A Model for Coordination of Production Planning, Forward and Reverse Logistics Management in a Multi-product and Multi-plant Environment, with Reusable Bottles Constraints

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Abstract. Integration of reverse logistics and forward logistics in closed loop supply chains is a recent tendency that look for achieve better global behavior measures. Because supply chain management should consider all levels of the supply chain and their relationships, we modeled it as an aggregate planning strategy for a system that produces several kinds of beverages, some of them bottled in returnable bottles. The model purposed can support decisions related with production and inventories volumes, distribution volumes transported between facilities and customers and collection volumes of bottles in the supply chain.

Keywords: Forward Logistics, Reverse Logistics, Supply Chain Management, Mathematical Programming, Beverage Industry.
1 Introduction

Logistics is an important function in the current enterprise, which should be considered as a fundamental part of the goods production enterprises. Today, it is not possible to think in production management as isolated from logistics management because logistics mediates the relationship between customers and production.

Currently, integrated logistics with production is a good alternative to improve the global behaviour of an enterprise. So, decisions as how much to produce in an industrial facility should also consider the transportation of products to the customers and final disposition of materials after consumption. The application of integrated logistics in a bottled beverages industry is an opportunity to optimize the supply chain cost, because of its complexity that implies both forward and reverse flows (for returnable bottled beverages).

Our objective is to build a model that could be used as a tool decision support to minimize the total costs of produce and distribute bottled beverage and recover returnable empty bottles, as a part of a strategy to integrate production management and logistics management. The purposed model was built using MathProg language, which is a subset of Ampl language, using the Gusek as an interface for GLPK (Andrew Makhorin, 2013; Luiz M. M. Bettoni, 2010).

Like Pochet and Wolsey suggest, there have been implementing computerized manufacturing planning systems, some of them only transactional, as a response to the increasing complexity on the business of large and medium sized enterprises, they stated that significantly better results can be obtained by change these tools into planning systems for coordination and optimization. Approaches of modelling and optimization imply separation between building of models and solving them, for making decisions (Pochet, 2006).

An integrated logistic network model, which considers production, distribution, consumption, collection, transportation, recycling, disposal, reuse and redistribution was considered as a strategy by Zhou and Xu, to design a supply chain network and establish localization of facilities, to a Chinese beer company (Zhou & Xu, 2009).

There could be used several behaviour measures to evaluate the closed loop cycle logistics system: total cost, total transportation cost, total of forward cost, total of reverse cost, total of environment costs, total cost in both forward network and reverse network, total purchasing cost and total profit gained recycling; as were purposed by Paksoy et al (Paksoy, Bektaş, & Özceylan, 2011).

Safaei, et al, modelled a multi-site production-distribution planning in a supply chain. Their model considers forward flows and production and inventory volumes; in an hybridization that uses mathematical programming and simulation (Safaei, Moattar Hussein, Z.-Farahani, Jolai, & Ghodsypour, 2010).

The principal aim of this paper is to start the integration of reverse logistics considerations in the making decision process in order to optimize enterprise operation.
In section two the problem description is showed; in section three the proposed model is described considering assumptions, sets, parameters, decision variables, objective function and constraints. Finally, in section four, we present conclusions of its application and future research ideas.

2 Problem Description

Firstly we made a review of a beverages production and distribution system, whose supply chain structure is presented in the figure 1. There are some plants of production, which produces beverages bottled in both returnable bottle and non-returnable bottle, other plants produce bottled water or are used as a store of external products. There is a Logistics Distribution Center (LDC) in a second level, there are store controllers in the third level, distributors in the fourth level and there are customers in the fifth level.

Some features of the system include:

- The first level is composed by: production plants, they can produce returnable bottled beverages and non-returnable bottled beverages. So, forward flows among the plant and the other supply chain levels depend of the products made in them.
- Second level is a DCs, which stores non-returnable bottled beverages and bottled water, and provides these products to the other levels.
- Third level is composed by store controllers, that distribute all kind of products

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4 Plants are represented separately in order to clarify it important level of the chain. There are not reversal flows of bottles to and from DCs, but it is possible in a further analysis include pallets or other transport material returns if proceed
Fourth level is composed by distributors of all kinds of products.

Finally, there are customers. The customers in this system could be: Hotels, restaurants and catering (HORECA), that are characterized by be returnable bottled beverage customers; big areas characterized by a high level of demand of non-returnable bottled beverages; and, other clients who demand all kind of products. A customer will be served by an anterior level of the supply chain (whatever) depending of the demand volumes. So, it is possible that a specific big customer be attended by one of the plants, directly.

As a consequence of the supply chain structure, there are flows in forward and reverse directions, the forward flow is products flow and the reverse one is empty bottles flow.

3 Purposed Model

The aim of the purposed model is to make decisions in production, inventory, and transport of finished products and empty bottles, to minimize total cost. These are the model assumptions:

- Transport costs only depend of distance between origins and destinies, and kind of product transported.
- Only direct routes between facilities are considered, but it is desirable to include vehicle routing furthermore.
- There are not a specific association between customers and providers; the considerations of send products depend of availability to get the minimal total cost.
- There are not considered vehicles in the transport decisions.
- Demand of products and empty bottles returns are independent, it is possible to identify a function to relation these parameters.
- Arrives of bought bottles is considered instantly.

In order to build a general model, these are the established sets:

- \( P_d \) Products
- \( R_t, R_t \subset P_d \) Products that use reusable bottles
- \( N_r, N_r \subset P_d \) Products in a non-reusable bottles
- \( E_n, E_n \subset P_d \) Reusable bottles
- \( T_P \) Time periods
- \( U_b \) Physical localization of locations
- \( P_l, P_l \subset U_b \) Production plants available
- \( D_S, D_S \subset U_b \) DCs
- \( A_R, A_R \subset U_b \) Regulations
- \( D_b, D_b \subset U_b \) Distributors
- \( C_l, C_l \subset U_b \) Customers
- \( A_{l,m}, l \in U_b, m \in U_b, l \neq m \) Direct routes between locations
These are considered parameters:

- \( T > 1 \)
- \( Dst_{l,m} \) \( l \in Ub, m \in Ub \) Planning periods
- \( LT_{l,m} \) \( l \in Ub, m \in Ub \) Distance between \( l \) and \( m \) points
- \( Cpc_r, l \in Pl \) Processing capacity of \( l \) plant (in time units)
- \( MI_r, l \in Ub \) Inventory capacity in location \( l \) (in product units)
- \( TPr_{l,i,d}, i \in Rd, l \in Pl \) Processing time for a product \( i \) in plant \( l \)
- \( TS_{l,i,d}, i \in Rd, l \in Pl \) Set up time for a production of one lot of \( i \) product
- \( ER_{l,r,k}, i \in Rt, k \in En \) Returnable bottles \( k \) that are required for \( i \) product
- \( UP_{l,i,d}, i \in Rd, l \in Ub \) Association of a product with a specific location. It is a one when \( i \) product can be in the \( l \) location and zero in otherwise

- \( DP_{l,t}, i \in Rt \cup Nr, t \in TP, l \in Cl \) External demand of \( i \) product, by the \( l \) client in \( t \) period
- \( RE_{l,t}, i \in En, t \in TP, l \in Cl \) \( i \) returned bottles to the \( l \) client in \( t \) period
- \( IP_{l,i,d}, i \in Rd, l \in Pl \) Initial inventory of \( i \) product in \( l \) plant
- \( LP_{l,t}, i \in Rt \cup Nr, t \in TP, l \in Ub \) Programmed arrivals of \( i \) product to the \( l \) location in \( t \) period
- \( CP_{l,i,d}, i \in Rd, l \in Pl \) Unitary cost of produce an \( i \) product in \( l \) plant.
- \( CS_{l,i,d}, i \in Rd, l \in Pl \) Set up cost of produce a lot of \( i \) product in \( l \) plant.
- \( CL_{l,i,d}, i \in Rd, l \in Ub \) Holding cost of an \( i \) product in the \( l \) location for one period.
- \( CD_{l,i,d}, i \in Rd, l \in Ub \) Deficit cost of a \( i \) product
- \( CT_{l,i,d} \) \( i \in Rd \) Unitary transport cost of \( i \) product by distance unit
- \( CE_{l,i,d} \) \( i \in En \) Cost of a \( i \) bottle
- \( VM_{l,i,d} \) \( i \in Rt \cup Nr, \forall l \in Ub \) Average of sales or dispatch of \( i \) product in \( l \) facility
- \( Ch_{l}, l \in Ub \) Coverture days of inventory in \( l \) facility
- \( M = \sum_{i \in Rt, l \in Cl, T, \cup Pl} DP_{l,t} \) Big value
- \( VM_{l,m}, l \in Pl, m \in Cl \) Minimal volume transported between \( l \) and \( m \)

Decision variables about production volume, inventory levels, material flows, procurement and deficits are the following:

- \( Fl_{l,t} \) Quantity of \( i \) product, made in \( l \) plant, in \( t \) period
- \( Sl_{l,t} \) Binary variable to represent setup presence.
- \( Hl_{l,t} \) Quantity of \( i \) product, stored in \( l \) installation, in \( t \) period
- \( Dl_{l,t} \) Deficit quantity of \( i \) product, in \( l \) installation, in \( t \) period
- \( TrP_{l,m,t} \) Quantity of \( i \) product, transported from \( l \) to \( m \), in \( t \) period
- \( Enl_{l,t} \) Quantity of \( i \) bottles, bought \( l \) in plant, in \( t \) period
- \( y_{1l,m,t}, y_{2l,m,t} \) Continuous variables to represent discontinues constraints
- \( y_{3l,m,t} \) Binary variable used to represent discontinues constraints

Purposed model:
Minimize Cost = \sum_{l \in L} CP_l P_l + \sum_{l \in L} C_{l1} S_{l1} + \sum_{l \in L} C_{l2} P_{l2} + \sum_{l \in L} C_{l3} B_{l3} + \sum_{l \in L} CP_l C T_{l0} \left( P_{l1} + B_{l3} \right) + \sum_{l \in L} C_{l4} E_{l4} (l) \left( m \right) (t) (s) (4)

Subject to:
\sum_{l \in L} P_{l1} + S_{l1} \leq C_{P1} \quad \forall l \in L, \forall t \in TP \quad (2)
\sum_{l \in L} B_{l3} \leq M_{l} \quad \forall l \in L, \forall t \in TP \quad (3)
P_{l1} \leq M + S_{l1} \quad \forall l \in L, \forall t \in TP \quad (4)
\sum_{l \in L} U_{l1} + U_{l2} - \sum_{l \in L} U_{l1} = P_{l2} \quad \forall l \in L, \forall t \in TP \quad (5)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l2} = P_{l1} \quad \forall l \in L, \forall t \in TP \quad (6)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l1} = D_{l1} \quad \forall l \in L, \forall t \in TP \quad (7)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l2} = P_{l1} \quad \forall l \in L, \forall t \in TP \quad (8)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l1} = D_{l1} \quad \forall l \in L, \forall t \in TP \quad (9)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l2} = P_{l1} \quad \forall l \in L, \forall t \in TP \quad (10)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l1} = D_{l1} \quad \forall l \in L, \forall t \in TP \quad (11)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l2} = P_{l1} \quad \forall l \in L, \forall t \in TP \quad (12)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l1} = D_{l1} \quad \forall l \in L, \forall t \in TP \quad (13)
\sum_{l \in L} U_{l3} - \sum_{l \in L} U_{l2} = P_{l1} \quad \forall l \in L, \forall t \in TP \quad (14)
\sum_{l \in L} E_{l4} (l) (m) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (15)
\sum_{l \in L} U_{l3} M_{l3} \left( l \right) (m) \left( t \right) = 0 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (16)
\sum_{l \in L} E_{l4} (l) (m) (t) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (17)
\sum_{l \in L} M_{l3} (l) (m) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (18)
\sum_{l \in L} E_{l4} (l) (m) (t) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (19)
\sum_{l \in L} E_{l4} (l) (m) (t) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (20)
\sum_{l \in L} E_{l4} (l) (m) (t) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (21)
\sum_{l \in L} E_{l4} (l) (m) (t) = 1 \quad \forall l \in L, \forall m \in M, \forall t \in TP \quad (22)
Objective function, presented in equation 1, is total cost minimization, which results as sum of production, set up, inventory or deficit, forward and reverse transports and new bottles costs, respectively. The model, which integrates reverse logistics with production decisions, has constraints of capacity production, capacity storage of products and product flows among installations.

There are two kinds of capacity constraints: in equation 2, the total time consumption for both production and setup is lower than capacity of each plant; and, in equation 3, total space of storage should be lower than available one. Setup presence is modeled with equation 4. In it we use big M number and a binary variable to represent the setup existence when there is a production volume.

Flow product constraints were modeled with the 5 to 9 equations; those consider the flows among different levels of the supply chain and their respective transport lead time. Equation 5 represents flows between plants and their respective next level in the supply chain (see in figure 1); the sum of inventory on hand and production minus transported products to other installations is equal to final inventory in each period. Equations 6, 7 and 8 represent the intermediate levels of supply chain, for DCs, store controllers and distributors; and equation 9 shows the flows to final customers. In those flow continuity is guaranteed as the sum of inventory on hand at the start of period, previously programmed arrivals, arrivals of transported products from anterior supply chain levels, minus products dispatched to posterior supply chain levels (or demand) is equal to inventory or deficit at the final of the period.

Reverse flow constraints are presented in equations 10 to 14. Equation 10 represents the flow of collected bottles between the customer and the previous level of the chain, so: sum of inventory on hand at start of a period, bottles received by the customer minus dispatched bottles to anterior levels is equal to final inventory; equations 11, 12 and 13 represent the intermediate levels of supply chain flows and equation 14 represents flows to the production plants. In those, sum of inventory on hand at start, previously shipped bottles, bottles that arrives from posterior levels of the supply chain, minus bottles dispatched to anterior levels is equal to final inventory; equation 14 includes the procurement of new bottles and their use in production system.

Equation 15 associates bottles and finished products, it let to establish bottle consumption in the production process; Equation 16 is used to guarantee a safety inventory level, which depends of average sales.

Equations 17 and 18 equations represent a discontinuous space for the flows between plants and a specific customers; flows between plants and customers should be bigger than a minimal parameter or cero and; equation 19 is used to give the value cero to forbidden flows.

Type of variables constraints are in equations 20 to 22. It is possible to relax some of integer variables constraints to reduce calculating time.
4 Conclusions and Further Research

The model was tested in two instances composed by three plants, plant 1 and plant 2, which produce returnable bottled beverages and non-returnable bottled beverages and plant 3, which produces bottled water, in the first level; a DC used for non-returnable bottled products and water; two store controllers; two distributors and six customers. Moreover, six products were considered: products 1 and 2 as returnable bottled soda, 3 is a non-returnable bottled soda, product 4 is bottled water, products 5 and 6 are empty bottles for products 1 and 2, respectively.

It was possible to solve the aggregated planning problem for a supply chains with returns modeled; model that was, written and tested in MathProg language, shows global consistence with beverage bottled industry behavior, like was evidenced after testing it.

The model let to formulate production, distribution and procurement (distribution of finished goods and collection of empty bottles), that minimize total cost. It is possible to include some different objectives in the future.

The further research includes the integration of production planning with distribution in a more detailed manner, in the operational level. It is important to support making daily complex decisions like include heterogeneous fleet of vehicles, time windows for pickup and delivery and other situations. Other considerations can be the evaluation of the allocation of geographic areas to the different Supply Chain members, and the evaluation of product distribution and collect bottles using alternative transports. All of alternatives purposed have the objective to achieve global minimal. It is important to observe that, as a consequence of the real size of the system, it is required to evaluate strategies to solve them in a reasonable time.

3 References


