Deterministic and Uncertain Methods and Models for Managing Agri-Food Supply Chain

Métodos y Modelos Deterministas e Inciertos para la Gestión de Cadenas de Suministro Agroalimentarias

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Abstract: The market for agricultural products has grown substantially. At the same time, social concern in food issues such as food safety, food quality, traceability and sustainability is constantly increasing. These reasons have pointed out the need of new models and tools to manage the agri-food supply chains while considering the characteristics that differentiate them from other industrial supply chains as well as the uncertainties present in the sector. Thus, the aim of this paper is to present the current status of a project which mains objectives are to describe the complexity faced by agri-food supply chain decision makers, and to develop new tools based on mathematical programming models to help the decision making process in agri-food supply chain planning. These models novelty will include the consideration of the inherent characteristics of agri-food supply chains and the sources of uncertainty present in the sector. The proposed models and tools will be applied to a real agri-food supply chain in order to prove their validity and applicability and to compare the results obtained by deterministic and uncertain tools.

Keywords: Agri-Food; Supply Chain; Mathematical Programming; Deterministic; Uncertainty;

Resumen: El mercado de productos agrícolas está en continuo crecimiento, al igual que la preocupación social en temas alimentarios como la calidad y seguridad alimentaria. Esto genera la necesidad de desarrollar modelos y herramientas para gestionar las cadenas de suministro agroalimentarias de manera ajustada y teniendo en cuenta sus características y fuentes de incertidumbre inherentes. Este articulo presenta el estado actual de un proyecto cuyos principales objetivos son: describir la complejidad enfrentada por los decisores de las cadenas de suministro agroalimentarias, y desarrollar nuevas herramientas basadas en programación matemática para apoyar la toma de decisiones en este sector.

Palabras clave: Agroalimentaria; Cadena de Suministro; Programación Matemática; Determinista; Incertidumbre;

1.   Introduction

In recent years, the market for agricultural products has grown substantially. In particular, the fresh fruit production has been increasing worldwide by 20 percent between 2003 and 2012, being the European Union who dominates the import/export market for these products (Soto-Silva et al., 2016). Despite the above figures, the more and more challenging requirements of the global markets in terms of products quality, variety and customization, government regulations related to food security, as well as severe environmental conditions, have pressured heavily the agri-food sector to improve its resilience capacity. All this in order to respond to abrupt changes in quality, quantity and availability of resources, especially under unexpected environmental circumstances, caused by existing uncertainty related to weather, pests and diseases, as well as the volatile market conditions and raw materials prices, among others.

To achieve an efficient, flexible and quick response capacity it is necessary for Agri-Food Supply Chains (AFSC) to adopt integrated strategies from raw material production to product distribution to customers in order to align demand and supply in the most competitive and dynamic way. However, achieving this objective in AFSC becomes even more complicated for various reasons primarily related to uncertainty sources present in this sector.

Uncertainty inherent to AFSC originates an important imbalance between demand and supply in terms of product variety, quantity, quality, customer requirements, times and prices, which greatly complicate its management. This is mainly because AFSC production process yield depends on uncontrollable factors related to natural features as the climate (temperature, humidity, day duration…), pesticides, water availability, soil characteristics, etc., causing unpredictable variations in supply quality and quantity (Verdouw et al., 2010). For AFSC it is difficult to predict their supply due to the heterogeneous quality of the raw materials caused by agronomic and climatic factors. Van Donk (2000) pointed out that food processing industries process natural materials, which vary in quality and composition, for this reason processes might be uncontrollable in their yield or the quality of the output.

In addition to the foregoing, the perishability aspect of products and market price volatility must be considered, which make it even more difficult to serve the customer not only with the quantity and date required as it is habitual in the majority of supply chains, but also with the quality, freshness and price required by the customer. The achievement of this objective increases its complexity when considering the perishability of products which causes a variation of its freshness and consequently, a decrease of its value (Amorim et al., 2012) and; when considering that AFSC have long lead times and limited possibility for inventorying.

It is necessary to combine the technological advances (traceability, cold chain, biosecurity, etc.) with the development of new solutions in management field that consider the particularities mentioned above, and in particular, the different sources of uncertainty. Given the relatively narrow margins that characterize the AFSC, it is noted that new methods and models need to be raised in order to improve the AFSC planning at all decision levels and along the supply chain since the inherent characteristics of this sector and the uncertainty associated to it have not been adequately addressed.

This project, which is in its initial stage, aims to describe the complexity faced by AFSC decision makers and to develop new tools based on mathematical programming models to facilitate the decision making process in AFSC planning. The specific objectives of the project are:

1.   To develop conceptual models for characterizing the AFSC, the exogenous and endogenous uncertainties present in the AFSC and their impact in the AFSC management.

2.   To identify the employed methods for addressing each type of uncertainty, as well as their advantages and disadvantages.

3.   To develop decision-making supporting integrated methods and models for design and operate the AFSC in deterministic and uncertain contexts that consider its differentiating characteristics and allow to:

a.   Adequately manage AFSC risks and uncertainties.

b.   Predict the impact of changing conditions in the AFSC efficiency and in the customer satisfaction.

c.   Provide alternative solutions when unexpected events or discrepancies between planning and reality due to the different uncertainty sources occur.

4.   To develop solution tools for deterministic and uncertain context, and to compare these approaches.

5.   To validate the project results through their application to a real AFSC.

The remainder of this paper is organized as follows. Section 2 describes relevant works related to AFSC and Operations Research (OR) where the need of models to design and manage AFSC considering the inherent uncertainties and the differentiating characteristics is pointed out. In Section 3, it is explained the proposed solution to fill this gap by the project while the work made to date is described in Section 4. Finally, the expected contributions of the project and the plan for their validation and evaluation are described in Section 5.

2.   Related work

There are numerous applications of OR to different supply chain management processes such as the supply chain design, operation planning (Grillo et al., 2016a; Mundi et al., 2016; Hegeman et al., 2014; Mundi et al., 2013; Alemany et al., 2011; Alemany et al., 2010) and order management (Grillo et al., 2016b; Alemany et al., 2015; Boza et al., 2014; Alemany et al., 2013). Lowe and Preckel (2004) claim that effective practices for other supply chains cannot be directly extrapolated to AFSC due to its own characteristics. However, intrinsic features of AFSC have not been realistically modelled as shown in the literature review.

Soto-Silva et al. (2016) state in their review of OR models applied to fresh fruits supply chain that there exist a gap of models to design and manage this type of supply chains. They point out that almost all the models used constant prices ignoring variations over time in the market due to product seasonality and deterioration. The authors note the need of models including the intrinsic characteristics of fresh fruits industry such as shelf-life, quality deterioration, wastage, price dependent on time and freshness. They also indicate that given the uncertainty and risk involved in fresh fruit sector, it is necessary to develop models that take into consideration these characteristics. The authors conclude that the number of publications in this field is scarce, although in recent years this number has increased and more models are expected to be published in near future, where OR models are being outlined as one route of facing uncertainty in AFSC.

In the field of AFSC operations planning there are some studies that model the uncertainty in supply quantities due to raw materials quality and composition (Munhoz and Morabito, 2014; Ahumada et al., 2012). Radulescu et al. (2008) deal with process uncertainty caused by crops yield and prices, while Bohle et al. (2010) and Begen and Puterman (2003) also relate to process un-certainty but that caused by perishability. Only Miller et al. (1997) approach the supply perishability from an uncertainty angle. It is observed that few papers consider the uncertainty in the number of obtained qualities, in the condition changes of perishable products nor price variations due to the seasonal factor and the loss of value caused by deterioration. These characteristics are often ignored and the problems are solved using "average" values, or "most probable" values (Bohle et al., 2010).

Ahumada and Villalobos (2009) carried out a review of AFSC planning models where it is highlighted the need for stochastic models for the tactical planning of agri-food products including more realistic features, such as un-certain information, logistics integration, risk modelling, regulatory environment, product quality, perishability and security of products. They point out that although some of risk reduction issues have been modelled in the past, the market, production, distribution and the uncertainty of the models' parameters have not been considered. The need for such logistical models has promoted the emergence of the field of "Agribusiness Logistics", which studies the impact of logistical issues in AFSC, particularly in the case of perishable products where the limited shelf life of the product requires a very careful planning of the transportation and inventory decisions to reduce the deterioration of the products and preserve their value. Ahumada and Villalobos (2009, 2011) noted that there

is a lack of adequate models for planning operational decisions in this field.

In their review of order promising models under uncertainty in lack of homogeneity in the product (LHP) contexts, Grillo et al. (2016a) identify the agri-food sector as the one with more simultaneous LHP characteristics and point out that any order promising model deal with the perishability of products either in deterministic or uncertain context. Finally, the authors conclude that very little research work has focused on order promising process in the agri-food sector and even less considering its uncertainties, suggesting that this is a new research area.

Therefore, it is necessary to investigate the better ways to design and operate an AFSC that is increasingly globally integrated (Ahumada et al., 2009). The agri-food sector evolution in the global market will largely depend on its capability to address these challenges, which cannot be addressed by applying trends from the past only. Thus, it is necessary to develop methods, models and tools to support decision making for the design and management of AFSC which are in continuous change because of the different sources of un-certainty (Soto-Silva et al., 2016).

3.   Proposed solution

The proposed solution by this project is to develop various mathematical programming models and their related tools to support the decision making pro-cess at all levels for AFSC planning in a deterministic and uncertain context. These models are supposed to be representative of the agri-food sector by including its differentiating characteristics such as perishability, food quality or food safety among others, which have not been adequately addressed by previous literature.

As a first step to justify the novelty of this project, a review of existing literature reviews (LR) related to OR and the AFSC has been made. This review is made up of a descriptive analysis in which the frequency of publication among years is analysed; an identification of the supply chain topics which have been analysed by AFSC LR; an analysis of the dimensions employed by these LR to classify the models; and, an analysis of the future research lines proposed by LR with the identification of which of them remain valid.

After this first approximation, a state of the art study of existing mathematical programming models for AFSC management at all decision levels will be performed. The aim of this state of the art is twofold: first, to identify which problems have to be solved by decision mak-

ers at each decisional level and which of them have not been addressed yet and, second to identify in each decisional level which AFSC characteristics or combination of AFSC characteristics have or have not been addressed by existing models. This twofold objective will help the identification of gaps in the literature that will justify the future proposed novelties presented by the mathematical models developed in this project.

Subsequently, a conceptual framework will be proposed in order to characterize the AFSC as well as the existing uncertainty sources in the sector and their impact on the AFSC management.

On the other hand, deterministic and uncertain methods, models and tools will be developed to improve the AFSC planning and to support decision making at different decision levels by integrating the decisions related to product cultivation, harvest, production and distribution. Likewise, models will consider the existing requirements of food quality and safety, government regulations, the complex aspects of logistics derived from global markets and, the high level of uncertainty and risk related to biologic aspects, diseases, pests, climate, limited shelf life of products, price volatility and demand variability. All of this in order to improve the competitiveness, sustain-ability and flexibility of the AFSC to adapt to market requirements under conditions of uncertainty and risk.

After these models and their related tools validation through a set of scenarios cases, the application of them to a real AFSC will be made. For that purpose, the real AFSC will be first characterized by using the conceptual framework designed in the project. After that, both deterministic and uncertain tools will be applied and their results will be compared in order to reach conclusions.

To finish with the project project, conclusions related to all the project pro-cess will be drawn and possible future research lines will be detailed.

4.   Preliminary work

A review of existing LR related to OR and the AFSC has been made as a first step before performing the state of the art. This review has been extended to OR-based models dealing with food or perishable products supply chains since they share one of its main characteristic: perishability.

40 relevant LR published between 1981 and 2016 were identified and analysed. The number of LR has signif-

icantly increased in the last seven years (65% of LR). 80% of LR analyse models related to AFSC management, AFSC planning, inventory management or the application of methods/techniques to AFSC.

After analysing each LR its shown that dimensions employed by them are generic ones that do not analyse specific characteristics of the agri-food sec-tor. 62.5% of LR analyse the models' characteristics and 37.5% analyse the problem, product and supply chain process to which these models have been applied.

To conclude, the future research lines proposed by found LR that still re-main valid are identified. The most remarkable valid future research lines are the need of models for design the AFSC and holistic approaches for its design and management and, the need to consider the intrinsic characteristics of agri-food sector that have not yet been handled properly such as perishability, existing uncertainties, food quality, food security and sustainability.

5.   Expected contributions and plan for evaluation and validation

Through the completion of this project, it is pretended to describe the complexity faced by AFSC decision makers and to develop new tools based on mathematical programming models to facilitate the decision making pro-cess in AFSC planning. Thus, new tools are going to be developed in order to faithfully represent the AFSC behaviour by including in the models the differentiating characteristics of the sector such as perishability, food quality and food safety, and the uncertainties present in the agri-food sector. In addition, these tools are expected to be useful for designing and operating AFSC in an efficient and sustainable way.

The developed models and tools will be internally evaluated by analysing their behaviour though the implementation of different scenarios. In these scenarios, different values will be assigned to each parameter in order to reach a known result or behaviour. Subsequently, the application of the designed tools to a real AFSC will be made in order to prove its validity and applicability and to compare the results obtained by deterministic and uncertain tools.

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