PLM (Product Lifecycle Management) Model for Supply Chain Optimization

Imane Bouhaddou[1], Abdellatif Benabdelhafid[2], Latifa Ouzizi[1] and Youssef Benghabrit[1]

[1]Ecole Nationale Supérieure d'Arts et Métiers, Meknès, Morocco.
b_imane@yahoo.fr, louzizi@yahoo.fr, you_benghabrit@yahoo.fr

[2]Université du Havre, le Havre, France
abdellatif.benabdelhafid@univ-lehavre.fr

Abstract. Product Lifecycle Management (PLM) is an integrated business approach to the collaborative creation, management and dissemination of engineering information throughout the extended enterprise.

Concretely, PLM enables a supply chain to become much more competitive by an effective collaboration among customers, developers, suppliers and manufacturers at various lifecycle stages of a product.

Our objective is to propose a PLM model for a supply chain in order to increase its overall performance through better control of products at all stages of their lives. Thus, we will track product's information on a supply chain composed, as a first step, by five actors (supplier, enterprise, warehouse, transporter and customer). Indeed, by integrating the logistics constraints in the early stages of product development, this will avoid additional costs and time waste caused by a product unsuitable for its supply chain.

Keywords: Product Lifecycle Management (PLM), supply chain, integrated logistics, optimization

1. Introduction

The changes of the TIC (Communication and Information Technologies) and their democratization, have strongly influenced the companies organization, hence the need for having strategies of cooperation between firms. The enterprise tends, by necessity, towards partnership.

Nowadays, it is recognized that competition is shifting from "firm versus firm perspective" to "supply chain versus supply chain perspective". Therefore, the ability to optimize the supply chain is becoming the critical issue for companies to win the competitive advantage.

Furthermore, all members of a given supply chain must work together to respond to the changes of market demands rapidly. In the actual context, enterprises not only must enhance their relationships with each others, but also need to integrate their business processes and information systems through product life cycle activities.

Indeed, different industrial activities with strong technological character generate and manipulate a lot of technical data that need to be exchanged, managed and stored in a consistent and standardized manner. They have led to the emergence of methods and systems to manage the technical data of the engineering process. It is in this context that the paradigm of PLM (Product Lifecycle Management) was born.

We show in this article the importance of PLM as an integrating element and supply chain optimizer. This integration is done through the Information System of Integrated Logistics (ISIL)

The objective of ISIL is to contribute to integration at the conceptual level of all technical data related to a product throughout its life cycle. The concept used is the "Extended Enterprise". The ISIL involves the integration of information through the production, storage locations and transport.

The goal of integrated logistics is to achieve a complete model of ISIL, formal and approved by all partners. We consider the analysis led by three objectives:

- Modeling of the product by all technical data related to it throughout its life cycle (PLM model).
- Modeling of communication between the different components of the extended enterprise (COM model),
- Modeling the organizational goal (ORG Model)

In this article, we treat the PLM axis.

So, there are mainly two parts in this paper: In the first part, we propose a model to manage the information's product in a supply chain and throughout the entire product life cycle. The constraints of the different partners of the supply chain will be integrated in the preliminary phases of the life cycle. In the second part, we present our optimization problem which aims to design simultaneously the product and its supply chain in a PLM context.

2. Concept of PLM

Manufacturers are facing increasing challenges of better product quality with tighter delivery requirements for customers and more profitability for shareholders. So, an effective collaboration among customers, developers, suppliers, and manufacturers throughout the entire product lifecycle is becoming much more important for the most advanced competitiveness.

PLM enables manufacturing organizations to obtain competitive advantages by creating better products in less time, at lower cost and with fewer defects than ever before.

From the different definitions of PLM in the literature, we chose the ones that suit with our context.

CIMdata [1] defines PLM as: "A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination and use of product definition information across the extended enterprise from concept to end of life, integrating people, processes, business system, and information ".

PLM can also be defined as “the capability to manage, coordinate and execute all the engineering and management activities along the product lifecycle to deliver products to the final user at acceptable acquisition and utilization cost” [2].

A PLM approach must "integrate and make available *all* information produced during *all* phases of the cycle product life for *all* stakeholders of the organization "[3].

In summary, PLM not only provides process management throughout the entire product lifecycle, but also enables effective collaboration among networked participants in product value chain, which distinguishes it from other enterprise application systems, such as enterprise resource planning (ERP), supply chain management (SCM), customer relationship management (CRM), etc [4].

Indeed, in an extended enterprise context, PLM support needs to connect the product design and analysis processes to the production and supply chain processes, including: product data management (PDM), component supplier management (CSM),enterprise resource planning (ERP), manufacturing execution systems (MES), customer relationship management (CRM), supply and planning management (SPM), and others that will undoubtedly follow. The benefits of PLM will be realized only when these disparate systems are horizontally integrated [5].

3. Product Lifecycle

We will adopt for our PLM model, a lifecycle composed by three main steps:

A first step "Beginning of Life" which includes the phases of:

- Requirements definition (customer requirements, feasibility study). At this level, the product is in draft form (project).
- Product development including design (the product will be called 'digital mock up' (DMU), prototyping and testing (the product is called 'prototype').

A second stage "Middle of life" where there are phases of:

- Production, which may be very complex and often includes manufacturing, assembling, quality control. We are talking here about 'product'.

- Distribution which includes storage, transportation and delivery (finished product)
- Use of the product by the customer: this is the proper product life phase and it represents all activities which take place during product use: they comprise product usage and consumption, maintenance and support.

And a third step "End of Life" which includes the phases of dismiss, disposal and recycling.

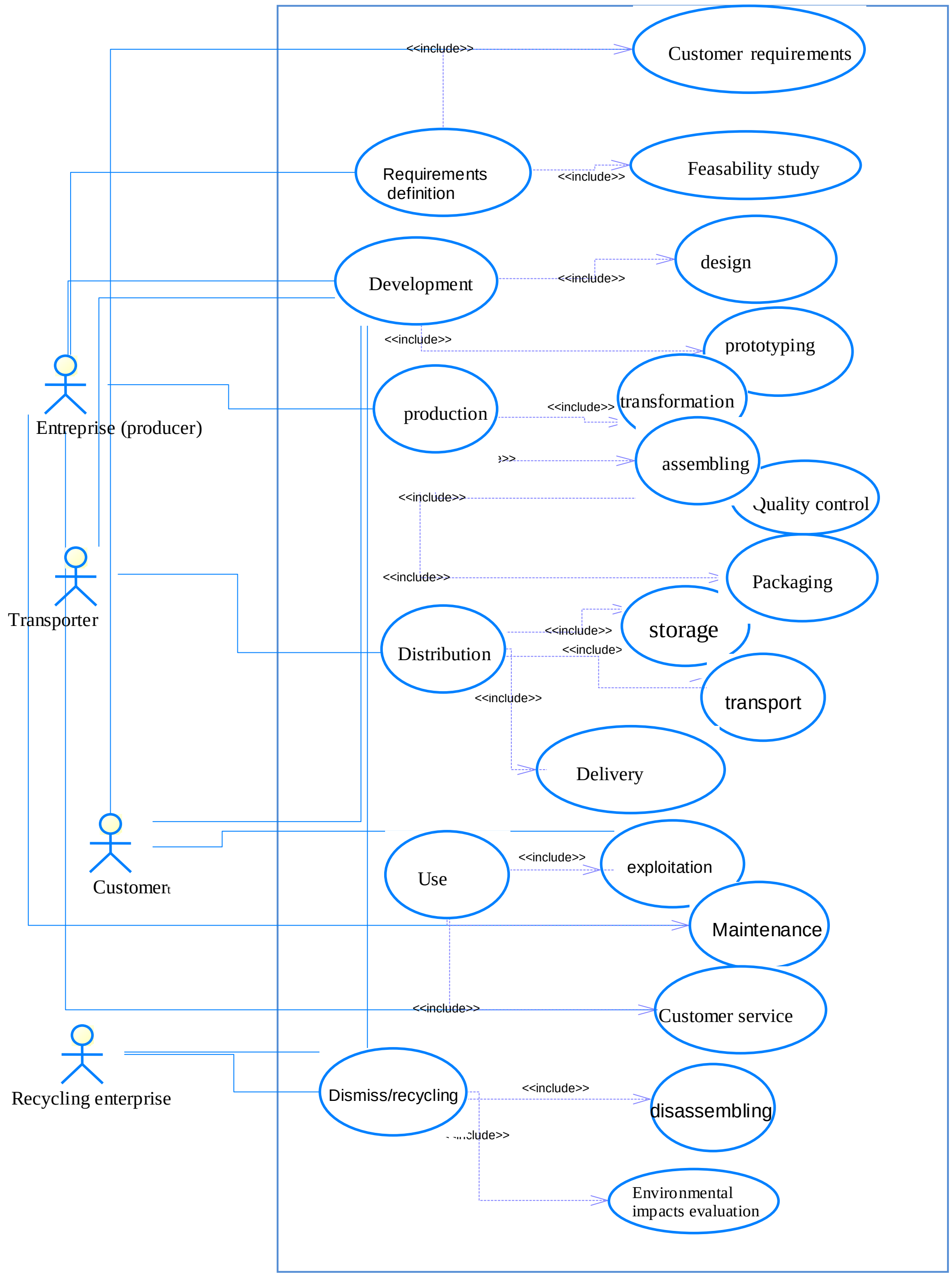

Fig. 1. Use case diagram modeling the product lifecycle (PLM approach)

4. Interaction between Product Lifecycle and its Supply Chain

The product lifecycle does not evolve without interaction with all the stakeholders of a given supply chain.

Indeed, in a PLM environment, there is a collaboration between several members of the chain in the early phases of the lifecycle, particularly in the product development phase : the constraints of production, suppliers' constraints, transport's constraints and customers' constraints are integrated in the digital mock up.

We considered a linear chain structure (or sequential) in which each entity of the chain supplies a downstream single entity.

The customer expresses its requirements and participates, with all others members of the chain, in defining the product's specifications. The enterprise (producer) collects all the feasible solutions to choose the one that minimizes the cost and the lead time (of design, production and transportation) and maximizes the quality. Then, it carries out production after being supplied with raw materials. As for the warehouse, after participating in the definition of the specifications, it handles the storage of finished or semi-finished products. Finally, the transport provider is responsible for distributing the products to the customer.

After analyzing different business models [6] and [7], we will consider a chain that works with build to order business model (BTO). In fact, BTO model uses more PLM approach because of the involvement of the customer and other partners in the product design. BTO is the business model that most frequently applies all PLM modules due to its focus of customized product design [8].

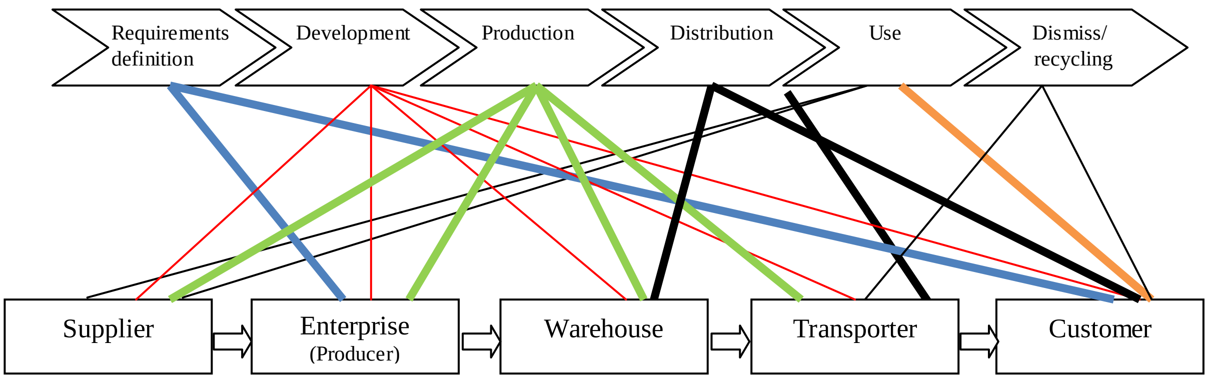

Fig. 2. Interaction between product lifecycle and its supply chain (with PLM approach)

By adopting a PLM approach, every member of the chain will contribute to the product development. Hence, they enhance their relationships with each others; integrate seamlessly their business processes and information systems for product lifecycle activities. PLM enables all activities in supply chain to operate more efficiently and coherently.

5. Logistics Constraints Integration

The literature suggests some methods that can facilitate the integration between engineering and logistics actors like Design For Logistics [9] and Design for Supply Chain Management [10]. These methods aim to formalize and clarify the criteria and rules to optimize logistics costs. The impact of these proposals in the product design is on two levels:

- In terms of choice of product architecture: modularity is recommended (response to the diversity of demand, delayed differentiation)
- In terms of components: standardization and reducing references are searched.

The work of Koike [11] consists of the use of an interface-based approach (Logistic Profile) to integrate logistics constraints in the early phases of product lifecycle especially in the phase of design. The tool allows the translation from the design view of an intermediary concept solution into its logistic view, fostering mutual learning between team members.

Our approach is to use PLM (tool and strategy) to take into account supply chain constraints in the preliminary phases of the lifecycle because 85% of logistics costs are driven by design choices [12] and over 70% of product cost is determined by decisions during this phase of development [13].
Indeed, the PLM

- manages product information from the beginning to the end of the lifecycle
- reduces costs and time of product development by taking into account the earlier constraints of the entire supply chain [14].
- improve collaboration with the different stakeholders of the supply chain

Our goal then is to design simultaneously the product and its associated supply chain. This supply chain should be, of course, optimized.
The mathematical models are no longer sufficient to optimize the supply chain and it is necessary to opt for a hybrid approach combining mathematical model and PLM.

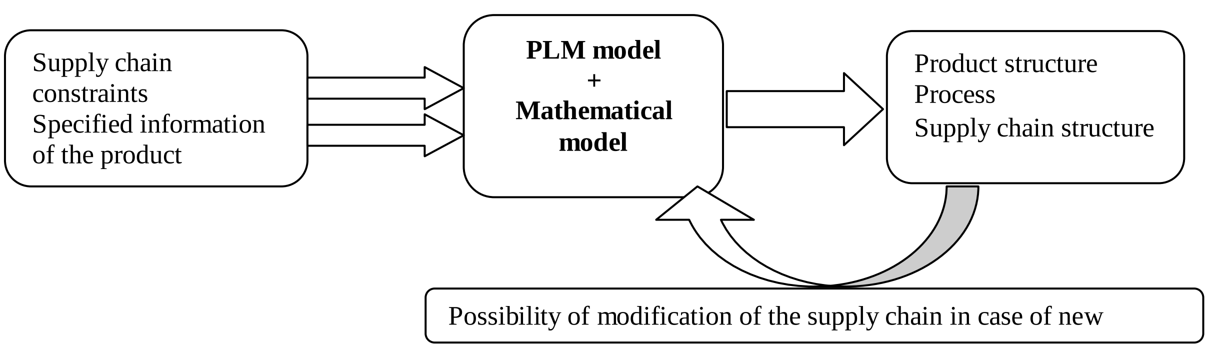

Fig.3. ISIL combining mathematical model and PLM model

The changing market, the instability of the environment, the change of sourcing (because of costs' constraints), the launching of new products continuously and the changes in the industrial process imply constant changes in the choice of transport modes, the location of suppliers and the organization of the whole supply chain.
So, PLM will make necessary modifications on each member of the supply chain whenever there are new hazards.

6. PLM Model Integrating Lifecycle and Supply Chain

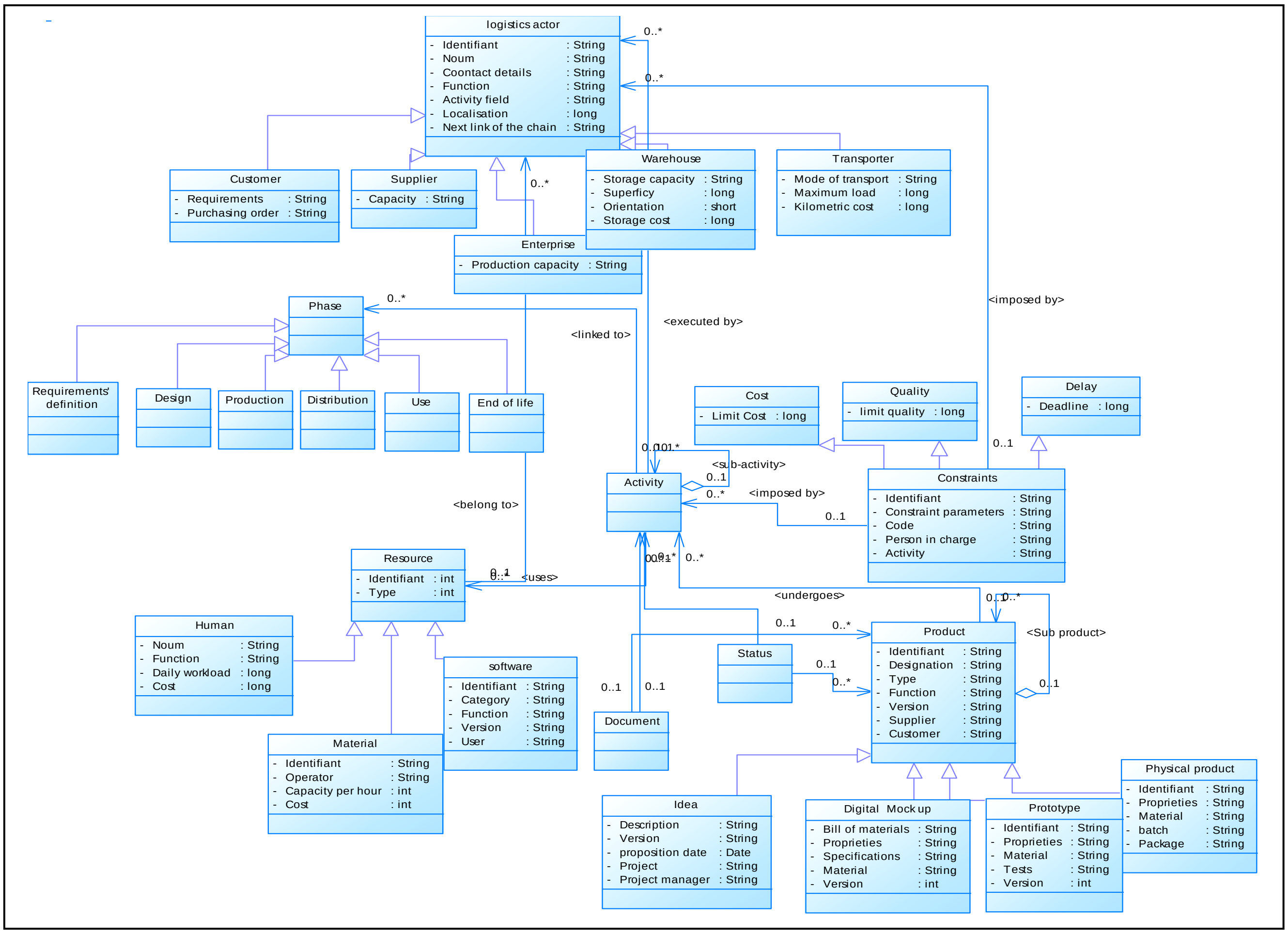

Fig. 4. PLM model integrating supply chain

The class "constraints" receives its elements either from members of supply chain or the activities done on the product during its lifecycle (each phase of the lifecycle has some activities). Indeed, the entity "product" receives constraints from the entity "constraints" which are incorporated by the designer in the pre-conception phase to select one solution among many. So, the designer considers the constraints as a criterion to evaluate all the preconception solutions. Finally, he selects an optimal solution minimizing a criterion (eg. one that minimizes transportation costs).

The relation 'product-document' allows better traceability and data capitalization so it will enhance the exchange of information in the supply chain and then improve its performance. In fact, the product has an intelligence characteristic (holonic approach used in [15]).

7. Supply Chain Optimization

Each element of the supply chain (supplier, enterprise, warehouse, transporter and customer) is represented by an UML class as described in the previous paragraph. Each class will be fitted by the mathematical model that optimizes this element. Our approach is local (we optimize each element in order to optimize the overall supply chain). This will allow us to make the necessary modifications on each element whenever there are changes in the general environment. The supply chain becomes then more flexible and more agile.
In a PLM context, when designing a new product, designers, manufacturers and other members of the extend enterprise have to define simultaneously the product structure and its supply chain.

Literature proposes different approaches to define simultaneously the product structure and its supply chain.
Lee [16] shows that the product design choices (modular design, standardization or delayed differentiation) have a strong influence on the supply chain design. Hence it is important to determine simultaneously the product family design and its associated supply chain. Agard and Penz [17] propose a model to determine the optimal set of modules able to define the bill of material of each finished product and to minimize assembly and production costs. Lamothe and al. [18] use a generic bill of material representation in order to identify simultaneously the best bill of material for each product and the optimal structure of the associated supply chain.

In these works, the authors focus on modular design and standardization. The production policy consists on manufacturing pre-assembly components, called modules that will be manufactured in distant facilities and shipped in a nearby location plant for a final assembly operation under time limits.

In our approach, we consider a product without standard components. It is composed by two levels of nomenclature (Finished product (FP), semi-finished products (SF) and raw materials (RM)).

The problem integrating supplying-production-storage-distribution aims to minimize the supplying costs, production costs (fixed and variable), storage costs and distribution costs (from enterprise to warehouse and from warehouse to customer.

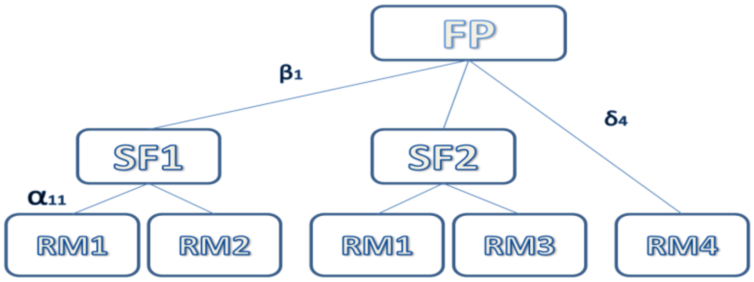

Fig. 5. The studied bill of material of the product

We consider two types of operations on the product: transformation (or manufacturing) of the raw material into semi-finished product and assembling of the semi-finished to have the final product or assembling of raw materials into the final product (without transformation).

7.1 Indexes

j:	raw material	j =1…… ...…...J
i:	semi-finished product	i =1………..….N
p:	supplier	p = 1………….P
k:	warehouse	k =1……….....K
l:	customer	l =1…………...L
m:	mode of transport	m =1…..……...M
t:	period	t =1…………..T

7.2 Minimizing supplying costs : Min Z1

$$Z1= \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{t=1}^{T} Cpurchase_{p,j,t} * Q_{p,j,t} + \sum_{p=1}^{P}\sum_{m=1}^{M}\sum_{j=1}^{J}\sum_{t=1}^{T} Ctransp_{p,m,j,t} * Q_{p,m,j,t}$$

$Cpurchase_{p,j,t}$: unit purchasing cost of the raw material j from the supplier p during the period t.
$Ctransp_{p,m,j,t}$: unit transportation cost of the raw material j from the supplier p , using the transport m, during the period t.
$Q_{p,m,j,t}$ *(decision variable)* : supplied quantity of the raw material j from the supplier p during the period t and transported by the mode of transport m.

Constraints:

$$Q_{p,j,t} \leq Qmax_{p,j,t} \quad \text{for each supplier p} \qquad (1)$$

$$\sum_{p=1}^{P}\sum_{t=1}^{T} Q_{p,j,t} = [\sum_{i=1}^{N}(\beta_i * \alpha_{ij}) + \delta j\,]\ X(t) \qquad (2)$$

$$Tsupplying \leq Tassembly \quad (3)$$

$Qmax_{p,j,t}$: the maximum quantity of raw material j that can be delivered by the supplier p during the period t
$Tassembly$: time required for assembly
α_{ij} : number of the raw material j required for the manufacturing of the semi-finished product i.
β_i : number of the semi- finished product i required for the assembly of the final product.
δj : number of the raw material j required for the assembly of the final product.
$X_{(t)}$: finished product quantity

(1) : Respect of the supplier capacity
(2) : Respect of the bill of material
(3) : Respect of the supplying delay

7.3 Minimizing production costs: Min Z2

$$Z2 = Cfa + Q * (\sum_{i=1}^{N} \beta_i * Ca_i + \sum_{j=1}^{J} \delta_j * Ca_j) + Cfm + Q * (\sum_{i=1}^{N} \beta_i * (\sum_{j=1}^{J} \alpha_{ij} * Cm_j))$$

Cfa : fixed cost of assembly
Ca_i : cost of assembly of the semi-finished product i
Ca_j : cost of assembly of the raw material j
Cfm : fixed cost of manufacturing
Cm_j : cost of manufacturing (transformation) of the raw material j
Q: Requested quantity

Constraints:

$$Tproduction \leq Tdelivery \quad (4)$$

With $Tproduction = Qe * [Q/Qe] * Tu \quad \text{if } Q/Qe \text{ is an integer}$
$= Qe * ([Q/Qe + 1) * Tu \quad \text{if not}$

$$Tu = max\ [max\ i\ [\beta_i * Da_i + max\ j\ (\alpha_{ij} * Dt_j)]\ ; max\ j\ (\delta_j * Da_j)]$$

$$C_{assembly} = Q * (\sum_{i=1}^{N} \beta_i * Da_i + \sum_{j=1}^{J} \delta_j * Da_j) \leq Cap_{assembly} \quad (5)$$

$$C_{transf} = Q * (\sum_{i=1}^{N} \beta_i * \sum_{j=1}^{J} \alpha_{ij} * Dt_j) \leq Cap_{transf} \quad (6)$$

Qe : batch size
Da_i: assembly time of the semi-finished i in the product
Dt_j : transformation time of the raw material j in a semi-finished product
Da_j : assembly time of the raw material j in the finished product
$C_{assembly}$: the load caused by the assembling operations

C_{transf} : the load caused by the transformation operations

(4) : Respect of time delivery
(5) : Respect of the assembly capacity in the production site
(6) : Respect of the transformation capacity in the production site

7.4 Minimizing transport costs: Min Z3

$$Z3 = \sum_{k=1}^{K}\sum_{t=1}^{T}\sum_{m=1}^{M} CT_{ktm} * X_{ktm} + \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{t=1}^{T} CT'_{lktm} \; Y_{lktm}$$

CT_{ktm}: unit transportation cost of the final product transported from the enterprise to the warehouse k using the means of transport m
CT'_{lktm}: unit transportation cost of the final product transported from the warehouse k to the customer l via the transport m
X_{ktm} *(variable decision)*: quantity of the final product transported from the enterprise to the warehouse k via the transport m
Yl_{ktm} *(variable decision)*: quantity of the final product transported from the warehouse k to the customer l via the transport m

With constraints:

$$X_{ktm} \leq C_{1m} \tag{7}$$

$$Y_{lktm} \leq C_{2m} \tag{8}$$

$$Y_{t-l} = \sum_{k=1}^{K}\sum_{m=1}^{M} X_{km(t-L')} \tag{9}$$

$$D_{lt} = \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{m=1}^{M} Y_{lkm(t-L')} \tag{10}$$

C_{1m}: Capacity of the transporter m_1 between enterprise and warehouse
C_{2m}: Capacity of the transporter m_2 between warehouse and customer
D_{lt} : Product demand required by the customer l in the period t

(7): Respect of the transporter capacity (transporter m_1 between the enterprise and warehouse k)
(8): Respect of the transporter capacity (transporter m_2 between the warehouse k and customer l)
(9): The quantity produced in the enterprise j is transported to the warehouse k
(10): The quantity required by the customer l in the period t is satisfied

7.5 Minimizing storage costs: Min Z4

$$Z4 = \sum_{k=1}^{K}\sum_{t=1}^{T} W_{kt} * Cs_{kt}$$

Cs_{kt}: Storage cost of the product in the warehouse k in the end of the period t
W_{kt} *(decision variable)*: Stock level of the product in the warehouse k in the end of the period t

With constraints:

$$W_{kt} \leq Caps_k \quad (11)$$

$$W_{kt} = W_{k(t-1)} + \sum_{k=1}^{K} \sum_{m=1}^{M} X_{ktm} - \sum_{l=1}^{L} \sum_{k=1}^{K} \sum_{m}^{M} Y_{lktm} \quad (12)$$

$Caps_k$: Storage capacity of the warehouse k

(11): Respect of the storage capacity of the warehouse
(12): Stock level of the product in the warehouse k in the end of the period t

For a bill of material BOM, we have an optimized supply chain (Z1, Z2, Z3, Z4). If we change the bill of material of the same product (BOM'), we will have another supply chain structure (Z1', Z2', Z3', Z4').
The optimization problem will be solved and applies to a case study in our future work.

8. Conclusion

The competitiveness of a product on the market no longer depends on the company that assembles or sells it, but to all companies involved in the manufacturing process of this product and thus its entire supply chain. Therefore, the complex management of an extended enterprise has increased needs for information exchange, sharing and archiving.

Our work contributes to the field of integrated engineering, specifically the integrated logistics in the early stages of the product lifecycle using PLM.
Concretely, PLM enables a supply chain to become much more competitive by an effective collaboration among customers, developers, suppliers and manufacturers at various lifecycle stages of a product.

We proposed a model to manage the product's information in a supply chain and throughout the entire product life cycle. Then, we showed the importance of the integration of logistic constraints in the preliminary phases of the life cycle. This will avoid additional costs and time waste caused by a product unsuitable for its supply chain.

Our next work will be to further develop this PLM model in order to optimize the supply chain. The PLM model classes representing the different partners of the supply chain will be fitted with decision support tools to select, for example, the best supplier or the best transporter. We will validate our PLM model and optimization problem on a case study.

References

1. CIMdata: Inc.,Product Lifecycle Management,"Empowering the future of business", 2003.

2. Garetti M., Macchi M., and Van De Berg R.: Digitally supported engineering of industrial systems in the globally scaled manufacturing, IMS-NoE SIG White Paper, Milano, 2003

3. Sudarsan R., Fenes S. J., Sriran R. D., Wang F.: A product modeling framework for product lifecycle management, Computer-aided design, vol. 37, 2005,

4. Ming X.G., Yan J.Q., Wang X.H., Li, S.N., Lu W.F., Peng Q.J., Mad Y.S.: Collaborative process planning and manufacturing in product lifecycle management, Computers in Industry 59 (2008) 154–166, Elsevier, 2007.

5. Rachuri S., Subrahmanian E., Bouras A., Fenves S., Foufou S., Sriram R.: Information sharing and exchange in the context of product lifecycle management : Role of standards, Computer-Aided Design 40 (2008) 789-800, Elsevier, 2008

6. François J.: Planification des chaînes logistiques : Modélisation du système décisionnel et performance, Thèse de doctorat, Université de Bordeaux 1, 2007

7. Thomas A.: Impact du concept de chaîne logistique sur les systèmes de gestion de production – Le nouveau rôle de la planification tactique et les nouveaux outils. Ecole d'été d'automatique – Gestion de la Chaîne Logistique. Session 24, Septembre 2003, Grenoble, France.

8. Chiang T., Trappey A.: Development of value chain collaborative model for product lifecycle management and its LCD industry adoption. Int. J. Production Economics 109 (2007), p. 90-104.

9. Dowlatshahi S.: The role of logistics in concurrent engineering, International Journal of Production Economics, 44, pp.189-199, 1996.

10. Lee, H.L., Billington C.: Managing supply chain inventory: pitfalls an opportunity, Sloan Management Review 33, 3, pp. 65-73, 1992.

11. Koike T.: Les interfaces pour l'intégration de la logistique dans les projets de conception-Une contribution basée sur le cas du projet d'un tracteur à chenilles, thèse de doctorat, Institut National Polytechnique de Grenoble, 2005

12. Laurentie J., Berthelemy F., Grégoire L., Terrier C.: Processus et méthodes logistiques, Supply chain Management, AFNOR, 2006

13. H'mida F., Martin P.: L'estimation des coûts en phase de conception : un cadre d'aide à la décion, CPI'07, 2007

14. Tang D., Qian X.: Product Lifecycle Management for automotive development focusing on supplier integration, Computer in Industry 59 (2008) 288-295, Elsevier, 2008

15. Terzi S., Cassina J., Panetto H.: Traçabilité des produits : une approche holonique, 5ème conférence francophone de Modélisation et Simulation, MOSIM'04 du 1er au 3 septembre 2004- Nantes, France.

16. Lee. H.L.: Product universality and design for supply chain management. Production Planning and Control, 6(3):270-277, 1995.

17. Agard B., Penz B.: A simulated annealing method based on a clustering approach to determine bills of materials for a large product family. International Journal of Production Economics (2007).

18. Lamothe J., Hadj-Hamou K., Aldanondo M.: An optimization model for selecting a product family and designing its supply chain. European Journal of Operational Research, 169:1030-1047, 2006.