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DRUG SUPPLY NETWORK COORDINATION: A CASE APPLIED TO THE COLOMBIAN HEALTH SECTOR

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ABSTRACT

This paper shows the evaluation of coordination scenarios in cancer drug supply networks using system dynamics. The current context and supply problems are described based on research conducted at healthcare service provider institutions (IPS) providing oncology services in different cities of Colombia. A review is conducted of the principal aspects related to coordination in supply systems. Two coordination scenarios are evaluated and analyzed based on the use of shared information together with decision making, utilizing reference parameters for high-cost medications that require adaptation in compounding centers (CCs) for the application of chemotherapy in patients with cancer. Results show close to 14% savings and around 98% compliance levels, which represents an important contribution to the Colombian healthcare system.

KEYWORDS: Logistics; Coordination; Supply networks; Supply chains; System dynamics; Cancer drugs.

COORDINACIÓN EN REDES DE SUMINISTRO DE MEDICAMENTOS. CASO APLICADO AL SECTOR SALUD COLOMBIANO

RESUMEN

Este artículo presenta la evaluación de escenarios de coordinación de actores en la red de suministro de medicamentos oncológicos utilizando la dinámica de sistemas. Se describe el contexto actual y la problemática del abastecimiento resultado de la investigación realizada en instituciones prestadoras de servicios de salud (IPS) con servicios de oncología de diferentes ciudades de Colombia. Se desarrolla una revisión de los principales aspectos relacionados con la

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coordinación en sistemas de suministro, se evalúan y analizan dos escenarios de coordinación basados en el uso de información compartida y la toma de decisiones conjunta utilizando parámetros de referencia de medicamentos de alto costo que requieren adecuación en centrales de mezcla (CM) para aplicación de tratamientos de quimioterapia en pacientes con cáncer. Los resultados dieron ahorros cercanos al 14% y niveles de cumplimiento alrededor del 98%, lo que implica una contribución importante al sistema de salud colombiano.

PALABRAS CLAVE: logística; coordinación; redes de suministro; cadenas de suministro; Dinámica de Sistemas; medicamentos oncológicos.

COORDENAÇÃO EM REDES DE FORNECIMENTO DE MEDICAMENTOS. UM CASO APLICADO AO SECTOR DE SAÚDE COLOMBIANO

RESUMO

O artigo apresenta a avaliação de cenários de coordenação de atores na rede de suprimento (fornecimento) de medicamentos oncológicos utilizando a dinâmica de sistemas. É descrito o contexto atual junto com a problemática do fornecimento como resultado da pesquisa realizada nas instituições fornecedoras de saúde (IPS) com distintos serviços de oncologia de distintas cidades da Colômbia. É desenvolvida a revisão dos principais tópicos relacionados com a coordenação em sistemas de fornecimento. Assim mesmo, são avaliados e analisados dois cenários de coordenação baseados no uso da informação compartilhada e a tomada de decisões conjunta utilizando parâmetros de referencia de medicamentos de alto custo que precisam adequação nas centrais de mistura (CM) para aplicação de tratamentos de quimioterapia em pacientes com câncer. Os resultados permitem poupanças perto dos 14% e níveis de conformidade perto dos 98%, o que representa uma importante contribuição para o sistema de saúde colombiano.

PALAVRAS-CHAVE: Logística; Coordenação; Redes de fornecimento; Cadeias de fornecimento; Dinâmica de Sistemas; Medicamentos contra o câncer.

1. INTRODUCTION

The fundamental purpose of coordination in supply systems is to connect the productive and operational capacities of the actors in the supply network (SN) under the restrictions of demand in space and time. Arshinder, et al., (2011) define supply coordination as the establishment of actions and the means necessary to manage interdependence among the members of an SN. The aim of supply coordination is to improve decision-making processes throughout the network for the purpose of obtaining a better overall performance (Arshinder, et al., 2008).

In the current context, in which SNs are more and more complex due to structure, size, objectives and specific interests (Choi y Krause, 2006),they present important challenges to organizations in reaching high levels of competitiveness through joint as opposed to individual work, and converting interdependency among network members into a relationship of "partnering" (in Spanish, *alianza*). Michalska, (2009) establishes that these relationships provide the means to obtain mutual benefits and guarantee continuity in organizations.

In the case of the healthcare sector in Colombia, reference will be made to the Oncological Medication Supply Network (in Spanish, *Red de Suministro de Medicamentos Oncológicos* or *RSMO*), in which high levels of complexity can be observed due to the number of actors and their roles in the different spheres that make up the network.

The principal members of the network are those that act as producers of raw materials and medications at the international level: importers, distributors and retailers, health promotion agencies (in Spanish, *Entidades Promotoras de Salud* or EPS), healthcare service provider institutions (in Spanish, *Instituciones Prestadoras de Servicios de Salud* or IPS), compounding centers (CCs) (in Spanish, *Centrales de Adecuación de Medicamentos* or *CM*) for the adaptation of dosage units, and agents that provide the logistical services of medication management and distribution.

Based on the research, it was determined that one of the main problems affecting the RSMO is related to the risk of interruptions in supply and medication shortages, which generate high costs in Colombia's healthcare system and thus negative effects on the level of service for patients with cancer. According to (Zamora, et al., 2013), for medications with high vulnerability to this kind of risk, it was found that the response level of supply systems corresponds to 56.91% and in supply logistics services to 71.31%, which shows there is a problem of deficit and opportunity in delivery times.

Comprehensive analysis of this situation allowed for the establishment that lack of coordination among the members of the network shows a need for defining the coordination mechanisms in SN supply operations, which allows vulnerability levels to be reduced and operation conditions to improve. In this context improving RSMO performance was established as the principal aim in terms of service levels and operation costs, by way of design and evaluation of coordination scenarios.

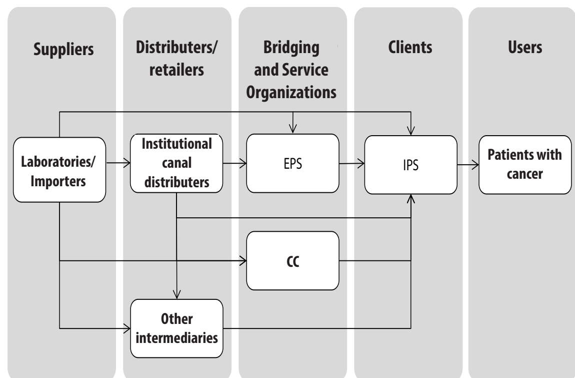
2. HEALTHCARE SECTOR CONTEXT

2.1. Oncological Medication Supply Network (RSMO)

The RSMO functions in a decentralized manner with high levels of intermediation due to the presence of multiple agents in commercial roles in the sale of medications throughout the network. **Figure 1** shows a diagram with the different actors and the medication distribution flows to the IPSs.

The relationships among the different actors of the network with the IPSs focus primarily on the commercial aspects of the sale of medications and services. This differs from the relationship between EPSs and IPSs where in some cases flow consolidation strategies are exhibited from the former to the latter with implicit benefits due to purchase volumes from the EPSs to different suppliers.

Figure 1. Structure of the RSMO



2.2. Risk in the Oncological Medication Supply Network (RSMO)

The risk factors of supply interruption and medication shortage in RSMOs have to do with the availability of information throughout the SN, the response capacity of logistics systems, dynamic conditions of demand, the infrastructure technology used and other relational factors among the members of the SN. The relational factors are associated with lack of coordination in planning, programming and use of resources and services, as well as with negotiation power within the network.

The implications observed are ruptures in product flow, failure to meet response times for patients, inadequate management of inventory, growth in intermediation costs due to medication purchasing, and instability in levels of service.

This provokes an unfavorable image of the healthcare institutions in the general population and possible negative effects in the health of the patients by creating interruptions in cancer treatment.

2.3. Management of the Oncological Medication Supply Network (RSMO)

Traditional focuses employed in management of the medication chain, commonly known as medication supply management, are fundamentally targeted at medication, technical information and price information flows (Organización Mundial de la Salud, 1998). The focus on supply networks (SNs) as opposed to the study of dyadic or triadic relationships in supply chains increases the possibility of improving outcomes for the supply system (Pilbeam, et al., 2012). For healthcare network supply systems, coordinated operations among the different network actors come together to overcome the challenges of fragmentation between assurance and healthcare services provision, and the guarantee of effective access to medication (Bigdeli, et al., 2013).

Medication shortages at the international level have reached a point where the International Pharmaceutical Federation insists that countries implement models that mitigate the risk from supply and demand management (International Pharmaceutical Federation, 2013).

In Colombia, although Law 1438 of 2011 (Ocampo-Rodríguez, et al., 2013) mandates the provision of healthcare services with a focus on networks, there are few models that encompass the application of coordination and collaboration mechanisms and techniques. Networks have focused on public health interest programs, such as tuberculosis, vaccination and others, and are not highly efficient when it comes to their levels of service and impact.

According to (Valdivieso, et al., 2008), in healthcare services supply chain governance in Colombia, vertical integration, marketing contracts and, to a lesser extent, strategic alliances are evidenced.

In the research project conducted, formal models for network care are not exhibited. Despite the scope of oncological services in the country, it is presented as a relevant characteristic for facilitating the position of the entities in fulfilling their role vis à vis national cancer policy (Suárez, 2008).

3. SUPPLY CHAIN COORDINATION (SCC)

Supply chain coordination (SCC) is defined as a means of redesigning the structure of resource flow to achieve improved performance (Lee, 2010). SCC can be witnessed in particular in the grade of the relationship among network members as a means of risk sharing, and in the benefits that result from superior business performance compared to what would be accomplished individually (Lambert, et al., 1999).

Supply risk conditions in SNs has led to the establishment of coordination actions among network partners to avoid and mitigate risk to the extent that the value and benefits generated are maximized and shared equitably (Kleindorfer y Saad, 2009).

SNs utilize coordination mechanisms (CMs) in an effort to improve performance and relationships among the members of the network (Danese, et al., 2004).The implementation of actions that involve different SN entities can generally be identified under four types of CM: i) contracts between agents of the SN; ii) information technologies; iii) shared information; and, iv) joint decision making (Arshinder et al. 2008).

The need to establish effective coordination mechanisms in the SN makes for a difficult task, and it involves tackling strategic and operational factors comprehensively due to the complex nature of the SN, especially due to the characteristics of actor concentration, its configuration, and how it operates(Harland, et al., 2004;Choi, et al., 2001).

In the case of specialized products that require multiple components, or in supply networks with a high number of suppliers, the implementation of CMs can generate a large operational load and high operational costs (Choi y Krause, 2006; Kim, et al., 2011). In this sense, the definition of these mechanisms must be in line with the particular context of each SN and its particular needs.

4. SYSTEM DYNAMICS (SD)

The use of system dynamics (SD) is founded on how the concept of feedback in systems can be utilized as a basic principal of monitoring that allows for decision making to align expected objectives with the present situation. Based on the contributions of (Forrester, 1958) in the analysis of industrial flows in production-distribution systems, the focus of feedback loops and delays makes a valuable tool for researching productive systems and analyzing their behavior.

Through system dynamics it is possible to understand the systemic behavior of supply networks through the relationships of physical and institutional structures in combination with the dynamic and strategy.

The physical structures of the networks have to do with the placement of inventories in relation to suppliers and clients, production operations, requests to be fulfilled, transport, and others. The institutional structures include the grade of horizontal and vertical coordination in the SN, competition among and within the companies, availability of information from each organization and from the functional areas (Sterman, 2005). The structures also involve elements of behavior in the form of decision making, which has implications for resource management.

In studying supply networks from the systemic point of view, one finds contributions like those of (Bellamy and Basole, 2012), who establish that the configuration of nodes and their levels, interrelationships, complexity and density, among other properties, make up the structure of the SN.

The dynamic is related to the specific behavior of the network, the capacity for response and resilience. The strategy is defined by the joining of operation policies, including monitoring through out the network, for which it is necessary to consider power relationships among the actors, confidence and governance.

5. METHODOLOGY

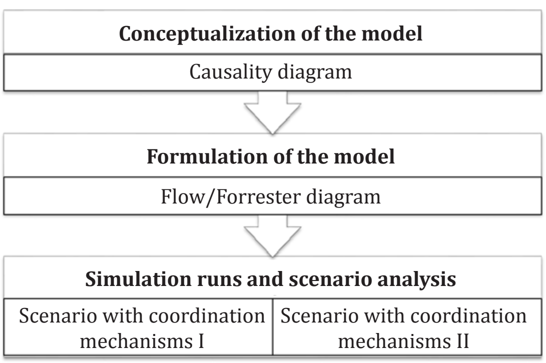
5.1. Methodology for RSMO characterization

The characterization methodology was developed based on the Initiative for the Integration of South American Infrastructure (in Spanish, *Iniciativa para la Integración de la Infraestructura Regional Suramericana*) (Martínez, et al., 2007). The collection of primary information was performed at the IPSs authorized for the provision of clinical oncology services under Code 709 of the diagnostic and therapeutic complementation support group (Ministerio de Salud y Protección Social, 2012), which were identified based on data from the Special Registry of Providers of Healthcare Services(in Spanish, *Registro Especial de Prestadores de Servicios de Salud*) (Ministerio de Salud y Protección Social, 2012). The population of these IPSs in Colombia with clinical oncology services corresponds to a total of 217 hospitals, specialized clinics and independent professionals. According to the scope of the project and the allocation of resources for the information collection activities, an alpha error of 10%, an estimated ratio of 0.5and an estimation error of 10% were established. These values allowed for the determination of a sample size of 56 IPSs, of which 42 supplied information. For the selection of the number of IPSs sampling was conducted with a probability proportional to the size of each IPS and to the number of oncology treatments based on the range of socioeconomic levels or stratums by applying the method developed by Sunter (Särndal et al., 1992).

5.2. Methodolgy for the formulation of scenarios with System Dynamics (SD)

The selection of the simulation technique in keeping with SD is based on the contributions of (Sterman, 2000; Sterman, 2005; Bellamy and Basole, 2012) for analyzing the behavior of supply chain flows under coordination mechanisms. The SD model is based on the general methodology developed by (Forrester, 1992). The supply network operation structure and conditions were considered using causality diagrams that enable the modeling of interactions of the components of the system and their influence on the other elements. The flow diagrams allow change relationships in the system to be established. The stages of the methodology utilized are shown in **Figure 2.**

Figure 2. Methodology for the application of the SD



6. MODELING AND SIMULATION

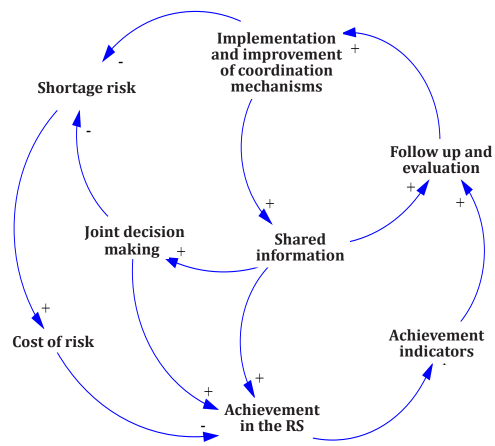
6.1. Conceptualization of the model

The conceptualization of the model is shown in **Figure 3**, which contains the research hypothesis, and where it is established that the implementation and improvement of coordination mechanisms (CMs) produce positive effects on the performance of the network through the use of shared information and joint decision making.

For their part, the CMs produce a decrease in risk due to the effect of joint management of risk factors that cause shortages in the different entities of the SN.

Risk mitigation can be seen reflected as a minor risk cost and therefore improved performance of the SN. The system has feedback based on the framework and performance indicators developed in (Zamora, et al., 2013), which allows for follow up and assessment to be conducted to determine improvements or implement new CMs.

Figure 3. Influence Diagrams – Model conceptualization



6.2. Formulation of the simulation model

The structure of the system, **Figure 4**, is established based on the representation of the flows and the accumulation of medications in the different agents of the supply network: laboratories/importers (LAB), intermediaries (I), health promotion agencies (EPS), compounding centers (CC) and healthcare service provider institutions (IPS).

In the simulation model the application of coordination mechanisms with shared information among IPS, EPS, LAB, I and CC are represented. The first case corresponds to data from real demand or scheduling of patient treatments, the second is the request for medications by the IPS, which is represented by the quantity of priority request medications missing.

For the simulation model, Vensim® PLE, Version 6.3 software was used. In **Table 1**, **Table 2**, **Table 3** and **Table 4** the components of the formulation of the model are described.

Figure 4. Forrester Flow Diagram

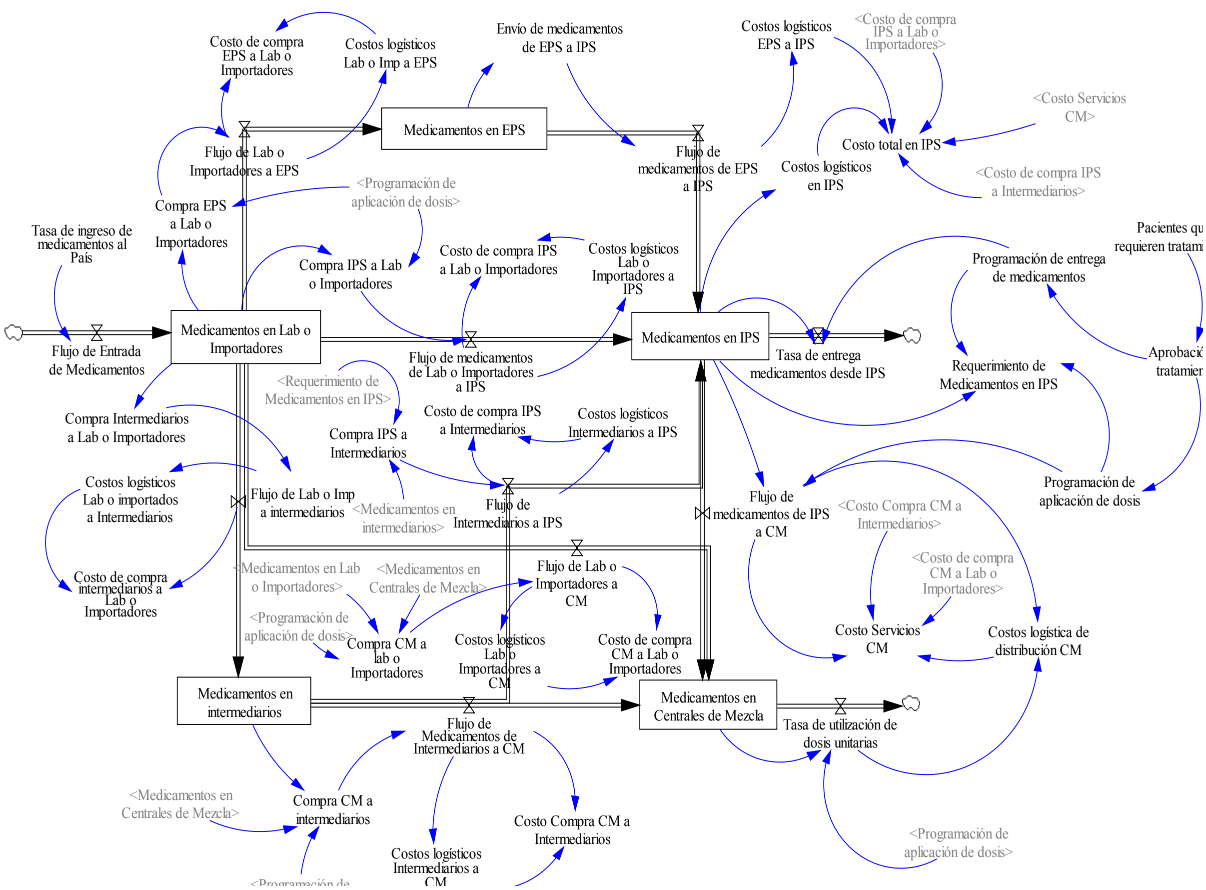


TABLE 1. ACCUMULATIONS

Levels	Definition	Input flows	Output flows
MECM	Level of medications in CC	FLCM, FICM, FHCM	FSDU
MEEP	Level of medications in EPS	FLEP	FEHC
MEHC	Level of medications in IPS	FIHC, FLHC, FEHC	FHCM, TEMH
MEIN	Level of medications in intermediaries	FLIN	FIHC, FICM
MELI	Level of medications in LAB	FEML	FLCM, FLEP, FLHC, FLIN

TABLE 2. FLOWS

Flows	Definition	Variables and parameters
FEHC	Flow of medications from EPS to IPS.	EHCE
FEML	Input flow of medications to the country	TIMP
FHCM	Flow of medications from IPS to CC.	MEHC, APAD
FICM	Flow of medications from Intermediaries to CC.	CMIN
FIHC	Flow of medications from Intermediaries to IPS.	CHIN
FLCM	Flow of medications from LAB to CC.	CMLI
FLEP	Flow of medications from LAB to EPS.	EPLI
FLHC	Flow of medications from LAB to IPS.	HCLI
FLIN	Flow of medications from LAB to intermediaries.	INLI
FSDU	Output flow of unitary dosages from CC.	MECM, APAD
FSME	Output flow of medications from IPS.	MEHC, APED

TABLE 3. AUXILIARY VARIABLES

Auxiliary variables	Definition	Formula
CCIN	Acquisition cost from CC to Intermediaries.	FICM*PRIC+CLIC.
CCLI	Acquisition cost from CC to LAB	FLCM*PRLC+CLLC
CELI	Acquisition cost from EPS to LAB	FLEP*PRLE+CLLE
CHIN	Acquisition cost from IPS to Intermediaries.	FIHC*PRIH+CLIH
CHLI	Acquisition cost from IPS to LAB	FLHC*PRLH+CLLH
CILI	Acquisition cost from intermediaries to LAB	FLIN*PRLI+CLLI
CLCM	Distribution logistics costs in CC	FSDU*CRUC
CLEH	Distribution logistics costs from EPS to IPS	FEHC*CRUE
CLHC	Logistics costs in IPS	MEHC*CRLH
CLIC	Distribution logistics costs from Intermediaries to CC.	FICM*CRUI
CLIH	Distribution logistics costs from Intermediaries to IPS.	FICH*CRUI
CLLC	Distribution logistics costs from LAB to CC.	FLCM*CRUL
CLLE	Distribution logistics costs from LAB to EPS.	FLEP*CRUL
CLLH	Distribution logistics costs from LAB to IPS.	FLHC*CRUL
CLLI	Distribution logistics costs from LAB to Intermediaries.	FLIN*CRUL
CMIN	Number of medications that the CC purchases from intermediaries.	IF THEN ELSE(MEIN >=APAD, IF THEN ELSE(MECM-APAD<=0,0,APAD-MECM),0)
CMLI	Number of medications that the CC purchases from LAB.	IF THEN ELSE(MELI >=APAD, IF THEN ELSE(MECM-APAD<=0,0,APAD-MECM), 0)
CSCM	Service costs in CC.	FHCM * CMCM + CCIN + CCLI + CLCM
CTHC	Total cost in IPS.	CHIN+CHLI+CSCM+CLHC+CLEH
EMEH	Medication delivery from EPS to IPS	IF THEN ELSE (MEEP>=0, MEEP, 0)
EPLI	Number of medications that the EPS purchases from LAB.	IF THEN ELSE(MELI>=APAD*PEPL,APAD*PEPL,MELI)
HCIN	Number of medications that the IPS purchases from the intermediaries.	IF THEN ELSE(MEIN >=RMHC*PHCI,RMHC*PHCI, MEIN)
HCLI	Purchase of medications from IPS to LAB.	IF THEN ELSE(MELI >=APAD*PHCL, APAD*PHCL, MELI)
INLI	Purchase from intermediaries to LAB.	IF THEN ELSE(MELI<=0, 0 , MELI*PINL)
RMHC	Requirement of medications in IPS	IF THEN ELSE((APED+APAD-MEHC)<=0 , 0 , APED+APAD - MEHC)

TABLE 4. PARAMETERS

Parameters	Definition
APAD	Scheduling of dosage administration
APED:	Scheduling of medication delivery from IPS
APRM:	Patients that require oncology treatments
CRUC:	Baseline unit logistics cost for compounding centers
CRUC	Baseline unit logistics cost for EPS
CRLH	Operation logistics cost by unit for IPS
CRUI	Baseline unit logistics cost for Intermediaries
CRUL	Baseline unit logistics cost for Laboratories or Importers
PEPL	Percentage of purchase through the EPS.
PHCI	Percentage of purchase of medication from IPS to intermediaries.
PINL	Percentage of purchase from intermediaries to laboratories or intermediaries.
TIMP	Number of medications that come into the country.

6.3. Simulation runs and definition of scenarios

The simulation is conducted in two scenarios for periods of 120 months using deterministic parameters that represent flows added in the different levels of the supply structure.

Coordination scenario I. The first scenario corresponds to the application of the coordination mechanisms with current levels of intermediation. For this case the simulation examines all the relationships present among IPS, EPS, LAB, I and CC.

Coordination scenario II. In the second scenario, the theoretical context of direct supply is established from the laboratory or distributer to the IPSs, EPSs and compounding centers, restricting the flow of medications from the intermediaries to the IPSs and compounding centers. What is sought is to evaluate performance with the coordination mechanisms in the SN based on the comparison of the current structure's cost behavior to a direct purchase structure with the laboratory or distributer.

6.4. Validation of the model

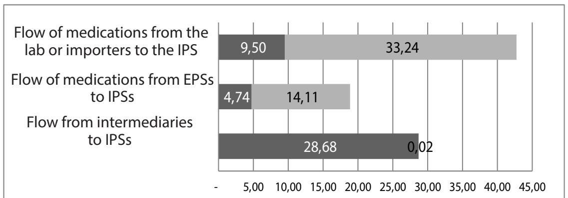
In accordance with the methodology developed by (Barlas, 1996),the validation of the structure of the model and its behavior was performed. For that purpose, the level of representation of the relationships currently present among the actors and the processes of the SN was defined as a criterion. The direct evidence was obtained based on (Barlas and Kanar, 2000) for each component of the model. This process was developed with the team of experts in health and supply chains that participated in the project. It was found that more than 95% of the relationships of the model are known or happen in reality. Thus, it is established that in the practice of the use of coordination mechanisms the performance of the SN would improve in accordance with the behaviors observed in the simulation.

7. RESULTS

Figure 5 shows the behavior of the flows of medications to the IPSs for the two scenarios. These values correspond to the average monthly number of medications as a result of the simulation of the two scenarios. In percentage terms for Scenario 1, 66.83% of the medications were acquired through intermediaries, 11.4% through the EPS and 22.13% directly from the laboratories or importers. For Scenario 2, the percentages change in the following manner: 0.05% of the medications were acquired through intermediaries, 29.78% through the EPS and 70.17% directly from the laboratories or importers.

The behavior of the flows of medications to and from the compounding centers is shown in **Figure 6**. The purchase of medications from the compounding centers to intermediaries can be observed in Scenario 1 at an average quantity of 5.74 units per month, which corresponds to 11.86% of the medications that come into the compounding centers.

Figure 5. Behavior medication flows to IPSs

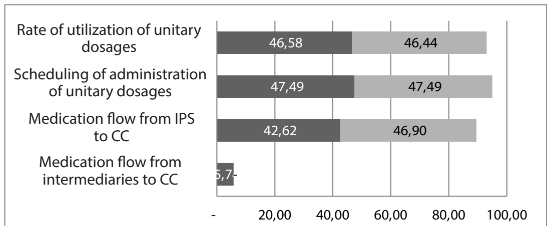


	Flow from intermediaries to IPSs	Flow of medications from EPSs to IPSs	Flow of medications from the lab or importers to the IPS
Scenario 1	28,68	4,74	9,50
Scenario 2	0,02	14,11	33,24

The percentage of delivery compliance for unitary dosages in accordance with the established schedule is 98.10% and 97.80% respectively for Scenarios 1 and 2, which indicates almost total compliance in both scenarios.

The cost behavior for each of the two scenarios is found to be associated with the amounts acquired through the different supplier entities in the supply network. The total cost in the IPSs is less in Scenario 2, where they acquire the medications at a higher percentage directly from the laboratories or importers or through the EPSs. The policy of using higher levels of intermediation (current scenario) results in a higher cost for the system. In the total cost for the IPSs in Scenario 2 a decrease of 13.99% is demonstrated in relation to the total cost in Scenario 1.

Figure 6. Medication flow behavior in medication compounding centers



	Medication flow from intermediaries to CC	Medication flow from IPS to CC	Scheduling of administration of unitary dosages	Rate of utilization of unitary dosages
Scenario 1	5,74	42,62	47,49	46,58
Scenario 2	-	46,90	47,49	46,44

The level of medications for Scenario 2 in the IPSs and EPSs is higher than for Scenario 1. This reflects on one hand the policy of establishing a higher participation in the schema of sending medications from the EPSs to the IPSs, and on the other hand the restriction of intermediation in medication flows from the intermediaries to the compounding centers, flows that are assumed in Scenario 1 from the IPSs. **Figure 7**, **Figure 8** and **Figure 9** show the behavior of the principal accumulations.

Figure 7. Level of medications in IPS

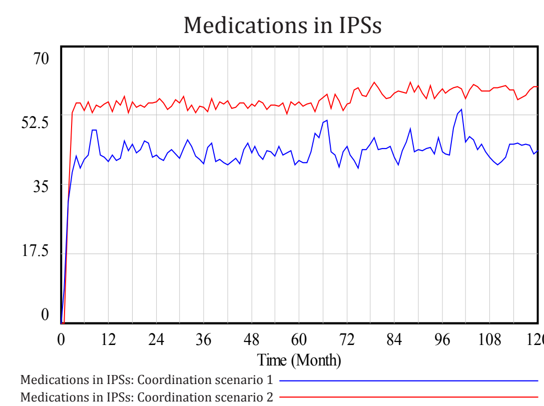


Figure 8. Level of medications in EPS

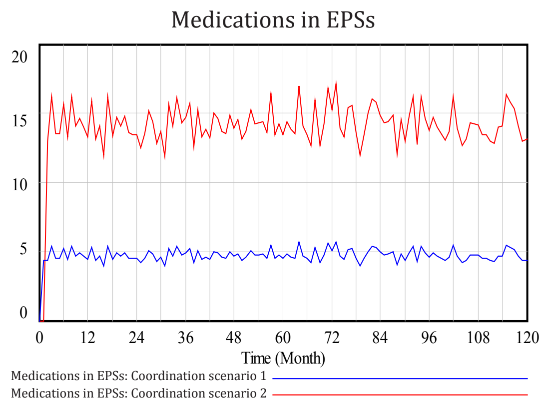


Figure 9. Level of medications in compounding centers

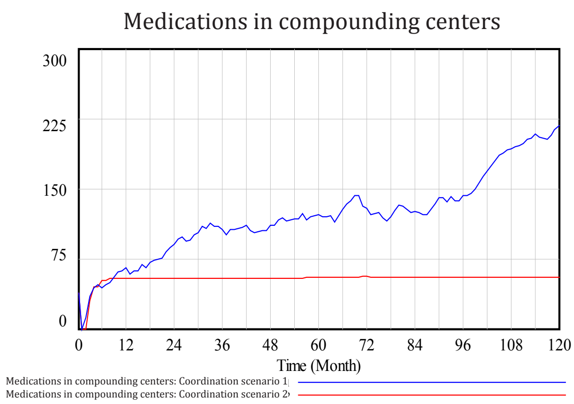


Figure 10. Behavior of total cost in IPSs

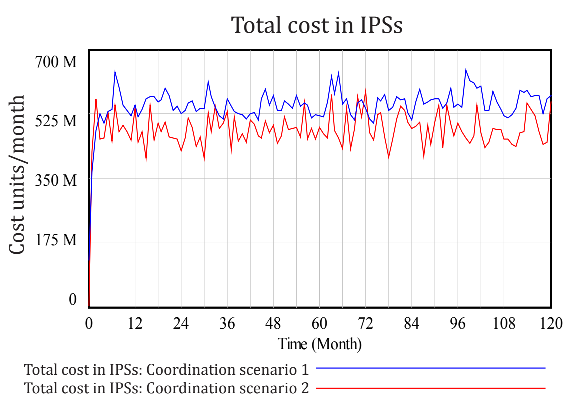
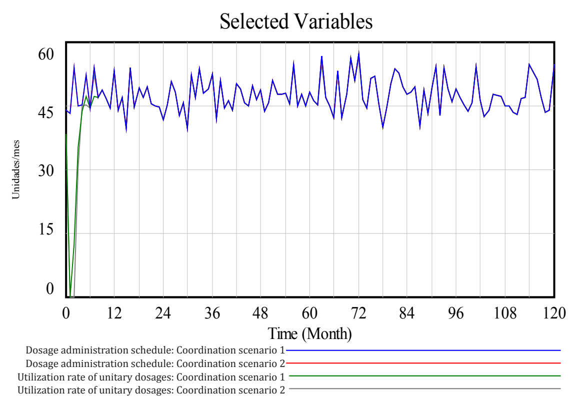


Figure 10 shows the behavior of the total costs in IPSs in both scenarios. In all the simulation periods a higher cost in the first scenario can be observed.

The compliance levels are the result of the behavior of the delivery rate of unitary dosages with the dosage schedule. **Figure 11** shows the result of the simulation of these two variables.

Figure 11. Usage rate of unitary dosages compared to unitary dosage scheduling



Units/month

8. CONCLUSIONS

The coordination scenario simulation for the Oncological Medication Supply Network makes it possible to visualize beneficial alternatives for supply management in healthcare service provider institutions (IPSs).The results in compliance levels of dosage scheduling of 98.10% and 97.80% for both scenarios show that the application of the coordination mechanisms of shared information and joint decision making improves the behavior of the medication supply flows in the different agencies of the network, reducing the shortage risk and therefore providing conditions for continuity, coverage and efficiency in the provision of oncology services.

The evaluation of the two scenarios that guides the use of negotiation and coordination policies and rules in the Oncological Medication Supply Network reflects the impact it can have at cost level on the Colombian healthcare system. The reduction of

13.99% on the total cost in IPSs in Scenario 2 could mean important savings in the system.

The search for strategies that prioritize the implementation of coordination and negotiation mechanisms in the Oncological Medication Supply Network becomes a fundamental tool for the definition of public policies and decision making in the Colombia's healthcare sector. The implementation of coordination mechanisms involves the adoption of agreements from one level to another within the network and the utilization of information and communication technologies that allow real time knowledge of the amounts of medications required in the system and the response capacities of the supplier levels in the different agencies of the SN.

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