Supply risk analysis: a case applied to the Colombian Health Sector, using System Dynamics.

Análisis del riesgo de aprovisionamiento: caso aplicado al sector salud colombiano, utilizando dinámica de sistemas.

Juan Pablo Zamora Aguas¹, Wilson Adarme Jaimes², Martín Dario Arango Serna³

ABSTRACT
In this paper, the problem of supply risk in the supply chain (SC) of oncological medicines in Colombia is addressed. A system dynamics model for assessing the impact of supply risk on operation and performance conditions of SC is developed. The costs of risk and logistics operations are valued in the current conditions and in a risk mitigation scenario. The model contributions are based on the systemic analysis of supply networks, mainly on the reduction of global costs from the chain and the improvement of service, quality and opportunity performance index. This article is the result of research on supply chain risk management (SCRM), carried out by the SEPRO (initials in Spanish of Society, Economy and Productivity) research group of Universidad Nacional de Colombia and cofounded by Colciencias in the project frame “Methodological approach for the definition of rules and policies for the coordination and negotiation in the oncological medication supply chain in Colombia”.

Keywords: Supply Risk, Supply Chain, Oncology drugs, System Dynamics.

RESUMEN
En este artículo se aborda la problemática del riesgo de aprovisionamiento en la cadena de suministro (CS) de medicamentos oncológicos en Colombia. Se desarrolla un modelo de dinámica de sistemas para evaluar el impacto del riesgo de aprovisionamiento sobre las condiciones de operación y desempeño de la CS. Se valoran los costos del riesgo y de la operación logística en las condiciones actuales y en un escenario con mitigación del riesgo. Las contribuciones del modelo se basan en el análisis sistemático de las redes de suministro, principalmente en la reducción de los costos globales de la cadena y en la mejora de los índices de desempeño en oportunidad, calidad y servicio. Este artículo es resultado de la investigación en gestión del riesgo en la cadena de suministro (SCRM – Supply Chain Risk Management), realizada por el grupo de investigación SEPRO de la Universidad Nacional de Colombia y cofinanciada por Colciencias en el marco del proyecto: “Propuesta metodológica para la definición de políticas, reglas de negociación y coordinación en la gestión de abastecimiento de los medicamentos oncológicos en Colombia”.

Palabras clave: Riesgo de aprovisionamiento, cadena de suministro, medicamentos oncológicos, dinámica de sistemas.

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Introduction

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The supply chain risk is referred to as the possibility of occurrence of shortages or disruptions in the material, product and service flows in the supply chain (SC). Generally, it implies the possibility and effect of a mismatch between offer and demand that can affect the needs and expectatives of customers regarding products and services, and the performance of the SC, causing overcosts and greater efforts for the organization.

An interruption on any level of the supply chain can affect the enterprise in terms of the delivery of products, customer service and the continuity of operations (Juttner, Peck, & Christopher, 2003).
In a study presented by (Sanchez-Rodrigues & Naim, 2010) it is observed that 60% of the most frequent problems that can have the greatest incidence on the risk of SC, are related to delays, information availability, demand knowledge, delivery restrictions, and supply chain coordination. Other ones, in a minor percentage, that have incidence on supply chain performance are related to infrastructure rigidity, operation costs, SC integration and technology.

The risk on the supply chain is presented by internal and external or environmental factors in which the process, control, supply, demand and environment risks are included (Christopher, 2005). In other similar classification the macro, safety, political, competitive and resource risks are distinguished additionally (Manuj & Mentzer, 2008).

Supply Risk

The supply risk is related to conditions that affect the availability of materials, products on processing or finished products in supply operations. This risk poses a threat for continuity of productive and services activities of organizations. This kind of risk has implications along the SC affecting the productivity levels, inventory and cycle times of the system (Eltantawy, Fox, & Giunipero, 2009).

The danger of shortages and interruptions jeopardize the objectives of supply on SC, especially regard product availability, quality conditions, and the total costs. On this sense, the actions of risk management are oriented to understand the risk sources of supply and state the best ways of management (T. Wu, Blackhurst, & Chidambaram, 2006).

Context and problems of risk on oncological drugs supply chain

It is estimated that each year appear more than 12 millions new cancer cases in the world (IARC/WHO, 2008), the major percentage (80%) appears in developing countries (Ministerio de la Proteccion Social de la Republica de Colombia, 2010). For 2008, in Colombia occurred 62,660 new cancer cases (IARC/WHO, 2008). According to the last report about Basic Indicators for Monitoring of Objectives of Millenium Development, Colombia records a mortality rate in about 76.5 per 100,000 inhabitants. In 2010, more than 34,000 people were died due these pathologies (OPS/MPS/INS, 2010).

Additionally, the National Pharmaceutical Policy, shows that some of main problems in Colombian health system are related to a poor supply, offer and availability of essential medicines. According to Pharmaceutical Policy, in 2008 from all the insured persons assisted by the system and who were prescribed medicines, only 63% received the complete formulation, 15.8% received it in a poor way, and 21.2% didn’t received nothing at all. (Consejo Nacional de Politica Economica y Social – DNP, 2012).

The problems with offer, availability and medicines supply is a critical risk for supply chain (SC) that affects patients and Colombian population, due to the public health, social and economic implications that they have to the country.

The shortage of medicines flow affect the continuity of oncological treatments, endangering the patient health due to adjustments and changes in treatment schemes. At international level, it has been identified that shortages of oncological medicines have forced to the treating physicians to set application priorities on patients and to prove changes on treatments. For example, the substitution of Capetitabina by 5-flourouracilo in the adjuvant therapy for colorectal cancer, although this kind of treatment options have not been proved in the cure of these diseases (Chapner, 2011).

On the other hand, the shortage of medicines lead to looking for substitutes, that in the case of Colombia, has caused overcosts due to the difference in prices with the available medicines in the market (United Nations, 2013).

In Colombia, shortages of active principles such as 5-flourouracil, Azatioprine, Citarabina, Clorambucil, Doxorubicin, Mercaptopurin, Metotrexate and Tioguanine, have occurred. This situation causes larger costs for the Colombian health system due to administrative weakening in contingency operations when searching for medicines in the market and to buying decisions for trading agents with different levels of intermediation.

Research Methodology

The study is focused on Health Care Institutions (HCI) that are enabled to provide clinical oncology services with the 709 code from the Diagnosis Support and Therapeutical Complementation Group, according with the Checking Procedures of Conditions for Qualifying Oncological Services Handbook (Ministerio de Salud y Proteccion Social, 2012), which were identified based on the data from Special Registration of HCI (Ministerio de Salud y Proteccion Social, 2012).

The population of these HCI in Colombia with clinical oncology services corresponds to a total of 217 hospitals and specialized clinical centers. According to the scope of plan and programming of resources for data recollection activities, a sample of 42 HCI was taken. For selection of HCI, a sampling with proportional likelihood to the size of HCIs and per oncology attentions number by the method of Sunter (Sárdal, Swensson, & Wretman, 1992).

Medicine selection

With in the research, the active principle of Doxorrubíne was defined as the study subject medicine, considering information from the Health and Social Protection Ministry (Ministerio de Salud y Proteccion Social), on those active principles, that in the past year had presented an regular supply behavior and over which a shortage in the system was reported.

Doxorrubíne is a chemotherapy medicine that is commercialized in two presentations: 10 mg and 50 mg vials. It is used for treating the non-Hodgkin lymphoma, the multiple myeloma (cancer of bone marrow cells), acute leukemia, Kaposi sarcoma, Ewing sarcoma, Wilm tumor, and breast, suprarenal crust, endometrium, lung and ovary cancer, in...
addition to cancer in other places of body (American Cancer Society, 2011).

The number of sales in Colombia during 2011 of Doxorubicin correspond with 229,573 units according to data of sold units and prices of database of SISMED (Ministerio de Salud y Protección Social, 2012).

**Identification, assessment and risk analysis**

The Identification, assessment and risk analysis are developed based on risk management methodology with systemic focus and is presented in Figure 1. Three stages are considered: 1) contextualization; 2) assessment and 3) decision and feedback. Interaction between these stages allows dealing with the complete cycle of risk management where the system performance is assessed over time, allowing to address the actions of management according to the evolution of danger levels and susceptibility to the risk.

In this research, the stages 1 and 2 are developed. Stage 3 will be research matter subsequently.

For developing the first stage of the methodology, the contributions of risk relational theory have the purpose of answering the key theoretical and practical questions about how and why something is considered a risk. For this, at least three conceptual elements on risk definition are presented: an object, the damage and a link based on some kind of causality among the object and damage (Boholm & Corvellec, 2011). The object is constituted into risk factor, which is the cause or risk generator agent and can be an internal or external circumstance, natural phenomena or behaviors within a social system.

Risk costs

which is a condition that affects the medicine production in pharmaceutical industry by scarcity of raw materials; the medicine availability in the market, that occurs by dynamics between the offer and demand of the market; capacities of logistics systems, associated with the opportunity of times of response and management and delivery quality of medicines; and the asymmetries of the information, which are a critical risk factor in the different chain links, that are a consequence of power relationships, competition conditions in the provider market, low coordination between SC agents and limited use of communication and information technologies.

The implications that these supply risks have for the system were summarized into two effects: medicine shortage in the SC and risk costs, that result from risk materialization.

![Figure 1. Risk Management Methodology](image)

**Figure 1. Risk Management Methodology**

The damage or risk properly said is the adverse circumstance that can be materialized and the linkage is the systemic association between risk objects and objects on risk that, in some cases, can be stronger than others.

In development of stage 1 about conceptualization, four supply risks were identified as shown in the Figure 2: 1) supply delays; 2) disruptions in the supply; 3) differences in quantities received and 4) demand forecast errors. These risks were set from the definition of internal and external risk factors; the depletion of medicine active principle, which is a condition that affects the medicine production in pharmaceutical industry by scarcity of raw materials; the medicine availability in the market, that occurs by dynamics between the offer and demand of the market; capacities of logistics systems, associated with the opportunity of times of response and management and delivery quality of medicines; and the asymmetries of the information, which are a critical risk factor in the different chain links, that are a consequence of power relationships, competition conditions in the provider market, low coordination between SC agents and limited use of communication and information technologies.

![Figure 2. Stage 1. Risk contextualization.](image)

**Figure 2. Stage 1. Risk contextualization.**

On stage 2 about assessment, the methodology of risk assessment considering the likelihood of occurrence and risk impact was applied. Likelihood and impact corening scales were set, which allowed establishing the risk areas: severe, major, medium and minor, as presented in Figure 3. As a result of the assessment, it was found that the disruption risks and the delays in the supply were placed within severe and major zones; the risk of difference in received numbers was placed in major and medium zones; and finally, the error risk in forecast of demand was placed in the medium region.

![Figure 3. Risk valuation.](image)

**Figure 3. Risk valuation.**
For the quantification of risk danger, the expression presented by Liu, Xu, Li, Wang, & Wu (2012) was used; Risk exposure = P(NO) * L(NO), where P(NO) is the likelihood of a negative result, and L(NO) is the loss or effect due to the result.

**System Dynamics (SD) Application**

The domain of system dynamics (SD) developed in the Massachusetts Institute of Technology (MIT) in 1950 by Jay Forrester, is based on structure and dynamics of complex systems. On the basis of control engineering theory and non-linear dynamic systems theory, the SD is used for developing formal models and simulation that allow capturing complex dynamics to create a favorable environment for learning and design of policies (Sterman, 2002).

SD combines the theory, methods and philosophy needed for analyzing the economical behavior, medicine, engineering and other issues (Forrester, 1991).

In the system dynamics methodology, diagrams of causals are used for representing the causality relationships and the inter-dependence between variables and Forrester or flow diagrams to represent the status of the system, the feedback processes and the making of decisions about the obtained information (Sterman, 2000).

Figure 2, explained previously, results from the application of the causal diagram that represents the current relationship between risk factors, risks and effects.

**System Dynamics Model**

In the model of system dynamics, the structure of system based on the representation of flows and accumulations of medicines in the different instances of SC, are presented. These instances do not represent a specific node in the SC, in or a physical place for storage or distribution, instead, they are composed of flows and accumulation of products in the system in an added way.

The risk danger of SC is posed by the risk factor of supply, associated to the provider market, the medicine availability in the market, the logistics services and the asymmetries of information in the SC, that cause alterations in the product entrance flows, producing instability when programming and attending patients and their consequent costs in the system operation.

**Model structure**

The simulation model developed is presented in Figures 4 and 5, the Vensim PLE 6.0 b software was used.

**Levels:**

- SMED: Level that corresponds to medicine stock in the systems (units).

**Flows:**

- ORRE: Entrance flow of medicines received in the systems (units/month).

- DISP: Out flow of medicines delivered by drugstore services (units/month).

- EMCP: Out flow of medicines sent to preparation centers (units/month).

**Auxiliar variables:**

- SOTR: Monthly value of added consumption of medicines in units/month.

- FCDE: Correction factor of demand.

- AEPS: Approval time of treatment by the EPS (months).

- PRTR: Number of programmed treatments by HCI (units/month).

- DEST: Stock Deficit is the difference of medicines stock in the system with respect to the demand (units/month).

- FRAI: Risk factor of asymmetries of information.

- ORPR: Number of medicine units ordered by the provider (units/month).

- FRDM: Risk factor of providers market.

- FRPA: Risk factor of availability of active principle.

- PROR: Provider response to the medicine purchase order (units/month).

- LTME: Provider response time (units/month).

- FSL: Risk factor of logistics services.

- FECP: Sending fraction of medicines to delivery.

- FECP: Sending fraction of medicines to the preparation centers.

- COOR: Ordering cost ($/month).

- CUOR: Ordering Unitary cost ($/month).

- COMA: Inventory maintenance cost ($/month).

- CUMA: Maintenance Unitary Cost ($/unit).
CODI: Distribución costo ($/mes).
CUDI: Distribución Unitario costo ($/unidad).
CORI: Riesgo costo ($/mes).
COPE: Multa costo ($/unidad).
TCPE: Multa aplicación tiempo (mes).

La diferencia entre el nivel de stock y la solicitud de tratamiento en el sistema hace el problema del riesgo de suministro evidente. El análisis de flujos de salida nos permite observar la respuesta del sistema durante los periodos de tiempo de la simulación.

<table>
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<tr>
<th>Variables</th>
<th>Media</th>
<th>Desv. Est.</th>
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<tbody>
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<td>AEPIS</td>
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<tr>
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<tr>
<td>PROR</td>
<td>7.206,38</td>
<td>1.370,55</td>
</tr>
<tr>
<td>ORRE</td>
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<td>1.156,13</td>
</tr>
<tr>
<td>LTME</td>
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<td>0,27</td>
</tr>
<tr>
<td>DEST</td>
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<td>2.255,70</td>
</tr>
<tr>
<td>DISP</td>
<td>1.779,46</td>
<td>437,08</td>
</tr>
<tr>
<td>EMCP</td>
<td>3.304,71</td>
<td>811,72</td>
</tr>
</tbody>
</table>

El comportamiento de costo en el primer entorno se presenta en la Figura 7, donde el alto costo de penalización se refleja por el actual estado del riesgo de suministro.

La formación del modelo

\[ \text{SMED} = \text{INTEG}(\text{ORRE}-\text{DISP} \times \text{EMCP} \times \text{SMED}, 0) \] (1)

\[ \text{ORRE} = \text{DELAY FIXED}(\text{PRTR} \times (1-\text{FRSL}), \text{LTME}, 0) \] (2)

\[ \text{DISP} = \text{IF THEN ELSE} (\text{PRTR} \geq \text{SMED}, \text{SMED} \times \text{FEDI}, \text{PRTR} \times \text{FEDI}) \] (3)

\[ \text{EMCP} = \text{IF THEN ELSE} (\text{PRTR} \geq \text{SMED}, \text{SMED} \times \text{FECP}, \text{PRTR} \times \text{FECP}) \] (4)

\[ \text{PRTR} = \text{DELAY FIXED}(\text{SOTR} \times (1+\text{FCDE}), \text{AEPS}, 0) \] (5)

\[ \text{DEST} = \text{IF THEN ELSE} (\text{PRTR} \geq \text{SMED}, \text{PRTR} \times \text{SMED}, 0) \] (6)

\[ \text{ORPR} = \text{IF THEN ELSE} (\text{SMED} \geq \text{PRTR}, (\text{PRTR} \times \text{SMED}), 0) \] (7)

\[ \text{PROR} = \text{ORPR} \times (1- (\text{FRPA} + \text{FRDM})) \] (8)

\[ \text{COOP} = \text{CODI} + \text{COMA} + \text{CORI} + \text{CUDI} \] (9)

\[ \text{CODI} = (\text{DISP} \times \text{EMCP}) \times \text{CUDI} \] (10)

\[ \text{COMA} = \text{SMED} \times \text{CUMA} \] (11)

\[ \text{COOR} = \text{ORPR} \times \text{CUDI} \] (12)

\[ \text{CORI} = \text{DELAY FIXED}(\text{DEST} \times \text{COPE}, \text{TCPE}), 0) \] (13)

Entorno de simulación y análisis de ejecuciones.

Dos entornos fueron evaluados con ejecuciones de simulación durante 100 meses. El primer entorno incluye los riesgos factores evaluados en el estudio y su impacto en el sistema operativo. Los resultados de simulación de este entorno, presentados en la Figura 6, muestran cómo el flujo de entrada es afectado por los riesgos factores, produciendo déficits en diferentes periodos debido a diferencias entre demanda y oferta global de medicinas.

Figura 5. Diagrama de flujo, costos del sistema.

El análisis de flujos de salida nos permite observar la respuesta del sistema durante los periodos de tiempo de la simulación.
included, which gives cross-support to the SC and provides reliable information for decision making.

The definition of these strategies will be developed in a subsequent stage of study. However, with the purpose of assessing a possible setting of mitigation, projected values are taken on the basis of a research project hypothesis. With this in mind, the simulation model was run with reduced risk factors for assessing the possible impacts on the system operation and associated costs. Figure 8 presents a comparison of both settings.

![Figure 8. The results of simulation, risk mitigation scenario](image)

In Figure 9, the operation costs behavior on a current setting and a theoretical setting is presented.

![Figure 9. Cost behavior, risk mitigation scenario.](image)

Other more optimistic settings will allow having better indicators of service and costs. However, the developed hypothesis considers the complex dynamics of market that surpasses the normative control and operation means under the current conditions of market in the country.

Conclusions

The research presents fundamental information about the effects of supply risk on the supply chain of oncological medicines in Colombia, the implications at operation settings and a theoretical setting is presented. With this in mind, the simulation model was run with reduced risk factors for assessing the possible impacts on the system operation and associated costs. Figure 8 presents a comparison of both settings.

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Conclusions

The research presents fundamental information about the effects of supply risk on the supply chain of oncological medicines in Colombia, the implications at operation settings and a theoretical setting is presented.

With these results show that the level of response of the market is 56.91%, which implies a deficit in the medication system. The percentage of the supply of logistics services is 71.31%, which represents the delays in the delivery times. It was found that in 52% of the cases, the waiting time for receiving treatment was longer than three months. On average, is known that of 100 patients requiring medicines, only 38 of them receive those medicines in normal conditions.

The risk cost accounts for 70.66% of total cases of operation. According to the analysis, it is seen that the use of high cost medicines, which substitute the active principle of doxorubicine, causes the increase of costs, that constitutes the main component of system cost.

In the theoretical setting, it is observed that shortage occurred by breaks in the supply is reduced in a obvious way, in which the level of response of the market will pass from 56.91% to 85.81%. On this setting, the cost could be reduced in 21.26%.

With results presented in the theoretical setting, the need for additional research on definition of strategies of risk management in the supply chain that allow to reduce the risk and impacts on more critical environments, like the system economy and health of cancer patients, is identified.

References


