Design and Development of an Industrial Solver for Integrated Planning of Production and Logistics

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***Abstract*—Faced with an increasingly hard competition, an increasingly unstable economic environment and ever-increasing customer requirements, companies should optimize costs and lead times not only at their level but also at the entire supply chain to which they belong. In such situation, an integrated supply chain management is necessary. In this paper, we discuss one of the essential building blocks of the integrated supply chain management, which is the integrated planning of the sup-ply chain. We introduce a new method for integrated planning of production and logistics, which is the MLRP (Manufacturing and Logistics Requirement Planning). This method allows supply chain planners to determine in advance, for the entire planning horizon, the manufacturing orders, the supplier's commands and the transport orders as well as vehicles routing for distribution of finished products and for the collection of components/raw materials. We will also discuss in this article the design and development of the solver which execute the MLRP method, this solver is the SMLRP that will be used to implement the proposed method on the different encountered industrial cases.**

Keywords*—MRP; VRP; production planning; transports planning; integration; MLRP

I. Introduction

The evolution of information and communication technologies (ICT) has been a key factor in the industrial revolution lived in recent decades. Due to its two-dimensional advantages (the processing information dimension and the real-time information sharing/transferring dimension), ICT have contributed to the creation of global supply chains aimed at optimizing the costs and lead times throughout these supply chains. In this study, we are interested in planning systems as the fundamental element of any industrial management system and particularly supply chain management. The supply chain planning matrix, Fig. 1, considers that any supply chain could be divided into several internal supply chains, each of these supply chains is composed by four main processes the supply, the production, the distribution and the sales [1].

This article is both an implementation and a generalization of the MLRP system "Manufacturing and Logistic Requirement Planning" that we introduced in [2]. The generalization aims to extend the proposed model to determine simultaneously production requirements and logistics requirements whether upstream logistics (related to replenishment) or downstream logistics (related to distribution). The implementation, meanwhile, consists in designing and developing a solver allowing determining for each period belonging to the planning horizon the different orders of production and replenishment as well as the logistic necessary means for the replenishment and / or distribution; it also allows generating vehicle routes and presenting them on geographical maps.

In this article, we first present the concepts used in the proposed approach, namely the MRP production systems and the vehicles routing problems, then we expose the new method of integrated planning of production and logistics requirements, the MLRP "Manufacturing and Logistic Requirement Planning". Next, we describe the MLRP solver from a software point of view (inputs / outputs, use case diagram and sequence diagram) and we conclude the article with a case study of a supply chain to expose the different features of the MLRP solver as well as its adaptability to different industrial configurations

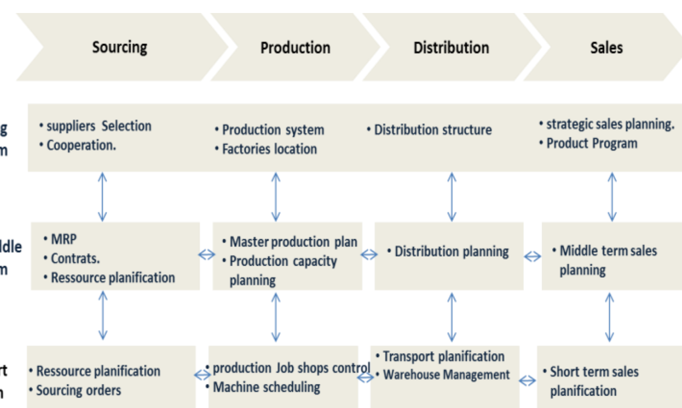

Fig 1. Supply Chain Planning Matrix.

II. MLRP: Manufacturing and Logistic Requirement Planning

In this section we present the MLRP method as an integrated planning solution for determining requirements of production and logistics, we will first introduce the different concepts that will be used by the MLRP which are the MRP production systems and vehicle routing problems.

A. MRP Planning Systems: Concepts and Evolutions

Based on the bill of materials and the forecasted needs of finished products, on the delivery or manufacturing lead times of the various components. The MRP systems determines in advance the components manufacturing orders as well as the supply orders that must be transmitted to the production units and to the different suppliers [3], Fig. 2 presents the MRP process flow diagram [4].

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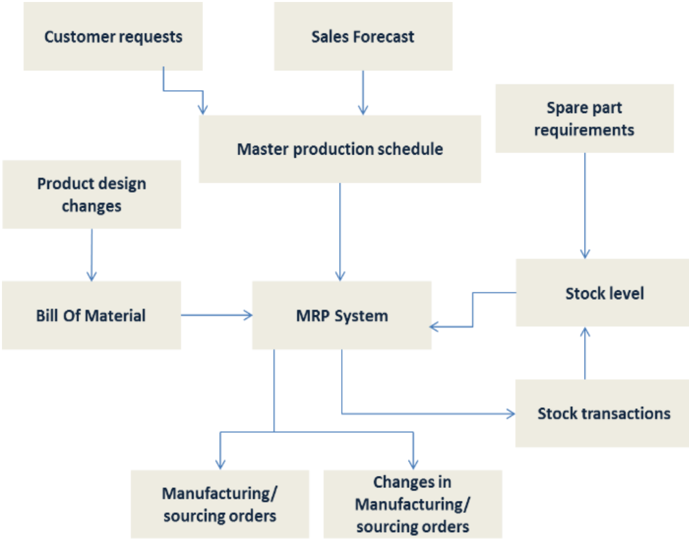


Fig 2. MRP Process Flow Chart.

As shown in Fig. 2, the MRP computation is based primarily on data collection: bill of material, order backlog and / or master production plan, quantities of available items and lead times for obtaining these items. Then from the top level, for each bill of material level, each item and at each period considered p, repeat:

1) Calculate the gross requirement GRp at the beginning of the period p, the gross requirement for an item Y of level n in the bill of material is the product of the estimated order of the higher-level item X in the bill of material and the assembly coefficient cm (Y) of the considered item:

$$GR_pY_n = PO_p(X, n-1) * cm(Y_n/X) \quad (1)$$

2) Calculate the available items, AIp, at the beginning of the period according to equation (2), where FSp is the forecasted stock expected after transactions made during the period. OLp is the production order in progress or the supply or-der expected at the beginning of the period p.

$$AI_p = FS_{p-1} + OL_p \quad (2)$$

3) Calculate net requirements, NRp, at the beginning of the period according to equation (3)

$$NR_p = Max\left(0, GR_p - AI_p\right) \quad (3)$$

4) Define the proposed orders to satisfy net requirements by specifying items quantities and the launch dates.

5) Calculate the forecasted stock, FSp, at the end of the period according to equation (4), where OLp is a supply order under delivery and OPp is a production order.

$$FS_p = FS_{p-1} + OL_p + OP_p - GR_p \quad (4)$$

As defined, MRP is very useful for determining accurately required orders quantities and required orders start dates of each component / raw materials for each period within the planning horizon. It is considered as a kernel of any MRP production system, however it has some limitations, among which we cite [4]:

a) Lead times are considered deterministic, which is not the case in reality, production/supply lead times are subject to be changed because of the various hazards that may affect production units or suppliers.

b) The quality of the product supplied by production units or suppliers is considered perfect (no non-compliances or rejects), which is not the case in reality, in this situation production orders and supply orders must take into consideration the quality of the supplied products.

c) Capacities of production units or suppliers are not taken into consideration by the MRP when it is computed.

Several studies have been initiated a bout the MRP systems to overcome these limitations, as regards the failure to take into account lead times variability and products quality, several approaches have been proposed that address uncertainty in MRP systems based on stochastic inventory control [5], and fuzzy logic [6]. Otherwise, production capacities, supplier constraints, cost minimization and demand variability are taken into account as part of mathematical models. [7] Provides a mathematical model based on integer linear programming that takes into consideration, the scheduling of manufacturing / supply orders, production capacities, changes in production plans, storage conditions and storage costs.

In parallel, other research work focuses on dealing with MRP and transport management issues in an integrated way instead of being processed sequentially, [8] proposes a conceptual model that integrates both the aspects related to production planning and those related to transports management into a single model, The MRP IV (Fig. 3). [10] Proposes a linear programming model based on the MRP IV framework proposed by [8].

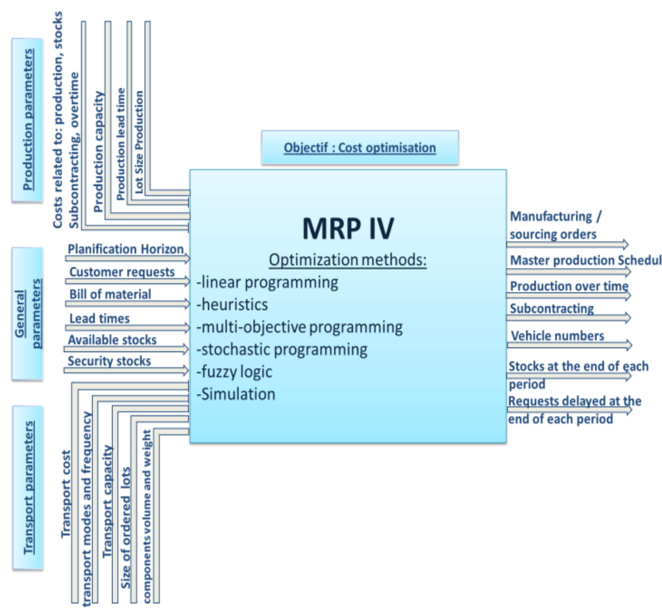


Fig 3. MRP IV Framework.

Except the works of Mula et al. [8 and 9] that presents a conceptual model, MRP IV, which integrates transports planning and the MRP model, as well as those of Diaz-Madronero [10] relating to the proposal of a linear programming model which optimize simultaneously production and transports costs based on the MRP IV. The transports planning integration into the MRP model is not sufficiently addressed in the literature, to our knowledge, there is a lack of concrete models and information systems that ensure integrated planning of production and logistics.

B. Vehicles Routing Problems: Concepts and Evolution

Vehicle routing problems were initially introduced by Dantzig and Ramser [11] to plan deliveries of fuel to gas stations, the basic version of vehicle routing problem, Fig. 4, consists in determining the optimal routes for a set of vehicles located in a depot to serve a set of customers [12].

Resolving vehicle routing problems is an important field of operational research and logistics management [13]; these problems are considered NP-hard because they cannot be solved in polynomial time [14].

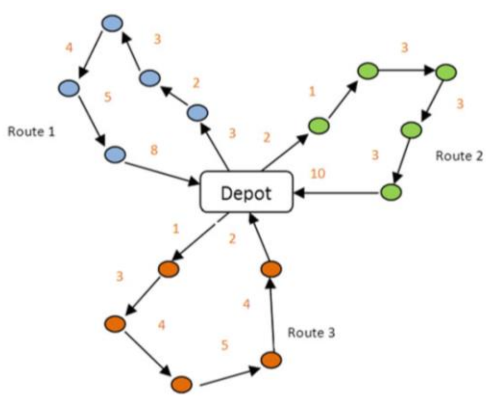


Fig 4. Vehicle Routes Example.

Vehicle routing problems could be modeled as a complete graph G (V, E) with V= {v_0, v_1, v_2... v_n} is a set of nodes, v0 is the warehouse and the other vi are the destinations to be served by a fleet of m vehicles with a limited capacity C_k. E= [{v_i, v_j}, (i, j) ∈ A={(i, j) : i, j=0,1,2, …, n, i ≠j}] is the set of edges connecting the different nodes. Equations (5) - (9) represents mathematically the vehicle routing problem with limited capacity of vehicles "CVRP" (P1).

$$Minimize \quad \sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=1}^{m} C_{ij}x_{ijk} \tag{5}$$

$$\sum_{i=1}^{n} x_{i0k} = \sum_{j=1}^{n} x_{0jk} = 1 \quad \forall \in \{1,2,3,\dots,m\} \tag{6}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{m} x_{ijk} = \sum_{j=1}^{n}\sum_{k=1}^{m} x_{ijk} = 1 \quad \forall i,j \in \{1,2,3,\dots,n\} \tag{7}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{n} d_j x_{ijk} \le C_k \quad \forall k \in \{1,2,3,\dots,m\} \tag{8}$$

$$\sum_{k=1}^{m}\sum_{(i,j)\in NxN} x_{ijk} \le |N|-1 \quad \forall N \subset \{1,2,3,\dots,n\} \tag{9}$$

Equation (5) represents the objective function that minimizes necessary costs to serve all customers from warehouse. Cij is the necessary cost to run through the edge (i, j), this one could be the amount of consumed fuel, the consumed time or the traveled distance between i and j. x_{ijk} is a binary variable which is equal to 1 if the vehicle k run through the edge (i, j) and 0 if it isn't.

Equation (6) expresses the fact that each vehicle leaving the warehouse to serve one or some customers must return to the warehouse. Equation (7) adds the constraint that node demand must be served once; a single vehicle must serve each node.

Equation (8) ensures that the capacity of each vehicle will not be exceeded. Equation (9) ensures the elimination of sub tours that do not start and / or do not end at the warehouse.

The basic version of vehicle routing problem has been transformed into several versions by adding one or more constraints on the initial problem variables. These variables could be the vehicles capacities, the traveled distance, the beginning or arrival time, the delivery or recovery lead-time of the products from warehouse or from customers, there are various types of vehicle routing problems, some of which are below [15]:

- MDVRP: This variant takes into consideration several warehouses that can provide products instead of a single warehouse.
- VRPTW: A time window constraint for serving customers is added to the classic vehicle routing problem.
- VRPB deals with two customer's subgroups, some will have to be delivered from warehouse and the others will forward products to the warehouse.
- OVRP: This is to deal with the problems of vehicle routes in which the routes are not closed circuits, the vehicles do not return to the warehouse.
- DVRP: They are problems of vehicle routes in which the customer requests are known before (quantities) but can be formulated during the transport operation, these problems are considered dynamic routes problems.
- Stochastic VRP [16]: In this VRP variant, no information, about customer requests, is available before starting routes. Vehicle routes are planned based on probability distributions of customer requests.

The vehicle routing problem was addressed in the literature by two types of methods [17], Fig. 5, exact methods and approximate methods. The exact methods allow finding the optimal solution by exploring all possible solutions. However, the increase of the studied problem dimension (number of served clients and / or number of logistics means) makes exhaustive exploration of all solutions impossible in a sufficiently small duration.

The approximate methods, on the other hand, make it possible to find acceptable solutions but do not guarantee that the solution found is the optimal solution. There are two types of approximate methods, heuristics and metaheuristics. Heuristics are by definition a way to guide an algorithm to reduce the problem complexity; they are specific to a given problem. We distinguish three heuristics specific to the vehicle routing problems:

- Constructive heuristics are iterative algorithms in which at each iteration a partial solution is completed. The most popular constructive heuristic is the "savings" heuristic [18], it starts from an initial solution where each destination is served by a vehicle then we try to merge routes by computing for each pair of customers (vi, vj) the savings made by going from vi to vj instead of returning to the warehouse. Savings are then ordered and the corresponding customers to the largest saving are grouped together on the same route.

- The improvement heuristics try to improve a solution by proceeding to exchanges customers within routes. The exchanges could be carried out either within the same route or between customers being part of different routes [19].

- The two-phase methods consist of breaking down the vehicle routing problem into two sub-problems, one relating to the clients clustering and the other relating to determining an optimal route for each subgroup. According to the order in which the sub problems are treated, there are two methods, the Cluster First-Route second method and the Route first- Cluster second method.

Metaheuristics are advanced and powerful heuristics that could be applied to any optimization problem; they are divided into two categories: single-solution or local search metaheuristics and metaheuristic population-based solutions. Among the metaheuristics proposed in the literature, we cite below examples of local search metaheuristics, the simulated annealing and the taboo search, and example of metaheuristic population-based solutions, the evolutionary algorithms [20]:

- The taboo search: this method was formalized in 1986 by Glover [21], its principle is based on the mechanism inspired by human memory. It performs updates to an initial solution during successive iterations; during each iteration, the method constitutes a set of initial solution neighbor's by performing a single elementary movement. Then it evaluates the objective function value corresponding to the different neighbors obtained and substitutes the initial solution by the best solution founded even if the latter is bad than the initial solution, this helps to avoid local minimums. To avoid going back to a solution already obtained in previous iterations, this method uses a list of taboo movements that it avoids when forming the neighborhood, and it inserts in this list the movement corresponding to the solution obtained during each iteration.

- Simulated annealing: this method was inspired by metallurgist's techniques that are used to obtain a material with well-ordered molecules in solid state; Annealing involves heating a material to a very high temperature and then slowly lowering the temperature. Simulated annealing [22] applies this process to an optimization problem solution; the objective function is assimilated to the material energy that is subsequently minimized by introducing a fictive temperature. For each iteration, a basic modification is performed to the solution, if this modification implies a decrease of the objective function (ΔE≤0) it is accepted, otherwise, it will be accepted with a probability equal to $e^{\frac{-\Delta E}{T}}$, T is a constant temperature until reaching the thermodynamic equilibrium. Once the equilibrium is reached, this temperature is reduced and the whole process is repeated until a reduced temperature is reached (cooled system).

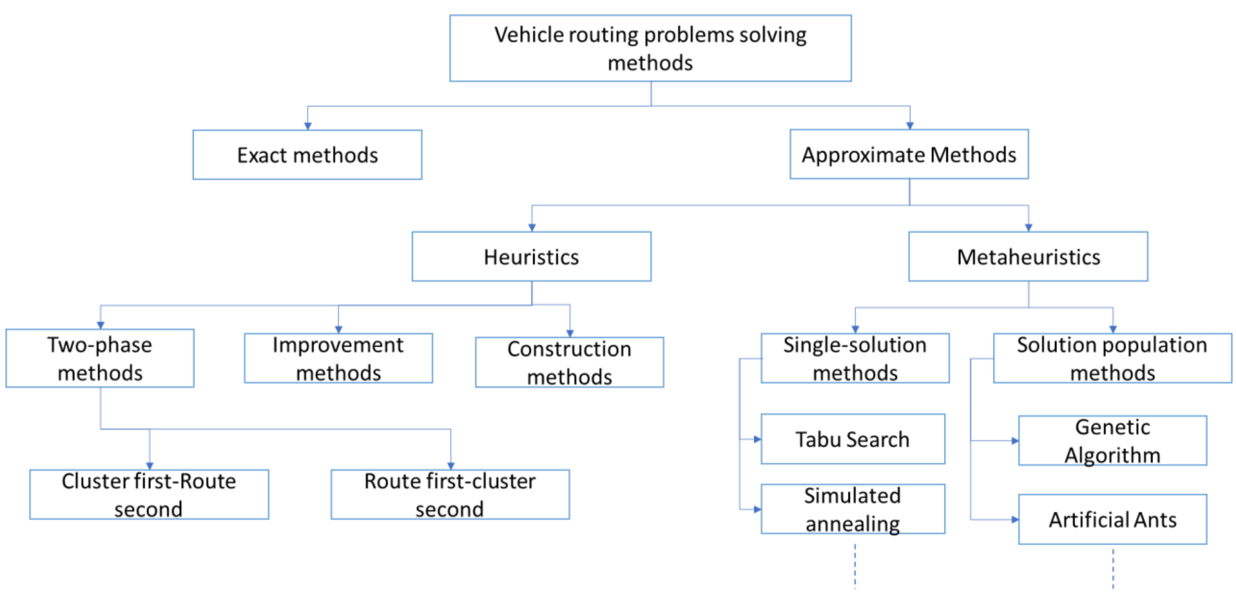


Fig 5. VRP resolution methods.

- Evolutionary algorithms are inspired by biological evolution of species; genetic algorithms [23] are the most popular evolutionary algorithms. They start from an initial solution population that they try to improve gradually over several generations by applying in a repetitive way the selection and reproduction principles. The selection principle consists to select the most suitable individuals for survival and reproduction (comparing the value of the corresponding objective function for each individual), and the principle of reproduction consists in mixing, recombining and changing (mutation) characteristics of solutions (parents) to form new solutions (descendants) with new potentialities.

C. MLRP: The Integrated Planning System for Production and Logistics Requirements

We introduced in [2] the MLRP as a method for determining production and up-stream logistics requirements (for components and raw materials). MLR takes into account customer requests, restructured bill of materials (composition of the finished product adapted to the MLRP), the lead times (transport and production), dimensions and weights of the components, volume and the maximum weight of the available means of transport and transport costs per trip.

Our goal is to extend the initial version of the MLRP, so that it can simultaneously plan production needs and either upstream logistics needs (related to supply) and downstream logistics needs (related to distribution). The new version of the MLRP will also allow vehicle routes scheduling for distribution and replenishment. We will use the same restructured bill of material presented in [2] as well as the generator already developed in order to create step-by-step the bill of material from the highest level (finished product) to the lowest level of the components. The only change introduced in the bill of material is the addition of the raw material/component supplier identifier when this one is supplied and not manufactured or assembled.

Fig. 6 shows an example of bill of material adapted to the MLRP of a product A in which cm is the assembly coefficient, LT_p is the lead-time of production or supply, LT_l is the component transport lead-time. V and W are component volume and weight and finally SS and S_t0 are the security stock and the initial stock of a component.

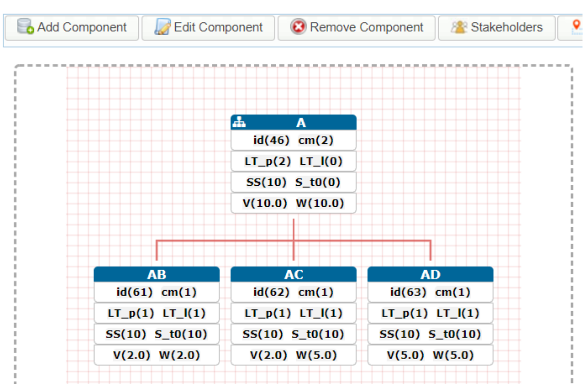


Fig 6. Bill of Material Example Adapted to the MLRP.

Fig. 7 illustrates the MLRP algorithm, this figure describes the MLRP first phase: the determination of manufacturing, supply and transport orders.

Once the transport orders have been determined, MLRP plans for each period of the planning horizon, the vehicle routes required for upstream logistics (recuperation of raw material and / or components) and for downstream logistics (distribution of finished products).

MLRP vehicle routing is based on the problem (P1) described by the equations (5) to (9) which describe the objective function and the constraints relating to the problems of routing heterogeneous vehicles with limited capacities (HCVRP), which is the case in the majority of the industrial problems.

As defined, (P1) does not consider nodes whose demand exceeds all available vehicle capacities (equation 9). To overcome this limitation, we proceed first to treat these nodes one by one trying to satisfy them by one or more trips using the available means of transport. The quantity Qit relative to node i (customer or supplier) and to period t, can be writ-ten according to equation (12) in which αk is the number of vehicles of type k or the number of trips that the type k vehicle will make. The parameter Cte is the rest of the Euclidean division of Qit on the vehicle's capacities (of all the possible combinations of the different vehicle types), Fk is the cost to make a trip using the Vk vehicle. We are looking in this situation for the combination of vehicles that generates the least cost, equation (10), while minimizing the rest of the Euclidean division, equation (11), the optimization in question can be formulated according to the problem (P0).

$$Minimize \sum_{k=1}^{K} \alpha_k F_k \tag{10}$$

$$Minimize\ Q_{it} - \sum_{k=1}^{K} \alpha_k C_k \tag{11}$$

$$Q_{it} = \sum_{k=1}^{K} \alpha_k C_k + Cte \tag{12}$$

After the resolution of P0, we retain the different combinations selected for the nodes having initially requests higher than all the available capacities, we denote by VCSj the vehicle combination selected for the node j. then we replace the requests at these nodes by the rest of the Euclidean division of the initial request on the selected combination. Next, we solve the problem (P1 ') obtained by replacing the dj in problem (P1) by dj'.

$$d'_j = d_j - \sum_{k=1}^{K} \alpha_k C_k \qquad k\epsilon\ VCS_j(P0) \tag{13}$$

Another limitation encountered in the vehicle routing for the supply chain upstream part is the heterogeneity of transported components, "we do not carry a single type of product as in the case of the distribution of finished products", in this situation, several cases are possible:

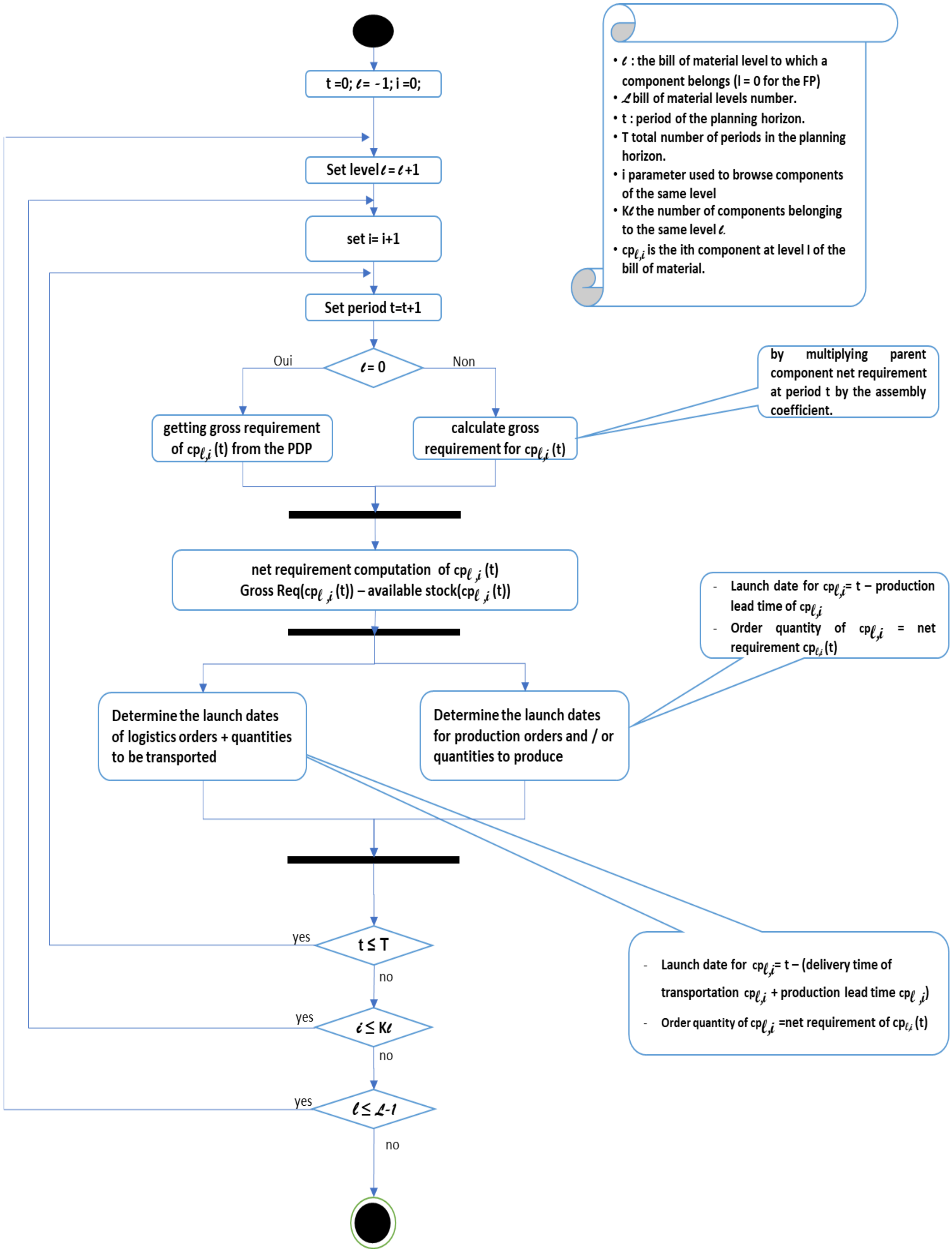


Fig 7. MLRP Algorithm.

a) The different components / raw materials cannot be shipped together; in this case, the transport requirements are determined separately for each node by determining the combination of vehicles corresponding to the minimum transport cost. This approach is already detailed as part of our works introducing the MLRP [2].

b) The different components / raw materials can be shipped together, in this case we convert, equation (14), all the quantities at the nodes taking into consideration the equivalence between a component of a node and another component that we choose as reference (we choose the one with the smallest density and the smallest weight). Then we apply successively the two optimization steps defined by (P0) and (P1 ').

$$d''_j = k * d_j \quad \& \quad k = Min\left(\frac{v_b}{v_{ref}}, \frac{w_b}{w_{ref}}\right) \qquad (14)$$

c) Some components can be embedded together and others cannot, in this case, we apply the approach a) for the first category and the approach b) on the second grouped category.

III. MLRP Solver Description

In order to describe the MLRP solver (SMLRP) which ensure integrated planning of production and logistics requirements, we present in this section a static view and a dynamic view of the developed system. First, we represent the static view by the input / output diagram, and then we represent the dynamic view by a sequence diagram. Fig. 8 shows the inputs and outputs of the SMLRP, Outputs are the various manufacturing, supply and transport orders spread over the different periods of the planning horizon. The SMLRP also generates, for all periods, necessary vehicle routes for the supply chain upstream and downstream transports. The SMLRP inputs are bill of material adapted to the MLRP, customer orders spread over the planning horizon, types of available logistic means, locations of stakeholders (customers, suppliers, production unit).

Fig. 9 shows sequence diagram of the operation "Op_MLRP" which is the main operation of the SMLRP, this operation implements the diagram previously detailed in Fig. 7. The sequence diagram shows the way in which "Op_MLRP" interacts with the other SMLRP objects to provide integrated planning for production and logistics requirements:

- OrderBacklogManagerImpl: This is a class that allows performing operations on the customer orders (database persistence, aggregations ...).
- ComponentManagerImpl: This manages bill of material components.
- MrpManagerImpl: This provides methods that insert and update manufacturing and transportation orders for each component at different times in planning horizon.
- Vc_mapManagerImpl: This object allows providing the capacity of each type of vehicle according to bill of material components.
- StakeholderManagerImpl: The Op_MLRP object interacts indirectly with this object through the operations planDistributionRouting and planRelenishmentRouting, these two operations plan vehicles routes by invoking JSPRIT, a dedicated java library for VRP.
- RouteManagerImpl: Ensures persistence of the JSPRIT provided solutions.

The JSPRIT library is an open source library developed in java, it implements local search metaheuristics to solve the travel salesman problem and vehicle routing problems. This library solves particularly problems of heterogeneous vehicles routing with limited capacities (HCVRP) which is the reference problem of the SMLRP, to which we converge each time by carrying out the necessary transformations for the various confronted situations (Section 2C).

We implemented the SMLRP Solver using a Java / J2EE architecture, the user accesses the solver through a web application that allows him to introduce the finished product bill of material, the master production plan and the logistic means. The solver presents production and transport orders in a summary table and plot the vehicle routes by period and by transport type (distribution or replenishment) on a geographical map. The SMLRP graphic user interfaces are presented in the case study exposed below.

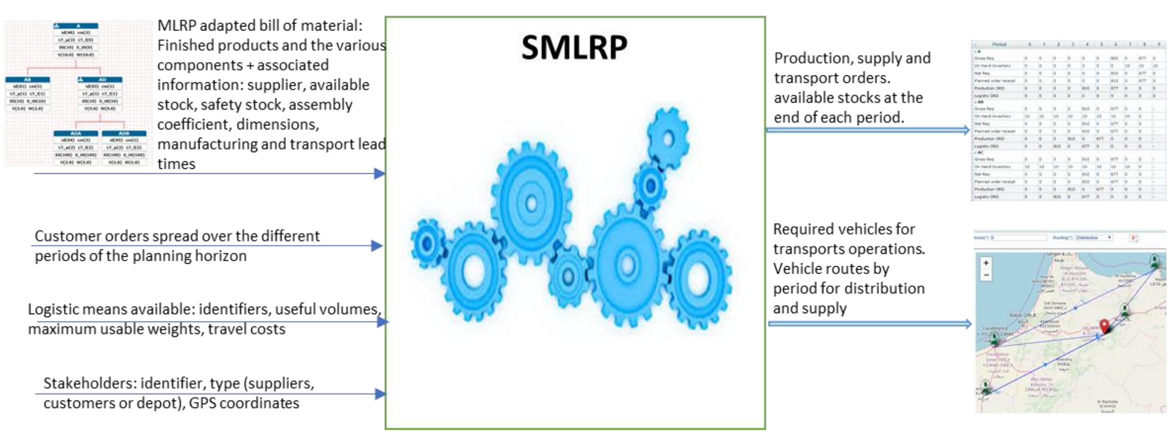


Fig 8. The MLRP inputs/outputs.

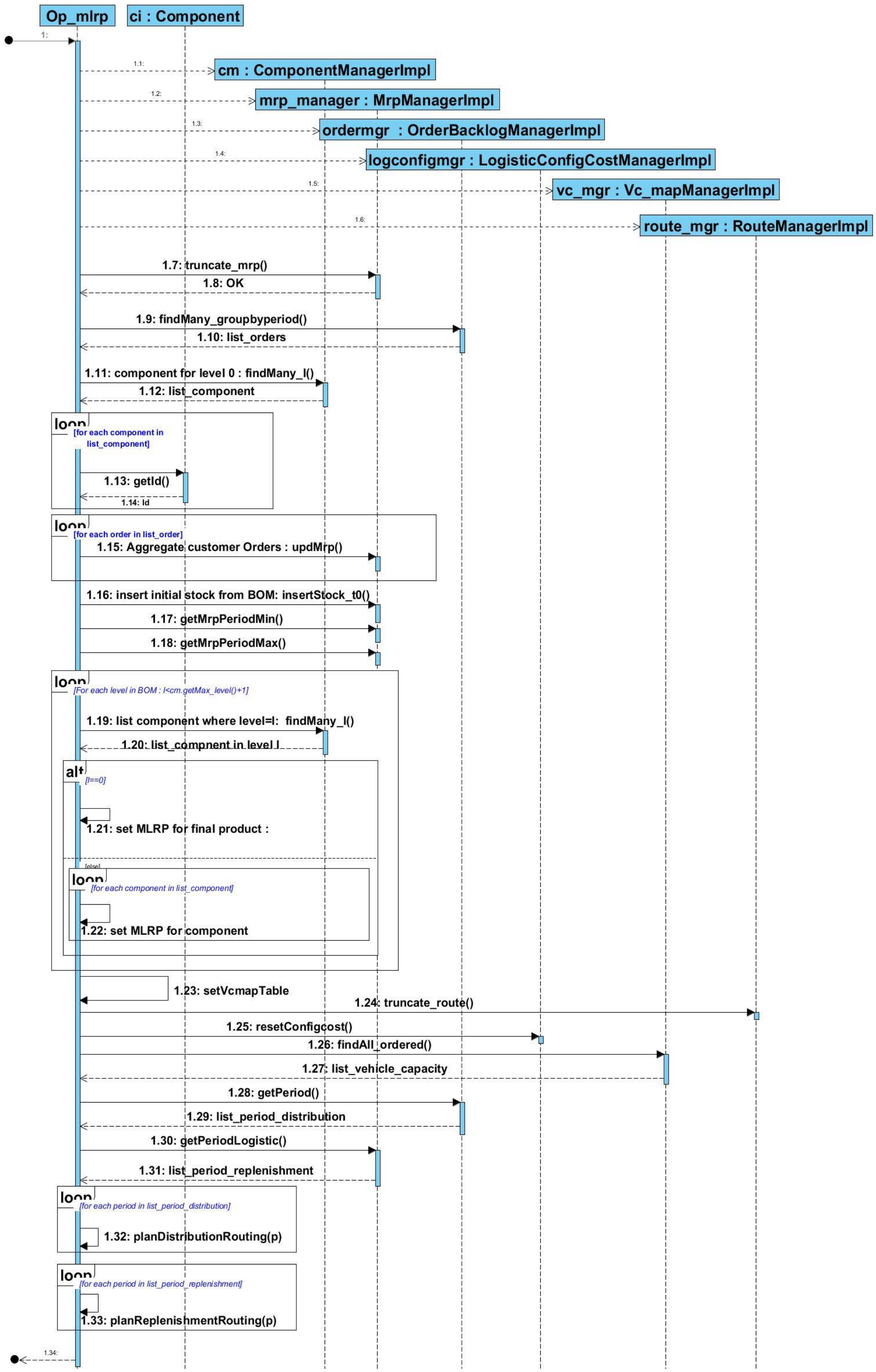


Fig 9. MLRP sequence diagram.

IV. Case Study

To expose the various SMLRP functionalities, we study in this section an example of a manufacturing supply chain of manual pallets trucks, Fig. 10. We will focus on a company that is a part of this supply chain, this company specializes in iron and steel metal structures manufacturing. This company manufactures the pallet truck metal components, acquires the other components from its suppliers, assembles all the components and packs the finished product to transport it to its customers.

Fig 10. Hand Pallet truck.

To demonstrate the integrated planning of production and logistics requirements provided by the SMLRP solver, we cite below the inputs / outputs presented in Fig. 8, relating to the studied problem.

A. The SMLRP Inputs for the Case Study

1) The MLRP adapted bill of material for the case study: As already mentioned in the previous paragraphs, the MLRP adapted bill of material, includes a panoply of information about the finished product structure, the component dimensions and component suppliers. Fig. 11 represents the hand pallet truck bill of material (HPT), it contains the assembly coefficients and the hierarchy of the different components, the data related to the production lead times (LT_p), the initial stocks (S_t0), the safety stocks (SS), the volumes (V) and the weights (W) of the components that need to be transported, as well as their transport lead time (LT_l). Below the dimensions of the items that will be transported:

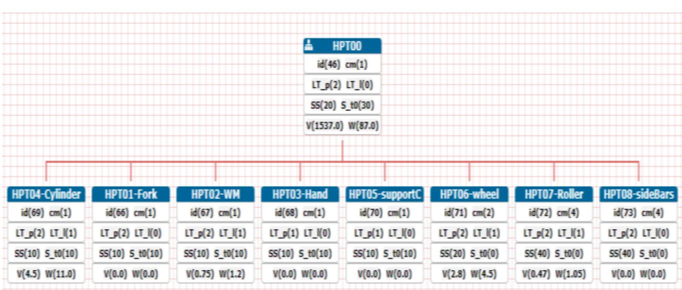


Fig 11. Hand pallet truck bill of material.

- The dimensions (in mm) of the packed pallet truck are 1230x1250x1000, which is the equivalent of 1537 liters; its weight is 87 kg.
- The dimensions (in mm) of the packaged cylinder (HPT04-Cylinder) are 100x128x350, which is the equivalent of 4.5 liters; its weight is 11 kg.
- The dimensions (in mm) of the pallet scale (HPT02-WM) are 100x100x75, which is the equivalent of 0.75 liters; its weight is 1.2 kg.
- The dimensions (in mm) of the steering wheel (HPT06-Wheel) are 200x200x70, which is the equivalent of 2.8 liters; its weight is 4.5 kg.
- The dimensions (in mm) of the pallet truck rollers (HPT06-Roller) are 82x82x70, which is the equivalent of 0.47 liters; its weight is 1.05 kg.

2) Stakeholders: All the companies belonging to the studied supply chain are located in Morocco. The company EP is located in Casablanca, it has a main warehouse in the same place as its production unit, and its suppliers are:

- S1 is located in Berrechid, it provides the steering wheels.
- S2 is located in Kenitra, it provides the scale pallets.
- S3 is located in Tetouan, it provides the cylinders.
- S4 is located in Bouskoura, it provides pallet truck rollers.

The EP customers are scattered all over the country, the SMLRP solver allows introducing, with precision, stakeholders GPS coordinates. Fig. 12 represents the GUI, which allow introducing data related to different stakeholders (type, GPS coordinates and component provided ...).

3) Types of available logistic means: There are three available vehicle types RK, RMa and RMi. The RK can support a weight of 635kg, has a useful volume of 2600 liters, while the RMa can support a weight of 2100kg, and has a useful volume of 10800 liters, and finally the RMi can support a weight of 5500kg and has a useful volume of 40000 liters. Fig. 13 shows the GUI which allow entering data related to the different logistic means (capacities and costs).

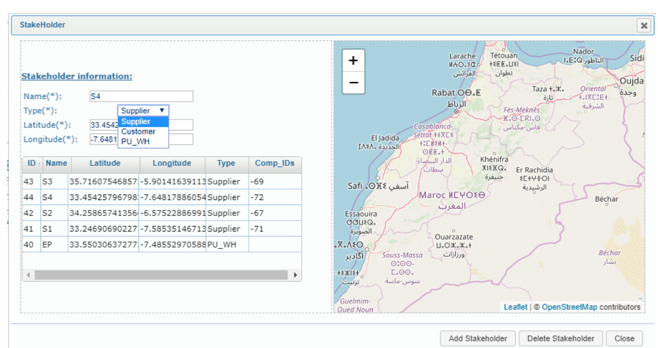


Fig 12. Stakeholders GUI.

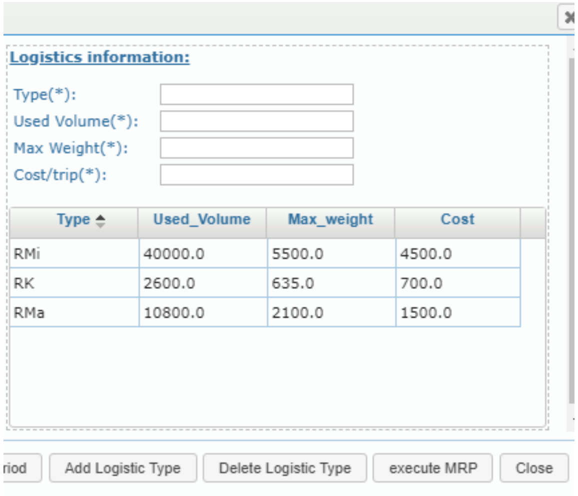


Fig 13. Logistic data GUI.

TABLE I. EP CUSTOMER ORDERS

		Period			
		5	8	9	10
Customer	C1	20	30		
	C2		15		40
	C3	30	5	10	
	C4		25		50
	C5	5		20	
	C6	30			10
	C7	20		40	
	C8	30	45		50
	C9			20	

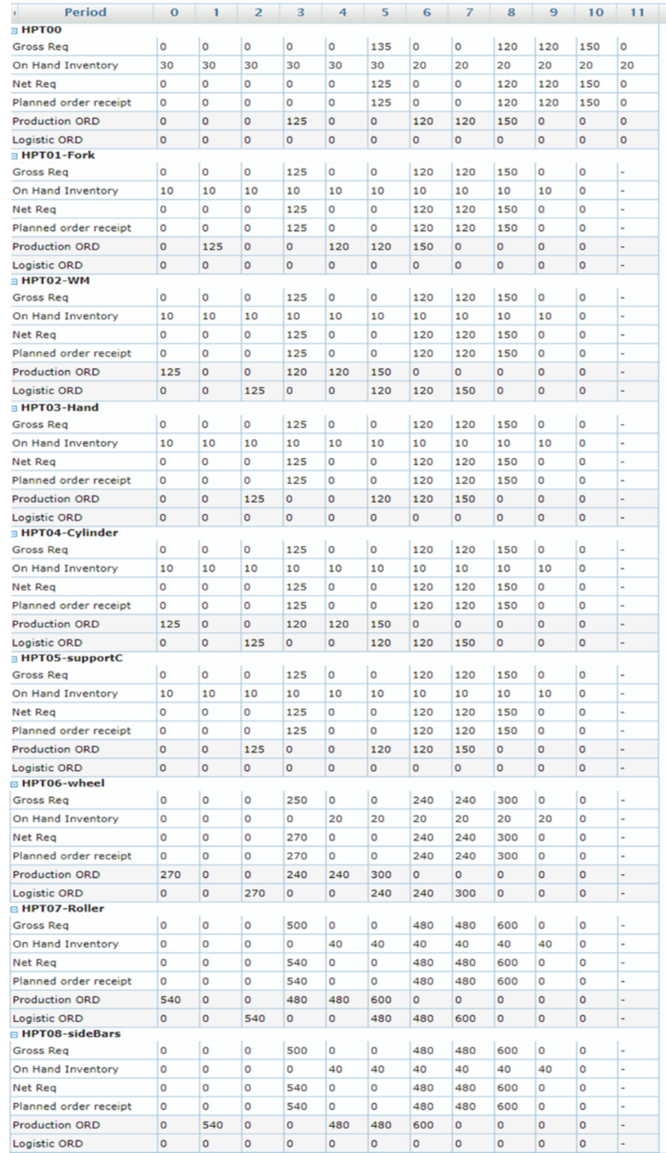
4) Customer orders by period: Table I shows the EP customer orders spread over several periods; these data are introduced in the SMLRP.

B. The SMLRP Outputs for the Case Study

Once the studied problem data are inserted into the SMLRP solver, we execute MLRP algorithm in order to get the production, replenishment and transport orders planned over the planning horizon. The solver presents these results as a table (Fig. 14). The lines corresponding to the "Production ORD" are production orders for the components manufactured in-house, and sourcing orders from suppliers for components provided by other companies. The lines corresponding to the "Logistic ORD" are the transport orders. The solver also provides per period and depending on the operation concerned by the transport (finished product distribution or components collection) the necessary vehicles and the associated vehicle routes.

Fig. 15 shows as example the distribution route relating to the period 9, in this route, the solver indicates that it is necessary to provide five RMi vehicles, four of these vehicles will make a round trip (deposit-client) for customers C3, C5, C7 and C9. As the capacity of the RMi is 27 HPT, C3 and C7 customers cannot be delivered by one trip, the fifth RMi vehicle will make a route deposit-C3-C7- deposit in order to deliver the rest of the products for C3 and C7.

Fig. 16 shows as example the component replenishment route relating to the period 5, a single RMi vehicle is used in this route to recover the necessary components by performing the depot-S3-S2-S1-S4-depot course, the vehicle filling percentage is 56%.



Period	0	1	2	3	4	5	6	7	8	9	10	11
HPT00												
Gross Req	0	0	0	0	0	135	0	0	120	120	150	0
On Hand Inventory	30	30	30	30	30	30	20	20	20	20	20	20
Net Req	0	0	0	0	0	125	0	0	120	120	150	0
Planned order receipt	0	0	0	0	0	125	0	0	120	120	150	0
Production ORD	0	0	0	125	0	0	120	120	150	0	0	0
Logistic ORD	0	0	0	0	0	0	0	0	0	0	0	0
HPT01-Fork												
Gross Req	0	0	0	125	0	0	120	120	150	0	0	-
On Hand Inventory	10	10	10	10	10	10	10	10	10	10	0	-
Net Req	0	0	0	125	0	0	120	120	150	0	0	-
Planned order receipt	0	0	0	125	0	0	120	120	150	0	0	-
Production ORD	0	125	0	0	120	120	150	0	0	0	0	-
Logistic ORD	0	0	0	0	0	0	0	0	0	0	0	-
HPT02-WM												
Gross Req	0	0	0	125	0	0	120	120	150	0	0	-
On Hand Inventory	10	10	10	10	10	10	10	10	10	10	0	-
Net Req	0	0	0	125	0	0	120	120	150	0	0	-
Planned order receipt	0	0	0	125	0	0	120	120	150	0	0	-
Production ORD	125	0	0	120	120	150	0	0	0	0	0	-
Logistic ORD	0	0	125	0	0	120	120	150	0	0	0	-
HPT03-Hand												
Gross Req	0	0	0	125	0	0	120	120	150	0	0	-
On Hand Inventory	10	10	10	10	10	10	10	10	10	10	0	-
Net Req	0	0	0	125	0	0	120	120	150	0	0	-
Planned order receipt	0	0	0	125	0	0	120	120	150	0	0	-
Production ORD	0	0	125	0	0	120	120	150	0	0	0	-
Logistic ORD	0	0	0	0	0	0	0	0	0	0	0	-
HPT04-Cylinder												
Gross Req	0	0	0	125	0	0	120	120	150	0	0	-
On Hand Inventory	10	10	10	10	10	10	10	10	10	10	0	-
Net Req	0	0	0	125	0	0	120	120	150	0	0	-
Planned order receipt	0	0	0	125	0	0	120	120	150	0	0	-
Production ORD	125	0	0	120	120	150	0	0	0	0	0	-
Logistic ORD	0	0	125	0	0	120	120	150	0	0	0	-
HPT05-supportC												
Gross Req	0	0	0	125	0	0	120	120	150	0	0	-
On Hand Inventory	10	10	10	10	10	10	10	10	10	10	0	-
Net Req	0	0	0	125	0	0	120	120	150	0	0	-
Planned order receipt	0	0	0	125	0	0	120	120	150	0	0	-
Production ORD	0	0	125	0	0	120	120	150	0	0	0	-
Logistic ORD	0	0	0	0	0	0	0	0	0	0	0	-
HPT06-wheel												
Gross Req	0	0	0	250	0	0	240	240	300	0	0	-
On Hand Inventory	0	0	0	0	20	20	20	20	20	20	0	-
Net Req	0	0	0	270	0	0	240	240	300	0	0	-
Planned order receipt	0	0	0	270	0	0	240	240	300	0	0	-
Production ORD	270	0	0	240	240	300	0	0	0	0	0	-
Logistic ORD	0	0	270	0	0	240	240	300	0	0	0	-
HPT07-Roller												
Gross Req	0	0	0	500	0	0	480	480	600	0	0	-
On Hand Inventory	0	0	0	0	40	40	40	40	40	40	0	-
Net Req	0	0	0	540	0	0	480	480	600	0	0	-
Planned order receipt	0	0	0	540	0	0	480	480	600	0	0	-
Production ORD	540	0	0	480	480	600	0	0	0	0	0	-
Logistic ORD	0	0	540	0	0	480	480	600	0	0	0	-
HPT08-sideBars												
Gross Req	0	0	0	500	0	0	480	480	600	0	0	-
On Hand Inventory	0	0	0	0	40	40	40	40	40	40	0	-
Net Req	0	0	0	540	0	0	480	480	600	0	0	-
Planned order receipt	0	0	0	540	0	0	480	480	600	0	0	-
Production ORD	0	540	0	0	480	480	600	0	0	0	0	-
Logistic ORD	0	0	0	0	0	0	0	0	0	0	0	-

Fig 14. Executed MLRP for the EP Company.

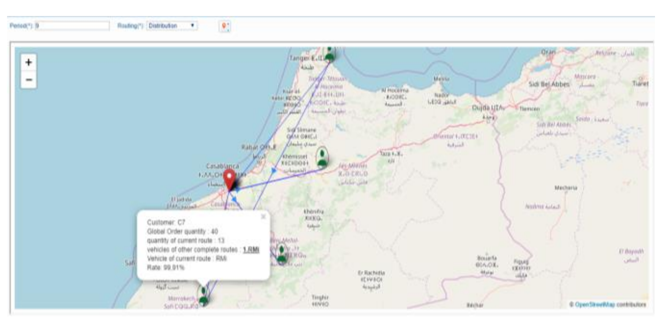


Fig 15. Distribution route for period 9.

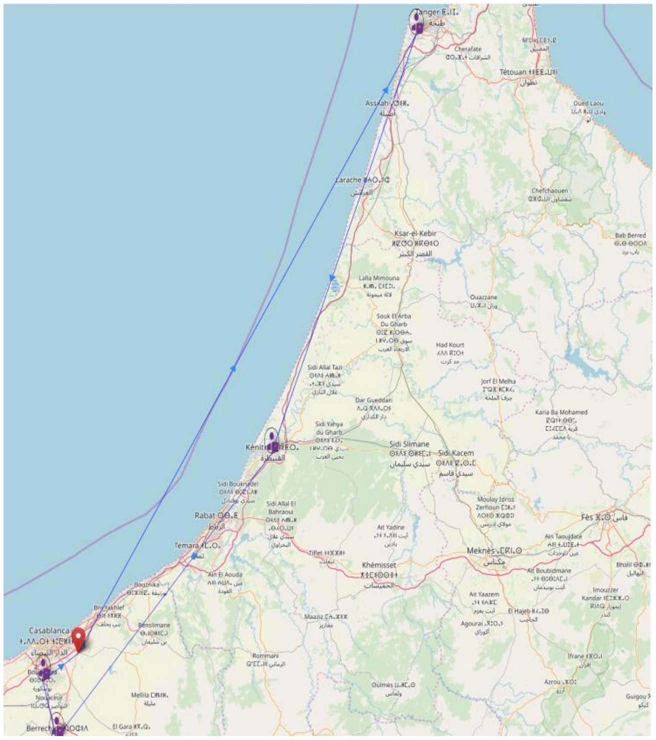


Fig 16. Component replenishment route relating to the period 5.

V. Conclusion

In this paper, we presented the implementation and extension of the integrated planning method for production and logistics needs, the MLRP, which already have been introduced in our previous works. This method allows planning managers to determine in advance, for the entire planning horizon, production orders, orders to be forwarded to suppliers and quantities to be transported upstream and downstream of the supply chain. By dint of the Java / J2EE technology we have implemented the SMLRP solver allowing to execute the MLRP algorithm and we have also benefited from the progress lived in recent decades in the field of vehicles routing problems to integrate the generation of vehicle routes within the MLRP algorithm execution.

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