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Application of the joint replenishment problem in a collaborative Inventory approach to define resupply plans in urban goods distribution contexts

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Abstract
This article presents an application of the joint replenishment problem (JRP) as the basis for proposing a collaborative inventory model with joint orders, in which multiple customers share the required information to define their supply plans. This information is consolidated by the supplier and it is responsible for carrying out the collaborative joint replenishment process. The application of the model allows generating a replenishment process that reduces costs compared to carrying out the individual plans for each customers and also generates a reduction in the number of trips required, which is a positive contribution to urban goods distribution processes.

Keywords: joint replenishment; collaboration; inventory optimization; urban freight distribution.

Aplicación del problema de reabastecimiento conjunto en un esquema de colaboración del inventario para definir planes de abastecimiento en contextos de distribución urbana de mercancías

Resumen
Este artículo presenta una aplicación del problema de reabastecimiento conjunto JRP como base para proponer un modelo de inventario colaborativo con órdenes conjuntos, en el cual múltiples clientes comparten la información requerida para el cálculo de los planes de abastecimiento. Esta información es consolidada por el proveedor y a partir de esta se realiza un proceso de reabastecimiento conjunto colaborativo. La aplicación de este modelo permite generar un proceso de reabastecimiento que reducen los costos en comparación a la realización de los planes de forma individual de cada uno de los clientes y genera una reducción en el número de viajes que se requieren para abastecer los clientes, lo cual es un aporte positivo para los procesos de distribución urbana de mercancías.

Palabras clave: reabastecimiento conjunto; colaboración; optimización del inventario; distribución urbana de mercancías.

1. Introduction

The urban goods distribution processes play a fundamental role in the competitiveness of companies and cities, since these activities generate logistics costs and are carried out in conditions in which goods transport interacts with passenger movement and other transport processes required in the city [1]. The intensity of the distribution process and the infrastructure constraints for vehicle mobility in urban areas usually increase the difficulties for goods transportation, evidenced in bottlenecks and in mobility restrictions imposed by city administrations, seeking to improve people's quality of life and mitigate negative impacts to the environment, such as greenhouse gases emissions [2].

In this way, it is necessary that companies propose new goods distribution processes and strategies for urban

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environments, pursuing several objectives, such as economic attractiveness for companies and the reductions of negative effects such as traffic congestions and chemical contaminants emissions [3]. Several strategies have been proposed by different authors and city administrators, as the implementation of city logistics platforms, the establishment of exclusive zones for goods transportation, information technologies application and time windows for trucks, among many others [4-6].

In order to generate better distribution processes, companies frequently concentrate their efforts in developing new advanced algorithms for goods transport [1], leaving aside two fundamental concepts: first, transportation is carried out by the need to distribute the inventory; and second, through collaboration between different actors, it is possible to generate synergies among several companies [1,3].

This article proposes a collaboration approach that allows generating joint supply plans for several products of different customers, seeking to reduce logistics costs and the number of trips required in the replenishment process. This collaborative approach enables to propose logistics replenishment plans which are attractive and easily applicable by companies, and also helps to mitigate the negative impact of logistics processes within cities, since reduction of the number of trips diminishes congestion and environmental pollution [7].

The proposed collaboration model is based on the joint replenishment problem - JRP, in which a group of customers replenish their products from a single supplier and share the required information for making the supply plans and the determination of the inventory allocation. The information is managed by the supplier following the Vendor Managed Inventory strategy. The supplier is responsible for assigning the collaborative replenishment and the distribution plans. The model is validated with the simulation of a logistics network composed by a single supplier and several customers, from which it was possible to observe a total inventory costs reduction as well as a decrease in the number of trips, compared to the case when the supply plans are made individually by each customer.

2. Collaboration in urban goods distribution

Collaboration between companies has a high potential in the supply chain [8] since it allows generating synergies between different organizations to reduce operating costs, increase flexibility [9], reduce stock amounts, increase capital turnover and produce better demand forecasting processes [10]. Several authors argue the importance of looking for new ways of carrying out goods distribution processes in urban environments [11-13] that can be economically attractive for companies and that can also reduce the negative impacts of transportation processes within cities [3,7]. Collaboration between actors is one of the most promising strategies in supply chain [1]. This is highlighted by [14,15], which mention the necessity to intensify collaboration between companies involved in the urban goods distribution processes.

The collaboration processes reported in the scientific literature are differentiated by the nature of the actors involved, considering, on the one hand, the collaboration between government and private actors and, on the other, the exclusive collaboration between companies (freight companies, cargo generators). The main collaboration interest between administrators and private companies is to organize the flow of goods through specific areas in the city, which is frequently achieved through mobility restrictions and the implementation of specialized infrastructure to improve transport processes, such as city logistics platforms, dedicated roads to cargo transportation and restricted parking and unloading areas [14]. The use of information systems that allow exchanging city information between the goods distribution actors is another way to encourage collaboration between companies and city administrators [16-18]. Exclusive collaboration between companies for urban goods distribution can be defined as the process in which several companies share vehicles, infrastructure or information, with the aim of reducing logistics costs and the negative effects of goods distribution within cities [19]. Collaboration for defining inventory plans is one of the most used strategies to achieve the mentioned goals [1,3,7,13].

Collaboration in inventory planning can be framed inside information sharing and there are several proposed strategies that support companies to incorporate this collaborative approach such as joint orders [20], efficient customer response (ECR) [21,22], collaborative planning, forecasting and replenishment (CPFR) [23], Just in Time [24], vendor managed inventory (VMI) [25-27], consignment stock [28], among others. The VMI and the CPFR approaches are the most popular collaborative approaches used to achieve cost benefits for companies [29]. A key element for the success of collaborative approaches in the supply chain is information sharing, as well as the role definition of the actors involved in such collaborative strategies [29]. In VMI the information of sales and inventory level is shared from customers to the supplier, who is in charge of defining the replenishment decisions and plans for the customers [26,29].

Several authors argue the importance of including inventory management decisions in goods distribution processes [30,31] since the intensity of transportation is a consequence of the inventory quantity required to be transported; e.g., the more cargo must be delivered, the more number of trips required [1]. Some authors who have integrated inventory and transport decisions in urban goods distribution processes through collaboration are [30,32,33].

3. Joint replenishment

In the scientific literature it is possible to find several inventory models that allow companies to carry out the joint replenishment of many products, making it possible to decide the optimal quantities to be ordered from a single supplier or multiple suppliers [34]. One of these models is the Joint Replenishment Problem (JRP), through which it is possible to determine the replenishment policy of different products from the same supplier, seeking to reduce the total replenishment cost that includes stored products, performing orders and stock-outs costs [35].

The JRP allows grouping different products that need to be ordered, which better distributes the fixed ordering costs among all the products [36], achieving cost savings in the total replenishment process. This reduction is reported by [37], indicating that using the JRP can save up to 13% compared with the individual inventory costs optimization for each product, using the economic order quantity (EOQ) model.

There are two strategies to find solution to the JRP model, which differ from the way in which the products are grouped: The Direct Grouping Strategy – (DGS) and the Indirect Grouping Strategy (IGS) [34]. In the Direct Grouping Strategy, the products are organized in several groups and each one has a different cycle time assigned in which the products are jointly ordered to the supplier. The products are ordered when the cycle time is reached. In the Indirect Grouping Strategy there is not a cycle time for each group of products to be ordered; instead, there is a unique cycle time and the products are ordered in integer multiple times of such cycle time. This multiple number indicates the moment in which every product must be ordered, thus the products with the same cycle time are always ordered together. The products with a cycle time equal to one must be ordered every cycle time and the other products must be ordered every two cycles, every three cycles, and so on. [34]. Several authors mention that the IGS produces more efficient results in terms of cost than the DGS [35-38].

In its simplest version, the JRP model seeks to optimize only the ordering and holding inventory costs at the customers' facilities. However, there are several variations to the original JRP model that consider elements such as capacity and resource constraints [36], dependent ordering costs [39], stochastic and dynamic demands [37], multi-level supply processes [37, 40] and inventory-routing problems (Joint Replenishment & Delivery Problem - JRD) [41-46].

4. Joint orders collaborative approach

This article presents a collaborative approach in which companies share product's information, such as demand, holding costs, among others, which is consolidated by the supplier, who is in charge of defining the joint replenishment plans for all customers. This collaborative approach is depicted in Fig. 1, where a dotted line indicates an information flow and a continuous line indicates a physical-material flow in the replenishment process.

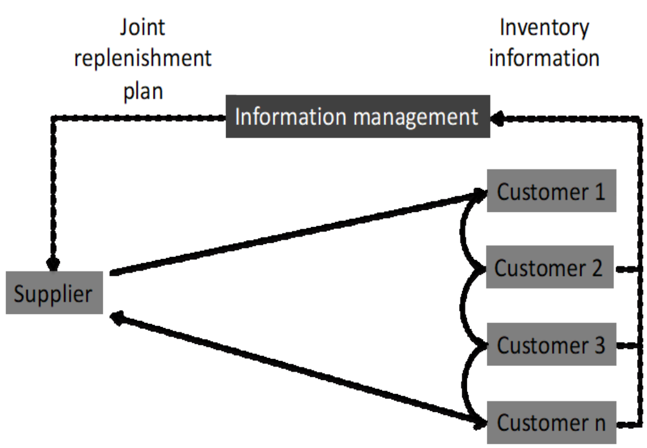

Figure 1. Collaboration model
Source: The authors.

The information required in the collaborative planning process is the products demands, inventory levels, ordering and storage costs in every customer. This information can be consolidated and managed by an actor of the distribution process or by an external entity, depending on the ability to make the distribution plans or for information security issues [1]. This entity, which in this article is the supplier, follows the Vendor managed strategy, defining the supply plans for all customers in the same time horizon through the application of the JRP. The JRP model is presented in equations 1 to 6, using the indirect grouping strategy (IGS). In this, the optimal common cycle time T* and the set of k_i integer numbers correspondent to multiples of the cycle time are calculated. Products with the same value of k are ordered at the same time. For example, a product with $k = 1$ is ordered every cycle time, a product with $k = 2$ is ordered every 2-cycle times, and so on [39].

The order quantity for each product (Q_i) in every cycle time is expressed in equation 1 and the total annual cost incurred for holding every product i can be calculated using equation 2. The ordering cost for each item is given by equation 3, which must be added to a fixed ordering cost S that is incurred every time a replenishment operation must be deployed with at least one product.

$$Q_i = Tk_iD_i \quad (1)$$

$$Tk_i \frac{D_i}{2} h_i \quad (2)$$

$$\frac{s_i}{k_i} \quad (3)$$

In those equations, i represents product index with $1 \leq i \leq n$, where n is the number of products to be ordered. D_i is the annual demand of product i, T is the order cycle time (time between orders) in years, h_i is the holding inventory cost and Si is the variable cost of including the product i in an order. The total replenishment cost can be calculated with equation 4.

$$TC = \frac{T}{2}\sum_{i=1}^{n} h_i k_i D_i + \frac{1}{T}\left(S + \sum_{i=1}^{n}\frac{s_i}{k_i}\right) \quad (4)$$

The optimal cycle time T* and the minimum total cost can be expressed in terms of the k_i integers for the n products, as expressed in equation 5 and 6. Therefore, the problem is reduced to calculate the k_i integer numbers as proposed by [47].

$$T^* = \sqrt{\frac{2(S+\sum_{i=1}^{n}\frac{s_i}{k_i})}{\sum_{i=1}^{n} k_i h_i D_i}} \quad (5)$$

$$TC = \sqrt{2\left(S + \sum_{i=1}^{n}\frac{s_i}{k_i}\right)\sum_{i=1}^{n} k_i h_i D_i} \quad (6)$$

Due to its combinatorial nature, the JRP is considered a NP-Hard problem, making it necessary to use advanced solution techniques, such as specialized heuristic and metaheuristic tools. Genetic and evolutionary algorithms [48-50] are a useful metaheuristic for solving complex mathematical problems, which can be used to find solutions to the joint replenishment problem [36,46,48]. A genetic algorithm developed to solve the JRP model in the collaborative inventory planning approach is presented in the next section.

5. Genetic algorithm for the joint replenishment problem

Genetic algorithms are advanced search techniques based on the evolutionary concept of natural selection, in which an individual represents a feasible solution to the problem and the more suitable individuals survive to future evolutions. In these algorithms, a population of individuals evolves by submitting each individual to operations of selection, crossing and mutation, from which new populations are obtained. It is expected that after a certain number of evolutions the optimal solution to the problem, or at least a closer one, will be found in a reasonable computation time [46,51]. Fig. 2 represents the evolution process of a genetic algorithm [46].

Genetic algorithms are good at solving complex computational problems [1,52,53] with characteristics of discontinuity, multimodality, noisy evaluation functions [54,55], non-linearity and non-convex solution spaces [56]. In the scientific literature it is possible to find several works that use genetic algorithms and other evolutionary computation techniques to solve the JRP, such as the works of [34,35,39,40,46-48,57-59,60,61].

The individual is represented by the chromosome. In the case of the Joint Replenishment Problem, this representation can be done through a vector of integer numbers [35], real numbers [47] or binary numbers [34]. In this article, a real number representation is used following the work of [47], as depicted in Fig. 3 for a 10-product joint replenishment process. In the proposed individual representation, a gene located in the position i represents the k_i value for the i^{th} product. These real numbers are coded into the k_i values by the procedure presented in [47]. Using real numbers coding facilitates determining the upper and lower limits for the k_i values in order to make a more accurate search in the solution space, as proposed by [34] and [47].

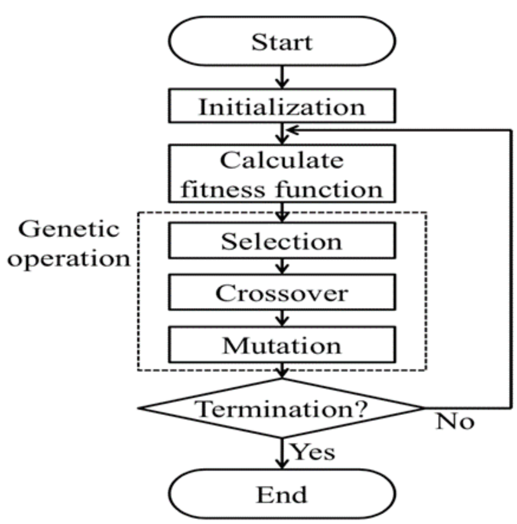

Figure 2. Genetic algorithms process.
Source: [46].

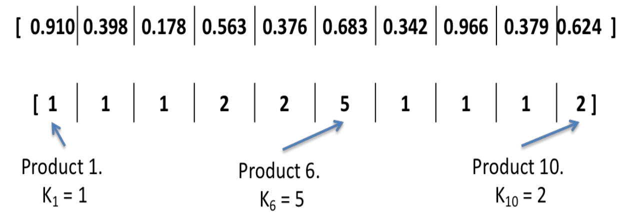

Figure 3. Chromosome representation for the JRP.
Source: [62].

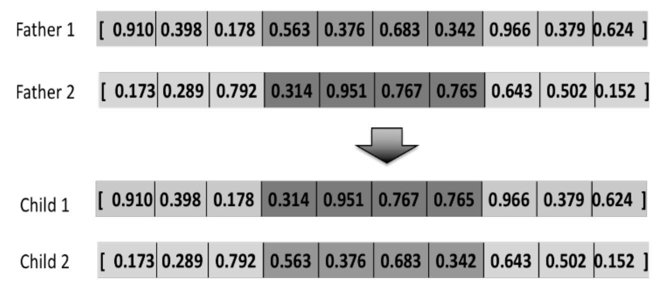

Figure 4. Two-point crossover operation for the IGS.
Source: [62].

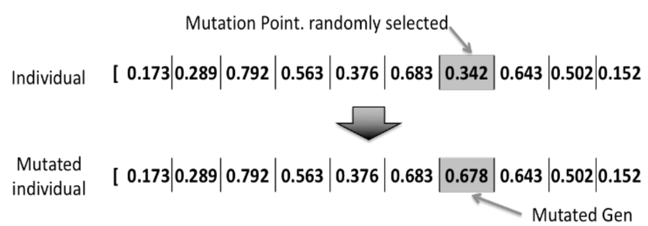

Figure 5. JRP One-point mutation operation for the IGS.
Source: [62].

The chromosome presented in Fig. 3 indicates that products 1, 2, 3, 7, 8 and 9 must be ordered every cycle time; products 4, 5 and 10 must be ordered every 2-cycle times; and product 6 must be ordered every 5-cycle times. The cycle time and total cost are calculated internally by the genetic algorithm using equations 5 and 6. Equation 6 corresponds to the algorithm fitness function.

The crossover operation is done by using a two-point crossing method, as shown in Fig. 4. For this procedure the crossing points are selected randomly. The mutation operation is carried out using the one-point method as shown in Fig. 5. The mutation gene is randomly selected and its value is changed by a random number between the lowest and the highest real value of the entire chromosome that represents the k_i.

The initial population is randomly generated and the selection for crossing is made using tournament, in which the individuals are randomly selected until completing groups with a capacity equivalent to the 10% of the population.

6. Methodology

The collaboration approach presented in this article is applied in the collaborative distribution process of 15 organizations in the city of Medellin, Colombia. These companies are located in the midtown area and are part of the food industry. 10 different products that are supplied from the

Table 1.
Product demands for the 15 collaborating customers

Demands										
	Product									
Customer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	3171	7164	2630	3137	6804	1504	7223	5535	1106	3064
2	2421	6374	4638	2966	3371	1858	7845	6797	3133	5652
3	1623	5219	2591	4251	5582	1584	7282	5957	3430	5453
4	5519	7159	4325	3621	3183	1469	7980	6291	3539	5536
5	5744	5467	2215	3014	5192	1996	7379	4470	1446	3374
6	6496	5568	3311	3247	6170	1729	7943	5832	3209	3288
7	6774	7354	2487	1941	3082	1089	7609	6006	1494	5707
8	1552	5176	2159	1724	5290	1284	7732	6481	2044	3900
9	7299	6793	2148	3018	4755	1749	7468	6358	1070	4506
10	7956	5912	2651	1649	4770	1153	7260	4516	2410	4728
11	6983	6559	2866	4165	3982	1479	7626	5921	3978	3300
12	1962	7044	2373	3644	5869	1639	7069	6481	2419	4574
13	2321	7165	4524	3710	4295	1836	7272	5244	2367	3403
14	4805	6079	4270	1530	3104	1319	7790	6089	1634	3101
15	1573	6866	4885	3645	6464	1321	7712	4356	1624	5345

Source: The authors.

Table 2.
Holding and individual ordering costs for the 15 customers

Si										
Customer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	36647	48978	37662	32556	42991	35715	44350	31497	32815	39062
2	30588	24089	31210	35759	24985	31883	25543	35416	38352	23701
3	41592	42236	46593	43202	36276	29212	24687	28752	30877	22426
4	28013	23151	23530	24684	26108	27472	23731	22133	21230	29226
5	43134	48611	43640	42758	40444	47277	42754	47939	44241	46211
6	49681	34129	35762	39344	32308	35231	47119	42783	34166	33858
7	26416	25647	38095	21345	30760	26831	34819	37016	37423	26727
8	46644	36247	47280	49687	34050	24532	36539	26887	45712	25304
9	25157	20395	23651	27786	25952	20014	26985	20367	27880	29658
10	41278	48491	45860	47973	43662	45180	46559	42711	41229	49861
11	39585	44363	46600	43178	34078	33738	45669	32234	45162	43938
12	36519	33042	32242	27657	25042	33382	27400	27722	24347	23769
13	26070	33630	30358	29720	39575	25714	28798	20931	35891	36363
14	26149	22947	22861	26835	26578	28253	24127	28110	26202	26805
15	42330	45378	48198	41706	41585	41911	48431	45921	40614	44175
hi										
Customer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1118	964	1068	950	875	1145	977	926	891	996
2	957	949	938	967	946	954	930	905	905	928
3	1090	1065	1058	1065	1066	1032	1054	1063	1099	1082
4	1153	1177	1192	1132	1197	1119	1136	1120	1115	1163
5	1090	1015	918	1065	1018	911	1072	1015	963	984
6	860	899	942	922	849	996	1187	1120	1036	824
7	996	976	959	937	991	960	939	917	942	907
8	1096	1043	1053	1003	1072	1067	1076	1023	1052	1060
9	1121	1144	1163	1130	1160	1174	1151	1122	1157	1186
10	943	969	1094	949	1078	1100	927	1096	1030	1095
11	910	875	807	1145	1088	1119	1133	845	1006	1077
12	990	984	908	988	977	984	929	925	996	932
13	1083	1081	1038	1033	1051	1024	1078	1059	1084	1074
14	1191	1190	1192	1138	1131	1127	1188	1113	1114	1198
15	997	1008	985	1066	927	1090	915	982	959	1084

Source: The authors.

same provider were selected for the analysis. The demands of each product for the 15 customers are presented in Table 1. As mentioned above, the supplier is in charge of consolidating and managing the information under the VMI strategy [29]. Table 2 presents the holding and individual ordering cost for each product in every customer. The fixed ordering cost is equal to 150,000.

The replenishment plans for the 15 customers were made by two ways: first, using the collaborative approach and then using only the JRP model to calculate the individual replenishment for every customer (Individual Approach). In the first case, there is only one plan that corresponds to the 15 customers, but in the single calculation there is one plan for every customer. The comparison of the two ways allows determining the alternative that reduces the logistics costs for the total supply network.

In the collaborative approach, the replenishment plan for the products of all the customers is calculated using the genetic algorithm presented in the previous section. In this approach, a genetic representation was used that consolidates all the products for all the customers, so a vector with 150 genes was necessary, corresponding to the 10 products of each of the 15 customers. In this chromosome, the first 10 genes correspond to the first customer, the next 10 genes correspond to the second customers, and so on. In the individual approach, as there is a single plan for every customer, the chromosome representation corresponds to the individual depicted in Fig. 2 for 10 products to be jointly replenished. According to this, the genetic algorithm presented is used for both approaches and it only differs in the chromosome representation.

Table 3.
Best individual for the collaborative approach

	Product									
Customer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.275	0.111	0.545	0.477	0.528	0.624	0.828	0.479	0.558	0.733
2	0.665	0.435	0.786	0.786	0.323	0.852	0.525	0.346	0.781	0.837
3	0.953	0.289	0.666	0.358	0.534	0.717	0.281	0.576	0.295	0.371
4	0.818	0.813	0.183	0.136	0.119	0.615	0.182	0.355	0.41	0.784
5	0.557	0.552	0.548	0.847	0.046	0.533	0.336	0.049	0.522	0.67
6	0.711	0.056	0.439	0.825	0.399	0.904	0.601	0.597	0.463	0.298
7	0.675	0.344	0.51	0.913	0.441	0.366	0.544	0.289	0.833	0.004
8	0.434	0.152	0.943	0.782	0.607	0.623	0.729	0.286	0.847	0.315
9	0.322	0.07	0.164	0.337	0.535	0.305	0.725	0.426	0.572	0.171
10	0.337	0.654	0.88	0.839	0.821	0.978	0.2	0.702	0.534	0.473
11	0.873	0.273	0.679	0.044	0.346	0.367	0.273	0.914	0.272	0.938
12	0.679	0.72	0.603	0.028	0.268	0.843	0.025	0.587	0.462	0.477
13	0.446	0.887	0.61	0.188	0.628	0.523	0.965	0.464	0.587	0.179
14	0.902	0.146	0.12	0.364	0.004	0.512	0.222	0.562	0.914	0.216
15	0.527	0.979	0.607	0.352	0.758	0.351	0.72	0.123	0.945	0.107

Source: The authors.

Table 4.
Results for the collaborative approach

T	**0.1079**	**Total Cost**		**82589889.6**	**# replenishment process**		**9.27**	**Total trips**		**148.32**
Customer	k_i									
1	1	1	2	1	1	2	1	1	2	2
2	2	1	1	2	1	2	1	1	2	1
3	2	1	2	1	1	2	1	1	1	1
4	1	1	1	1	1	2	1	1	1	1
5	1	1	2	2	1	2	1	1	2	2
6	1	1	1	2	1	2	1	1	1	1
7	1	1	2	2	1	2	1	1	2	1
8	2	1	2	2	1	2	1	1	2	1
9	1	1	1	1	1	1	1	1	2	1
10	1	1	2	2	1	3	1	1	2	1
11	1	1	2	1	1	2	1	1	1	2
12	2	1	2	1	1	2	1	1	1	1
13	1	1	1	1	1	2	1	1	2	1
14	1	1	1	2	1	2	1	1	2	1
15	2	1	1	1	1	2	1	1	2	1

Source: The authors.

7. Results

Table 3 presents the best individual obtained with the genetic algorithm for the collaborative approach, which produces the lowest replenishment costs. It must be noted that this individual is a vector of 150 genes, but for presentation purposes it is depicted as a table. This best individual for the collaborative approach can be easily decoded to the k_i integer numbers corresponding to the multiples of the cycle time using the procedure established by [47]. Table 4 shows the results for the collaborative approach, in which k_i values are expressed as integer numbers, as well as the cycle time, the total cost and the number of trips required for the replenishment plan.

In the individual approach a single replenishment plan is produced for every customer. In this case collaboration occurs only between a single customer and the supplier, and the inventory information of the other customers is not considered for determining the replenishment plans. In this sense the replenishment plan for every customer is also established by the supplier following the VMI.

The distribution plans for every customer obtained with the individual approach are presented in Table 5. As expected, for every customer there is an assigned optimal cycle time T*, a total cost and a yearly number of trips. It must be considered that in each case the number of trips is multiplied by two, indicating at least one round trip between a single customer and the supplier. From this table it can be observed that the k_i values for the products of customers 2, 6, 11 and 13 are equal to 1, indicating that all products must be jointly replenished every cycle time in order to reduce the logistics costs. For this individual approach, the highest k_i value is 2 while in the collaborative approach it is 3, but only for one product. However, the k_i assignment between the two approaches is very different, indicating significant changes in the distribution plans.

Table 6 shows the comparison for the collaborative and individual supply plans calculated using the genetic algorithm for the JRP model. From this table it is possible to observe that through collaboration the total costs and the number of trips are reduced. This is attractive for companies and city administrators since through the collaborative effort companies can lower their operating costs and also reduce a negative impact to the city, as the congestion caused by trucks circulating within the urban areas because the number of required trips is also reduced.

Table 5.
Results for the individual approach

Customer	T	Total cost	# trips	k_i
1	0.16	6513491	12.63	1, 1, 1, 1, 1, 1, 1, 1, 2, 1
2	0.15	6163968	13.65	1, 1, 1, 1, 1, 1, 1, 1, 1, 1
3	0.14	6726914	14.16	2, 1, 1, 1, 1, 1, 1, 1, 1, 1
4	0.12	6666565	17.29	1, 1, 1, 1, 1, 2, 1, 1, 1, 1
5	0.16	7006558	12.71	1, 1, 1, 1, 1, 2, 1, 1, 2, 1
6	0.15	6985624	13.07	1, 1, 1, 1, 1, 1, 1, 1, 1, 1
7	0.14	6095016	14.41	1, 1, 1, 1, 1, 2, 1, 1, 2, 1
8	0.13	6358583	15.29	2, 1, 2, 2, 1, 2, 1, 1, 2, 1
9	0.12	6378000	16.61	1, 1, 1, 1, 1, 1, 1, 1, 2, 1
10	0.16	7175180	12.90	1, 1, 1, 2, 1, 2, 1, 1, 1, 1
11	0.16	7196589	12.88	1, 1, 1, 1, 1, 1, 1, 1, 1, 1
12	0.14	6029130	14.21	1, 1, 1, 1, 1, 2, 1, 1, 1, 1
13	0.14	6398973	14.00	1, 1, 1, 1, 1, 1, 1, 1, 1, 1
14	0.13	6145518	15.57	1, 1, 1, 1, 1, 2, 1, 1, 1, 1
15	0.15	7108670	13.47	2, 1, 1, 1, 1, 2, 1, 1, 2, 1
	Total	98948779	213	

Source: The authors.

Table 6.
Collaborative and individual approaches comparison

Approach	Individual	Collaborative	Saving
Total cost	98948778	82589889.65	17%
Number of trips	213	148.32	30%

Source: The authors.

4. Conclusions

In this article a collaborative approach was presented to deal with the problem of jointly replenishing products from several companies, using the joint replenishment problem – JRP model. The single JRP model allows that multiple products in the same organization can be ordered together, reducing total costs. This model can be expanded for several organizations through a collaborative process in which the individual information is shared for the calculation of the joint replenishment processes. The application of this collaborative approach is done by grouping all the products in a single calculation, which is solved by using a genetic algorithm, due to the mathematical complexity that it implies.

From the comparison of the collaborative approach and the results obtained when determining the supply plans individually for every customer, it was observed that in the collaborative proposal, the replenishment plan produces lower costs and a reduced number of trips required for the replenishment process. These results make the collaboration approach attractive for companies and very relevant to the urban goods distribution processes, in the sense that it allows more economical replenishment operations for companies and reduces the number of vehicles circulating inside the cities, contributing positively to city congestion and to reducing greenhouses gas emissions.

As future research lines, the inclusion of capacity and resource restrictions in the JRP model is suggested, as well as considering joint replenishment problems with several suppliers. The integration of the joint replenishment problem with the Vehicle Routing Problem (VRP), looking for their simultaneous optimization, could be another interesting research line in urban goods distribution that will probably produce cost savings and the mitigation of negative impacts to society and the environment.

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