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## ► To cite this version:

Laurent Deroussi, Nathalie Grangeon, Sylvie Norre. Optimization of logistics systems using metaheuristic based hybridization techniques. Metaheuristics, 2016. hal-02023692

**HAL Id: hal-02023692**

**<https://hal.science/hal-02023692>**

Submitted on 10 Mar 2021

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# **Chapter 1**

## **Optimization of logistics systems using metaheuristic based hybridization techniques**

Laurent Deroussi, Nathalie Grangeon, Sylvie Norre

In the post-war years, the development of operational research provided companies tools to deal with their logistic problems in a quantitative way. For a long time, these problems were split into unrelated sub-problems, each sub-problem being often separately tackled. This is mainly due to the fact that considered sub-problems, such as localization problem, planning problem, scheduling problem or transportation problem are generally NP-hard problems and their computational complexity is still a significant issue for many researchers. Nevertheless, in an increasingly competitive industrial environment, companies continue to have a strong demand for decision aid tools able to get a global view of their organization.

The aim of this chapter is to present the challenges of such a vision, to understand the consequences in terms of logistics system modeling and to state on new optimization techniques.

This chapter is organized as follows. The first part describes logistics systems in general and supply chain in particular. In this part, concepts of horizontal and vertical synchronization to allow a comprehensive vision of supply chain is developed. We also show that metaheuristic based hybridization techniques are especially suitable to logistics system characteristics. The second part is devoted to hybridization techniques: metaheuristic / optimization method and metaheuristic / evaluation model. In the last part, we present some issues about synchronization as well as hybridization methods proposed in the literature.

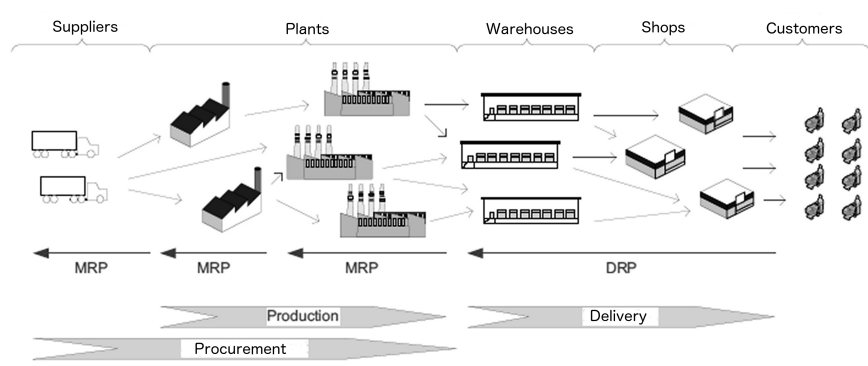
### **1 Logistics systems**

#### ***1.1 Definitions and general considerations***

According to Ganeshan & Harrison a supply chain "is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distri-

bution of these finished products to customers” [17]. This definition chosen among many others illustrates a supply chain as a network of physical entities (sites, organizations or actors) crossed by physical flows, information flows and financial flows. It integrates a set of activities from the raw material procurement to the final consumption.

In this chapter we refer to logistics systems as any set of physical entities interconnected by a logistics network ensuring both material and immaterial flows. So, a logistics system represents both a global supply chain and a part of it (by focusing for instance on the entities in the same organization even a site). Internal logistics represents the set of flows passing through the system. Procurement logistics (or inbound logistics) include inflows (from any-tiers component supplier), whereas distribution logistics (or outbound logistics) gather outflows (customers, wholesalers, retailers, end consumers). Figure 1 presents an example of a supply chain.



**Fig. 1** A supply chain

Works of Forrester about systems dynamics were used to highlight that the efficiency of an organization arises from its components coordination [15]. The concept of Supply Chain Management first proposed in 1982 by Oliver & Weber was born [?].

A very large number of definitions of Supply Chain Management has been proposed by Wolf [48]. Among them, we keep those proposed by Simchi-Levi et al. which describes the Supply Chain Management as a set of approaches used to integrate effectively actors taking part to the manufacturing process (suppliers, plants, warehouses, stores, ...) so as to manufacture and dispatch goods in right quantity, at the right place and at the right time, with the objective to minimize the set of costs while ensuring a quality of service [41].

## 1.2 Integrated view of supply chain

Optimizing a single component of a logistics system may have a positive or negative impact on the global performance of the system. Thus, it is important to consider the system in its whole by integrating inbound and outbound logistics. There are several integrations:

**Functional** the smooth running of a logistics system includes many activities to coordinate (facility location, logistics network design, goods transportation, warehouse management, inventory management, production logistics, product design and product life cycle, information system, procurement logistics, distribution logistics, ...). The MRP concept (Material Requirement Planning) also called "Net requirements Calculation" is born in 70s from the need to synchronize the raw material quantities and the semi-finished products in order to satisfy a demand expressed by the consumers. We speak about physical flows synchronization [34].

**Temporal** Wight proposed the MRPII (Manufacturing Resources Planning) a development of the MRP particularly by taking into account the capacities (procurement, production, storage, distribution, financial) [47]. This approach lies on the definition of a hierarchical structure in five levels, each of them working on a temporal horizon with their own data precision level. These levels are: strategic plan, Sales & Operations Planning (S&OP), Master Production Schedule (MPS), Net Requirements Calculation and Shop Floor Control (SFC).

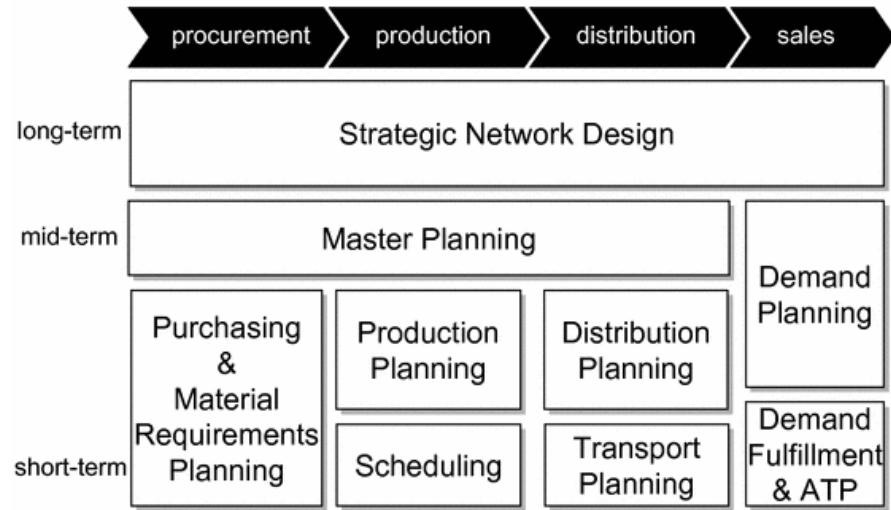
**Geographical** Originally MRPII is a mono site approach. However current logistics systems are mostly multi-site which implies to take decisions in terms of facility location, goods transportation (procurement, production, and distribution), lead time addressing, ... Thomas & Lamouri consider the concept of supply chain management as an extension of the MRPII approach [45].

Kouvelis et al. define the coordination as any action or approach leading the actors of a logistics system to act in a way to improve the system running as a whole [20]. The coordination among various actors constitutes a great challenge for operational research, whether in a centralized view (actors are grouped in a same organization which takes decisions for the whole) or a decentralizes view (each actor is empowered in its decision-making). Schmidt & Wilhelm describe logistics network models which may address each of the three decisional levels, namely strategic, tactical and operational [40]. The strategic level (long-term) gathers decisions about logistics network design and in particular Facility Location Problem (FLP). The tactical level (mid-term) describes flow management policies with for instance Lot Sizing Problems. The operational level (short-term) concerns the supply chain control and covers scheduling problems (Flow-Shop problem, Job-Shop problem, ...). The author concludes that each level interacts with the others and an approach unifying the three levels is necessary to design and manage a competitive logistics network.

Lemoine defines the concept of horizontal and vertical synchronization which gathers the two previous examples [23]. The horizontal synchronization addresses

the synchronization difficulties between the entities of a supply chain (for instance a plan for a production site may be not feasible for procurement constraints). The vertical synchronization consists in planning decisions in time. The levels of the MRP II approach are recomputed at various frequencies and it may induce a desynchronization between them. It is not sure that a modification done at a given level remains consistent for the other levels.

Figure 2 details problems linked to the supply chain planning et shows the need of synchronization concepts for a better flows coordination.



**Fig. 2** Problems linked to the supply chain planning [28]

### ***1.3 Difficulties for performance optimization in a supply chain***

The process of adopting an global view of logistics systems and integrating synchronization constraints allows to optimize its performance and makes it more competitive. Some difficulties have to be overcome. These difficulties are linked to:

model design: a logistics system is hard to model, actors, entities, activities and interaction between entities must be defined. Management rules may be complex or hard to establish. knowledge and data gathering may be a long and difficult task.

algorithmic complexity: most of classical models regardless the decision level are NP-hard problems. We mentioned only few of them but it becomes necessary to combine them in an aim of horizontal or vertical synchronization.

size of studied systems    the big size of logistics systems (number of actors, products, ...) makes them often hard to solve.

consideration of uncertainties:    high decision level results in greater uncertainties. tactical level concerns a relatively long time horizon, generally from two to five years. For such a horizon, great uncertainties concern demand or economic environment. It is important that a system can be adapted and remains efficient facing uncertainties. Snyder presents a state of the art about the uncertainties consideration in Facility Location Problems [42].

model precision    logistics system has got a huge quantity of data. It is necessary to aggregate more or less these data according to the considered decision level and the objectives. For instance, the S&OP works on product families whereas the MPS considers only products.

Competitiveness evaluation:    Performance criteria are generally cost (transport, storage, production, ...) and consumer service rate. Apart from the fact that they may be difficult to evaluate, they are often conflicting.

Risk management:    machine breakdown at an operational level; maintenance management of production units; study of system reactivity face to natural disaster.

#### ***1.4 Decision Support System***

Performance of logistics system is measured as its ability to manage flows passing through them whether they are physical, informational or financial. One of the key is data sharing between actors of the system. Each actor must be able to read at any time all the informations he needs to take the best possible decisions. It is one of the major role of the Information System (IS) which gathers increasingly data for instance through tools such as ERP (Enterprise Resource Planning). If these tools allow to manage information flows, they are often difficult to use to take decisions. It is the very issue of Business Intelligence defined by Krmac as the set of tools who helps the enterprise to better understand, analyze, explore and forecast what happens in its enterprise and its environment [21]. Figure 3 shows interactions between these tools. ETL type tools (Extract-Transport-Load) allow to extract data from many sources and format them (validation, filtering, transformation, aggregation) and store them in a Data Warehouse. These data are then available to be used by analyze and decision aid tools like those tackled in this chapter.

#### ***1.5 Interest of metaheuristics***

We have pointed out some difficulties to overcome to optimize a logistics system. A whole supply chain is composed of a complex network of sites and organizations with interconnected activities but aiming at various and contradictory objectives. Lourenco points out the major role of metaheuristics in decision aid tools for the

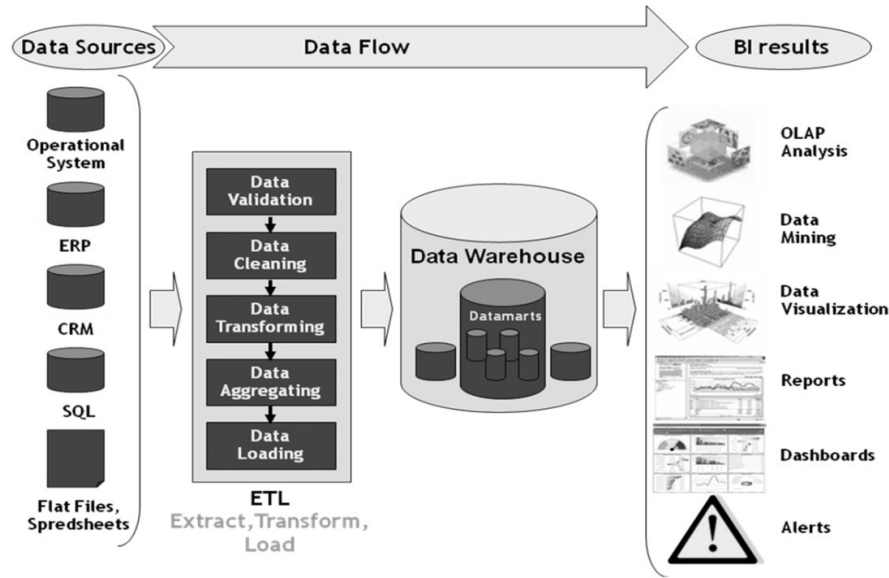


Fig. 3 Decision Support System [21]

supply chain [24]. They have got good qualities to solve very complex problems that arise in supply chain management. Outlined elements are the following:

- These methods are generally simple, easy to implement, robust and have already proven successful in hard optimization problems.
- Their modular nature leads to short implementation and maintenance times which provide them advantages compared to other technics for industrial applications.
- Their ability to manipulate a large amount of data, rather than aggregating data or simplifying a model to obtain a solvable problem but with a partial representation of reality.
- Their ability to manage uncertainties, to build many scenarios rather than offering a exact solution for a model with an estimation of many data.

A global problem would be considered as composed of many sub-problems, each of one been of NP-hard problem, in order to optimize one or more performance indicator under data uncertainties. But in the meantime there is no model tackling the whole complexity of a logistics system. Decision aid tools are generally developed with a precise purpose and an appropriate vision of the system (horizon choice, data precision degree, one or more performance criterion, ...) making simplifying assumptions. However it seems essential to be able to ensure that proposed solutions remain consistent whether for other actors or for other time scales.

## 2 Hybridization techniques

There is no question that metaheuristics play an important role in the integration of the whole complexity of logistics system but it is equally clear that alone metaheuristic is not sufficient. That is why we wish to highlight metaheuristic based hybridization techniques in this section.

### 2.1 Generalities

Optimization methods allow to optimize the running of a system while minimizing (or maximizing) one or more performance criterion. Methods for combinatorial optimization problems are usually split into two categories: exact methods and approximate methods. Exact methods may provide optimal solution and prove their optimality. They gather techniques issued from integer linear programming (ILP) such as Branch-and-Bound, Branch-and-Cut or Lagrangian relaxation. Approximate methods are used whenever an optimal solution can not be obtained (because of the size of the instance, the impossibility to model the problem as a linear model, the time allocated for solving, ...). Among the approximate methods we find metaheuristics based mostly on local searches. Optimization methods are well suited to tackle the algorithmic complexity of studied systems.

In some cases, the system performance criterion may not be easily computed. It is then necessary to call to a performance evaluation model (deterministic or stochastic simulation model, markovian model). For these systems Norre defines the notion of functional and structural complexity [33]. The author introduces the notion of dual complexity (figure 4) and proposes a combination between an optimization method and a performance evaluation model to solve the problems linked to the dual complexity. In the following a method will represent an optimization method or an evaluation model.

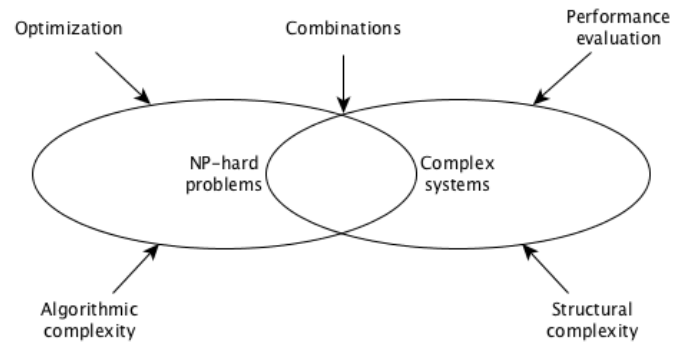
In the previous section we have shown that logistics system we want to study are characterized by two elements:

- on the one hand the wish to support an integrated view as part of horizontal or vertical synchronization which may lead to consider the logistics system as a combination of many optimization problems.
- on the other hand, the aim of improving the system competitiveness. Performance must be evaluated by taking into account sometimes contradictory criterion under uncertainties.

Hybridization techniques between a metaheuristic and another method whether optimization or performance evaluation can be organized into three categories:

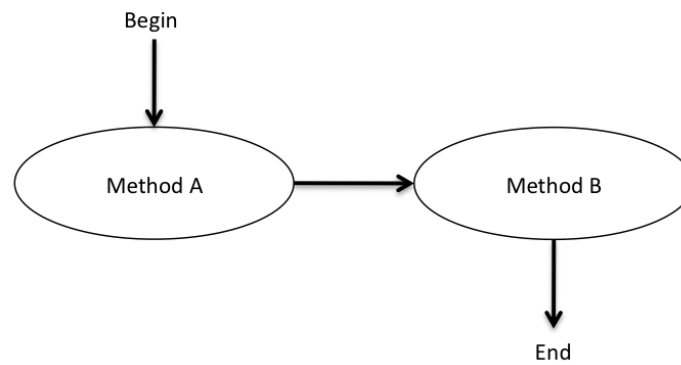
sequential linking ( $A \rightarrow B$ ) - figure 5: method A and method B are sequentially used. Method A solves a part of the problem (for instance for a given sub-set of variables). The other part of the problem is solved by method B. A classical





**Fig. 4** Dual complexity

example is the use of an optimization method to determine a feasible solution of the problem and then a metaheuristic for optimize this solution.

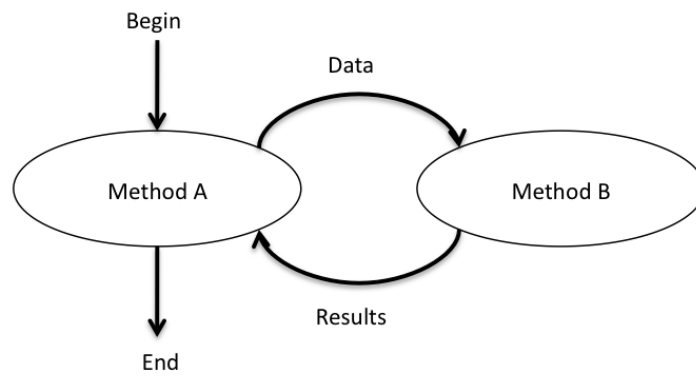


**Fig. 5** Principle of two method sequential linking

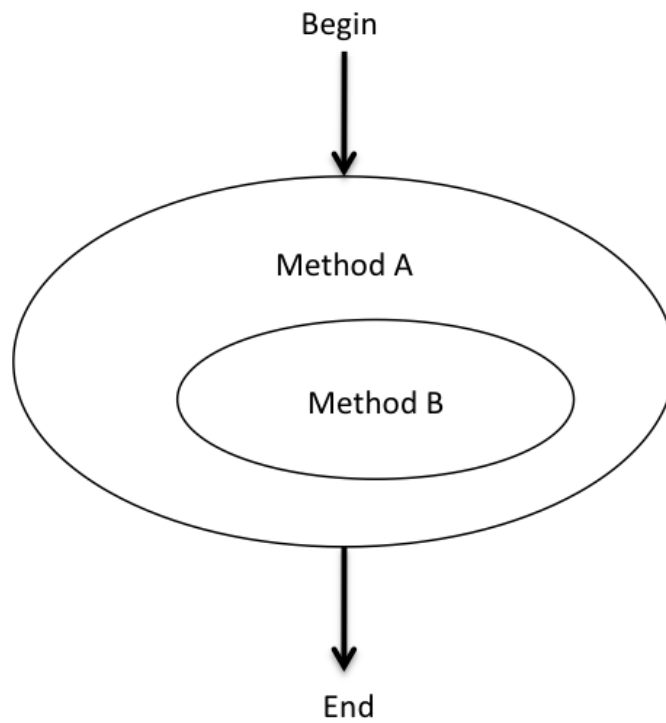
sequential and iterative linking ( $A \rightleftharpoons B$ ) - figure 6: method A and method B are used in a sequential and iterative way. The result of method B is an input of method A which allows to iterate the resolution process..

hierarchical linking ( $A \downarrow B$ ) - figure 7: method are used according a "master - slave" scheme. For instance method A builds one or more solutions evaluated or optimized by method B.

These three techniques may be combined to obtain more elaborated hybridization methods. For instance:  $(A \rightarrow ((B \downarrow C) \rightleftharpoons D))$  means that a hierarchical linking between method B and C follows method A and is sequentially linked with method D.



**Fig. 6** Principle of two method sequential and iterative linking



**Fig. 7** Principle of two method hierarchical linking

In this section we propose to consider two types of metaheuristic based hybridization methods: metaheuristic / optimization method hybridization which is well suited when a problem can be decomposed as sub-problems and metaheuristic / performance evaluation method hybridization which is usefull when performance criterion are hard to evaluate.

## 2.2 *Metaheuristic / Optimization method hybridization*

Blum et al. note that an increasing number of published metaheuristics are not strictly in accordance with the paradigm of a single traditional metaheuristic [6]. On the contrary they combine algorithmic elements which come from optimization method from other domain than those of metaheuristics. Such approaches are defined by the author as hybrid metaheuristics. Hybrid metaheuristics appeared near two decades ago. Since then they proved their efficiency to solve hard optimisation problems. We present first hybridization between two metaheuristic before talking about hybridization with another optimization method.

The metaheuristic / metaheuristic hybridization technic consists in combining two metaheuristics. The aim is to conceive a method which profit from each of them. An example often given is the hybridization (Pop  $\downarrow$  Ind) between a population algorithm (for instance an evolutionary algorithm or a particule swarm optimization) and an individual based method (for instance a local search, a simulated annealing or a tabu search). Such an hybridization takes advantage from the exploratory nature of the population algorithm and the ability of an individual based method to intensify the search in a promising area of the search space. Many hybridization examples exists in the litterature, most of them combining a metaheuristic with a local search (Meta  $\downarrow$  LS). Hybridization (Genetic algorithm  $\downarrow$  LS) is a technique often used in the literature and known as memetic algorithms [29] or Genetic Local Search [27]. Hybridization (simulated annealing  $\downarrow$  LS) is known as C-L-O (Chained Local Optimization) [25] or SALO (Simulated Annealing Local Optimization) [10] and is part of the set of iterated local searches [24] in which acceptance criterion follows the simulated annealing process. Talbi proposes a taxonomy of hybrid methods essentially based on the encapsulation degree of a technique in another and the parallelization degree [44].

During the last years many approaches combine a metaheuristic or annoter optimisation method. Several classifications were proposed in the literature [11], [36] and [19]. For example in the first cited reference the author split hybridization techniques into five categories:

- to use exact methods to explore big size neighboring systems in local search algorithm,
- to run several replication of a local search algorithm and exploit the information contained in good quality solutions to define a sub-problem with a reduce size which can be solved by a exact method,
- to exploit bounds in greedy algorithms,

- to guide local search with information obtained by relaxing a ILP model ,
- to solve exactly specific sub-problems in hybrid metaheuristics.

Fernandes & Loureno present mapping of hybrid methods according to the considered problems [13]. Among problems about logistics systems, many references concern logistics network design (p-median), vehicle routing problems (TSP or VRP), planning problems (lot-sizing) or scheduling problems (flow-shop, job shop, ...).

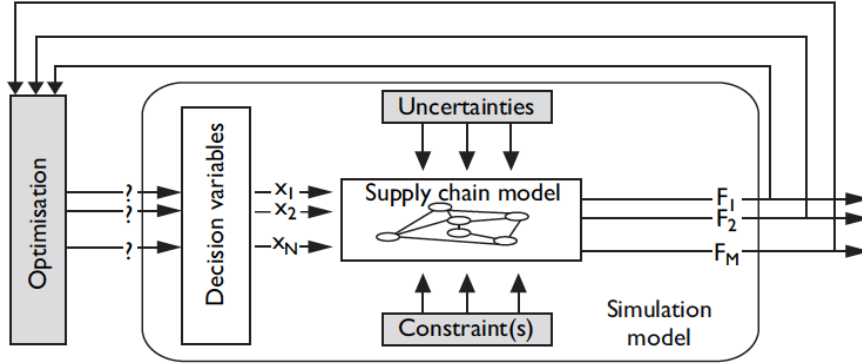
Constraint programming (CP) is a programming paradigm wherein relations between variables are stated in the form of constraints. The search is based on constraint propagation which reduces the set of variables possible values. Contrary to metaheuristics, CP is known as efficient technique for decision problems but not for optimization problems. Hybridization of these two techniques is a good idea to profit from their respective advantages. Two strategies are possible strategies according to the optimization piloting the hybrid method. The first one is a metaheuristic in which constraint programming is used as an efficient tool to explore big size neighborhood. The second one is a tree search algorithm in which a metaheuristic is used to improve nodes or to explore neighbor paths. [14] and [46] are suggestion of two first reading on the subject. This hybrid technique has been successfully used on vehicle routing problems [8] and scheduling problems [5].

### ***2.3 Metaheuristic / Performance evaluation method hybridization***

Performance evaluation models take into account functional and structural complexity of logistics systems. Their use is particularly well adapted when:

- defined performance indicators can not be computed by simple analytical functions as complex rules define system running. It is then necessary to simulate the system running to evaluate its performance.
- some data are described by distribution functions and are necessary to run many times the model to know its robustness..

In this part, we will focus our talk on simulation models. Terms of optimization by simulation or joined simulation / optimization approach are often used in the literature. As proof optimization components based on evolutionary algorithm, scatter search, simulated annealing or tabu search are part of discrete event simulation software as we can see in [16] or [2]. Resulting hybridization technique (simulation model  $\downarrow$  optimization method) is the following: the optimization method provides solutions for evaluation to the discrete event simulation software. Fu [16] discuss about other types of link existing between optimization method and simulation model. In the context of supply chain management many works show the interest of hybridization. Abo-Hamad & Arisha give a recent state of the art[1]. Figure 8 from this article shows interactions between optimization components and simulation model. Simulation model allows to manage uncertainties and system complexity.



**Fig. 8** Example of Optimisation / simulation model hybridization for a supply chain [1]

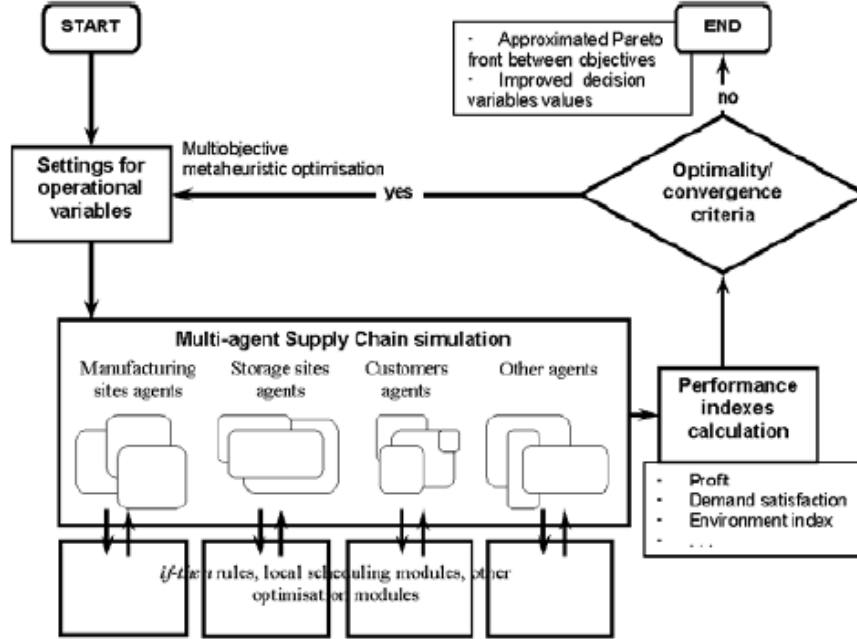
Mele et al. use this hybrid technique for a decentralized approach of a supply chain [26]. Each actor of the chain is represented by an agent and all the agents are integrated in a simulation model. The model is combined (figure 9) with a genetic algorithm for the optimization part. More recently a similar approach has been proposed by Nikolopoulou & Lerapetritou [32] with ILP.

### 3 Application to the supply chain management

#### 3.1 Preamble

We have emphasized the importance of considering a logistics system in its whole. Griffis et al. note that being able to take into account many problems simultaneously is one of the major interests of metaheuristics for logistics system study (authors use the term of hybrid problems) [18]. The author give the following examples:

- **Location Routing Problem:** consists in opening a subset of depots, assigning customers to them and determining vehicle routes, to minimize a total cost including the cost of open depots, the fixed costs of vehicles used, and the total cost of the routes.
- **Inventory Routing Problem:** consists in the distribution of a single product, from a single facility, to a set of customers over a given planning horizon. Each customer consumes the product at a given rate and has the capability to maintain a local inventory of the product up to a maximum.
- **Vehicle Routing Problem:** What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?



**Fig. 9** Example of metaheuristic / simulation model hybridization for a decentralized supply chain [26]

- **Multi-level Logistics Network Design Problem:** relates to the establishment of supply, warehousing and distribution infrastructure. It encapsulates procurement, value-add and postponement activities and inventory control policies.

The three first problems define a vertical synchronization with two decision levels: one about the logistics network design (choice of site location, choice of supply, delivery frequency) and the other about the route design. Joint problem solving allows to obtain better results than solving them apart. The last example define an horizontal synchronization between the levels of the supply chain. The author considers this problem as an hybrid problem as a combination of many network design problems, one for each level (choice of production location, choice of distribution infrastructure for instance).

In addition many other problem combinations are interesting to study in the supply chain management context. Among them, we mention for horizontal synchronization:

- tactical planning: with the study of multi-site lot sizing problems,
- multi-site scheduling: which takes into account product transport between sites,
- end product distribution: transport sharing

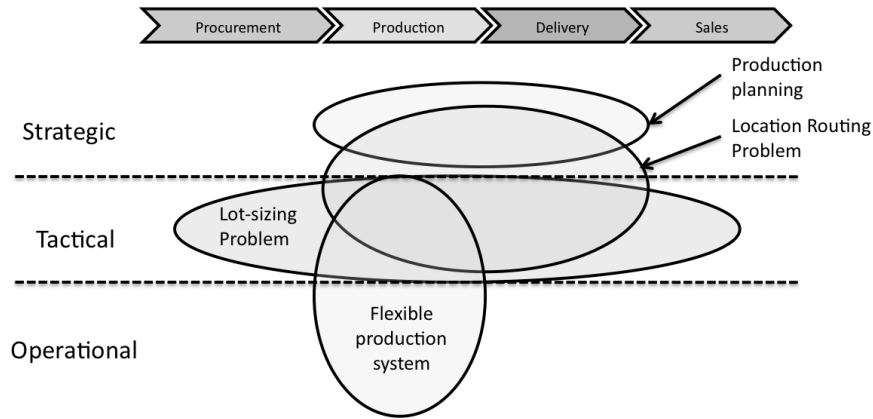
and for vertical synchronization:

- tactical planning: synchronization between Sales & Operations Planning and Production Planning,
- scheduling: synchronization between predictive and reactive scheduling (off line and on-line scheduling).

Method implemented to solve these problems are generally based on a decomposition into basic problems. An optimization method is associated to each basic problem. We have the three categories defined in the previous section:

- sequential linking: this technique can be used for a vertical synchronization problem where decisions taken at a high level may have an impact on lower level. Solution obtained by the first method is an input of the second method.
- sequential and iterative linking: the previous scheme is iterated. Informations are transmitted by the second method to the first one restarting the process. In this technique, methods are considered at the same level. The difficulty of this approach is to define informations transmitted from one method to the other.
- hierarchical linking: contrary to iterative methods, this combination induces precedence among the methods. During its execution the first method calls the second method to solve a sub-problem.

Problem combinations are a first step allowing an integrated view of supply chain to take decisions. That is why we propose to highlight some of them (Production Planning, Location Routing Problem, Lot-Sizing Problem and Flexible Production System) and to present for each of them some metaheuristic based hybrid methods proposed in the literature. Figure 10 shows synchronization types associated to each problem.



**Fig. 10** Chosen problems and synchronization types

### 3.2 Production/distribution planning

Suon et al. covers an international two-echelon production/distribution problem. This is a strategic planning problem which aims to define the movement of goods within a logistics network from tier-1 suppliers to end customers [43].

The aim is in planning the manufacture of product types ( $N$ ). The logistics network considered is composed of production zones ( $PZ$ ), sales zones ( $SZ$ ) and distribution links ( $DL$ ) between the production and sales zones.  $o_{k,u} = 1$ , if distribution link  $k$ ,  $k = 1, DL$  begins at production zone  $u$ ,  $u = 1, PZ$ ,  $d_{k,v} = 1$ , if distribution link  $k$ ,  $k = 1, DL$  ends at sale zone  $v$ ,  $v = 1, SZ$ .

Each sales zone forecasts its requirements by type of product ( $fd_{i,v}$  for type of product  $i$ ,  $i = 1, N$  and sale zone  $v$ ,  $v = 1, SZ$ ). Many production technologies ( $PT$ ), available in production zones, are required to manufacture one type of product. Each production zone may not offer all production technologies but all production zones may not manufacture certain products. Some production zones may be used for several types of products, others may be dedicated to only one type of product.  $xc_{i,t}$  is the ratio between a product of type  $i$ ,  $i = 1, N$  and the reference product for production technology  $t$ ,  $t = 1, PT$ . Each production technology  $t$ ,  $t = 1, PT$  and  $u$ ,  $u = 1, PZ$  has a minimum production capacity  $cap\_min_{t,u}$  which represents the break-even point of installed industrial equipment and maximum production capacity  $cap\_max_{t,u}$ .

The problem is to determine the quantity of each type of product manufactured in each production zone and the delivery method to the sales zones, showing the quantity assigned to each distribution link.

The objective is to minimize global delivery costs of the supply chain for all product types and distribution links.  $sc_{i,u}$  represents supply charge for bill of material of type of product  $i$ ,  $i = 1, N$ , manufactured by production zone  $u$ ,  $u = 1, PZ$ .  $fc_{t,u}$  (resp.  $vc_{t,u}$ ) represents the fixed charge (resp. variable charge) for production technology  $t$ ,  $t = 1, PT$  and production zone  $u$ ,  $u = 1, PZ$ .  $tc_{i,k}$  (resp.  $dr_{i,k}$ ) is the unitary transportation charge (resp. duty rate) for type of product  $i$ ,  $i = 1, N$  and distribution link  $k$ ,  $k = 1, DL$ .

Variables are:

- $P_{i,u}$  is the number of product of type  $i$ ,  $i = 1, N$  manufactured by production zone  $u$ ,  $u = 1, PZ$ .
- $Y_{i,k}$  is the number of product of type  $i$ ,  $i = 1, N$  assigned to distribution link  $k$ ,  $k = 1, DL$
- $mc_{i,u}(P)$  unitary manufacturing cost for a product of type  $i$ ,  $i = 1, N$  and production zone  $u$ ,  $u = 1, PZ$  according to the variable  $P$
- $dc_{i,k}(P)$  unitary delivery cost for a product of type  $i$ ,  $i = 1, N$  and distribution link  $k$ ,  $k = 1, PZ$  according to the variable  $P$

$$\min z = \sum_{i=1}^N \sum_{k \in DL} Y_{i,k} \cdot dc_{i,k} \quad (1)$$

under constraints:



$$\sum_{k \in DL} d_{k,v} \cdot Y_{i,k} = f d_{i,v}, \quad \forall i \in N, \forall v \in SZ \quad (2)$$

$$\sum_{i \in N} x c_{i,t} \cdot P_{i,u} \leq cap\_max_{t,u}, \quad \forall t \in PT, \forall u \in PZ \quad (3)$$

$$\sum_{i \in N} x c_{i,t} \cdot P_{i,u} \geq cap\_min_{t,u}, \quad \forall t \in PT, \forall u \in PZ \quad (4)$$

$$\sum_{k \in DL} o_{k,u} \cdot Y_{i,k} = P_{i,u}, \quad \forall i \in N, \forall u \in PZ \quad (5)$$

$$m c_{i,u} = \sum_{\substack{t \in PT / \\ x c_{i,t} > 0}} \left( \frac{f c_{t,u}}{\sum_{\substack{i' \in N / \\ x c_{i',t} > 0}} P_{i',u}} + x c_{i,t} \cdot v c_{t,u} \right) \quad \forall i \in N, \forall u \in PZ \quad (6)$$

$$d c_{i,k} = t c_{i,k} + d r_{i,k} \cdot \left( \sum_{u \in PZ} o_{k,u} \cdot (s c_{i,u} + m c_{i,u}) \right) \quad \forall i \in N, \forall k \in DL \quad (7)$$

$$P_{i,u} \geq 0, \quad \forall i \in N, \forall u \in PZ \quad (8)$$

$$Y_{i,k} \geq 0, \quad \forall i \in N, \forall k \in DL \quad (9)$$

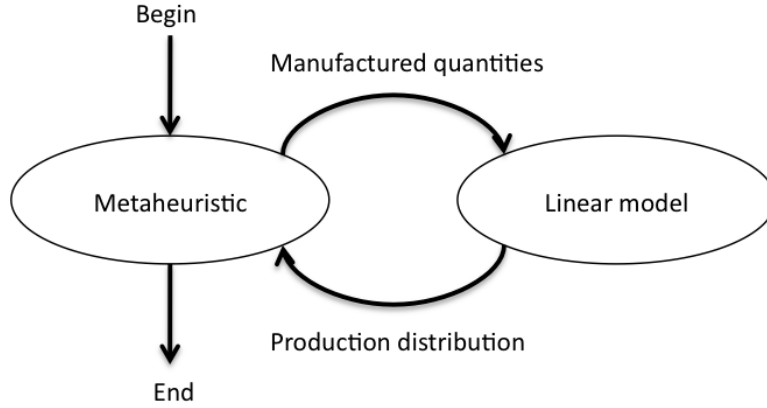
Contraints 2 concern the forecast demand. Contraints 5 specifies that no storage is permitted in either zone; all manufactured goods must be delivered.. Contraints 3 and 4 concern production technologies capacities. Contraints 6 compute the unitary manufacturing cost. Contraints 7 compute the unitary delivery cost. Manufactured and delivered quantities are non negative according constraints 8 and 9.

The problem is modeled by linear constraints and a non linear objective function. The non linearity is due to the fixed manufacturing costs, the economy of scale and the duty costs. Moreover this objective function is non convex (proven by a counterexample).

To tackle the non linearity the problem has been decomposed into two sub-problem: the first one concerns the manufacturing quantity determination for each production zone and the second one deals with distribution of the determined quantities toward the sales zones. This decomposition comes from the fact that the second model is a classical transportation problem which can be modeled as a linear model. A hybrid metaheuristic has been proposed (figure 11) with an iterated local search for the manufactured quantities ( $P_{i,u}$  and a part for solving the transportation model. The proposed method is noted (ILS  $\Leftrightarrow$  LP).

### 3.3 Location Routing Problem

This synchronization problem is one of the oldest and the most studied problems. Location Routing Problem combines two NP-hard problems: Facility Location Problem (FLP) and Vehicle Routing Problem (VRP). The aim is to determine



**Fig. 11** Hybrid metaheuristic proposed par [43]

facility location among many potential locations, to assign customers to an open facility and to solve a vehicle routing problem. The objective is to minimize a set of costs i.e. facility opening costs, vehicle costs and travel costs.

Let  $V = I \cup J$  be the set of vertices where  $I$  designs the set of potential depot nodes and  $J$  the set of customers to be serviced. A capacity  $W_i$  and an operating cost  $O_i$  are associated to each depot  $i \in I$ . Each customer  $j \in J$  has got a demand  $d_j$ . Traveling cost for edge  $(i, j)$  is denoted  $c_{i,j}$ .  $K$  designs a set of available vehicle with  $Q$  capacity.  $F$  is a fixed cost per vehicle used.

Variables are the following:

$y_i = 1$  if depot  $i \in I$  is opened, 0 otherwise,

$f_{i,j} = 1$  if depot  $i \in I$  delivers customer  $j \in J$ , 0 otherwise,

$x_{i,j,k} = 1$  if edge  $(i, j) \in V^2$  is traversed by vehicle  $k \in K$ .

$$\min z = \sum_{i \in I} O_i y_i + \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} c_{i,j} x_{i,j,k} + \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} F x_{i,j,k} \quad (10)$$

under constraints:

$$\sum_{k \in K} \sum_{i \in V} x_{i,j,k} = 1, \quad \forall j \in J \quad (11)$$

$$\sum_{j \in J} \sum_{i \in V} d_j x_{i,j,k} \leq Q, \quad \forall k \in K \quad (12)$$

$$\sum_{j \in V} x_{i,j,k} - \sum_{j \in V} x_{j,i,k} = 0, \quad \forall k \in K, \forall i \in V \quad (13)$$

$$\sum_{i \in I} \sum_{j \in J} x_{i,j,k} \leq 1, \quad \forall k \in K \quad (14)$$

$$\sum_{i \in S} \sum_{j \in S} x_{i,j,k} \leq |S| - 1, \quad \forall S \subset J, \forall k \in K \quad (15)$$

$$\sum_{u \in J} x_{i,u,k} + \sum_{u \in V \setminus J} x_{u,j,k} \leq 1 + f_{i,j}, \quad \forall i \in I, \forall j \in J, \forall k \in K \quad (16)$$

$$\sum_{j \in J} d_j f_{i,j} \leq W_i y_i, \quad \forall i \in I \quad (17)$$

$$x_{i,j,k} = \{0, 1\}, \quad \forall i \in V, \forall j \in V, \forall k \in K \quad (18)$$

$$y_i = \{0, 1\}, \quad \forall i \in V \quad (19)$$

$$f_{i,j} = \{0, 1\}, \quad \forall i \in V, \forall j \in V \quad (20)$$

Objective (10) is to minimize a sum of three terms: operating costs, travel costs and vehicle costs. Constraints (11) guarantee that every customer belongs to one and only one route and that each customer has only one predecessor in the tour. Capacity constraints are satisfied through inequalities (12) and (17). Constraints (13) and (14) ensure the continuity of each route and a return to the depot of origin. Constraints (15) are subtour elimination constraints. Constraints (16) specify that a customer can be assigned to a depot only if a route linking them is opened. Finally, constraints (18) to (20) state the Boolean nature of the decision variables.

This model is based on CPLP (Capacitated Plant Location Problem) model and VRP model. The CPLP is a mono period location problem. Once defined, the network structure can not change over time. Further works would combine multi period model with the VRP.

Nagy and Salhi propose a state of the art for the LRP [30]. Authors indicate that out of specific problems for which exact methods are efficient, most of proposed methods are hybrid methods based on the decomposition into two sub problems: FLP and VRP.

Prins et al. propose a two phase iterative method [35]. The principle is to alternate between a depot location phase and a routing phase, exchanging information on the most promising edges. In the first phase, the routes and their customers are aggregated into supercustomers, leading to a facility-location problem, which is then solved by a Lagrangean relaxation of the assignment constraints. In the second phase, the routes from the resulting multidepot vehicle-routing problem (VRP) are improved using a granular tabu search (GTS) heuristic. At the end of each global iteration, information about the edges most often used is recorded to be used in the following phases. This method can be noted  $(LR) \Leftarrow ((TS) \downarrow (LS))$ .

Boccia et al. tackle a two echelon LRP [7]. A first echelon is composed of great capacity depots, generally far from the customers and a second echelon contains satellite location of less capacity. They decompose the problem in two LRP mono-echelon, each of which is then decomposed into two sub-problems: a problem of localization with capacity (CFLP - Capacitated Facility Location Problem) and a VRP multi-dpt. The authors propose a tabu search in which they combine an iterative approach on the two mono-echelon problems, and hierarchical for each of them  $((TS) \downarrow (TS)) \rightleftharpoons ((TS) \downarrow (TS))$ .

### 3.4 Le Multi-Plant Multi-Product Capacitated Lot-Sizing Problem

Les problèmes de taille de lots consistent à déterminer sur un horizon moyen terme (de 6 à 18 mois) le découpage en périodes, les quantités de produits à fabriquer de manière à minimiser la somme des coûts (production, lancement et stockage) tout en garantissant la satisfaction de la demande chaque période. Les coûts de lancement sont en général une estimation de la perte de productivité due à un changement de production et qui nécessite des réglages sur la ligne de production. La contrainte de capacité assure que le potentiel de production chaque période n'est pas dépassé. Il y a plusieurs sites de production. Le modèle présente plusieurs produits ce qui permet de gérer une nomenclature et de faire du CBN (calcul des besoins nets).

We give the mathematical model proposed by Sambasivan and Yahya [39]. Data are the following:

$M$  design the set of production sites,  $N$  the set of product types and  $T$  the set of periods.  $d_{i,j,t}$  represents the demand for product  $i$  and site  $j$  at period  $t$ .  $P_{j,t}$  is the production capacity of site  $j$  during period  $t$ .  $M_{i,j,t}$ ,  $V_{i,j,t}$  and  $H_{i,j,t}$  represent respectively production costs, setup and inventory holding costs for product  $i$  and site  $j$  during period  $t$ .  $r_{j,k,t}$  is the unitary transportation cost from site  $j$  to site  $k$ .  $u_{i,j}$  represents the production rate and  $s_{i,j}$  the lead time of product  $i$  and site  $j$ .

Decision variables are :

- $x_{i,j,t}$  quantity of product  $i \in I$  manufactured by site  $j \in M$  during period  $t \in T$ ,
- $I_{i,j,t}$  quantity of product  $i \in N$  held by site  $j \in M$  during period  $t \in T$ ,
- $w_{i,j,k,t}$  quantity of product  $i \in N$  transported from site  $j \in M$  to site  $k \in M$  during period  $t \in T$ ,
- $z_{i,j,t} = 1$  if there is a production setup for product  $i \in N$  and site  $j \in M$  during period  $t \in T$ , 0 otherwise

$$\min z = \sum_{i \in N} \sum_{j \in M} \sum_{t \in T} \left( M_{i,j,t} x_{i,j,t} + V_{i,j,t} z_{i,j,t} + H_{i,j,t} I_{i,j,t} + \sum_{k \in M \setminus \{j\}} r_{j,k,t} w_{i,j,k,t} \right) \quad (21)$$

under constraints

$$I_{i,j,t} = I_{i,j,t-1} + x_{i,j,t} - \sum_{k \in M \setminus \{j\}} w_{i,j,k,t} + \sum_{l \in M \setminus \{j\}} w_{i,l,j,t} - d_{i,j}, \quad \forall i \in N, \forall j \in M, \forall t \in T \quad (22)$$

$$x_{i,j,t} \leq \left( \sum_{j \in M} \sum b = t^T d_{i,j,b} \right) z_{i,j,t}, \quad \forall i \in N, \forall j \in M, \forall t \in T \quad (23)$$

$$\sum_{i \in N} \left( \frac{x_{i,j,t}}{u_{i,j}} + s_{i,j} z_{i,j,t} \right) \leq P_{j,t}, \quad \forall j \in M, \forall t \in T \quad (24)$$

$$x_{i,j,t} \geq 0, I_{i,j,t} \geq 0, \quad \forall i \in N, \forall j \in M, \forall t \in T \quad (25)$$

$$w_{i,j,k,t} \geq 0, \quad \forall i \in N, \forall j \in M, \forall k \in M \setminus \{j\} \quad (26)$$

$$z_{i,j,t} \in \{0, 1\}, \quad \forall i \in N, \forall j \in M, \forall t \in T \quad (27)$$

The objective function encodes the goal of the optimization, which is the minimization of the total cost, i.e., production, setup, inventory, and transfer costs. Constraints (22) refer to the inventory balance of the quantity of item  $i$  during period  $t$  at plant  $j$ . Constraints (23) ensure that if item  $i$  is produced at plant  $j$  in period  $t$  then the setup of the plant is to be considered. Constraints (24) ensure that the available capacity is not violated. Finally, constraints (25-27) impose the non-negativity of variables  $x$ ,  $I$ , and  $w$ , and ensure that  $z$  variables are binary.

Nascimento et al. propose an hybridization GRASP/Path relinking ((GRASP)  $\Leftrightarrow$  (PR)) [31]. GRASP [12] is a multi-start metaheuristic similar to iterated local search. GRASP typically consists of iterations made up from successive constructions of a greedy randomized solution and subsequent iterative improvements of it through a local search. Initially path-relinking has been proposed for Tabu search but has been successfully hybridized with genetic algorithms [37] or GRASP [38]. This technique is a way of exploring trajectories between elite solutions. The fundamental idea behind this method is that good solutions to a problem should share some characteristics. Hybridization consists in keeping a memory of the set of elite solutions and building new solutions by connecting elite solutions with those generated by GRASP.

For this kind of problem, we find a lot of work using techniques such as Lagrangian relaxation (production capacities and costs) or constraint programming. Metaheuristics are less used because it is not easy to define neighboring systems for lot sizing problem. Increasing or decreasing even slightly the quantity produced by a site during a period may impact upstream and downstream periods. An example of neighboring system is detailed by Lemoine [23]. New hybridization between metaheuristic and constraint programming seems to be a promising issue for that kind of problem.

### 3.5 Les systmes flexibles de production

Nous consacrons cette partie l'tude d'un systme logistique rduit un site de production : les systmes flexibles de production (SFP). Dans la chane logistique, les SFP sont ddis la transformation d'un produit. Les SFP sont des systmes entirement automatiss dans lesquels on retrouve des lots de production (que nous dsignerons par abus de langage par machines) interconnects par un systme de transport. Les systmes de transport les plus communent utilisss sont les vhicules automatiquement guides ou chariots filoguids. Les SFP ont la rputation d'tre coteux et difficiles piloter, mais ils offrent l'avantage d'tre flexibles, c'est--dire de pouvoir s'adapter aux fluctuations de la demande. La littrature les concernant est abondante. Nous conseillons [22] en premire lecture.

Un des intrts des SFP est que nous retrouvons l'intrieur d'un site des problmatiques analogues celles nonces pour les systmes logistiques multi-site. Nous retrouvons les problmes de conception de l'atelier avec le Facility Layout Problem qui consiste positionner les lots de production dans l'atelier de manire minimiser les flux physiques qui transiteront l'intrieur, de conception du systme de transport, du positionnement des points de chargement / dchargement, de dimensionnement de la flotte de vhicules, d'ordonnancement hors-ligne (prdictif, les vhicules utilisent un parcours prdfini pour aller d'un point A un point B), d'ordonnancement en ligne (dynamique, les vhicules dterminent leur parcours en temps rel en fonction du trafic). Ces problmes sont en gnral traits sparment en raison de leur difficult, bien que de nombreux auteurs en reconnaissent les limites.

[9] ont tudi la synchronisation verticale entre les problmes de conception et d'ordonnancement dans un SFP. Les auteurs se sont placs dans le cadre d'un ragencement d'atelier (niveau tactique) pour lequel les zones de production et le rseau de transport restaient inchangs. Seules des permutations de machines taient possibles l'intrieur des zones de production. Le problme considr se formalise sous la forme d'un problme d'affectation quadratique.

Le problme est modlis sous la forme d'un atelier de type job-shop.  $M$  dsigne l'ensemble des machines et  $L$  l'ensemble des zones de production (l'objectif tant d'affecter les machines aux zones de production, nous avons clairement  $|L| = |M|$ ).  $O$  dsigne l'ensemble des oprations effectuer,  $o_{i,j} \in O$  tant la  $i^{\text{me}}$  opration de la  $j^{\text{me}}$  pice. Une opration fictive est ajoute en dbut de gamme pour chaque pice correspondant l'entre de la pice dans l'atelier.  $O^+$  dsigne l'ensemble de toutes les oprations (relles et fictives).  $\mu_{i,j}$  renseigne sur le type de machine requis pour raliser l'oprations  $o_{i,j} \in O$  et  $\tau_{m,\mu_{i,j}} \in \{0, 1\}$  est une matrice de compatibilit entre les machines et les types. Enfin,  $t_{l_1,l_2}$  est la matrice des temps de transport entre les zones  $l_1$  et  $l_2$ .

Les variables de dcision sont :

$x_{m,l} = 1$  si la machine  $m \in M$  est affecte la zone  $l \in L$ , 0 sinon  
 $y_{o_{i,j},l} = 1$  si l'oprations  $o_{i,j} \in O^+$  est affecte la zone  $l \in L$ , 0 sinon

$$\min z = \sum_{o_{i,j} \in O} \sum_{l_1 \in L} \sum_{l_2 \in L} t_{l_1,l_2} y_{o_{j,i-1},l_1} y_{o_{i,j},l_2} \quad (28)$$

sous les contraintes

$$\sum_{m \in M} x_{l,m} = 1, \quad \forall l \in L \quad (29)$$

$$\sum_{l \in L} x_{l,m} = 1, \quad \forall m \in M \quad (30)$$

$$\sum_{l \in L} y_{o_{ji},l} = 1, \quad \forall o_{i,j} \in O^+ \quad (31)$$

$$y_{o_{i,j},l} \leq \sum_{m \in M} \tau_{m,\mu_{i,j}} x_{m,l} \quad \forall o_{i,j} \in O^+, \forall l \in L \quad (32)$$

$$x_{m,l} \in \{0, 1\}, \quad \forall m \in M, \forall l \in L \quad (33)$$

$$y_{o_{i,j},l} \in \{0, 1\}, \quad \forall o_{i,j} \in O^+, \forall l \in L \quad (34)$$

La fonction objectif minimise la somme des temps de transport (28). Les contraintes (29) et (30) assurent une bijection entre l'ensemble des machines et des zones de transport. Les contraintes (31) attribuent une zone de production à chaque opération tandis que les contraintes (32) garantissent que les opérations seront effectuées sur des machines compatibles.

Les limites de ce modèle est qu'il ne permet pas la prise en compte des déplacements charge des véhicules. Or, [4, 3] soulignent que les déplacements vides des véhicules sont aussi coûteux que les déplacements charge, et qu'il est donc important de pouvoir les prendre en compte. La difficulté est que les temps vides dépendent de la séquence des transports et sont très difficiles à estimer sauf pour des cas particuliers. [9] proposent alors une métaheuristique hybride pour résoudre ce problème tout en considérant la prise en compte des temps de transport. La première phase consiste à résoudre avec une méthode exacte le problème d'affectation quadratique présent ci-dessus. La deuxième phase prend en compte les temps de déplacement vides en utilisant une approche s'apparentant à un GRASP. Des solutions sont générées en utilisant le paradigme des colonies de fourmis. L'affectation obtenue lors de la phase 1 sert à définir les probabilités utilisées dans la construction de nouvelles affectations. Ces nouvelles affectations sont évaluées en résolvant un problème de job-shop avec transport (ordonnancement conjoint des moyens de production et de transport). La technique utilisée est une recherche locale itérative couplée avec un modèle de simulation événements discrets. Les résultats montrent que même sur des instances de petite taille (cinq zones de production), l'affectation obtenue à l'issue de la phase 1 peut être améliorée dans plus de 50% des cas. La méthode proposée se note  $((PLNE) \rightarrow ((ACS) \downarrow (ILS \rightleftharpoons simul)))$

## 4 Conclusion

Les systèmes logistiques en général, et la chaîne logistique en particulier, sont des systèmes complexes composés de nombreux acteurs qui ont chacun leur intérêt propre mais qui doivent collaborer pour que l'ensemble du système soit le plus efficace possible.

sible. Dans ce chapitre, nous avons voulu montrer toute la complexité qui pouvait résulter de l'étude de ces systèmes, et donner quelques pistes pour les résoudre. Pour cela, nous avons relayé l'intérêt que représentent les métaheuristiques pour les chercheurs du domaine. Ces méthodes d'optimisation possèdent en effet de nombreux atouts qui leur permettent de répondre beaucoup des spécificités des systèmes logistiques.

Nous avons également expliqué en quoi la prise en compte de la synchronisation horizontale et/ou verticale était pertinente. Pour ce type de problématique, la mise en place de techniques hybrides est souvent une solution qui s'impose. Nous avons introduit les concepts de chaînage, de couplage séquentiel et de couplage hiérarchique qui permettent de combiner une métaheuristique avec une autre méthode d'optimisation ou une méthode d'évaluation des performances. Si l'importance de la synchronisation dans les systèmes logistiques est reconnue depuis longtemps par de nombreux chercheurs, le champ d'investigation dans le domaine est encore largement ouvert. Avec l'apparition de problématiques émergentes telles que la logistique inverse, la logistique verte ou l'intégration de la gestion des risques, les systèmes logistiques s'enrichissent de nouvelles activités, de nouvelles règles de fonctionnement ou de nouveaux indicateurs de performances qui viennent encore largir les perspectives d'étude.

Gageons que l'activité scientifique dans le domaine restera très active durant les prochaines années.

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