Drugs Cross-Distribution Management in Urban Areas through an Incentives Scheme

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Abstract: The modern societies have witnessed several developments and changes in cities in the recent years. In order to make cities smart, new technological infrastructures are required to connect networks of actors, sensors and actuators embedded throughout the urban ground, and to interact with wireless mobile devices. In this context, this paper proposes an innovative approach for optimizing drug delivery and cost saving, inspired by the collaborative urban logistics concept. More in detail, the proposed approach is based on the use of a shared city warehouse managed by a network of pharmacies where it is possible to pick up the missing drugs. The paper develops a pharmacy supplying method based on an incentive system to engage pharmacists in the drug distribution process. An interactive drug distribution algorithm, based on an Integer Linear Programming problem, is proposed to minimize the external and transport costs. Finally, a case study is introduced, and the method efficiency is shown through the related simulations.

Keywords: Supply logistics, Urban Mobility, Sustainability, Service systems engineering, Integer Linear Programming.

1. INTRODUCTION

European Commission (2016) considers delivery distribution in urban areas a very important issue due to the growing logistics related to globalization and the online market. New strategies in the last mile logistics allow reducing costs and increasing service quality.

Korzhenevych et al. (2014) study positive and negative impacts generated by human activities where the negative impacts are also defined as externalities. The transport sector is one of the main responsible for externalities, especially in urban areas, according to Van Essen et al. (2019). The externalities caused by transport sector can be classified in air and noise pollution, land use, accidents congestion and oil dependence.

In the urban context, the pharmacy sector is a sensitive sector in which drugs delivery can be improved and related externalities can be reduced thanks to new strategies and approaches. Nowadays, the supply chain for the drugs distribution is efficient and widespread. It allows to deliver the required medicines in few hours, but to increase the service quality and reduce the cost, new strategies are needed. In the last years, several technological changes have been proposed in the pharmacy sector. Automated dispensing systems are available in pharmacy for over a decade and have been applied to a range of repetitive technical processes with high risk of error, including record keeping, item selection, labelling and dose packing. Most of the applications of this technology have been proposed at local level, such as in hospital, pharmacies or single-site community pharmacies until today. However, the widespread implementation of a more centralised automated dispensing model, such as the ‘hub and spoke’ model currently being debated in the United Kingdom, could cause a ‘technology shock’, delivering industry-wide efficiencies, improving medication accessibility and lowering costs to consumers and funding agencies, according to Spinks et al. (2016). There are studies such as Facchini et al. (2016) that focused on the hospital logistic optimization, but more efficient strategies can be applied for the last mile delivery of drugs in urban areas, reducing the related externalities. Literature review proposes several solutions to reduce such externalities, according to Ranieri et al. (2018), mainly related to the use of more ecological vehicles, such as Electric Vehicles (EVs), Hybrid Electric Vehicles, Fuel Cell Electric Vehicles like in Fanti et al. (2018) and Roccotelli et al. (2018), or to innovative methods and strategies, both in warehouse activities and freight transport as well as in last mile delivery such as in de Souza et al. (2014) and Wang et al. (2016).

Several examples of urban delivery of parcels, especially in the food sector, have been proposed. In this context, several new delivery players have been set up, such as Deliveroo, Just-eat, Foodpanda, UberEATS, and they use bikes as means of transport. Iannone et al. (2014) propose an example of new strategy for the drugs delivery. In this case, it is basically a matter of safety in delivering particular drugs.

In addition, the collaborative urban logistics concept is a new vision of the last mile delivery where the processes have a better consolidation and synchronization of existing resources (de Souza et al. 2014). Cooperative urban logistics concept is based on the sharing of the resources and the revenue for a more efficient last mile delivery. Urban Consolidation Centres

(UCC) concept is a development of these strategies and, together with innovative management strategies and business models, can allow to improve solutions of the urban logistics problems (Handoko et al. (2014)). These approaches are essential in an eco-friendly sector and for the reduction of externalities, because their use leads to the following advantages: less vehicles use; use of light transport means and with low or zero emissions (e.g., EVs, ELVs, FCEVs). Less and smaller vehicles circulating in the city also reduce congestion and infrastructure wear and tear.

Another IT-enabled open innovation that can be used in this context is the crowdsourcing. Howe (2008) defined crowdsourcing as a process in which organization outsources tasks that have traditionally been performed by the organization's members to a crowd of external individuals.

In this paper, an innovative approach for optimizing drug delivery and cost is proposed that is inspired by the collaborative urban logistics concept. More in detail, the innovative approach is based on the use of a city warehouse managed by the pharmacies where it is possible to pick up the missing drugs in the shops. The proposed method is based on the crowdsourcing paradigm with the involvement of the pharmacists through an incentive system. Some work such as Angelopoulos et al. (2016), proposed incentives in mobility sector. In this paper, awards are provided in the form of a discount to purchase drugs in order to manage the drugs distribution from a centralized warehouse to each pharmacy.

To this aim the paper develops an innovative cross distribution method based on an incentive system implemented with an interactive assignment algorithm that can be available through an Information Technology (IT) application.

The proposed approach is formalized as an Integer Linear Programming (ILP) problem to manage the drugs distribution in order to minimize the external and distribution costs. The novelty of the proposed formulation is the use of an incentive mechanism able to involve pharmacists in the distribution process with a lower overall cost. Finally, a case study shows the application of the methodology for the optimal drugs distribution.

The rest of the paper is organized in four sections: the Drugs Distribution problem in urban area is shown in Section 2; Section 3 describes the optimization approach to solve the Drugs Distribution Problem. Section 4 proposes a case study and the potential advantages of the incentive approach to the drugs distribution in urban area, involving pharmacists. Finally, Section 5 presents conclusions and future works.

2. DRUGS DISTRIBUTION PROBLEM IN URBAN AREA

In a city context, the presence of several pharmacies requires the delivery of a large number of drugs and a high number of trips by truck. The fast distribution is essential for customers, especially in the case of drugs that are not available in a pharmacy.

In this context, the optimization of the drugs distribution phase is very important to provide drugs in a more efficient daily sales service. Moreover, the supply chain mainly uses heavy and polluting vehicles, such as trucks, to distribute drugs to the pharmacies. Therefore, new transport solutions are needed.

Recently, new concepts of transport are proposed that are transforming it in a service. The mobility is no longer addressed as a means of transport, but it is seen as a service. Mobility as a Service (MaaS) is the new vision in smart mobility.

The UCC idea is based on a depot placed close to the city where the goods are stored before being delivered to the retailers to reduce the city centre traffic congestion, emissions and externalities. The same concept can also be implemented with refinements in the pharmaceutical sector through collaborative urban logistics approaches: an automated drug warehouse managed by city pharmacies, can be established within the city and every pharmacist can access it in order to quickly collect and retrieve the missing drugs. This approach allows reducing the purchasing cost of drugs because the pharmacies can benefit of economic advantages in buying a higher number of drugs, with consequent economies of scale.

Furthermore, the incentive system approach to engage the customers are used in different fields as well as in the mobility sector as proposed Fanti et al. (2019).

Based on these concepts, an innovative approach is proposed to distribute the drugs in the different city pharmacies involving pharmacists with an incentive system. The proposed approach aims to reduce the transport externalities in urban area, distribution costs for the pharmacies through an incentive mechanism.

The idea is to propose to pharmacists a prize in the form of a purchase vouchers for drugs as a reward for the delivery from warehouse to the receiver pharmacy shop. The proposed pharmacist's incentive system can be provided through an IT application for smartphone and it is described by the procedure in Fig. 1. In the first phase, the pharmacists send a request of drugs to warehouse, in order to check the availability. It is assumed that all the necessary drugs are present in warehouse.

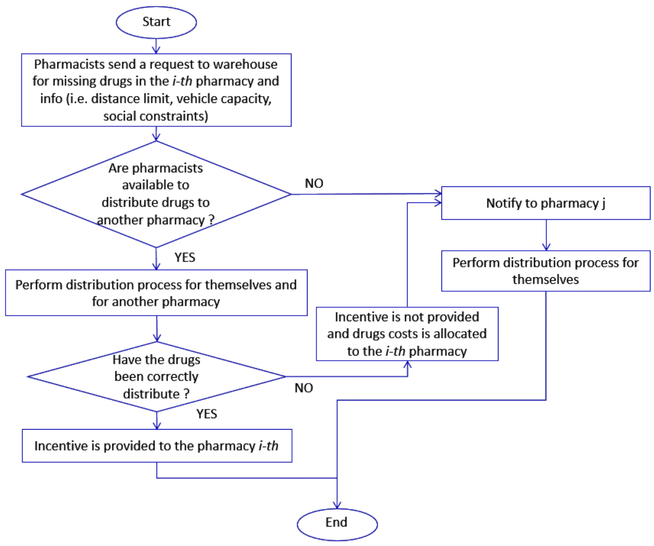

Fig. 1. Algorithm of incentive scheme in drugs distribution.

The system checks if there are pharmacists available to distribute drugs for themselves and to another pharmacy; in this case it sends an incentive proposal to the available pharmacists and info to perform the distribution activity. If the cross-distribution process is completed, the pharmacist that delivers the drugs to another pharmacy receives the credits; otherwise, the delivery pharmacist is charged for the not delivered drugs cost and the receiver pharmacy is notified of the failure. In this case, a self-distribution process is performed by the receiver pharmacy itself if no other pharmacist is available to deliver drugs. The drugs distribution cost can be reduced by the proposed incentive system or at worst it remains unchanged.

3. OPTIMIZATION METHOD FOR DRUGS DISTRIBUTION

In this Section, an optimization method to solve the drugs distribution problem within a city involving pharmacists with an incentive system is proposed. The models are formulated under the following assumptions:

- the distribution cost is proportional to the distance between warehouse and each pharmacy shop and it is considered two times (round trip), based on a destination-source matrix. It is a variable cost and fixed cost (e.g. salary, equipment, etc.) are not considered;
- the external costs are related to congestion, accidents, air pollution, noise pollution and climate change, as reported in and the values are considered for light commercial vehicles;
- the distribution process is performed by pharmacists who go to the warehouse, takes the necessary drugs and deliver it to another pharmacy shop and then to his/her shop, through the shortest route;
- there is only one distribution process per day for each pharmacy shop;
- a distance limit is proposed by each pharmacist to distribute drugs to another pharmacy;
- the drugs are organized in packages;
- the drugs distribution demand is considered as the number of drugs packages required by each pharmacy;
- a capacity constraint is considered for each van in each pharmacy. In addition, the number of packages to be delivered by a pharmacy is always less than the capacity of the pharmacy van.

The drugs distribution is performed by pharmacists with the use of the warehouse in an urban area as in the scheme shown in Fig. 2. The externalities cost related to drugs delivery by trucks can be reduced because the pharmacy uses smaller and more efficient vehicles than trucks, such as vans or cars. In the distribution process, each pharmacist performs at least a roundtrip from pharmacy to warehouse.

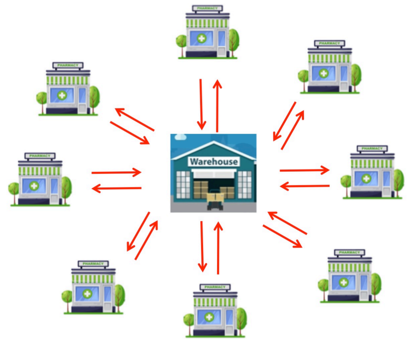

Fig. 2. Drugs distribution with warehouse in urban area.

3.1 Drugs Distribution Problem with Incentives

The drugs distribution problem is formulated as an ILP problem that aims to minimize the cost of the distribution involving pharmacists in the activities. The incentive value is paid by the *j-th* pharmacist that receives the drugs in the distribution process performed by the *i-th* pharmacist in form of credits.

Moreover, we assume that there is a *DC* of pharmacy pairs that do not accept to collaborate for the drugs distribution, i.e., $(i,j)\in DC$ if the *i-th* pharmacist is not willing to distribute drugs to *j-th* pharmacy, under incentive payment. We assume that the pharmacist of the *i-th* pharmacy can distribute drugs to no more than one pharmacy j. In addition, a kilometric distance limit $\overline{D}_i$ is imposed by each pharmacy in order to accept a drug distribution to another pharmacy.

The variables and parameters of the problem are defined as following:

$I = \{i = 1, \dots, P\}$: set of P pharmacies;

$i = 0$: the warehouse;

$D_{i,j}$: the distance between pharmacy i and pharmacy j [km];

$\overline{D}_i$: the distance limit of pharmacy i [km];

$D_{i,0}$: the distance between pharmacy i and the warehouse [km];

N_i: number of drugs packages required by pharmacy i [package];

N_j: number of drugs packages required by pharmacy j [package];

LF_i: load factor for the vehicle of pharmacy i [package/vehicle];

c: cost per kilometre [€/km];

e: external cost per kilometre [€/km];

The following decision variables are defined:

$x_{i,i}$ is the binary decision variable indicating the need to go to the warehouse to get missing drugs in the *i-th* pharmacy;

$x_{i,j}$ is the binary decision variable indicating the availability of the *i-th* pharmacy staff to distribute drugs to another pharmacy j, in the process of withdrawal drugs from the warehouse.

The incentive provided to the *i-th* pharmacist depends on the trip distance saved by the *j-th* pharmacist and the number of delivered packages. It is computed as follows:

$$IN = \begin{cases} 2 \cdot c \cdot D_{j,0} \cdot x_{j,j} \cdot \frac{(LF_i - N_i)}{N_j}, if \frac{(LF_i - N_i)}{N_j} \le 1 \\ 2 \cdot c \cdot D_{j,0} \cdot x_{j,j}, if \frac{(LF_i - N_i)}{N_j} > 1 \end{cases} \quad (1)$$

The rationality of the incentives is the following:

1- if $(LF_i - N_i) > N_j$ then pharmacy i can deliver all the required packages of pharmacy j, hence the incentives are proportional to the distance between warehouse and the pharmacy j;

2- if $(LF_i - N_i) \le N_j$ then the number of drug packages that pharmacy i can deliver to pharmacy j is less than N_j, hence the incentive is decreased by the factor $\frac{(LF_i - N_i)}{N_j}$.

Now, we define the *Total Daily Distribution Cost* (TDC) [€/day] that includes the external costs related to the distance among the pharmacies and the warehouse. The TDC can be obtained as follows:

$$TDC = 2(c+e)\sum_{i=1}^{P} D_{i,0}. \quad (2)$$

Moreover, the object of the optimization problem is the TDC that includes incentives as follows:

$$TDC' = (c+e)[\sum_{i=1}^{P}\sum_{j=1,j=i}^{P}(D_{i,0} + D_{0,j} + D_{i,j}) \cdot x_{i,j} + \\ + \sum_{i=1}^{P} 2D_{i,0} \cdot x_{i,j}]. \quad (3)$$

The ILP problem that formalizes the described problem is the following:

min *TDC'*

subject to:

$$x_{i,j} = 0 \text{ for } i,j \in DC \quad (4)$$
$$x_{i,j}D_{i,j} \le \overline{D_i} = 0 \text{ for for } i,j = 1, \ldots, P \quad (5)$$
$$x_{i,j}(N_i + N_j) \le LF_i \text{ for } i,j = 1, \ldots, P \text{ with } i \ne j \quad (6)$$
$$x_{i,j} \in \{0,1\} \text{ for } i,j = 1, \ldots, P \quad (7)$$

Constraints (4) take into account the so called disagree couples $(i,j) \in DC$ as described in Section 3.1.

Constraints (5) guarantee that the travelled distance between the considered pharmacies does not overcome $\overline{D_i}$. Moreover, constraints (6) impose that the load in the vehicles used by each pharmacy does not overcome the load capacity and constraints (7) requires that each pharmacy receive the drugs delivery (from himself or another pharmacist). We assume that if the number of packages to be delivered is higher than the load capacity, only part of the packages destined to pharmacy j will be transported.

The problem admits always the feasible solution because in case no pharmacist accepts to deliver drugs to another pharmacy, each pharmacy staff will perform it by itself.

4. CASE STUDY

4.1 The Case Study Specification

This section presents and discusses a case study of the city of Bari, in southern Italy. The case study analyses P=6 different pharmacies characterized by c=0,50 [€/km] and the destination-source matrix reported in Table 1. Moreover, the values of $\overline{D_i}$, for $i = 1, \ldots, 6$, are reported in Table 2; N_i and LF_i are defined in Table 3 and Table 4, respectively. Van Essen et al. (2019) propose external costs values for vans that are compared with diesel Euro 3 light commercial vehicles (see Table 5). A Monte Carlo simulation is used to define a set of scenarios related to the willingness of pharmacy couples to perform or not drugs cross-distribution on the basis of the incentive applications. One of the most probable scenarios is reported in Table 6 that allows determining the set *DC*.

Table 1. Distance between pharmacy shops and warehouse in km

	0	1	2	3	4	5	6
0	0	3	4	2	5	4	3
1	3	0	3	4	8	6	4
2	4	3	0	2.5	7.5	8	6.5
3	2	4	2.5	0	5	6	5
4	5	8	7.5	5	0	6	6.5
5	4	6	8	6	6	0	2.5
6	3	4	6.5	5	6.5	2.5	0

Table 2. Limit distance imposed by each pharmacist in km

Pharmacy *i*	$\overline{D_i}$
1	3
2	5
3	4
4	6
5	4
6	5

Table 3. Drugs demand from each pharmacy shop in number of packages

Pharmacy *i*	N_i
1	3
2	2
3	5
4	4
5	3
6	2

Table 4. Load factor for each vehicle of pharmacy shop in number of packages

Pharmacy i	LF_i
1	5
2	4
3	6
4	5
5	6
6	4

Table 5. External costs for the distribution activity

	LCV [€/km]
Accidents (Table 8 in Van Essen et al. (2019))	0.041
Air Pollution (Table 16 in Van Essen et al. (2019))	0.034
Climate Change (Table 25 in Van Essen et al. (2019))	0.026
Noise Pollution (Table 35 in Van Essen et al. (2019))	0.011
Congestion (Table 48 in Van Essen et al. (2019))	0.994
Total External Costs	1.106

Table 6. Willing to deliver package in the cross-distribution process

	1	2	3	4	5	6
1	-	1	0	0	1	1
2	0	-	0	0	0	0
3	0	0	-	0	0	0
4	1	1	0	-	1	1
5	1	0	0	1	-	1
6	0	0	0	0	0	-

4.2 The Case Study Solution

The formulated ILP problem is solved by a standard solver, i.e. MatLab (LinProg), on an Intel-Core i5, 2.7 Ghz CPU with 8 GB RAM. All the performed tests are solved in less than 2 seconds.

The TDC obtained by (2) and taking into account the defined data and parameters is equal to 68.70 €. The cost includes the distribution cost and the external costs.

The proposed methodology allows calculating the total daily distribution cost with incentive scheme (TDC'). Solving ILP, the TDC' is equal to 54.79 €. In this case the external costs are also included. In addition, the provided incentive values are equal to 6 € for pharmacy 1 (provided by pharmacy 2) and 5 € for pharmacy 5 (provided by pharmacy 6), respectively. Note that pharmacies 3 and 4 do not participate in the strategy with incentives and the drugs distribution is carried out by each pharmacist for himself.

The solution of ILP is drawn in Fig. 3: the red lines show the self-distribution performed by the pharmacies and the green lines represent the cross-distribution performed by pharmacists through the incentives.

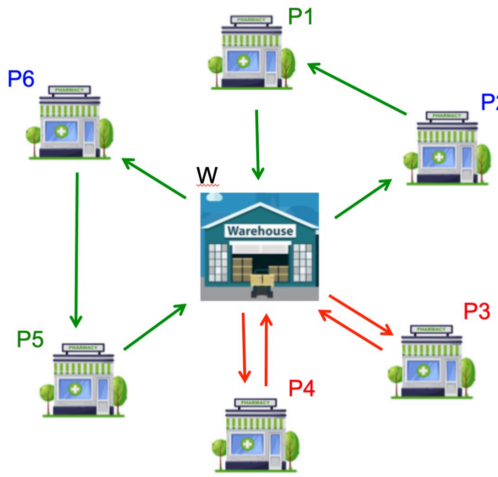

Fig. 3. Drugs distribution with warehouse in urban area.

The comparison of the results obtained by the ILP problem solution that includes the incentives and the case without incentives is shown in Table 7. The results enlighten that by the proposed method the drugs distribution problem solution shows a significant reduction (over 20%) of the external costs and distribution operative cost.

Table 7. Simulation results

	Drugs distribution without incentive system [€/day]	Drugs distribution with incentive system [€/day]
External costs	46.45	37.05
Distribution operative cost	21	16.75
Incentive values	-	11
Overall cost	67.45	64.80

Although the overall cost, including incentives, shows a minimum saving of around 4% between the two conditions (drugs distribution with and without an incentive system), the proposed method has undeniable benefits. In fact, the value of the incentives really is not a cost for all but it is a transfer of value between pharmacies to the pharmacists who also distribute drugs for another. Therefore the overall cost should be considered without this value. Finally, this approach allows a significant reduction in externalities cost, a very important factor as it does not only involve pharmacies but all the citizens.

5. CONCLUSIONS

In this paper a new methodology to distribute drugs in pharmacies in urban areas is presented. The proposed approach is based on an incentive scheme to engage pharmacists in the drugs cross-distribution process with another pharmacy shop. The rewards are provided to delivery pharmacy in form of credits and can be used to purchase drugs from the warehouse.

An Integer Linear Programming Problem is formulated to model and solve the drugs distribution problem performed under incentive system. The pharmacists willing to distribute drugs to another pharmacy shop, pick up the drugs packages from the warehouse and deliver them. In this process, if the load factor of delivery vehicle is equal to the maximum load capacity, the next available pharmacist will deliver the remaining packages. In case no pharmacists are available to perform the distribution under incentives, each pharmacy shop will perform the distribution by its staff. It is exhibited that the proposed method allows reducing the external costs and the total drugs distribution cost. In addition, the case study shows the benefit of the innovative approach to improve the resources sharing by using the proposed incentive scheme.

In future works, a routing problem will be developed to involve more than two pharmacies in the drugs distribution process.

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