workers in the United Kingdom. The problem consists in determining optimal routes for each care worker in order to minimize the distance traveled providing that the route durations and service time window constraints are respected, while having a multi-depot condition. The authors used a *Particle Swarm Optimization* (PSO) technique to solve the problem. PSO is a population-based searching technique, based on observations of the social behaviors.

The work presented in [49] studied the combination of vehicle routing and scheduling with precedence and synchronization constraints. The problem was formulated and solved in a home care environment, as a single-depot single-period case, with time windows, shift guidelines and heterogeneous staff skills. Authors proposed a mixed-integer programming model with the formal constraints of the VRPTW and temporal and balancing constraints. They considered four different objective functions: minimize preferences violations, traveling time, maximal workload difference, and a combination of the second and third functions. To solve the problem, they introduced an optimization based heuristic approach [50]. The idea of the approach is to solve significantly restricted mixed integer programs (MIP) problems to iteratively improve the best known feasible solution. The solution approach was tested in a home care staff scheduling application [47], and proposed for forest applications.

Later on, authors of [51] also studied the combination of the vehicle routing problem and the nurse rostering problem and developed a hybrid approach that uses constraint programming and the large neighborhood search metaheuristic to solve the model in a periodic HHC problem. The model is proposed for a week-period and its objective is to minimize a weighted function composed of the number of nurses that visit a patient during the schedule, the nurses cost, and the traveling distance. The solution method was tested on randomly generated data and on instances of the *periodic vehicle routing problem with time windows* (PVRPTW) [52].

The work presented in [53] studied the Home Care Crew Scheduling Problem (HCCSP) in the context of the Danish home care company Zeland Care, where the problem was tackled as a combination of the VRPTW and the Crew Scheduling Problem with Time Windows (CSPTW). In their problem, a staff of caretakers had to be assigned to a number of tasks, such that the total number of assigned tasks is maximized. In the model formulation, the authors considered a list of competences for each caretaker, and for each competence a level from zero to five that measures their expertise level. Caretakers' shift assignments and their location were also considered. For each patient a list of tasks were considered, and for each task, its address, duration and time windows, and priority were included in the model. The objective included three components: maximizing the total number of assigned tasks, maximizing the face-to-face time with patients, and minimizing the number of violated home care requirements. To solve the problem, the authors developed an exact algorithm based on a branch-and-price approach using column generation. The solution method was tested on four real-life instances and seven generated instances. According to the authors, in most of the cases, near-optimal solutions were found, and significant improvements were achieved when comparing with manual and heuristically built solutions. Results of this work were recently published by in [54].

Authors of [55] described a mixed integer linear programming model to assign each nurse to a set of patients to be visited within each route. The objective of the model was to minimize the total travel time and it considered time windows, staff lunch breaks, patient-staff regularity (to make the same staff member visits the same patient), and synchronization among staff members. The authors solved one instance of the model by two solvers: LINGO of LINDO SYSTEMS and OPL-CLPEX by ILOG Studio. The instance included seven patients, three nurses and a planning horizon of five days.

In [23], quantitative methods for the home health nurse routing and scheduling problem are developed, considering the decision as a dynamic periodic routing problem with fixed appointment times. The author considered a set of patients that must be visited by a home health nurse according to a prescribed weekly frequency for a prescribed number of weeks. The costs of offering fixed appointment times are quantified, and a distance-based heuristics is presented to solve the problem. The author also developed a new rolling horizon capacity-based heuristic for the problem, which considered interactions between travel times, service times, and the fixed appointment choices when inserting appointments of new patients. Based on computational experiments, the new heuristic developed outperformed the distance-based heuristic on metrics related to the satisfaction of patient demands.

More recently authors of [56] developed a collaborative model for planning and scheduling caregivers' activities in a homecare context in France. In the model, patients' time windows, precedence and synchronization relations among visits to patients were considered. The model is based on the VRPTW structure. The authors evaluated the model with an instance composed by two caregivers and eight patients. In the same year, authors of [57] worked on the optimization of daily scheduling for home care services in Austria. In the model, the authors considered working time regulations, hard time windows, mandatory breaks, and feasible assignment of nurses to clients. For solving the model, a metaheuristic solution approach based on a *Variable Neighborhood Search* (VNS) was developed. According to the authors, the proposed method finds global optimal solutions for small problem instances and numerical studies show that the algorithm is capable of solving real life instances with up to 512 home visits and 75 nurses.

The work of [58] presented a mid-term and short-term planning support for HHC services in Germany. The authors first introduced the HHC problem as a full-sized weekly model, which task is to create a service plan with nurses and patients such that the patients are served with the provided nurses. Then, they developed a second model that takes a current planning process into account and considers the construction of good master schedules. The master schedule problem (MSP) addresses the task to create optimal master schedules for a current patient pool in a given week, and to generate a schedule with a minimum number of tours, such that all patients visits are performed. Third, the authors studied an operational planning problem (OPP) that considers the requirements to incorporate last minute changes into an existing plan resulting from a solution to the HHC problem or an assignment of nurses to a master schedule. To solve each of the problems, the authors used different metaheuristics such as *adaptive large neighborhood search* (ALNS) and Tabu Search, combined with constraint programming. The capabilities of the solution approaches were evaluated with two real-world data sets, and results were reported for the HHC problem and the master schedule problem, showing an improvement on the solutions.

Bennett [24] identified four common formulations to deal with the home health nurse routing and scheduling problem: m-TSPTW, MD-VRPTW, PMD-VRPTW, CPMD-VRPTW. According to the author, the *multiple travel salesman problem with time windows* (m-TSPTW) formulation is useful when the assignment of patient visits to nurses and days are treated as exogenous decisions. The *multi-depot vehicle routing problem with time windows* (MD-VRPTW) formulation can be used when it is required to include nurse assignment decisions and additional side constraints that match patient requirements and preferences with nurse characteristics. The third formulation (*periodic multi-depot vehicle routing problem with time windows* - PMD-VRPTW) is useful when decisions to include the assignment of patient visits to days must be considered. Finally, the *consistency periodic multi-depot vehicle routing problem with time windows* (CPMD-VRPTW) formulation is presented by the author for the cases where nurse consistency, defined as the continuity of care, is a desired objective of the problem.

Critical review and lack of features

Tables 1 to 3 summarize the main models found in the literature at the three planning horizons respectively. By observing these tables it can be concluded that the majority of the models to support logistics decisions in HHC have been developed at the *operational* level and for *staff routing* and scheduling problems. Moreover, the literature review reveals that all works are based on developed countries. Two implications derive from these findings. On one hand, the research gap in HHC services between developed and developing countries contrasts with the financial investment levels on public or national health systems. The majority of the countries where research works for HHC services have been undertaken are countries with a solid National Health System, where the government is responsible for the largest part of the health expenses. On the contrary, no evidence was found of a scientific publication nor a practical implementation, with the use of models and methods to support this kind of decisions in HHC in developing countries.

These results evidence the lack of attention that the scientific community has had over these important decisions in developing countries.

Controversially, these countries are the ones facing the most severe health care crisis, and the ones where private companies are responsible for providing the larger part of health care services. These companies are facing more and more complex challenges to support logistics decisions in HHC services. Moreover, many of them face the risk of losing financial feasibility, due to the increasing demand and the incremental costs for providing the service. There is therefore a strong need to develop models and methods to support logistics decisions in those contexts.

Table 1 Characteristics of the models and methodologies to support logistics decisions in HHC: *Design and Planning Decisions*

Work	*Problem Type*	*Problem Characteristics*	*Objective(s)*	*Model Structure*	*Solution Method*
[21]	Districting Problem	Indivisibility of basic units, respect of borough boundaries, connectivity, mobility and work load equilibrium	Multi-objective: Mobility of visiting staff, workload equilibrium	Non linear	Tabu Search
[23]	Districting Problem	Connected service region, known demand, known set of nurses, balanced workload	Minimize the total cost of all districts: total travel time of nurses to serve a fraction of demand within each district	Set partitioning	Column Generation: Optimization and Local Search

Table 2 Characteristics of the models and methodologies to support logistics decisions in HHC: *Resource Planning and Allocation*

Work	*Problem Type*	*Problem Characteristics*	*Objective(s)*	*Model Structure*	*Solution Method*
[34]	Patient admission	Patients classification, variability of the number of patients and service time, transition rates	Max the number of patients admitted	Stochastic linear problem	Not provided
[35]	Patient admission	Waiting lists, institutional capabilities	Evaluate waiting lists policies	Linear recursive stock-flow	Simulation
[36]	Patient admission	Patients and services classification	Evaluate admission and referral policies	Multinomial logistic	Simulation
[25]	Staff assignment	Geographical location of patients, nurses workload, basic units pre-assigned to nurses, nurses classification, patients classification	Weighted quadratic relation - three measures of the workload: the average number of visits, the average number of cases and the travel load	MILP (Mixed integer linear programming) with non-linear constraints	Tabu Search and CPLEX

Table 3 Characteristics of the models and methodologies to support logistics decisions in HHC: *Resource Planning and Allocation*

Work	*Problem Type*	*Problem Characteristics*	*Objective(s)*	*Model Structure*	*Solution Method*
[39]	Staff routing	Time windows	Max the number of patients admitted	Stochastic linear problem	Not provided
[44]	Staff routing	Time windows, multi-depot, lunch breaks	Evaluate waiting lists policies	Linear recursive stock-flow	Simulation
[45]	Staff routing	Dynamic stochastic demand	Evaluate admission and referral policies	Multinomial logistic	Simulation
[46]	Staff routing	Time windows, heterogeneous staff, shift guidelines	Min assignment cost Max patients and staff preferences	Assignment problem	Hybrid: linear programming, constraint programming, metaheuristics
[47]	Staff routing	Time windows, synchronization, heterogeneous staff	Min total costs: travel time, travel cost, inconvinient working hours	VRPTW Set partitioning	Repeated matching algorithm
[48]	Staff routing	Time windows, multi-depot	Min travel distance	VRPTW multi-depots	Particle Swarm Optimization
[49]	Staff routing	Time windows, precedences, synchronization, heterogeneous staff, shift guidelines	Multi-objective - Minimize: preferences violations, traveling time, the maximal workload difference	VRPTW with temporal constraints	Optimization based heuristic
[51]	Staff routing	Time windows, frequencies, nurse availability priorities, shift guidelines	Multi-objective - Minimize: number of nurses that visit a patient, nurses cost, traveling distance	Assignment - routing problem	Hybrid: constraint programming, large neighborhood search
[53]	Staff scheduling and rostering	Time windows, precedences, synchronization, task priority, heterogeneous staff, multi-depot, shift guidelines	Multi-objective Maximize: the total number of assigned tasks and the face-to-face time with patients. Minimize: the number of violated home care requirements	VRPTW multi-depots	Branch and price

Work	Problem Type	Problem Characteristics	Objective(s)	Model Structure	Solution Method
[55]	Staff routing	Time windows, staff lunch breaks, patient-staff regularity, synchronization	Min travel time	Assignment - routing problem	LINGO of LINDO SYSTEMS OPL-CLPEX by ILOG Studio
[23]	Staff routing	Time windows, frequencies, shift guidelines, multi-depots, dynamic, periodic problem	Maximize nurse productivity	Periodic-Dynamic m-TSPTW	Scheduling heuristic procedure
[56]	Staff routing	Time windows, precedences, synchronization	Min travel and waiting times	Mixed integer linear programming VRPTW	LINGO of LINDO SYSTEMS
[57]	Staff routing	Working time regulations, hard time windows, mandatory breaks, and feasible assignment of nurses to clients	Weighted objective function: Min the traveling time of the nurses and the dissatisfaction level of clients and nurses	Mixed integer linear programming	Metaheuristic VNS (Variable Neighborhood Search)
[58]	Staff scheduling and rostering	Time windows, precedences, synchronization, task priority, heterogeneous staff, multi-depot, shift guidelines	Multi-objective Maximize: the total number of assigned tasks and the face-to-face time with patients. Minimize: the number of violated home care requirements	VRPTW multi-depots	Branch and price

On the other hand, the fact that most of the research has been focused on operational decisions, could derive in a low impact of the use of models and methods over the HHC systems performance. For each of the logistics functions, there is a hierarchy among management decisions that impose constraints in lower planning levels and influence the performance of the HHC delivery network. This hierarchy suggests that models and methods used to support logistics decisions at the operational level will not have a significant impact on the system performance, if decisions made at upper levels are not based on proper methodologies to design the network and to assign resources.

The above considerations allow us to claim that there exist several research opportunities to improve models and methods to support logistics decisions in HHC at the *strategic* and *tactical* levels. Real features can be considered to develop more comprehensive models to support in *districting*, *transportation*, *staff* and *inventory* management decisions. Specific research opportunities are the following:

- consideration of the increase in the diversification of HHC service references, and its impact on the workload measurement in *districting* and *staffing* problems;

- the inclusion of the limited access to specific areas in urban settings in the *districting* problem;
- modeling of the *staffing* problems in HHC environments, that explicitly considers the work legal regulation for medical staff in the respective context;
- the development of models to support *fleet selection and sizing* and *supplier selection*;
- inclusion of insurance coverage and *districting* configurations on patient admission;
- modeling of work legal regulations in models to support *shift scheduling* decisions in HHC;
- development of models to support *inventory policies* for medicines, supplies and devices along the HHC delivery network;

The evolution of models and methods reported in the literature, shows that the integral study of different logistics decisions in different planning horizons is an important research opportunity in HHC management. Nickel et al.[58] demonstrated how tactical and operational decisions can be integrated to build weekly staff service plans, to schedule staff and to program patient visits. The integration of decisions of different logistics functions, such as *districting* and *staffing*, and the impact of their result on tactical decisions, it is also a research opportunity that can provide a better support to improve the performance of HHC delivery systems.

Conclusions and research perspectives

This paper provides a critical review of models and methods used to support decisions logistics in HHC. A three-dimension framework was presented to characterize HHC logistics management problems. The first dimension deals with the duration and impact of the planning decisions through three *planning horizons*: *strategic*, *tactical* and *operational*. The second dimension differentiates the logistics functions by groups of four *management decisions*: *network design*, *transportation management*, *staff management* and *inventory management*. The third dimension describes the *services processes*, defined as the set of steps performed when the HHC service is delivered to a patient: *medical services*, *patient services* and *support services*. For each dimension a sampling of the available literature of models and methods used to support logistics decisions is provided.

Three perspectives of future research emerge from our review. First, due to the limited nature of resources and the restrictive budgets for health care, especially in developing countries, most of the critical management problems faced by HHC providers are not related to short-term or real-time scheduling decisions. Instead, the location and allocation of long-lasting resources at strategic and tactical levels are key decisions that determine the performance of the health delivery system in a large proportion. As life expectancy continues to increase, demands for health care will grow in quantity and diversification, and HHC providers will continue to face the challenge to design and operate more efficient health care delivery systems. These management problems do not rely only on short-term decisions to schedule medical staff visits to patients. Therefore, more research attention should be placed on models and methods to support decisions of resources location and allocation.

Second, few researches have focused on the inclusion of real features in the modeling process of HHC logistics management problems. The major interest observed in the literature consists of designing efficient solution methods to short-time decision problems. However, key real features as the diversification of patients' pathologies and HHC service references, as well as work legal regulations for medical staff have received little attention in the research literature. The inclusion of these features in districting problems and staff management problems such as staffing and shift scheduling can provide significant improvements in HHC systems.

Finally, more research attention should be placed on the study of the hierarchical integral structure of logistics management decisions in HHC. For example, at the staff management dimension, the staffing decisions and their allocation to districts are long-term decisions that are influenced by the distribution of patients' demands. Nevertheless, these demands are dynamic over time and thus new hiring decisions and staff configurations for districts might be required in the medium-term. This suggests that an integrated analysis of logistics decisions among different decision levels can provide a better support, if the impact of long-term and medium-term decisions is integrally evaluated.

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