



# Scheduling of internal materials supply operations in a pre-milling type concentrate food plant<sup>1</sup>

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**Programación de las operaciones de suministro interno de materiales en plantas de alimento concentrado tipo premolienda**

**Programação de operações de fornecimento interno de materiais em uma planta de concentrado de pré-moagem**

## ABSTRACT

**Introduction.** This research addresses the problem of internal materials supply operations in a pre-milling type concentrate food plant. The required amount of raw materials for production in the internal supply chain is determined by minimizing the total relevant operational cost, made up by the setup cost and the stock maintenance cost, which maximizes efficiency of the resources used in the process. This study takes into account such factors as capacity of the hoppers, the time-dependent setup sequence, routes of supply hoppers, filling rates and supply times, based on a model of mixed-integer linear programming. **Objective:** Provide a strategy that allows efficient use of resources in the production process, subjected to the demand of materials from the material requirements planning (MRP) of the company under study. **Materials and methods.** The short-term multi-period model defines the scheduling of elevators and conveyors for each time period, and the amount of raw materials that is sent to each hopper and bins. **Results.** This research determines the amount of initial stock required to operate, as well as the operations strategy that the company under study must follow, so that it meets the demand for raw materials, making efficient use of the resources used in the production process. **Conclusion.** In the analysis of results and presentation of scenarios, the most representative cost, the

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one related to stock maintenance, could be observed. Since this is a critical factor for companies belonging to this sector; we present an innovative proposal, both in practice and in the literature, to contribute to minimizing the total setup cost and the cost of

maintenance of raw material stock in hoppers through a rational use of resources.

**Keywords:** operations scheduling, total relevant cost, materials requirements, linear programming.

## RESUMEN

**Introducción.** Esta investigación aborda el problema de programación interna de materiales en una planta de alimentos concentrados, tipo pre-molienda. La cantidad necesaria de materias primas para la producción en la cadena de alimentación interna se determina mediante la minimización del costo total relevante de la operación, compuesto por el costo de alistamiento y el costo de mantenimiento del inventario, lo cual maximiza la eficiencia de los recursos empleados en el proceso. Para ello se consideran factores tales como la capacidad de las tolvas, las rutas y velocidades de llenado y los tiempos de suministro contenidos en un modelo de programación lineal, entera, mixta. **Objetivo.** Brindar una estrategia que permita el uso eficiente de los recursos empleados en el proceso, sujetos a la demanda interna de materiales del plan de requerimiento de materiales (MRP) de la empresa objeto de estudio. **Materiales y métodos.** El modelo multi-período a corto plazo define en cada período de tiempo la programación

de los elevadores o transportadores, y la cantidad de materias primas que se envía a cada tolva. **Resultados.** La investigación determina la cantidad de inventario inicial requerido para la operación, además de la estrategia de operaciones que la compañía objeto de estudio debe seguir con el fin de satisfacer la demanda de materias primas, haciendo una utilización eficiente de los recursos empleados en el proceso productivo. **Conclusión.** En el análisis de los resultados y en la presentación de los escenarios, el costo más representativo es el relacionado con el mantenimiento del inventario; este es un factor crítico en las empresas pertenecientes a este sector. Por ello, se presenta una propuesta innovadora para este tipo de procesos productivos, con el fin de contribuir a minimizar el costo de total de alistamiento y el costo de mantenimiento de las existencias de materia prima en tolvas mediante un uso racional de los recursos.

**Palabras clave:** Programación de operaciones, costo total relevante, requerimientos de materiales, programación lineal.

## RESUMO

**Introdução.** Esta investigação aborda o problema de programação interna de materiais numa planta de alimentos concentrados, tipo pré-moagem. A quantidade necessária de matérias primas para a produção na cadeia de alimentação interna se determina perante a minimização do custo total relevante da operação, composto pelo custo de preparação e o custo de manutenção do inventário, o qual maximiza a eficiência dos recursos empregados no processo. Para isso se consideram fatores tais como a capacidade das funis, as rotas e velocidades de enchimento e os tempos de subministro contidos num modelo de programação lineal, inteira, mista. **Objetivo.** Brindar uma estratégia que permita o uso eficiente dos recursos empregados no processo,

sujeitos à demanda interna de materiais do plano de requerimento de materiais (MRP) da empresa objeto de estudo. **Materiais e métodos.** O modelo múlti-período a curto prazo define em cada período de tempo a programação dos elevadores ou transportadores, e a quantidade de matérias primas que se envia a cada funil. **Resultados.** A investigação determina a quantidade de inventário inicial requerido para a operação, ademais da estratégia de operações que a companhia objeto de estudo deve seguir com o fim de satisfazer a demanda de matérias primas, fazendo uma utilização eficiente dos recursos empregados no processo produtivo. **Conclusão.** Na análise dos resultados e na apresentação dos cenários, o custo mais representativo é o relacionado com a manutenção do inventário; este é um fator crítico nas empresas pertencentes a este setor. Por isso, se

apresenta uma proposta inovadora para este tipo de processos produtivos, com o fim de contribuir a minimizar o custo de total de preparação e o custo de manutenção das existências de matéria prima em funis perante um uso racional dos recursos.

**Palavras chave:** Programação de operações, custo total relevante, requerimentos de materiais, programação lineal.

## INTRODUCTION

Production planning is needed in a company, and is particularly important regarding the requirements for specific delivery times in each organization. Thus, an appropriate material requirements planning (MRP) is essential to ensure that the right quantity of raw materials is available all the time for the internal supply of materials necessary for manufacturing products in the organization.

MRP can set up the quantity of materials and the timing when these must be available to ensure compliance with the master production scheduling; however, in some manufacturing industries, ensuring the availability of materials is a complex problem due to certain characteristics of the process: the large quantity of materials, production volume, range of products, constraints on handling equipment, among others. Therefore, setting up a methodology to achieve this goal based on information in the MRP is needed. Ramos (2004) states that appropriate MRP can meet this objective.

Specifically, in the animal-feed industry, the process of internal supply of materials is related to moving large volumes of raw materials, which involves labor scheduling, equipment, and setup time (Torné, Ramírez & Orejuela, 2012). For the production process, the required raw materials for different hoppers, according to the MRP, must be determined in advance.

This paper presents an operations scheduling model performed in a pre-milling type complex production system for the supply, storage and dosing of milling hoppers. Different factors are included, and the system constraints related to the demand for raw materials and the supply sequence, based on routes or materials supply routes and allocation of elevators, are described. These factors include hoppers' capacity, setup time, supply routes, filling rates of elevators, displacement, and required time for delivery from the raw materials storage area to the hoppers.

A multi-period model of mixed-integer linear programming is presented, in which setup and maintenance costs are minimized, and compliance with raw materials stock and demand, specified in the MRP, is guaranteed. The model focuses on the need to plan all the activities for raw materials internal supply, by determining the quantity of raw material to be filled into the hoppers, and the timing of material supply, so that the required quantity is met.

There are several studies on scheduling and its relationship with the internal supply of materials. Ramos (2004) devised a Planning System of Material Requirements in the Food Industry, whose main objective is to design a methodology for obtaining an appropriate system of MRP, so that costs could be reduced.

An optimization model for calculating components requirement planning, where input is the production planning in the master plan, is formulated by Bahl and Ritzman (1984) and Toro and Delgado (2010). Moreover, other authors such as Hastings, Marshall and Willis (1982), Ho and Chang (2001), Fallah and Shayan (2002), Chen and Ping (2007), Masuchun and Thepmanee (2009), and Shah and Lerapetritou (2012), present mixed-integer linear programming models to set up a system to integrate production planning of items in the MRP and operations scheduling, guaranteeing an appropriate materials supply in the plant. In these models, capacity constraints, operation sequences, setup timing, and delivery deadlines in a multi-item setting are considered. In Torné, Ramírez and Orejuela (2012), a model of mixed-integer linear programming is also presented to set up a material-supplying program for dosing hoppers in a pre-milling type concentrate food plant, so that the required quantity and timing of materials are met. The difference between this research and the one conducted by Torné, Ramírez and Orejuela (2012) is mainly based on a different production scheme, in which three types of hoppers with different functionality are involved, which means that the management of resources for dosage, grinding and storage operations are complex.

Another important difference lies in the fact that various types of elevators and storage modes of raw materials are handled, generating a significant impact on the total relevant cost.

Similarly, in Kayhat, Langevin and Riopel (2005), a linear programming model is designed, whose purpose is to determine the right supply and material handling by taking into account limited resources in a manufacturing floor environment, so that the makespan is minimized. Finally, Babiceanu, Chen and Sturges (2004) and Babiceanu and Chen (2008) present an optimization and simulation model to address the problem of materials handling in a dynamic manufacturing environment; this model contributes to the decision-making process regarding the allocation and material-supplying sequence for every timing defined in a planning horizon.

## MATERIALS AND METHODS

The manufacturing system under study (see Figure 1) consists of several operations involving equipment and different resources before the dosing process is performed. Concentrate food industries currently have two different production systems. One of them is the pre-mixing type where raw materials are first passed through a dosing process in which they are mixed and then passed through a milling activity as designed by Torné, Ramírez and Orejuela (2012).

In contrast, in the other system, called pre-milling, raw materials are taken to hoppers, where some of them are first passed through a temporary storage activity. After that, they are ground, dosed and finally mixed; this makes the activities related to this manufacturing system more complex as compared to the pre-mixing type.

It should be noted that the company under study has a pre-milling type production system that consists of three types of hoppers, where each one has a particular function within the production system and a series of elevators, whose function is to transport raw materials from the material storage areas, as warehouses and silos, to the different types of hoppers, based on predetermined supply routes. Afterwards, these materials must go through a fine milling process and then through pelletizing and extrusion processes.

## Mathematical Model

An overview of the pre-milling type manufacturing system and methodological developments to design a mixed-integer linear programming model are included in the methodology of this study. This model integrates relevant factors related to the raw materials supply based on an analysis of the problem or description of the current system and its impact in meeting demand for raw materials. Constraints related to the production system under study were also identified in this characterization, and the relationship between MRP and operation scheduling in the production system could be understood (Masuchun, Masuchun & Thepmanee, 2009).

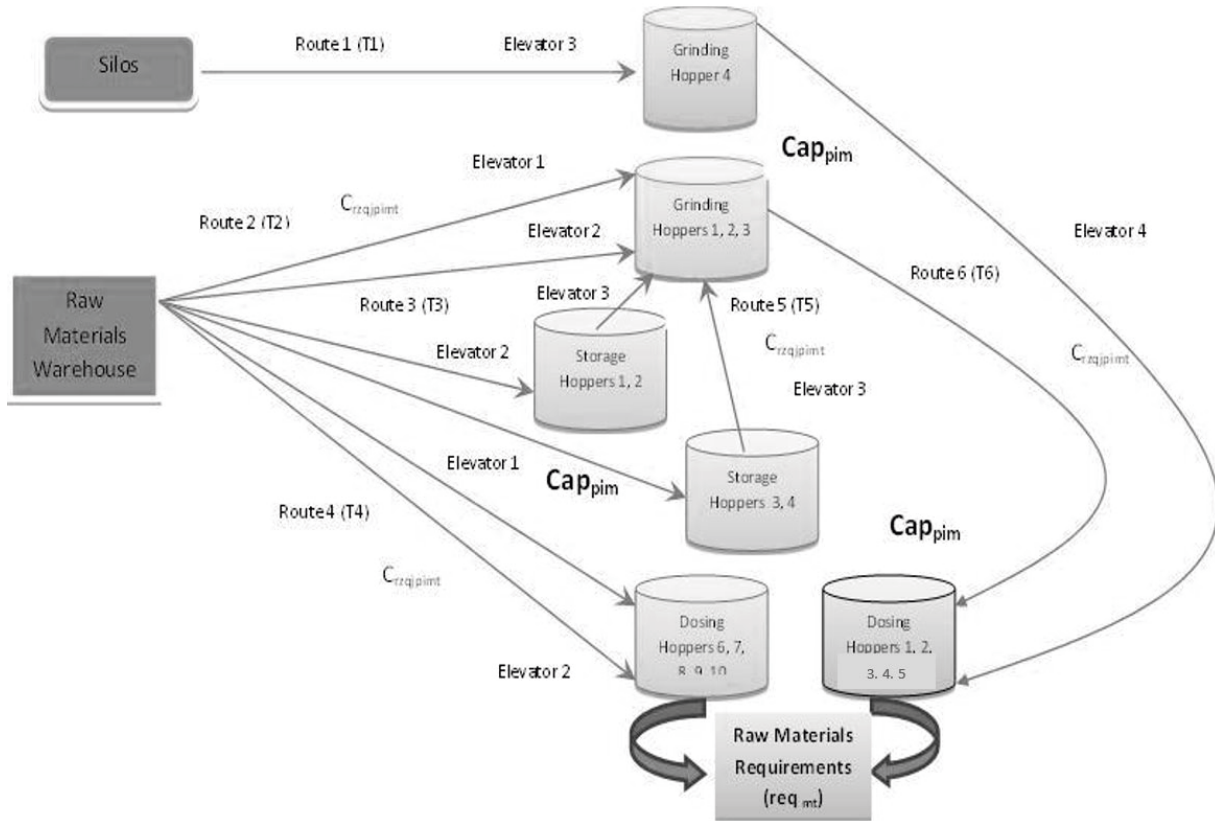
### Design of the Mathematical Model

In this study, the following assumptions on the mathematical model were made:

- The raw materials requirements of the production scheduling and nutritional diets needed to disaggregate the products are known.
- Raw materials are always available in storage silos and warehouses.
- Stock maintenance costs, which are different for each raw material, and those related to setup, are all known. The costs depend on energy cost, associated to timing when supply routes of raw materials are not being used, and labor operation costs.

### Parameters Definition

Parameter  $v_{rzm}$  is defined as the filling rate when raw material  $m$  is sent to the hoppers through Route  $r$  and by means of Elevator  $z$  (Kg of raw material/minute);  $ta_{rzm}$  is the associated setup time when raw material  $m$  is sent in time  $(t-1)$  into the hoppers through Route  $r$  and by means of Elevator  $z$ , and raw material  $g$  is sent in the previous period  $(t-1)$  (Minutes);  $req_{mt}$  represents the required quantity of raw material  $m$  in the time period  $t$  (Kg of raw material);  $vt$  is the length of Time Window (Minutes);  $cap_{pim}$  is the filling capacity of raw material  $m$  associated with the type of hopper  $p$  and hopper  $i$  (Kg of raw material);  $CA$  is the setup cost of raw material ( $\$/minute$ ); finally,  $Cl_m$  is related with the maintenance cost associated with raw material  $m$  ( $\$/kg$  of raw material at each time period).



**Figure 1. Supply of raw material in different types of hoppers**  
**Source: Authors' own elaboration**

### Decision Variables

$I_{pimt}$ : Final Stock of raw material  $m \in MP [p,i]$  in the  $p$ -type hopper  $i$  in time period  $t \in TPO$ .

$C_{rzqipimt}$ : Binary variable that is equal to 1, if raw material  $m$  is sent from the Storage Area or  $q$ -type origin hopper  $j$  to  $p$ -type hopper  $i$  through route  $r$  by means of Elevator  $z$  in time period  $t$ ; 0 if otherwise.

$T_{rzqipimt}$ : Binary variable that is equal to 1 if, in period  $t$ , raw material  $m$  is sent from the Storage Area or  $q$ -type origin hopper  $j$  to  $p$ -type hopper  $i$ , and in the previous period ( $t-1$ ) the raw material goes through route  $r$  by means of Elevator  $z$ ; 0 if otherwise.

$W_{pimt}$ : Binary variable that is equal to 1 if raw material  $m$  is deposited in the  $p$ -type hopper in time period  $t$ ; 0 if otherwise.

### Objective Function

$$Z_{\min} = \sum_{r \in TR} \sum_{z \in EL[r]} \sum_{q \in TIP} \sum_{j \in TTO[q]} \sum_{p \in TIP} \sum_{i \in TTO[p]} \sum_{m \in MP[p,i]} \sum_{g \in MP[p,i]} \sum_{t \in TPO} ta_{rzmg} * T_{rzqjpimgt} * CA$$

$$+ \sum_{p \in TIP} \sum_{i \in TTO[p]} \sum_{m \in MP[p,i]} \sum_{t \in TPO} I_{pimt} * CI_m \quad (\text{Equation 1})$$

### Constraints

$$I_{pimt-1} + \sum_{r \in TETT[p,i]} \sum_{z \in ET[r]} \sum_{q \in TASS[p,i]} \sum_{j \in TTO[q]} \left[ vt * C_{rzqjpimt} - \sum_{g \in MP[p,i]} ta_{rzmg} * T_{rzqjpimgt} \right] * v_{rzm}$$

$$= \sum_{r \in TSTT[p,i]} \sum_{z \in ET[r]} \sum_{q \in TREC[p,i]} \sum_{j \in TTO[q]} \left[ vt * C_{rzqjpimt} - \sum_{g \in MP[p,i]} ta_{rzmg} * T_{rzqjpimgt} \right] * v_{rzm} + I_{pimt}; \forall p$$

$$\in TIP, i \in TTO[p], m \in MP[p, i], t > 1 \quad (\text{Equation 2})$$

$$\sum_{p \in TIP} \sum_{i \in TTO[TD,m]} \sum_{r \in TETT[p,i]} \sum_{z \in ET[r]} \sum_{q \in TASS[p,i]} \sum_{j \in TTO[q]} \left[ vt * C_{rzqjpimt} - \sum_{g \in MP[p,i]} ta_{rzmg} * T_{rzqjpimgt} \right] * v_{rzm}$$

$$+ \sum_{p \in TIP} \sum_{i \in TTO[TD,m]} I_{pimt-1} = \sum_{p \in TIP} \sum_{i \in TTO[TD,m]} I_{pimt} + req_{mt}; \forall m \in MP, t > 1 \quad (\text{Equation 3})$$

$$\sum_{p \in TIP} \sum_{i \in TTO[TD,m]} I_{pimt} \geq req_{mt+1}; \forall m \in MP, t < T \quad (\text{Equation 4})$$

$$I_{pimt} \leq cap_{pim}; \forall p \in TIP, i \in TTO[p], m \in MP[p, i], t \in TPO \quad (\text{Equation 5})$$

$$\sum_{r \in TREL[z]} \sum_{q \in TIP[r,z]} \sum_{j \in TTO[q]} \sum_{p \in TIP[r,z]} \sum_{i \in TTO[p]} \sum_{m \in MP[p,i]} C_{rzqjpimt} \leq 1; \forall z \in EL, t \in TPO \quad (\text{Equation 6})$$

$$\sum_{r \in TR[z]} \sum_{q \in TIP[r,z]} \sum_{j \in TTO[q] \cap TOMP[m]} \sum_{p \in TIP[r,z]} \sum_{i \in TTO[p] \cap TOLMP[m]} \sum_{g \in MP[p,i] \cap MP[z]} T_{rzqjpimgt} \leq 1; \forall z \in EL, m \in MP[z], t$$

$$\in TPO \quad (\text{Equation 7})$$

$$C_{rzqjpimt} + C_{rzqjpigt-1} \leq T_{rzqjpimgt} + 1; \forall z \in EL, p \in TIP[z], i \in TTO[p], r \in TETT[p, i], q \in TASS[p, i]; \forall j$$

$$\in TTO[q]; \forall (m, g) \in MP[p, i]; \forall t > 1 \quad (\text{Equation 8})$$

$$C_{rzqjpimt} \geq T_{rzqjpimgt}; \forall z \in EL, p \in TIP[z], i \in TTO[p], r \in TETT[p, i], q \in TASS[p, i]; \forall j \in TTO[q]; \forall (m, g)$$

$$\in MP[p, i]; \forall t > 1 \quad (\text{Equation 9})$$

$$C_{rzqjpigt-1} \geq T_{rzqjpimgt}; \forall z \in EL, p \in TIP[z], i \in TTO[p], r \in TETT[p, i], q \in TASS[p, i]; \forall j \in TTO[q]; \forall (m, g)$$

$$\in MP[p, i]; \forall t > 1 \quad (\text{Equation 10})$$



$$I_{pimt} \leq M * W_{pimt}; \forall p \in TIP, i \in TTO[p], m \in MP[p, i], t \in TPO \quad (\text{Equation 11})$$

$$\sum_{z \in EL[p, i]} \sum_{r \in TETT[p, i]} \sum_{q \in TASS[p, i]} \sum_{j \in TTO[q]} C_{rzqj} p_{igt+1} \leq (1 - W_{pimt}); \forall p \in TIP, i \in TTO[p], m \in MP[p, i], t < T \quad (\text{Equation 12})$$

$$\sum_{m \in MP[p, i]} W_{pimt} \leq 1; \forall p \in TIP, i \in TTO[p], t \in TPO \quad (\text{Equation 13})$$

$$C_{rzqj} p_{imt}, T_{rzqj} p_{imgt}, W_{pimt} \in \{0, 1\}; \forall r \in TR, z \in EL, q \in TIP, j \in TIP, j \in TOL, p \in TIP, i \in TOL, m \in MP, t \in TPO \quad (\text{Equation 14})$$

$$I_{pimt} \geq 0; \forall p \in TIP, i \in TOL, m \in MP, t \in TPO \quad (\text{Equation 15})$$

where MP is the set of raw materials using subscripts m, g; EL refers to the set of elevators, and it uses subscript z; TIP refers to the set of types of hoppers represented by subscript p; TOL refers to the set of hoppers indexed by i; TR refers to the set of routes indexed by r; and TPO is the set of time periods using subscript t. Similarly, some induced sets are defined, of which the most relevant are: MPEL [z]: Set of Raw Materials to be carried by elevator z; MP [p, i]: Set of Raw Materials associated with the p-type Hopper and Hopper i; TASS [p, i] and TREC [p, i], which refer to sets of hoppers that assist and receive both p-type hoppers and hopper i; TETT [p, i] and TSTT [p, i], which refer to all incoming and outgoing Routes associated with both p-type hopper and hopper i; TTO [p]: the set of hoppers that are related to p-type Hopper; TOMP [m]: the set of hoppers that can receive raw material m. Finally, TR [z] refers to the set of routes associated with each elevator z.

Equation (1) represents the objective function of the model, whose purpose is to minimize setup and stock maintenance costs in different types of hoppers. Constraint (2) provides that the initial stock of raw material m in the hoppers, and the quantity of material that comes from storage areas and hoppers at time t, must be equal to the quantity that comes out from different types of hoppers related to the corresponding associated hoppers and raw material stock m at the end of time t. Constraint (3) determines that the initial raw material stock m in dosing hoppers, and the quantity of material coming from the origin hoppers to the related dosing hoppers at time t, must be equal to raw material requirements at time t and raw material stock in dosing hoppers at time t. Constraint (4) ensures that the available

quantity of raw material stock m in dosing hoppers k related to the current time is greater than or equal to this raw material requirement in the next time period.

Constraint (5) is the capacity constraints of hoppers, whose purpose is to ensure that the quantity of stored stock of raw material m at a particular time is less than or equal to the available capacity in the corresponding type, so that the related raw material can be stored. Constraint (6) is the allocation constraints which establish that just one type of raw material can be transported in each corresponding elevator in time t.

Constraints (7) - (10) are functional constraints of setup time, which determine that just some raw material can be changed for each corresponding elevator in time t. Constraints (11) - (13) are raw material-allocated constraints for each type of hopper, which ensures that some different raw materials can be sent to the corresponding hopper at a certain time, only if the existing stock of raw material in the hopper at the initial time is equal to zero. This also guarantees that there is no cross contamination in different types of hoppers in each time t.

Finally, constraints (14) and (15) are Non-negativity or Logical constraints of the mathematical model.

### Case Study

Raw material requirements are obtained from a production master plan that leads to the MRP; based on this plan, the supply of different types of hoppers

is scheduled (Rojas, Saavedra & Orejuela, 2013). Raw materials are stored in silos, in bulk, and in packages. Grain raw materials whose granulometric size is greater than 350 microns are stored in silos. The company has some elevators that transport the raw material to each type of hopper.

Raw materials come from different sources. One way is through vehicles arriving at the plant and going to the delivery area. Another way is by supplying materials that are transported in trailer trucks and plates from the supply area to the delivery area according to routes and types of hoppers. The material-supplying activities may involve a lot of setup time, displacement, and labor.

For raw material-supplying activities, there is a set of elevators, and each one of these is associated with a filling rate (Rojas, Saavedra & Orejuela, 2013) and a set of hoppers that have a determined volumetric capacity (Rojas, Saavedra & Orejuela, 2013). About 20% of raw materials arrive in bulk and 80 % in packages; the latter makes supply activities slow because of packages being opened and raw material being unloaded in delivery areas. Supply operations are performed during the first 4 hours of each shift (time horizon equal to 4 hours). The company has three different eight-hour shifts.

Raw materials that come from the storage area are routed to the milling hopper through supply route No. 2, which has two elevators. Finally, materials are routed to storage and dosing hoppers through routes 3 and 4, which use elevators 1 and 2.

Raw materials in the silos are transported by using route No. 1, which has an elevator, and sent to the related milling hopper. When raw materials are in the milling hoppers, these are transported to dosing hoppers through route No. 6, which is associated with an elevator. Raw materials in storage hoppers must usually be sent to milling hoppers by using route No.5, associated with elevator 3 (see Figure 1).

It should be noted that the company under study has not established a supply sequence of raw materials into the hoppers or a sequence related to the quantity of raw material to be sent to the hoppers. Supplying is initially performed with raw materials having a higher proportion in formulas (diets). Sometimes there is an over-supply of some raw materials and on other occasions some other raw materials are not available, which are needed to meet production scheduling.

## RESULTS

The model was programmed and implemented in the programming language AMPL® together with the Gurobi Solver of the NEOS Server Platform for Optimization, generating 4814 variables (of which 4429 were binary) and 6400 constraints. Two types of validation were performed in the model. Firstly, the model structure was validated, which led to the approval of the consistency in the chain of equations and the variables relationships. Secondly, output information of the model regarding presentation and analysis of optimal results, and a sensitivity analysis by taking into account factors related to the variation of the filling rate of elevators and variation of nutritional diets, were validated.

### Model Results

Table I shows the analysis of the minimum stock quantities obtained in each type of dosing hopper and its relation to the total requirements for raw materials. The initial stock obtained in the milling and storage hoppers was zero, which makes sense since the quantities in stock associated with these types of hoppers are characterized by temporary storage. Therefore, it is sufficient that the minimum stock different from zero is associated with the dosing hoppers, since the real hopper-filling system behaves logically, thus validating the result of the model compared to the behavior of the actual supply operation of raw materials in the company under study.

Results show that in the initial raw materials supply operations, 20.53 % of the total requirements of yellow corn, 12.21 % of the requirements of Soybean Cake, 82.48 % of the requirements of Soy Plus, and 27.16 % of the total requirements of Rice Flour are needed, among other raw materials. It can also be concluded that there must be at least a total of 82,609 kilograms of raw materials, which amounts to 27.3 % of raw materials requirements, for the initial supply operations of filling the hoppers. These results show that raw materials within the set of those having granulometric sizes over 350 microns are needed (i.e., raw materials that are to be milled); and they are transported to the hopper through elevators 1 and 2.



**Table I. Proportional analysis of initial inventory in dosing hoppers**

| #Number of Raw Material in Model | Raw Material           | Requirement (Kg) | Percentage according to Total Requirement | Initial stock according to Model (Kg) | Percentage of Requirement |
|----------------------------------|------------------------|------------------|---|---------------------------------------|---------------------------|
| 1                                | Yellow Corn            | 110345           | 36.47%                                    | 22649                                 | 20.53%                    |
| 2                                | Soybean Cake 48%       | 67545            | 22.33%                                    | 8247                                  | 12.21%                    |
| 3                                | Soy Plus               | 22455            | 7.42%                                     | 18522                                 | 82.48%                    |
| 4                                | Rice Flour             | 35214            | 11.64%                                    | 9565                                  | 27.16%                    |
| 5                                | Wheat Bran             | 25648            | 8.48%                                     | 7429                                  | 28.97%                    |
| 6                                | Precooked Carbohydrate | 16569            | 5.48%                                     | 9849                                  | 59.44%                    |
| 7                                | Fodder Preparations    | 12900            | 4.26%                                     | 3779                                  | 29.29%                    |
| 8                                | Corn Gluten            | 11875            | 3.92%                                     | 2569                                  | 21.63%                    |
|                                  | <b>Total</b>           | <b>302551</b>    | <b>100.00%</b>                            | <b>82609</b>                          | <b>27.30%</b>             |

Source: Authors' own elaboration

The minimum total cost corresponding to the sum of setup and stock maintenance costs was COL\$ 566,406.3; and the hopper setup time in the filling operation during the time horizon of 4 hours is 35.74 minutes. This generated a total cost of COL\$ 16,654.84, which is 2.94 % of the minimum total cost. The remaining percentage, i.e., 97.06 %, is the total maintenance cost of raw materials stock in the hoppers. Setup costs are a very small part of the total cost, since the objective of modeling is to avoid wasting time in setup, so that the use of equipment can be increased. While setup costs are minimized, stock maintenance costs increase.

#### **Model sensitivity according to filling rate variation**

Proportional changes were made in all elevators, and the following results were obtained (Figure 2). Based on these results, it can be concluded that filling rates for the elevators are increased in percentage, while

the total stock shows a decreasing trend; however, when variation ranges from 25 % through 50 %, the initial stock shows a stable behavior for 77.125 tons. The opposite occurs with the total cost; while the filling rate of elevators simultaneously increases, the total cost has a growing trend, which is generated by the increasing costs of stock maintenance for other time periods.

#### **Model sensitivity according to nutritional diet variation**

Table 2 shows the requirements obtained when changes in the diets for the production plan are made. These requirements were performed under advice from a specialized dietitian with the purpose of meeting raw materials needs based on real formulations and not based on assumptions. It can be seen that in the proposed diets, total requirements are approximately equal in order to keep balance compared to the initial optimal diet.

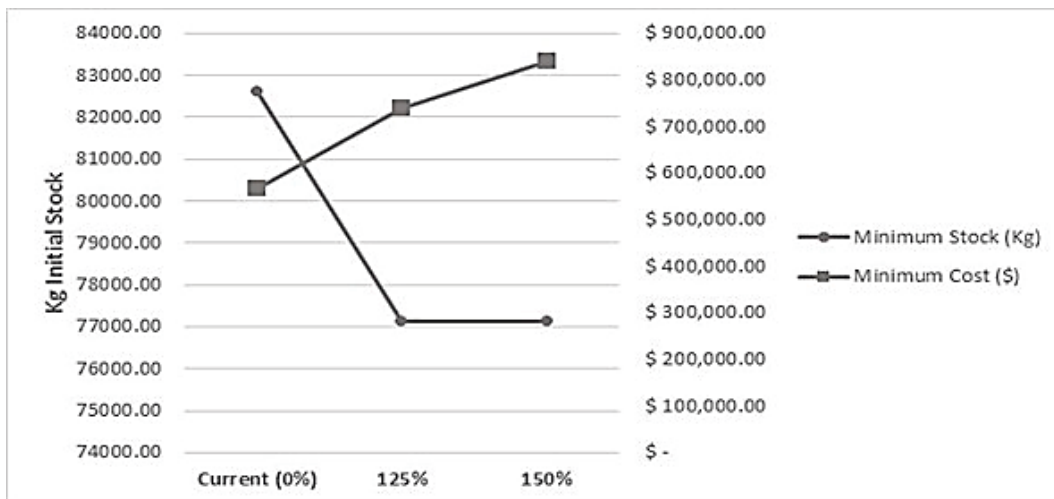
**Table 2. Percentages of raw material requirements according to diets**

| PR           | Percentage requirements (PR) according to diets |               |               |               |               |               |               |               |
|--------------|---|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|              | Initial Diet                                    |               | Diet 1        |               | Diet 2        |               | Diet 3        |               |
|              | Kg  | %             | Kg            | %             | Kg            | %             | Kg            | %             |
| 1            | 110345  | 36.5%         | 172138        | 57.3%         | 55173         | 18.3%         | 55173         | 18.2%         |
| 2            | 67545   | 22.3%         | 81054         | 27.0%         | 102668        | 34.1%         | 67545         | 22.3%         |
| 3            | 22455   | 7.4%          | 26946         | 9.0%          | 40419         | 13.4%         | 22455         | 7.4%          |
| 4            | 35214   | 11.6%         | 7043          | 2.3%          | 35214         | 11.7%         | 35214         | 11.6%         |
| 5            | 25648   | 8.5%          | 5130          | 1.7%          | 19236         | 6.4%          | 71814         | 23.7%         |
| 6            | 16569   | 5.5%          | 3314          | 1.1%          | 16569         | 5.5%          | 19883         | 6.6%          |
| 7            | 12900   | 4.3%          | 2580          | 0.9%          | 14190         | 4.7%          | 19350         | 6.4%          |
| 8            | 11875   | 3.9%          | 2375          | 0.8%          | 17813         | 5.9%          | 11875         | 3.9%          |
| <b>Total</b> | <b>302551</b>                                   | <b>100.0%</b> | <b>300579</b> | <b>100.0%</b> | <b>301281</b> | <b>100.0%</b> | <b>303309</b> | <b>100.0%</b> |

Source: Authors' own elaboration

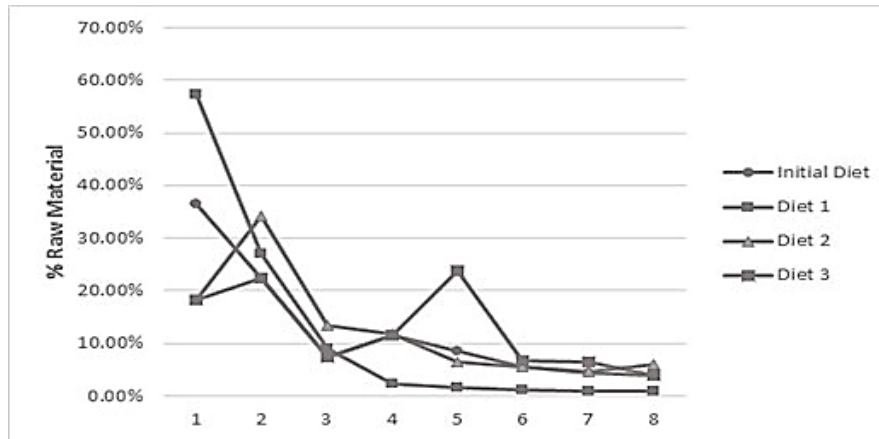
Figure 3 shows the variations in the quantity of raw materials according to each diet. Diet 3 shows low values in raw material 3 and fairly high levels in raw material 1. Diet 1 has the highest initial stock (103,432 kg) as it raises the quantity of substances 2 and 3 in order to meet the very high needs of raw material 1, since the filling capacity of elevators 3 and 4 is considerably increased to meet the requirement in each time window. Diet 2 has a low initial stock value of 38,562.5 kg; this shows that the distribution percentage of these requirements allows the elevator system to have the right capacity to meet the requirements in different time periods. Diet 3 shows

a value of 97,960.2 kg, since the requirement of raw material 5 has the highest value, this being one of the materials that does not go through milling; and the initial stock of other raw materials that are not required to be ground is increased. Meanwhile, Diet 1 has high costs because stock maintenance grows, especially in raw materials 1 and 2. Diets 2 and 3 show a downward trend in setup and maintenance costs because, according to their requirements, there are low quantities of raw materials that must be milled, and raw materials that are set up by skipping milling and storage hoppers are increased.



**Figure 2. Variation analysis of simultaneous filling rates of elevators**

Source: Authors' own elaboration



**Figure 3.** Variation analysis of minimum raw material quantity according to each diet

Source: Authors' own elaboration

This scenario shows that setup and stock maintenance costs can be minimized by changing diets, but this is not viable as in a real scenario diets depend on the functionality of each product and the availability of raw materials, since some of them have a seasonal demand.

## DISCUSSION

When this proposal was designed, the characterization of the manufacturing system facilitated the identification of such parameters as filling rate, setup time, supply routes, elevators, capacity of hoppers, and materials requirements. The decision variables and constraints of the model such as stock balance, demand, allocation, capacity, and setup, belonging to the system under study, were also determined.

In the analysis of results and presentation of scenarios, the most representative cost observed is the one related to stock maintenance. This situation, and its implications related to changes made on the filling rates of elevators and changes in formulation of nutritional diets, represent a critical factor in companies belonging to the sector. Additionally, this project can be extended to other industry sectors such as flour mills, whose manufacturing system is similar to those of the concentrate food sector.

## CONCLUSIONS

In this research, a proposal to address the problem of operations scheduling for filling hoppers and materials supply was designed for a concentrate food company that operates under a pre-milling type production system. This research used a model of mixed-integer linear programming, which contributes to meet the needs of raw materials from the MRP.

For future work it is desirable to develop a software application as a tool to support decision making in the supply of raw materials for companies belonging to the sector or other related companies, so that, for implementation purposes, this becomes an interface between the results of the optimization model and the application of a tool for regular use in the company, similar to the study developed by Toro and Delgado (2010).

Finally, the modeling of this case study associated with this research project is presented as an innovative approach to the supply scheduling of raw materials for an industry that currently shows that such activities are left to chance and informality, resulting in higher costs because of raw materials shortages that eventually lead to a marked operational inefficiency.

## REFERENCES

- Babiceanu, R.; Chen, F. & Sturges, R. (2004). Real-time holonic scheduling of material handling operations in a dynamic manufacturing environment. *Robotics and Computer-Integrated Manufacturing*, 21(1), 328-337.
- Babiceanu, R. & Chen, F. (2008). Distributed and centralized material handling scheduling: Comparison and results of a simulation study. *Robotics and Computer-Integrated Manufacturing*, 25(1), 441-448.
- Bahl, H. & Ritzman, L. (1984). An Integrated Model for Master Scheduling, Lot Sizing and Capacity Requirements Planning. *Operational Research Society*, 35(5), 389-399.
- Chen, K. & Ping, J. (2007). A Mixed Integer Programming Model for Advanced Planning and Scheduling. *European Journal of Operational Research*, 181(1), 515-522.
- Fallah, H. & Shayan, E. (2002). Integrated Material Planning and Operations Scheduling (IMPOS). *Taylor & Francis Group*, 40(16), 4285-4304.
- Hastings, N.; Marshall, P. & Willis, R. (1982). Schedule Based M.R.P.: An Integrated Approach to Production Scheduling and Material Requirements Planning. *Journal of the Operational Research Society*, 33(1), 1021-1029.
- Ho, J. & Chang, Y. (2001). An Integrated MRP and JIT framework. *Computers & Industrial Engineering*, 41(2), 173-185.
- Kayhat, G.; Langevin, A. & Riopel, D. (2006). Integrated production and material handling scheduling using mathematical programming and constraint programming. *European Journal of Operational Research*, 175(1), 1818-1832.
- Masuchun, R., Masuchun, W. and Thepmanee, T. (2009). Integrating Production Scheduling and Material Requirements Planning. *ICIC Express Letters*, 3(3), 501-506.
- Ramos, J.R. (2004). *Sistema de Planificación de los Requerimientos de Materiales en una Industria Alimenticia*. (Msc. Thesis). Guatemala: Universidad de San Carlos de Guatemala.
- Rojas, C.; Saavedra, L. & Orejuela, J. (2013). Programación de llenado de tolvas de materias primas en una planta de alimentos concentrados. (Msc. Thesis). Colombia: Universidad del Valle.
- Shah, N. & Lerapetritou, M. (2012). Integrated Production Planning and Scheduling Optimization of Multisite, Multiproduct Process Industry. *Computers and Chemical Engineering*, 37(1), 214-226.
- Torné, M.; Ramírez, G. & Orejuela, J. (2012). Programación de Operaciones para el Llenado de Tolvas Dosificadoras en un Empresa de Concentrados. *Revista de Ingenierías Universidad de Medellín*, 11(20), 165-178.
- Toro, H. & Delgado, L. (2010). Optimizing a two-echelon capacity-constrained material requirement manufacturing system using a linear programming model. *Ingeniería e Investigación*, 30(1), 168-173.