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Lean Distribution

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DEPARTMENT OF MANAGEMENT AND ENGINEERING
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DOCTORAL SCHOOL OF INDUSTRIAL ENGINEERING
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CYCLE XXII

LEAN DISTRIBUTION

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Mechatronics and Industrial Systems

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INTRODUZIONE

Il tema della distribuzione, e quindi della logistica distributiva, è oggi sempre di più al centro del dibattito e coinvolge contemporaneamente attori diversi all'interno dell'intera comunità internazionale: il mondo delle aziende, il mondo della Ricerca Universitaria ed in molti casi le nazioni e le organizzazioni internazionali.

A livello macroeconomico negli ultimi anni i confini dei mercati di riferimento all'interno dei quali operano le aziende e il livello di competizione sono drammaticamente mutati.

Tali trend hanno a loro volta modificato significativamente la struttura delle reti distributive che sono diventate più grandi e più complesse.
Al tempo stesso gli obiettivi che ogni rete distributiva si deve porre sono diventati ancora più sfidanti: la minimizzazione dei costi totali (trasporto, gestione delle scorte e movimentazione dei materiali) e dei tempi di attravarsamento delle merci da un lato, la massimizzazione del livello di servizio e della qualità distributiva dall'altro.

Il lavoro di ricerca svolto durante gli anni di dottorato è basato sullo studio, sulla comprensione delle reti distributive e sui modelli e le tecniche di ottimizzazione di questo elemento cardine dell'Operations Management.

Gli obiettivi che si pone questo lavoro possono essere quindi esplicitati attraverso i seguenti punti:

1) Studiare in maniera critica il funzionamento, la struttura di costi e l'organizzazione delle reti distributive e la loro ottimizzazione.

2) Comprendere in modo profondo quali sono le logiche costituenti la lean production e il Toyota Production System che persegue gli stessi obiettivi delle moderne reti distributive: riduzione dei costi e dei lead time, e aumento della qualità e del livello di servizio.
3) Analizzare come l'approccio e le tecniche *lean* possano essere trasferite da un ambito squisitamente produttivo ad un ambito distributivo; e come questo può impattare i modelli di ottimizzazione di una rete distributiva.

La struttura della Tesi riflette gli obiettivi che il lavoro di Ricerca si pone e si arrichisce di due pubblicazioni scientifiche, di cui sono co-autore, che rappresentano il carattere innovativo e sperimentale dello stesso percorso di Ricerca.

ABSTRACT

The distribution topic plays today a more and more central role in the public debate and at the same time involves different actors within the global community: the world of companies, the world of Academic Research and in many cases nations and international organizations.

In recent years, at the macroeconomic level, the boundaries of the markets within which companies play and the competition level have dramatically changed.

These trends have also significantly modified the distribution networks structure: they have become definitely larger and more complex.
At the same time the objectives that each distribution network has to pursue, have became even more challenging: the continuous total costs (transportation, inventory management and material handling) and lead times minimization on the one hand, service level and quality in the distribution maximization on the other hand.

The research work done during the PhD program is based on the study, the understanding of the distribution networks and on the optimization models of this Operations Management's pivotal point.

The goals set by this work can be easily summarized through the following elements:

1) Critically study the operations, the costs' structure and the organization of distribution networks and their optimization models.
2) Deeply understand the rationales and techniques behind the Lean Production and the Toyota Production System, which pursue the same

objectives of the modern distribution networks: reducing costs and lead times, and increase the quality in the distribution and the service level.

3) Analyze how the *lean* approach and techniques can be transferred from a strictly manufacturing environment to a distributive one; and how this can influence the distribution network optimization models.

Thesis' structure reflects the objectives that the research work sets and it is enriched by two attached scientific papers, of which I'm co-author, that represent the innovative and experimental character of the same Research path.

ACKNOWLEDGEMENTS

First person I want to thank is Professor Alessandro Persona: he has introduced my self to the topics of Logistics and Industrial Plants and he has always supported me to achieve significant results, both at the Academic and at the professional level.

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I am grateful to Professor Alberto Trevisani, Curriculum Coordinator, for helping and assisting me over during this path over years.

I am indebted to Maurizio Faccio for providing me insights, energy and a lot of discussions during so many days spent working together. Many thanks also to the other members of the Industrial Plants team I had the pleasure to work with, Daria Battini e Fabio Sgarbossa.

Dedicated to Chiara and Our Future

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1 Distribution Network

1.1 Distribution Network definition and role within a Supply Chain

Logistics and more in general Supply Chain Management have to be considered as a whole discipline: their operations and their components cannot exist in isolation.
A distribution network can be defined as the *infrastructure* across which goods move from different business entities (i.e., suppliers, manufacturers, distributors and retailers) to other ones, all belonging to the same supply chain.
Distribution networks and more in general supply chains are becoming more and more crucial strategic levers in order to win the market competition.
Their full control and optimization allow to the organizations to improve both *internally* and *externally*.
Internally because the distribution network cost control is vital to understand and then minimize the supply costs in order to maximize the company's profitability.
Externally means that a company understanding and controlling the distribution network used to serve their customers can leverage an important competitive advantage by tuning the presence in a particular geographical area or the service level dedicated to a certain customer. These elements can support the new market entry, the market share growth or a new client acquisition.
This chapter firstly aims to give a clear understanding of the cost drivers impacting the distribution network management and then to offer a distribution network classification, or taxonomy.

Then a complete review of existing literature, in terms of distribution network design and optimization, is examined.
Finally the chapter closes with the presentation of an innovative model developed within the research team led by Professor Alessandro Persona, basically my first *formal* step of my academic work.

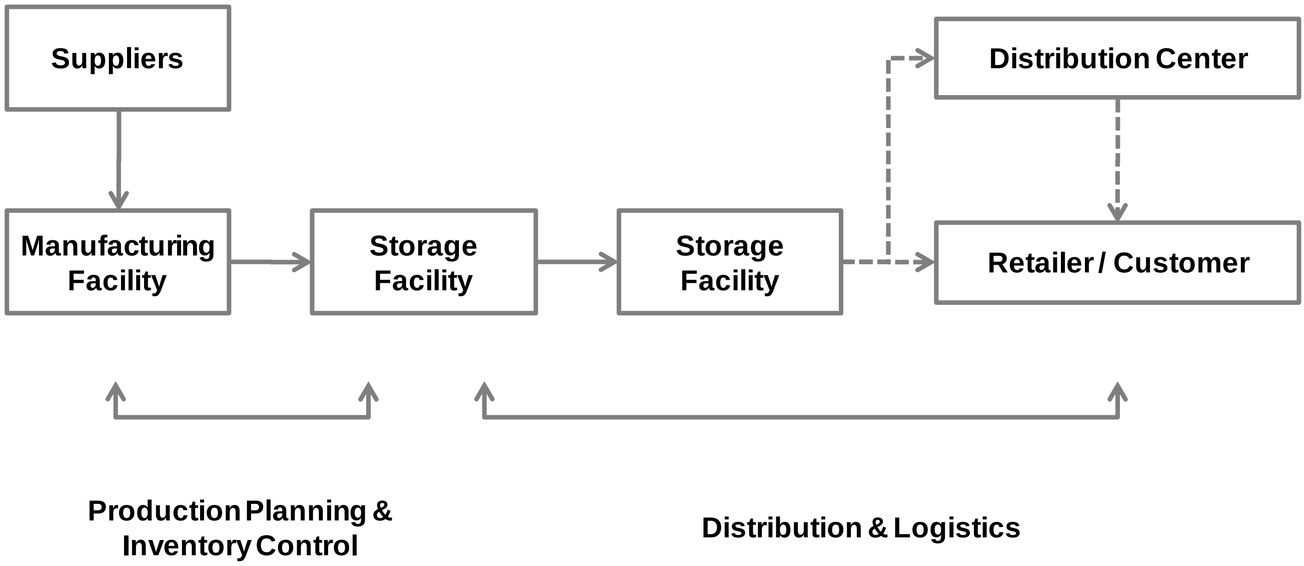


Fig 1.1: The interaction of a distribution network within a supply chain system (Beamon, 1998)

1.2 Cost structure in a distribution network

Distribution networks performance and differentiation (S. Chopra, 2003) basically depends on two *clusters* of variables:

- Customers needs that are met (*revenues* side)
- Cost of meeting customer needs (*cost* side)

Then the goal for a distribution network's key decision makers is serving the customer in the most effective and efficient way. In the next part of the chapter we will observe that most of the variables belonging to the two clusters of variables are often in trade-off among themselves.

Customer needs *impactable* trough the distribution network management

Meeting customers' needs means increasing revenues, one of the two crucial profit's dimensions. To pursuit this goal, Operations manager can lever some distribution network core dimensions:

- Response time is the time frame between the customer's order placement and the entire order content receipt
- Product variety is the product/products family set that a customer can demand to a company or in more in general to a distribution network
- Product availability is the condition for which a distribution network can deliver to the customer the right product, in the right quantity, in the right condition, in the right place at the right time.
- Customer experience is the ease with which a customer can place and replace an order to a distribution network
- Order visibility is the opportunity for a customer to track the delivery from the order placement until the receipt of the order's content
- *Returnability* is the ease that allows to a customer to give an unsatisfactory good

The below chart in Figure shows the effects, in terms of facilities investment, of reducing the lead time to satisfy the market demand: the more the desired time to serve a customer decrease, the more the number of required facilities increases.

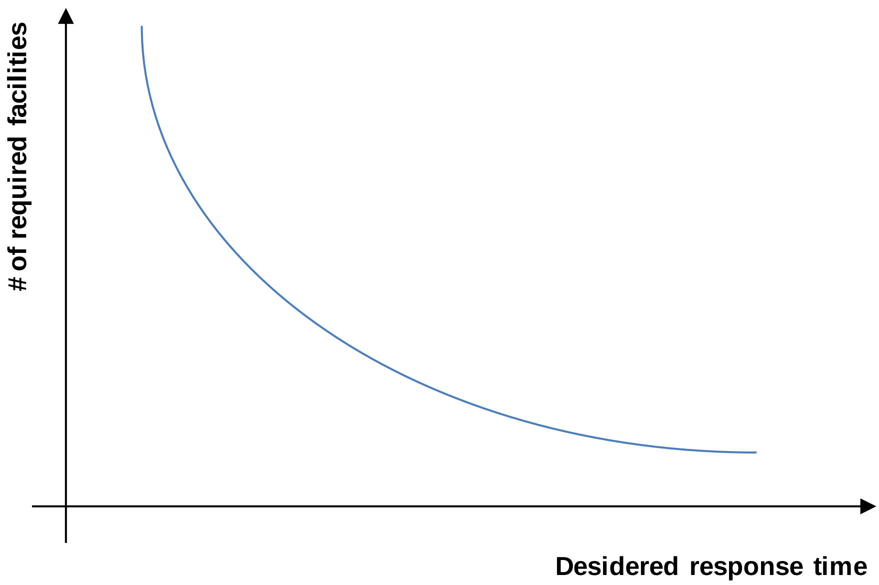


Fig 1.2: Relationship between desired response time and number of facilities (S. Chopra)

<u>Cost drivers behind a distribution network management</u>

As in every business environment also in a distribution network is fundamental considering the cost *side* of the problem. Key cost drivers to be taken in account are:

- <u>Inventories and holding</u> costs are created by warehousing and storage activities, and by plant and warehouse site selection. Companies are often at various levels of sophistication in terms of warehouse accounting and control. Major inventory cost drivers are:
  - ✓ Capital costs, or opportunity costs, which is the return a company could make on the money tied up in inventory

- ✓ Inventory service costs, which includes insurance and taxes on inventory
- ✓ Storage space costs, which include those warehousing space-related costs relative to level of inventory
- ✓ Inventory risk costs, including obsolescence, pilferage, movement within the inventory system and damage.

– Transportation costs include all costs involved in the movement or transport of a shipment. Transportation costs can be categorized by customer, by product line, by type of channel, by carrier, etc. The costs vary considerably with volume, weight of shipment, distances, transport mode, etc. Key transportation cost drivers are:
  - ✓ Goods delivery quantities
  - ✓ Physical characteristics of goods delivered
  - ✓ Transportation policy used (direct delivery/groupage and inter-company shipment/company-to-customer shipment)
  - ✓ Distance

– Facilities and handling are all the costs related to the internal movement and internal transportation. This means the cost of the adopted equipment, the cost of employees dedicated to internal handling (usually these workers belong to an external player, a cooperative, and this is the reason why this handling cost driver can be considered a variable cost in a short/medium time horizon)

– Information and other technology costs are increasing more and more their relative importance on the total costs related to a distribution network management. In particular they include: RFID tracking systems, inventory management software and more in general all the cost linked to the flow of information with the network.

– *Lack of service level* costs: all the cost that a distribution network's actor has to pay in order to balance a lack in the service dedicated to meet customers' expectations (eg: delay, lack of compliance in terms of quality, quantity, etc). This cost category is highly dependent from the type of served customer, the type of delivered goods and more in general to the reference industry which the distribution network and the corresponding supply chain belongs to.

Figure 1.3 shows how different cost key drivers' are impacted by the different number of facilities adopted to satisfy the market demand. The figure underlines the concept economies of scale assume different meaning for different network distribution cost functions (Inventory, facility and transport)

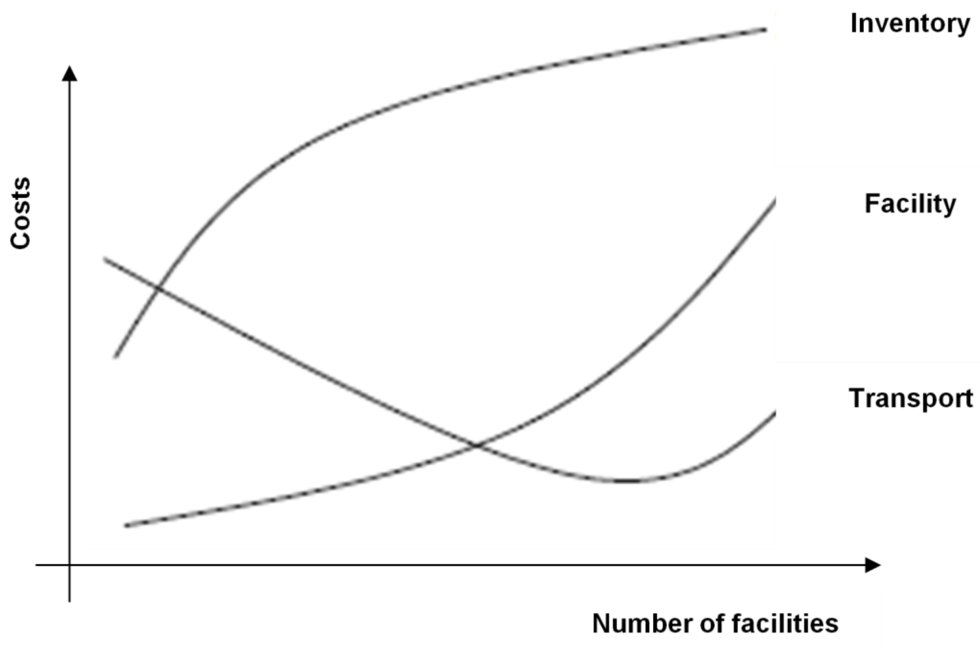


Fig 1.3: Relationship between number of facilities and logistics cost (S. Chopra)

As anticipated above distribution network core dimensions and related cost drivers are clearly used to be in a trade-off position.

The next chart (Figure 1.4) allows investigating how some elements of the two sides of a network (revenues enablers side and the cost side) are dependently linked. In particular, as a firm wants to further reduce the response time to its customers, it may have to increase the number of facilities beyond the point that minimizes logistics costs. A firm should add facilities beyond the cost-minimizing point only if managers are confident that the increase in revenues because of better responsiveness is greater than the increase in costs because of the additional facilities

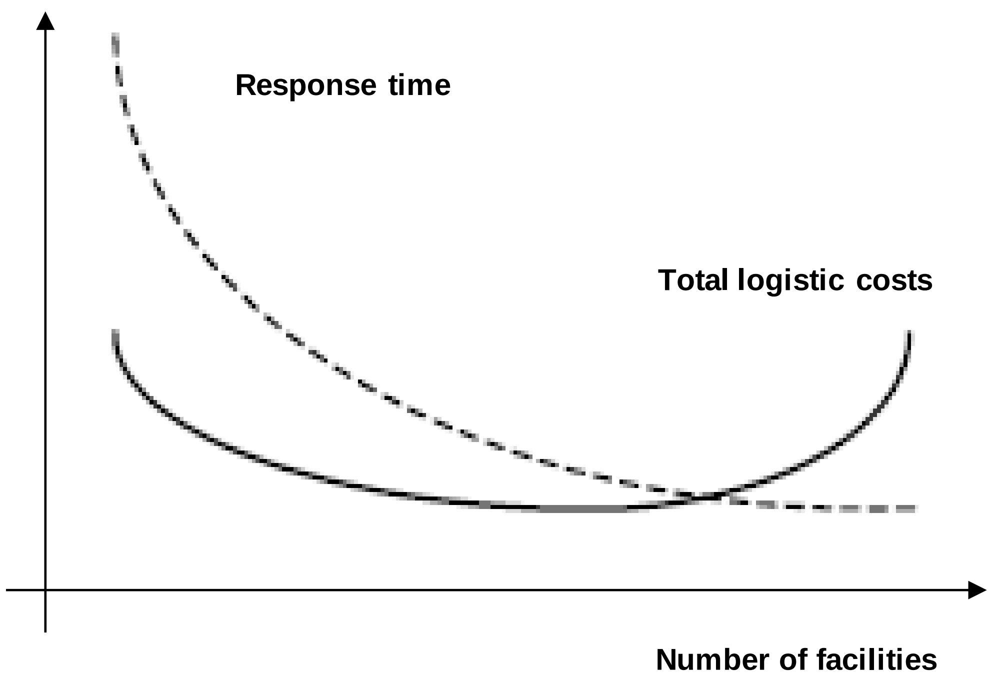


Fig 1.4: Variation in logistics cost and response time with number of facilities (S. Chopra)

1.3 Distribution network taxonomy

Based on previous paragraph (1.2) assumption, distribution networks performance and differentiation basically depends on two clusters of variables:

- Customers needs that are met
- Cost of meeting customer needs

According to Chopra (2001, 2003) there are two key questions to be answered in order to effectively design a distribution network:

i. Will product be delivered to the customer location or picked up from a preordained site?
ii. Will product flow through an intermediary (or intermediate location)?

Based on the choices for the two decisions, there are six distinct distribution network designs:

1. Manufacturer storage with direct shipping
2. Manufacturer storage with direct shipping and in-transit merge
3. Distributor storage with package carrier delivery
4. Distributor storage with last mile delivery
5. Manufacturer/distributor storage with costumer pickup
6. Retail storage with customer pickup

1.3.1 Manufacturer storage with direct shipping

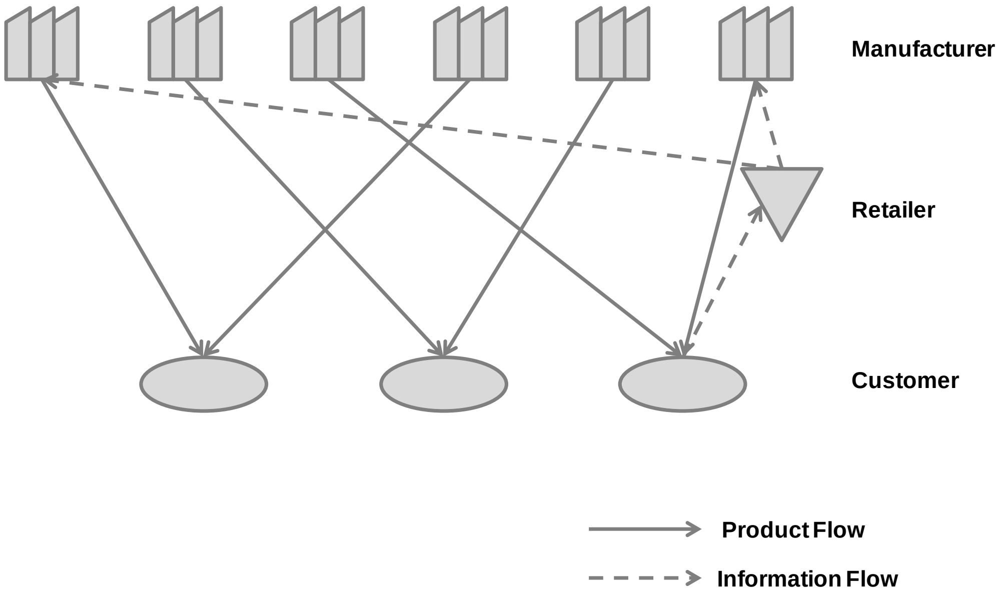


Fig 1.5 : Manufacturer storage with direct shipping (S. Chopra, 2003)

This distribution option, also known as *Direct Delivery Distribution* (Bowersox et al., 2002, Lumsden K., 2002), implies that goods are directly delivered to the customers without any material's stop in an intermediate logistic point.

For this reason all inventories are stored at the manufacturer.

The only role that an intermediate logistic point can play is conveying the information from downstream to upstream within the distribution network.

The biggest *pro* of drop shipping is maximizing inventories centralization at the manufacturer level. A manufacturer can aggregate demand and provide a high level of product availability with lower levels of inventory in comparison with individual intermediates.

The benefits from centralization are highest for high value, low demand items with unpredictable demand. The inventory benefits of aggregation are small for items with predictable demand and low value (Chopra and Meindl, 2001).

Another opportunity offered to the manufacturer by the drop shipping is the *postponement* of the customization until after the customer order has been placed.

Transportation costs are high with this distribution policy because the average outbound distance to the end consumer is often high and parcel carriers must be used to ship the product. Parcel carriers have high shipping costs per unit compared to truckload (TL) or less-than-truckload (LTL) carriers.

With a direct distribution policy, a customer order with items from several manufacturers will involve a number of shipments to the customer equal to the number of shipping manufacturers.

This loss in aggregation in outbound transportation is a clear inefficiency in terms of transportation costs.

Supply chains save on the fixed cost of storage facilities when using drop shipping because all inventories are centralized at the manufacturer. There can be some savings of handling costs as well because the transfer from manufacturer to retailer no longer occurs.

Handling costs can be significantly reduced if the manufacturer has the capability to ship orders directly from the production line.

A manufacturer storage network is likely to have difficulty handling returns, hurting customer satisfaction. The handling of returns is more expensive under drop shipping because each order may involve shipments from more than one manufacturer. There are two ways that returns can be handled. One is for the customer to return the product directly to the manufacturer. The second approach is for the retailer to set up a separate facility (across all manufacturers) to handle returns.

The first approach incurs high transportation and coordination cost while the second approach requires investment in a facility to handle returns.

Given its performance characteristics, manufacturer storage with direct shipping is best suited for a large variety of low demand, high value items where customers are willing to wait for delivery and accept several partial shipments.

Manufacturer storage is also suitable if it allows the manufacturer to postpone customization, thus reducing inventories. For drop shipping to be effective, there should be few sourcing locations per order. It is thus ideal for direct sellers that are able to build-to-order. Drop shipping is hard to implement if there are more than 20–30 sourcing locations that have to ship directly to customers on a regular basis. For products with very low demand, however, drop shipping may be the only option.

1.3.2 Manufacturer storage with direct shipping and in-transit merge

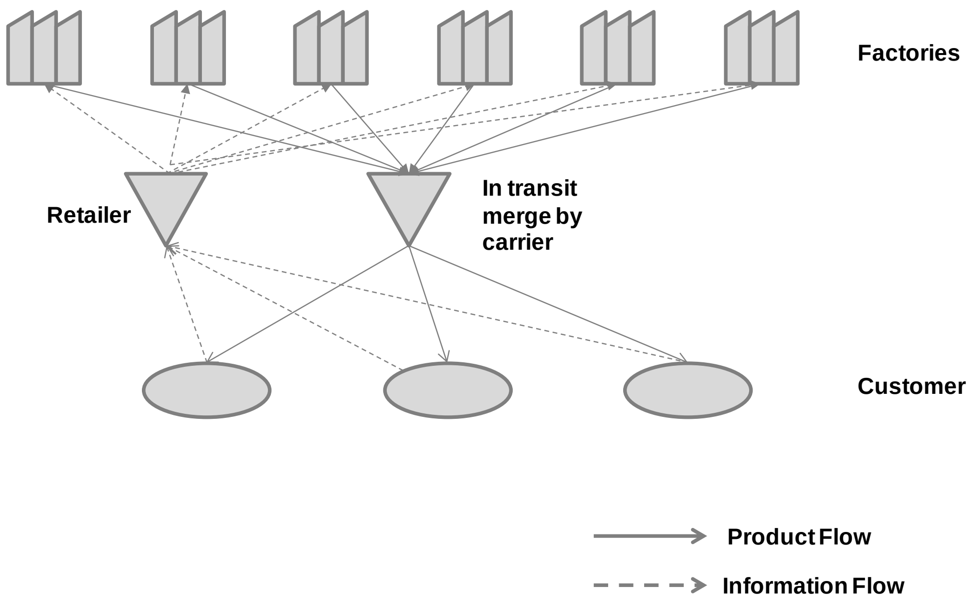


Fig 1.6 : Manufacturer storage with direct shipping and in-transit merge (S. Chopra, 2003)

The key feature of this distribution policy is that In-transit merge consolidates pieces of the order coming from different locations so that the customer gets a single delivery.

As with drop shipping, the ability to aggregate inventories and postpone product customization is a significant advantage of in-transit merge. This approach will have the greatest benefits for products with high value whose demand is hard to forecast, in particular if product customization can be postponed.

In most cases, transportation costs are lower than drop shipping because of the merge that takes place at the carrier hub prior to delivery to the customer. An order with products from three manufacturers thus requires only one delivery to the customer compared to three that would be required with drop shipping. Fewer deliveries save transportation cost and simplify receiving.

Facility and processing costs for the manufacturer and the retailer are as in drop shipping. The party performing the in-transit merge has higher facility costs because of the merge capability required. Receiving costs at the customer are lower because a single delivery is received. Overall supply chain facility and handling costs are somewhat higher than drop shipping.

The main advantage of in-transit merge over drop shipping is the somewhat lower transportation cost and improved customer experience. The major disadvantage is the additional effort during the merge itself.

Given its performance characteristics, manufacturer storage with in-transit merge is best suited for low to medium demand, high value items where the retailer is sourcing from a limited number of manufacturers. Compared to drop shipping, in-transit merge requires a higher volume from each manufacturer to be effective. If there are too many sources, in-transit merge can be very difficult to coordinate and implement.

In-transit merge is best implemented if there are no more than four or five sourcing locations and each customer order has products from multiple locations.

1.3.3 Distributor storage with package carrier delivery

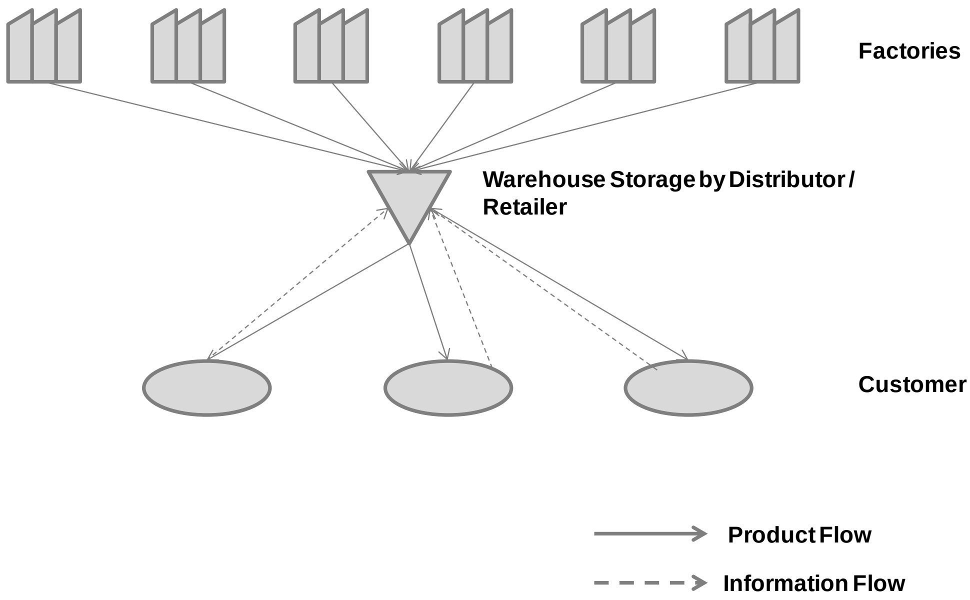


Fig 1.7 : Distributor storage with package carrier delivery (S. Chopra, 2003)

According to this option, inventories are not stored at the manufactures' warehouses but at retailers' site in intermediate warehouses and parcel carriers are used to transport products from these intermediate locations to the end customers.

In comparison with the *manufacturer storage* options, the inventory management is more difficult for the distributors / retailers because they aggregate demand uncertainty to a lower level than the manufacturer.

From an inventory perspective, distributor storage makes sense for products with somewhat higher demand.

Postponement activities can be pursued only if at the distributor level assembling activities are possible.

Considering transportation costs they are usually lower in comparison with *manufacturer storage* options because more cost-saving solutions (truckload , TL and less-than-truckload, LTL) can be adopted to manage goods distribution between manufacturer's plant and distributor's warehouses.

Unlike manufacturer storage where multiple shipments may need to go out for a single customer order with multiple items, distributor storage allows outbound orders to the customer to be bundled into a single shipment further reducing transportation cost. Transportation savings from distributor storage relative to manufacturer storage increase for faster moving items.

In terms of handling costs they are higher in comparison with the first two options because similar costs occur both at the manufacturer level and at the distributor level. From a facility cost perspective, distributor storage is not appropriate for extremely slow moving items.

Distributor storage with carrier delivery is well suited for medium to fast moving items. Distributor storage also makes sense when customers want delivery faster than offered by manufacturer storage but do not need it immediately. Distributor storage can handle somewhat lower variety than manufacturer storage but can handle a much higher level of variety than a chain of retail stores.

1.3.4 Distributor storage with last mile delivery

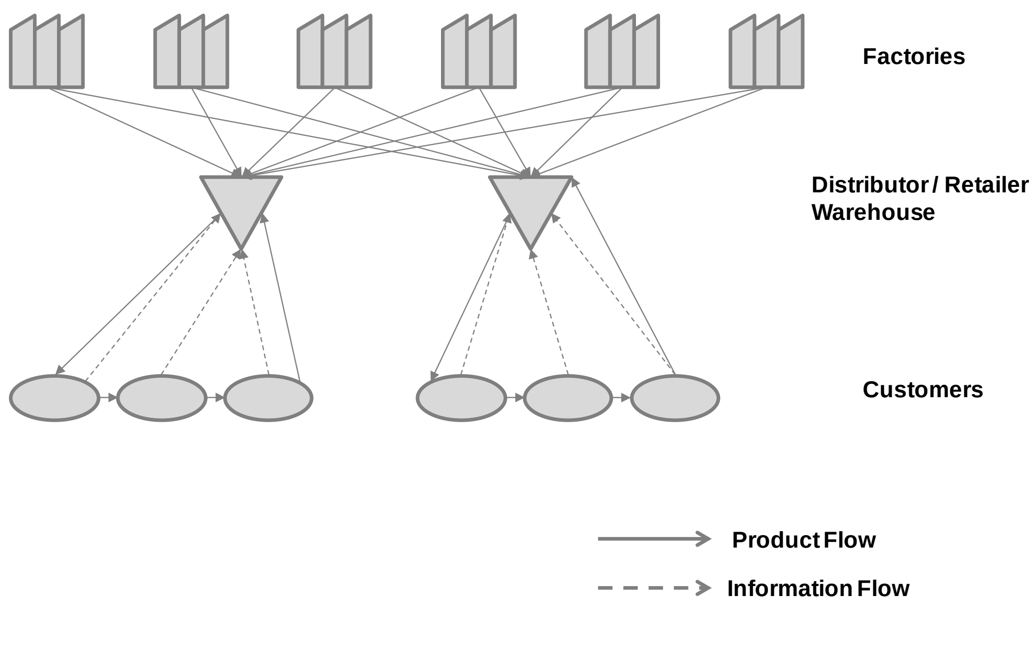


Fig 1.8 : Distributor storage with last mile delivery (S. Chopra, 2003)

This distribution network structure is based on distributor/retailer delivering the product to the customer's home instead of using a package carrier.

Unlike package carrier delivery, last mile delivery requires the distributor warehouse to be much closer to the customer, increasing the number of warehouses required.

Distributor storage with last mile delivery requires higher levels of inventory than all options other than retail stores, because it has a lower level of aggregation. From an inventory perspective, warehouse storage with last mile delivery is suitable for relatively fast moving items where disaggregation does not lead to a significant increase of inventory.

Transportation costs are highest using last mile delivery. This is because package carriers aggregate delivery across many retailers and are able to obtain better economies of scale than available to a distributor/retailer attempting last mile delivery.

Facility and processing costs are very high using this option given the large number of facilities required. Facility costs are somewhat lower than a network with retail stores but much higher than either manufacturer storage or distributor storage with package carrier delivery.

Processing costs, however, are much higher than a network of retail stores because all customer participation is eliminated.

In areas with high labour cost, it is very hard to justify distributor storage with last mile delivery on the basis of efficiency or improved margin. It can only be justified if there is a large enough customer segment willing to pay for this convenience. In that case, an effort should be made to couple last mile delivery with an existing network to exploit economies of scale and improve utilization. Last mile delivery may be justifiable if customer orders are large enough and customers are willing to pay for this service.

1.3.5 Manufacturer or distributor storage with consumer pickup

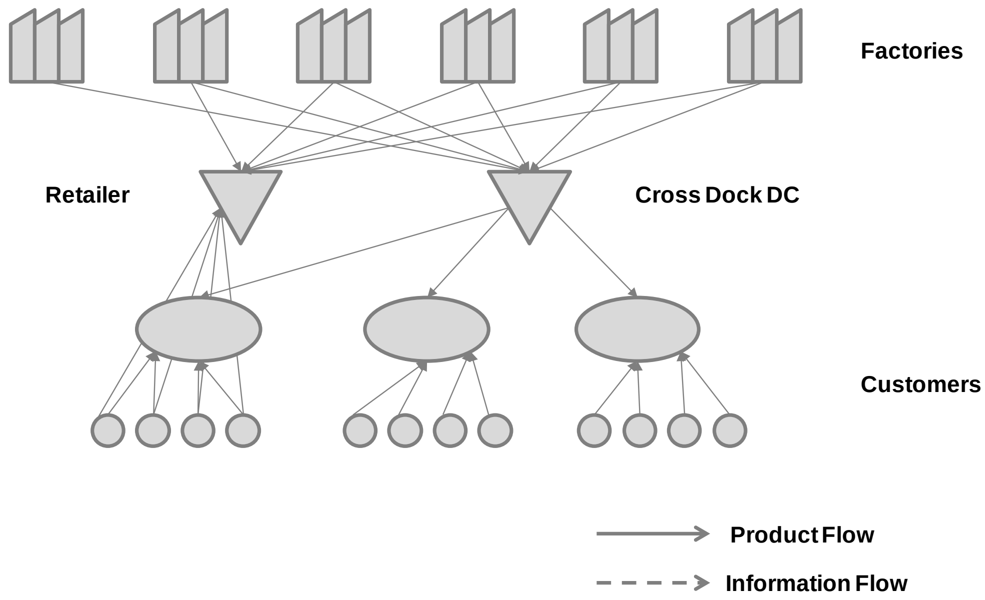


Fig 1.9 : Manufacturer or distributor storage with consumer pickup (S. Chopra, 2003)

This distribution policy is based on the concept that the inventory is stored at the manufacturer or distributor warehouse but customers place their orders remotely and then come to designate pickup points to collect their orders.

Orders are shipped from the storage site to the pickup points as-needed.

Inventory costs using this approach can be kept low with either manufacturer or distributor storage to exploit aggregation.

Transportation cost is lower than any solution using package carriers because significant aggregation is possible when delivering orders to a pickup site. This allows the use of TL or LTL carriers to transport orders to the pickup site.

Facility costs are high if new pickup sites have to be built.

Processing costs at the manufacturer or the warehouse are comparable to other solutions. Processing costs at the pickup site are high because each order must be matched with a specific customer when they arrive. Creating this capability can increase processing costs significantly if appropriate storage and information systems are not provided.

Increased processing cost at the pickup site is the biggest hurdle to the success of this approach.

The main advantage of a network with consumer pickup sites is that it can lower delivery cost, thus expanding the set of products sold as well as customers served online. The major hurdle is the increased handling cost at the pickup site. Such a network is likely to be most effective if existing locations such as convenience or grocery stores are used as pickup sites because such a network improves the economies from existing infrastructure. Unfortunately, such sites are typically designed to allow the customer to do the picking and will need to develop the capability of picking a customer specific order.

1.3.6 Retail storage with customer pickup

In this option, inventory is stored locally at retail stores. Customers either walk into the retail store or place an order online or on the phone, and pick it up at the retail store.

Local storage increases inventory costs because of lack of aggregation. For very fast moving items, however, there is marginal increase in inventory even with local storage.

Transportation cost is much lower than other solutions because inexpensive modes of transport can be used to replenish product at the retail store. Facility costs are high because many local facilities are required.

The main advantage of a network with local storage is that it can lower the delivery cost and provide a faster response than other networks.

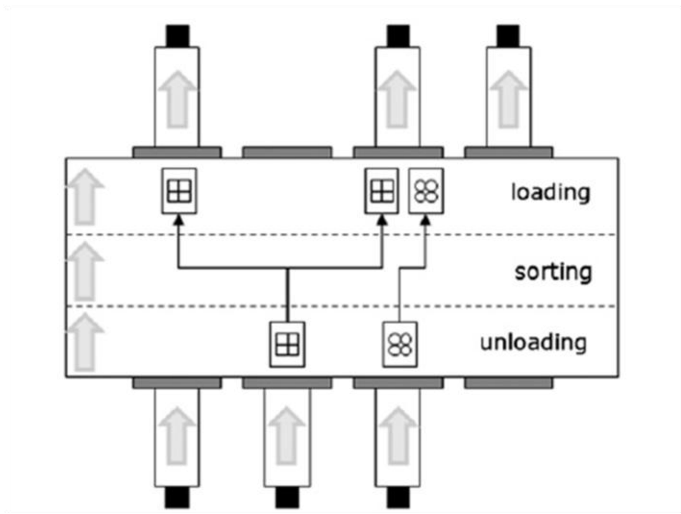
The major disadvantage is the increased inventory and facility costs. Such a network is best suited for fast moving items or items where customers value the rapid response.

1.4 The role of a cross dock in a distribution network

According to Boysen and Fliedner (2009), a cross docking (or cross dock) terminal is an intermediate node in a distribution network dedicated to the transshipment of truck loads. In contrast to traditional warehouses, a cross dock carries no or at least a considerably reduced amount of stock.

Whenever a truck arrives at the yard of a cross dock, it is assigned to a dock door where inbound loads are unloaded and scanned to determine their intended destinations. The loads are then sorted, moved across the dock and loaded onto outbound trucks for an immediate delivery elsewhere along the distribution network.

OUTBOUND TRUCKS



INBOUND TRUCKS

Fig 1.10 : Schematic representation of a cross docking terminal (Boysen and Fliedner, 2009)

The primary purpose of a cross dock is to enable a consolidation of differently sized shipments with the same destination to full truck loads, so that economies in transportation costs can be reached. This advantage makes cross docking an important logistics strategy receiving increased attention in today’s globalized competition with its increasing volume of transported goods. Successful case histories about cross docking adoption can be easily found across different industries: fast mover consumer goods (FMCG), mailing companies, automobile manufacturers and LTL logistics providers.

In comparison with the traditional point-to-point transportation policies, an additional transhipment of goods at the cross docking terminal slows down the distribution process and generates a significant amount of double handling. Consequently, efficient transhipment process are required where inbound and outbound truckloads are synchronized, so that intermediate storage inside the terminal is kept low and on-time deliveries are scheduled and ensured.

In order to design a cross dock logistic node some crucial aspects have to be considered and optimized:

- Location of cross docking terminals
- Layout of the terminal
- Assignment of destinations to dock doors
- Vehicle routing (this aspect can be considered a subset of the whole distribution network vehicle routing management)
- Truck scheduling
- Resource scheduling inside the terminal
- Unpacking / packing loads into / from trucks

1.5 Distribution network design and optimization

The design of a supply chain requires managers to determine the number, location, capacity, and type of manufacturing plants and warehouses to use; the set of suppliers to select; the transportation channels to use; the amount of raw materials and products to produce and to ship among suppliers, plants, warehouses, and customers; and the amount of raw materials, intermediate products, and finished goods to hold as inventory at various locations (Bilgen and Ozkarahan, 2003).

There are three levels of planning, which can be distinguished depending on the time goal, namely, strategic, tactical, and operational (Vidal and Goetschalckx, 1997).

The goods delivery policies optimisation problem can be included into the Distribution and Logistics Process (Beamon, 1998) with a strategic–tactical time goal and requires an integrated approach on many of the correlated issues defined before, in particular for facility location, warehousing, transportation and inventory decisions.

Published literature propose many different optimisation models. Bilgen and Ozkarahan (2004) analyse previous researches and review models for the production and distribution problem giving a classification in terms of the solution methodology: optimisation-based models, metaheuristic-based models, Information Technology (IT)-driven models and hybrid models. Vidal and Goetschalckx (1997) propose a classification inside the Optimisation Models dividing them into Mixed-Integer Programming Model (MIP) and other optimisation approaches as analytical formulas, stochastic models and others.

In their works, they show that optimisation models are for the large part based on mixed-integer programming with the minimisation or maximisation of a linear function subject to linear constraints sometimes with a supporting heuristic method.

In fact, from a mathematical point of view, linear programming, mixed-integer programming, fractional programming, and multi-objective linear fractional programming in distribution problems can generate optimal solutions even if they are usually time consuming in computation and complicated in model construction (Abdinnour-Helm, 1999).

In the non-linear situation, such as the delivery cost changes along with the delivery quantity/batch size, non-linear programming is required, which makes the modelling and computation even more complex. Near-optimal solutions determined by heuristic approach (sometimes optimal) are more preferable and acceptable because they can be obtained relatively more efficiently (Chan and Chung, 2005).

In the distribution problem optimisation, many authors deal with the inventory control decision as a key issue.

Das and Tyagi (1997) determine the optimal degree of centralisation as a trade-off between inventory and transportation costs analysing the impact of different factors (service level, distance cost factor on the degree of centralisation, number and location of warehouses) minimising the sum of aggregate ordering costs, aggregate cycle stock costs, aggregate safety stock costs, and aggregate transport costs.

Axsater (2002) deals with approximate optimisation of reorder points for continuous review installation stock policies in a two-echelon distribution inventory system with stochastic demand, considering holding costs and shortage costs. The model does not consider the transport and handling (or replenishment) costs and assumes the delivery lead time as a constant. Andersson and Marklund (1999) consider a two-level distribution system model approximating holding costs and backlog costs with a stochastic lead time, decomposing the problem with N retailers into an n + 1 single-level problems.

Abdul-Jalbara et al. (2002) focus on one-warehouse and N-retailers distribution system considering the sum of holding and replenishment costs in two cases:

- when warehouse and the retailers belong to the same firm (centralisation)
- when warehouse and retailers belong to different firms (decentralisation)

For years, the distribution network design was studied as a Location–Routing Problem (LRP) as well, in which facility location and the vehicle routing aspects are solved simultaneously (Ambrosino and Scutellà, 2004), but without considering other important factors like inventory cost, handling cost or impact of the production rate, i.e., batch production.

In the last few years, the proposed models offer a more integrated approach.

Ambrosino and Scutellà (2004), for example, study the complex distribution network design problem that involves not only locating production plants and distribution warehouses, but also searching the best distribution strategy from plant to warehouses and from warehouses to customers using an MIP model for the minimisation of global costs given by the sum of six factors, each containing a binary variable in order to define:

- fixed cost of establishing a facility
- warehousing cost at each facility
- vehicle transportation cost
- fixed cost for vehicle usage
- shipping cost for transferring goods from the plant to central warehouses
- inventory cost at each warehouse

Amiri (2004) defines an important strategic element: the best sites for intermediate stocking points, or warehouses introducing an MIP model that minimises total costs on three different levels: costs to satisfy customers' demands from the warehouse, shipment costs from the plants to the warehouse, and costs associated with opening and operating both warehouses and the plant.

Miranda and Garrido (2004), in order to solve the distribution network design problem, propose a simultaneous approach to incorporate inventory control decisions, such as economic order quantity and safety stock decisions into typical facility location models using a non-linear model.

Gümüs and Bookbinder (2004) approach the cross-docking installation problem in a two-level distribution network with direct delivery capability, minimising a linear function, which considers the following costs: cross-docking installation cost, handling costs at the transit point, vehicles fixed costs for each level, direct delivery cost, and transportation cost through transit point.

Eskigun et al. (2004) design an outbound supply chain network considering lead times, location of distribution facilities and method of transportation. They study a network design model that includes lead-time related costs as well as the more traditional fixed costs of locating facilities and transportation costs.

Manzini et al. (2006) introduce a set of MIP models for the design and management of distribution systems. This work is innovative because it considers not only transportation costs (from one level to another) and fixed and variable costs due to the use of distribution centres, but also delay costs, such as costs associated with product quantities not delivered for breach of contract.

Nozick and Turnquist (2000) define a model to identify optimal locations for distribution centres and introduce the inventory cost, and minimise a cost function that has two addenda: the first for the fixed costs of creating a facility at a candidate site (which also includes a linear approximation of safety stock inventory needed for an additional centre), and the second for transportation costs.

All these works develop models to solve the distribution problem with the possibility to re-design the network, introducing new facility or changing their positions.

Other authors study the problem creating the optimisation without changing the network structure, but optimising the distribution policy.

Chan and Chung (2005) develop an optimisation algorithm to solve the problem of distribution in a given supply network, taking into account variables like demand allocation and production scheduling. They use a linear total cost function that has to be minimised, defining a genetic algorithm that first determines the demand allocation and transportation policy and second determines the production scheduling.

Lee et al. (2006) consider the distribution problem in terms of distribution of stock from retailers with stock on hand to retailers without stock (lateral trans shipment policy).

This literature analysis shows that many approaches have been taken to design and optimise the distribution network, managing the inventory control, and the facility location. For a given distribution network, new methodologies are necessary to help managers in the decision of the best set of goods delivery policies. This critical issue needs more investigation, particularly to permit an effective and rapid decision-making.

1.6 Goods delivery optimization within a distribution network: a proposal

At the beginning of my research work I had the opportunity to work with the team led by Professor Alessandro Persona on distribution network optimization topics.

Basically what we did has been designing an innovative model managing delivering goods within an existing distribution network.

A three-level distribution network has been selected as the reference: firstly, the manufacturers, secondly, the intermediate warehouses that can be used to deliver goods and third, the customers.

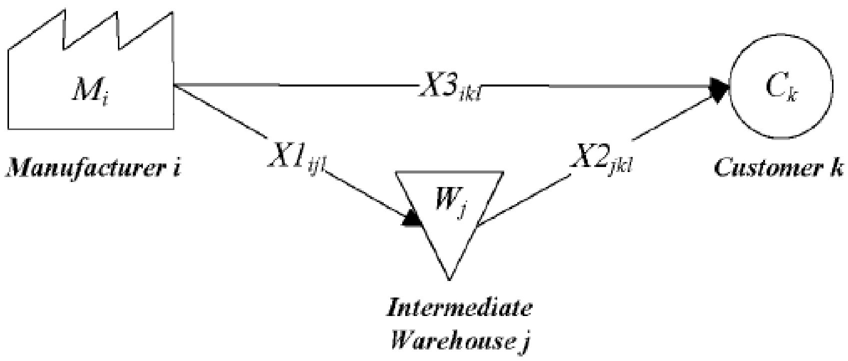


Fig 1.11: 3-levels reference distribution network

Indices:

i: manufacturer (M); i=1,...,I

j: intermediate warehouse (W); j=1, ,J

k: customer (C); k=1, ,K

l: product s family (PF); l=1, , L

Decision Variables:

$X1_{i,j,l}$ quantity of product's families PF_l delivered from manufacturer M_i to intermediate warehouse W_j

$X2_{j,k,l}$ quantity of product s families PF_l delivered from intermediate warehouse W_j to customer C_k

$X3_{i,k,l}$ quantity of product s families PF_l delivered from manufacturer M_i to customer C_k

Input Data:

$CT1_{i,j,l}$: transport cost of a cube meter of product's families PFl from manufacturer Mi to intermediate warehouse Wj (€/km m3)

$CT2_{j,k,l}$: transport cost of a cube meter of product's families PFl from intermediate warehouse Wj to customer Ck (€/km m3)

$CT3_{i,k,l}$: transport cost of a cube meter of product's families PFl from manufacturer Mi to customer Ck (€/km m3)

$MD1_{i,j}$: distance matrix from manufacturer Mi to intermediate warehouse Wj, (km)

$MD2_{j,k}$: distance matrix from intermediate warehouse Wj to customer Ck (km)

$MD3_{i,k}$: distance matrix from manufacturer Mi to customer (km)

H_l: handling cost per cube meter of product's families PFl (€/m3)

C_l: cost per cube meter of product's families PFl (€/m3)

s_i: inventory cost rate at manufacturer Mi

s_j: inventory cost rate at warehouse Wj

$r_{l,l}$: inventory rotation index related to product's family produced by manufacturer Mi (number of rotation/year)

$$r_{i,l} = \frac{\sum_{k=1}^{K} MC_{i,k,l}}{g_l}$$

g_l: average inventory level of product's families PF_l

$$g_l = \frac{1}{2} \sum_{k=1}^{K} \frac{MC_{i,k,l}}{p_{i,k,l}}$$

$MC_{i,k,l}$: total demand matrix of product's families PFl by customer Ck to manufacture Mi (m3/year)

$q_{i,k,l}$: average order quantity of product's families PFl by customer Ck to manufacturer Mi (m3/order)

$p_{i,k,l}$: number of production cycles of product's families PFl in manufacturer Mi for customer Ck (number of time/year)

$d_{i,k,l}$: number of supplies to customer Ck product's families PFl by manufacturer Mi (number of time/year)

$$d_{i,k,l} = \frac{MC_{i,l,k}}{q_{i,l,k}}$$

$SS_{i,l}$ safety stock in manufacturer's M_i warehouse of product s family PF_l calculated with the following formula (Persona et al., 2005)

$$SS_{i,l} = k \cdot \sigma_{\%} \cdot F_{i,l} \cdot \sqrt{LT_l}$$

$SS_{j,l}$ safety stock in manufacturer's M_i warehouse of product s family PF_l calculated with the following formula (Persona et al., 2005)

$$SS_{j,l} = k \cdot \sigma_{\%} \cdot F_{j,l} \cdot \sqrt{LT_l}$$

Where,

k adjusting parameter for customer service level

$\sigma_{\%}$ standard percentage demand deviation of the product's family PF_l

$F_{i,l}$ forecasted annual demand of the product's family PF_l directly delivered from manufacturer's M_i warehouse. The model assumes that $F_{i,l}$ is, during a year time, equal to:

$$\sum_{k=1}^{K} \sum_{i=1}^{I} X3_{i,k,l}$$

$F_{j,l}$ forecasted annual demand of the product's family PF_l delivered from manufacturers' warehouses to intermediate warehouse W_j. The model assumes that $F_{j,l}$ is equal to

$$\sum_{j=1}^{J} \sum_{k=1}^{K} X2_{j,k,l}$$

σ_{l}: Distribution Index, it is the percentage of the annual quantity of product's family PFl produced by manufacturer Mi and then delivered to customers through the intermediate warehouse, with values from 0 to 1

- If $\sigma = 0$ → *"Fully Direct Distribution"*
- If $\sigma = 1$ → "*Fully by Intermediate Warehouse* "

Model:

Minimizing the following objective function, sum of different components:

1) *Transportation*

$$\sum_{j=1}^{J} \sum_{i=1}^{I} X1_{i,j,l} \cdot CT1_{i,j,l} \cdot MD1_{i,j} + \sum_{j=1}^{J} \sum_{k=1}^{K} X2_{j,k,l} \cdot CT2_{j,k,l} \cdot MD2_{j,k} + \sum_{k=1}^{K} \sum_{i=1}^{I} X3_{i,k,l} \cdot CT3_{i,k,l} \cdot MD3_{i,k}$$

2) *Handling*

$$\sum_{j=1}^{J} \sum_{i=1}^{I} X1_{i,j,l} \cdot H_l$$

3) *Inventory*

$$\sum_{k=1}^{K}\sum_{i=1}^{I}\frac{X3_{i,k,l}}{r_{i,l}}\cdot C_l\cdot s_i+\sum_{i=1}^{I}SS_{i,l}\cdot C_l\cdot s_i+\sum_{j=1}^{J}\sum_{i=1}^{I}\frac{X1_{i,j,l}}{r_{i,j}}\cdot C_l\cdot s_j+\sum_{j=1}^{J}SS_{j,l}\cdot C_l\cdot s_j$$

Subjected to:

$$\sum_{j=1}^{J}X1_{i,j,l}+\sum_{k=1}^{K}X3_{i,k,l}=\sum_{k=1}^{K}MC_{i,k,l}$$

$$\sum_{j=1}^{J}X2_{j,k,l}+\sum_{i=1}^{I}X3_{i,k,l}=\sum_{i=1}^{I}MC_{i,k,l}$$

$$\sum_{i=1}^{I}X1_{i,j,l}=\sum_{k=1}^{K}X2_{j,k,l}$$

$$\sum_{j=1}^{J}X1_{i,j,l}=\sigma_{i,l}\cdot MP_{i,l}$$

For a given distribution network, with I manufacturer, J intermediate warehouses, L product’s families, K final customers, the procedure developed consists of four steps and an input–output process as showed in the below figure.

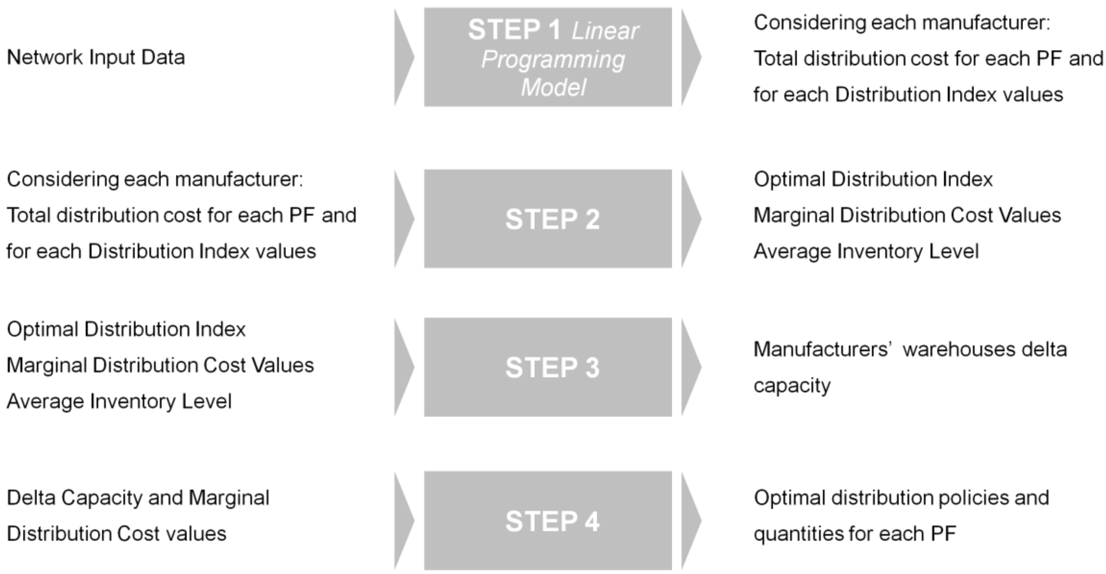


Fig 1.12: Iterative procedure functioning

For the whole procedure and the outcomes of the industrial application it's needed to refer to the attached paper (Battini, Vecchiato et al., 2007).

2 Lean Production

2.1 The genealogy of Lean production

According to Holweg (2006), lean production not only successfully challenged the accepted mass production practices in the automotive industry, significantly shifting the trade-off between productivity and quality, but it also led to a rethinking of a wide range of manufacturing and service operations beyond the high-volume repetitive manufacturing environment.

The book ‘The machine that changed the World’ that introduced the term ‘lean production’ in 1990 has become one of the most widely cited references in operations management over the last decade.

Despite the fact that the just-in-time (JIT) manufacturing concept had been known for almost a decade prior, the book played a key role in disseminating the concept outside of Japan.

2.1.1 The Toyota productions system history

The foundation of the Toyota Motor Company dates back to 1918, when the entrepreneur Sakichi Toyoda decided to sell his company to start a new automotive company up for his soon Kiichiro.

At the time the Japanese market was dominated by the local subsidiaries of Ford and General Motors (GM) which had been established in the 1920s, and starting Toyoda's automotive business was fraught with financial difficulties and ownership struggles after Sakichi's death in 1930. Nevertheless, Kiichiro prevailed – helped by the newly released Japanese automotive manufacturing law in 1930 – and began designing his Model AA by making considerable use of Ford and GM components (Cusumano, 1985).

The company was rebranded in *Toyota* and it moved under the control of Eiji Toyoda. The same Eiji Toyoda (still representing the second generation of Toyoda family as automotive company's owner) was sent to US in 1950 in order to fully understand the current automotive production system, universally considered as *state of the art* for this industry.

The concept of the Total Production System was born during the 1950s both due to *infrastructural* rationales (the Toyota capital constraints and the low volumes demanded by Japanese automotive market) and to the pragmatism of an experienced Toyota mechanical engineer, Taiichi Ohno.

Ohno joined the Toyoda Spinning and Weaving company about ten years before the automotive business start up, he did not have any experience in manufacturing automobiles, and it has been argued that his 'common-sense approach' without any preconceptions has been instrumental in developing the fundamentally different just-in-time philosophy (Cusumano,1985).

Studying the western automotive production systems, Ohno came up with two different flaws:

i. Producing components in large batches meant more defects and unnecessary large inventories, which took up costly capital and warehouse, instead of a better ability to match the market requests
ii. Not differentiating the offers would have not allowed to Toyota to effectively play in the market: Ford T case already had demonstrated that a certain customization had to be preferred in comparison with the pure standardization.

At the same time Ohno recognized that in general car manufacturers had to strive for large scale production and economies of scale as much as possible.
Starting from 1948 Ohno exported the concept of small-batch production from the engine assembly workshop throughout the whole company.
After the visits to U.S. automobile factories during late 1950s, Ohno consolidated some ideas, among them that related to 'Kanban supermarket' to control material replenishment.
Moreover Ohno defined the two pillars of TPS as *autonomation* (or Jidoka), and *JIT* (or Just-In-Time for which 'The best way to work would be to have all the parts for assembly at the side of the line just in time for their user', Ohno, 1988).
Ohno had to modify the machine changeover procedures to produce a growing variety in smaller lot sizes, thanks to the fact that much of the machinery Kiichiro had bought was simple. Change-over reduction was further advanced by Shigeo Shingo, who was hired as external consultant in 1955 and developed the single-minute exchange of dies (SMED) system (Shingo, 1983).
Toyota gradually found ways to combine the advantages of small-lot production with economies of scale in manufacturing and procurement, but counter to common perception, this implementation was highly time-consuming.
According to Fujimoto (1999), Toyota's production organization adopted various elements of the Ford system selectively and in unbundled forms, and hybridized them with their ingenious system and original ideas. It also learnt from

experiences with other industries (e.g. textiles). Thus, the Toyota-style system has been neither purely original nor totally imitative. It is essentially a hybrid. Over the years the TPS was not documented until 1965 when *kanban* systems supporting material was delivered to a supplier.

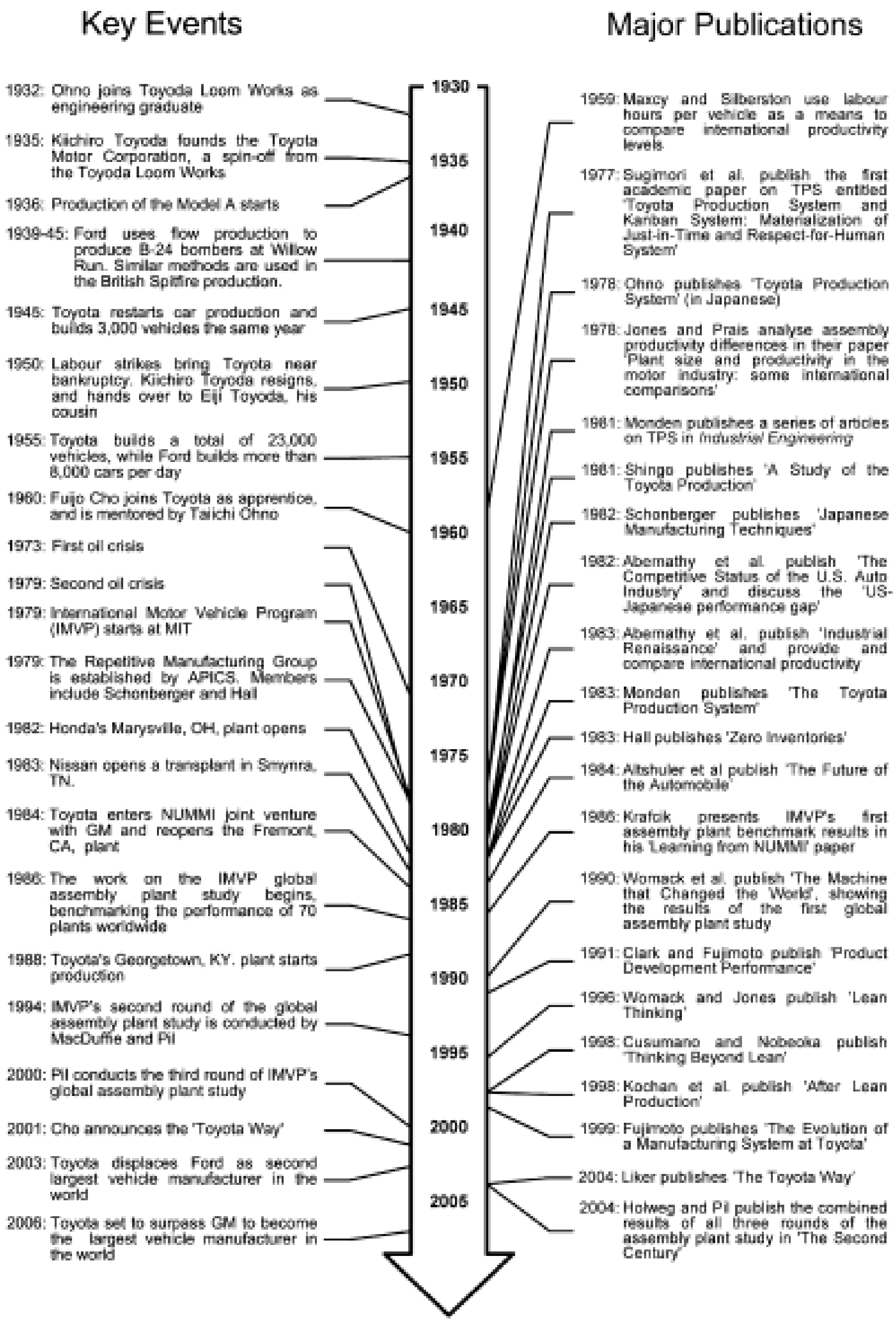


Fig 2.1 : The research and dissemination of lean production timeline (M. Holweg, 2006)

2.2 The Lean Thinking concept and the evolution of Toyota Production System

As already mentioned during the previous paragraph, the *Lean Thinking* discipline landed in the Western World during the 1990s.

The definition given by the real *importers*, James P. Womack and Daniel T. Jones (2003) is the best way to introduce the idea behind this innovative methodology:

Lean Enterprise is a way to do more and more with less and less: less human effort, less equipment, less time, less space, while coming closer and closer providing customers with exactly what they want.

2.2.1 Lean Principles

Lean Thinking and its industrial and operational application, the Toyota Production System, started from on a new angle, a new point of view to allow a firm's management to view an organization in a holistic way, in order to maximize the value for the client by being focused on value stream and minimizing the wastes.

There are five principles which form the *Chart* of the Lean Thinking, according to the concept of *Value Maximization* (Womack and Jones, 1996):

1. **Identify Value**: the value of a good has to be strictly connected to well defined product design, than to a mapped process and it cannot forget the value related to the customer' standpoint.
2. **Map the Value stream**: it's mandatory mapping the whole value stream through the three key activities of product design, information management and physical transformation.
3. **Create Flow**: the value-creating steps have to occur in tight sequence so the product will flow smoothly toward the customer.

4. **Establish Pull**: an organization has to build the skills to design, plan and manufacture only what market need and ask, only when the market need and ask.
5. **Seek Perfection**: a company should have the opportunity to seek the perfection just focusing on the previous principles and on the productive synergies made by them.

2.2.2 The 7 wastes (*muda*)

In order to focus an organization on the real value stream mapping, the management has to eliminate all the wastes from the processes, isolating the *value-adding* activities from the *non-value adding* ones.
To understand which are the *non-value adding* activities it's necessary to introduce the lean concept of waste, quoted the first time by Taiichi Ohno.
In particular the wastes' taxonomy defined by Toyota's Chief Engineer includes:

1. **Overproduction** occurs when more assets than needed are used to deliver to the customer. E.g.: large batch production that exceeds the strict quantity ordered by the customer. Extra parts will be stored and not sold. Overproduction is the worst muda because it hides or generates all others, especially inventory and it's a huge source of incoming costs.
2. **Inventory** in the form of raw materials, work-in-progress (WIP), or finished goods always represent a set of costs: capital cost (or opportunity cost), inventory service cost, storage space cost and inventory risk cost.
3. **Waiting** happens when a machine setup is needed, when components are not moving in front of a queue. Always waiting is a source of inventory.
4. **Motion** all the parts have to move should belong to a continuous flow including all the moving parts.
5. **Unnecessary transportation** is clearly a non-adding value activity implying the risk that products are damaged, lost or delayed.

6. **Defects** generate extra costs due to reworking the part, rescheduling production and other non-adding value activities
7. **Over-processing** occurs each time more workload/time is dedicated to an activity than it should be dedicated

<u>2.2.3 The concept of the *Lean House*</u>

Often approaching the topic of the Lean Thinking and Toyota Production System a lot of confusion comes up both in the terminology and in the way practitioners and the academia try represent and organize holistically the set of foundations, objective and tools behind this discipline.

The way I chose to give a complete representation is the *Lean House*.

There is a basis, that gives *Stability* to the house; there are the who pillars, *Just-in-Time* and *Jidoka* (definable as intelligent automation or automation with a human touch, T. Ohno, 1988); there is a roof representing the real objective, the *Value for the client* and then there is a core, *Kaizen*.

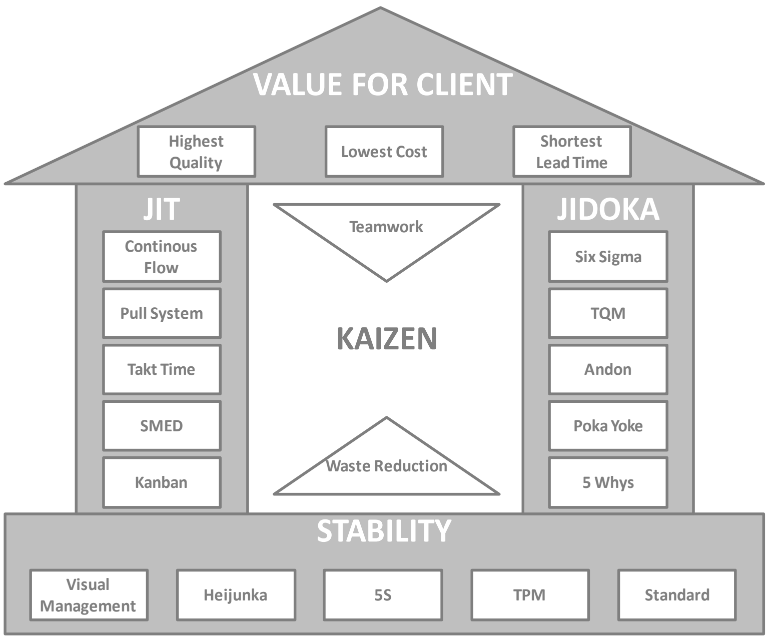


Fig 2.2: Lean House as a representation of the Toyota Production System

2.3 *Stability*

In order to effectively applying the Toyota Production System the first step is adopting and putting in place a set of preparatory fundamental techniques.
These practices, often underestimated, are the necessary enablers of the two pillars (*Just in Time* and *Jidoka*) in order to get the final goal of the customer satisfaction.

2.3.1 Visual Management

The Visual Management theory is really quite simple and based on using visual cues to prompt logical actions.
This means that all information needed to know about the right process progress have to be visible and shared in real time among all the involved employees.
This so accurate flow representation enables potential improvements discovering, due to the fact it becomes easier identifying problems and the information sharing is easy and simple.
The key tricks to be adopted in order to maximize the positive effects of the Visual Management are:

- Creating and sharing Key Performance Indicators (KPI)
- Adopting flashing lights to underline interruptions / waiting
- Organizing well-recognizable spaces hosting right and wrong samples for the same product/product's family
- Adopting visual control systems (e.g.: Kanban)
- Indicating process flows through easily recognizable signals

Examples of visual control systems are: color-coded pipes and wires, painted floor areas, shadow boards for parts and tools, indicator lights, workgroup display boards (with charts, metrics, procedures), production status boards and direction of flow indicators.

In the *lean* organization the correct use of the Visual Management evolves to the tool that operators are used to adopt in order to block a non-compliant process.

2.3.2 Heijunka, or Production leveling

Heijunka concept (Huttmeir, 2008) aims to controlling the variability of a job arrival sequence to permit higher capacity utilization: in other words, the objective of heijunka is to avoid peaks and valleys in the production schedule.
Two are the enablers of the Heijunka adoption:
An example of how this *production smoothing* tool works has given by Huttmeier (2008).
Consider a workstation that produces two products, A and B, with A requiring 1.5 min, and B requiring 1 min of processing, respectively. Suppose that the company receives an order for 100 units of both A and B. The easiest schedule would be to produce 100 units of one product and then 100 units of the other, resulting in a situation in which the demand faced by the workstation would vary considerably.
Transport this workstation to a production line with a cycle time of 1.4 min, and the workstation is overloaded (and a bottleneck for the entire line) for 100 cycles and under loaded for another 100 cycles.
Accommodating this schedule requires increasing the cycle time for the entire line, at least during the period when A is being produced. On many production lines it is not realistic to change the cycle time to accommodate such workload fluctuations, hence this workstation might well be obliged to operate at relatively low average capacity utilization.
Heijunka calls for distributing the jobs requiring more labor input throughout the production schedule to permit higher average utilization assuming that the cycle time is held constant over time.

In this simple example, products A and B would be alternated, so that the workstation could either work in lots of one unit of A and one unit of B, with cycle time determined based on the combined work content of 1.5+1.0=2.5 min, or allowing the workstation to get a bit behind during the cycle when A is produced, catching up during the cycle when B is produced.

2.3.3 5S

5s is a workplace organization methodology based on implementation, maintenance and improving of a certain order.

Fundamental in order to effectively adopt this methodology is building a clear understanding among employees of how work should be done.

Undoubtedly a clear effect of this methodology is the ownership of the process in each employee.

1. **Sorting** – ***Seiri*** : keep only essential items and eliminate what is not required; everything else is stored or discarded.
2. **Setting in order – *Seiton***: there should be a place for everything and everything should be in its place. The place for each item should be clearly labeled or demarcated. Items should be arranged in a manner that promotes efficient work flow, with equipment used most often being the most easily accessible. Each tool, part, supply, or piece of equipment should be kept close to where it will be used – in other words, straightening the flow path.
3. **Systematic cleaning – *Seiso***: keep the workplace tidy and organized. The cleaning activity should be part of the daily work – not an occasional activity initiated when things get too messy.
4. **Standardizing – *Seiketsu***: work practices should be consistent and standardized
5. **Sustaining the discipline – *Shitsuke***: maintaining and continuously improving acquired standards.

2.3.4 TPM, Total Productive Maintenance

The concept of Total Productive Maintenance has been introduced the first time by Nakajima (1988).

According to this author the word *total* has three different meanings:

- *Total effectiveness* indicates that TPM aims to economic efficiency and profitability. This statement is useful also to underline the contrast the TPM with the conventional approach to the maintenance, the *Corrective Maintenance.*
- *Total maintenance system* includes *Maintenance Prevention* and *Maintainability Improvement*, as well as *Preventative Maintenance*. Basically, this refers to ‘‘maintenance-free’’ design through the incorporation of reliability, maintainability, and supportability characteristics into the equipment design.
- *Total participation* of all employees includes *Autonomous Maintenance* by operators through small group activities. Maintenance is accomplished through a ‘team’ effort, with the operator being held responsible for the ultimate care of his/her equipment

Other differential elements introduced by TPM approach (Chan, 2003) are:

- TPM aims to maximize equipment effectiveness (overall efficiency)
- TPM establishes a thorough system of PM for the equipment’s entire life span
- TPM is implemented by various departments in a company
- TPM involves every single employee, from topmanagement to workers on the shop floor
- TPM is based on the promotion of PM through ‘‘motivation management’’ involving small groups activities

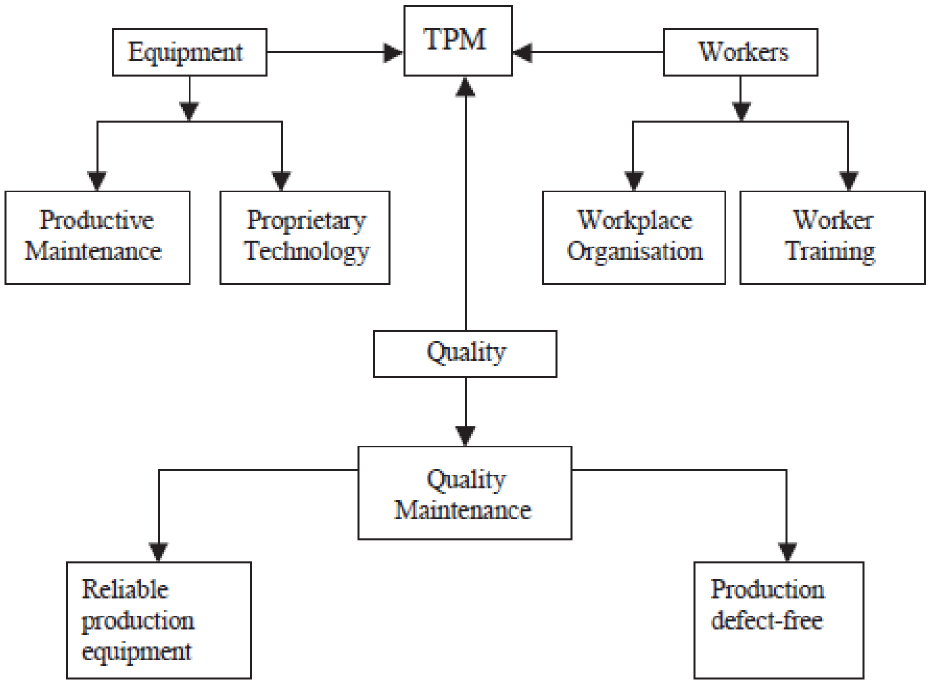


Fig 2.3: Key supporting elements of TPM (Chan, 2003)

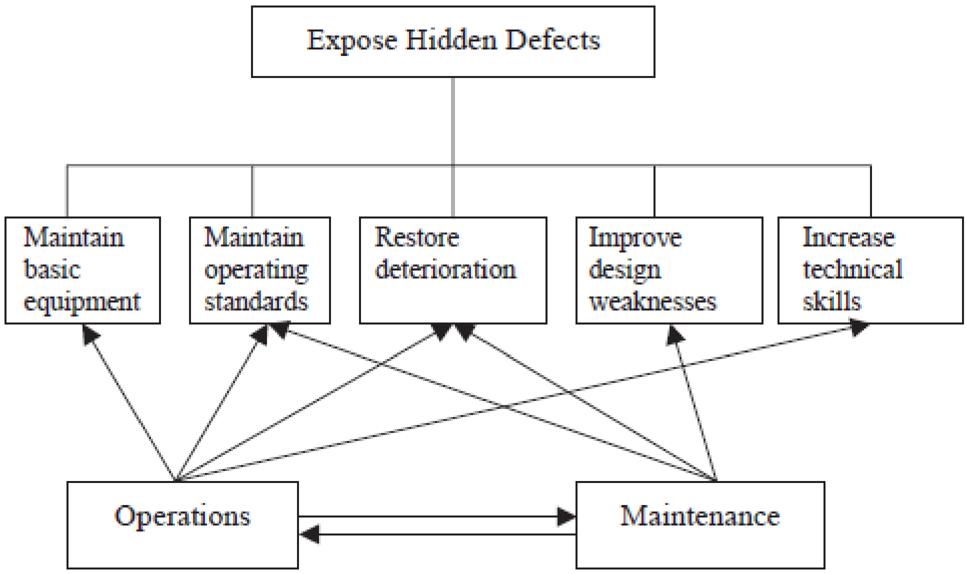


Fig 2.4: Relationship between Operations and Maintenance (Chan, 2003)

2.3.5 Standard

A Taiichi Ohno famous quote was:
"Where there is no Standard there can be no Kaizen"
The most important goal of each and every company, emphasized also by the Lean House framework, is creating value for its clients.
How can an organization achieve this objective?
Creating a standardized process than could offer a standard level of quality of its products, based on simple and repeatable activities.
The concept of standardization is also viewed the starting point of the continuous improvement: only standardized, repeatable and well-known processes can be optimized over time.

2.4 *Just In Time*

Before deep diving into Just In Time philosophy and its technical applications, some definitions coming from the literature review can be useful:

- Just in time production system makes *only the necessary products, at the necessary time, in the necessary quantity* (Sugimori et al., 1977)
- Kanban system, production smoothing and setup time reduction are critical components of any JIT system (Monden, 1981)
- JIT philosophy is associated with three constructs: total quality, people involvement, and JIT manufacturing techniques (Hall, 1987)
- Programs associated with JIT include *elimination of waste, and full utilization of people, equipment, materials, and parts* (Davy et al., 1992)
- JIT is a comprehensive approach to continuous manufacturing improvement based on the notion of eliminating all waste in the manufacturing process (Sakakibara et al., 1993)
- JIT is based on the notion of eliminating waste through simplification of manufacturing processes such as elimination of excess inventories and overly large lot sizes, which cause unnecessarily long customer cycle times (Flynn et al., 1995)
- JIT is composed of three overall components, namely, flow, quality and employee involvement (McLachlin, 1997)

2.4.1 Continuous Flow

Continuous Flow is one of the key elements forming JIT approach and it's based on the Value Stream Mapping tool.
A value stream is a collection of all actions (value-added as well as non-value-added) that are required to bring a product (or a product's family) through the main flows, starting with raw material and ending with the customer (Rother and Shook, 1999).

These actions consider the flow of both information and materials within the overall supply chain. The ultimate goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate these (Rother and Shook, 1999).

According to Fawaz et a. (2006), while researchers have developed a number of tools to optimize individual operations within a supply chain, most of these tools fall short in linking and visualizing the nature of the material and information flow throughout the company's entire supply chain. Taking the value stream viewpoint means working on the big picture and not individual processes. VSM creates a common basis for the production process, thus facilitating more thoughtful decisions to improve the value stream (McDonald et al., 2002).

2.4.2 Pull System

The *Pull System* is one of the "flags" of the whole Toyota Production System framework.

To better understand what's the difference between the *Pull* and the *Push* approach is useful referring to Lee (1989):

- *Push* approach: jobs on entry into the system are queued at the first required process. Queue priority is resolved according to the selected scheduling rule. On completion of a process, the job proceeds to subsequent processes on the designated process route. When all processes are completed the job exits from the system
- *Pull* approach: Activities at the process station are triggered by depleted output kanban stock at the process stations. Each depleted kanban stock constitutes a queue unit at the station. Before a job can be loaded a check is made to ensure that the precedence constraint is satisfied; that is, there must be sufficient inventory in the output kanban stock of the upstream processes of that job. If so, a draw is made from the output

kanban stock. Should this cause the output kanban stock to fall below the re-order level, the job is queued at that station.

According to Kenworthy and Little (1995), MRP II and kanban are frequently regarded as competing techniques, with proponents of kanban disparagingly referring to MRP II as a push technique, implying that materials are pushed into production faster than they emerge as finished goods, thus leading to high work in progress. Kanban in contrast, is described as a pull technique because the kanban signal or card pulls material forward only when it is required by the next stage of production.

The advantages of the *pull* approach versus the *push* are:

- On-time goods delivery: the client receives the right product at the right time
- Higher productivity because all the materials are available, pulled by market demand
- In production systems with lower WIP and shorter lead times it's easier keeping and improving the quality
- The production system is more efficient than a traditional one because of a lower WIP use.

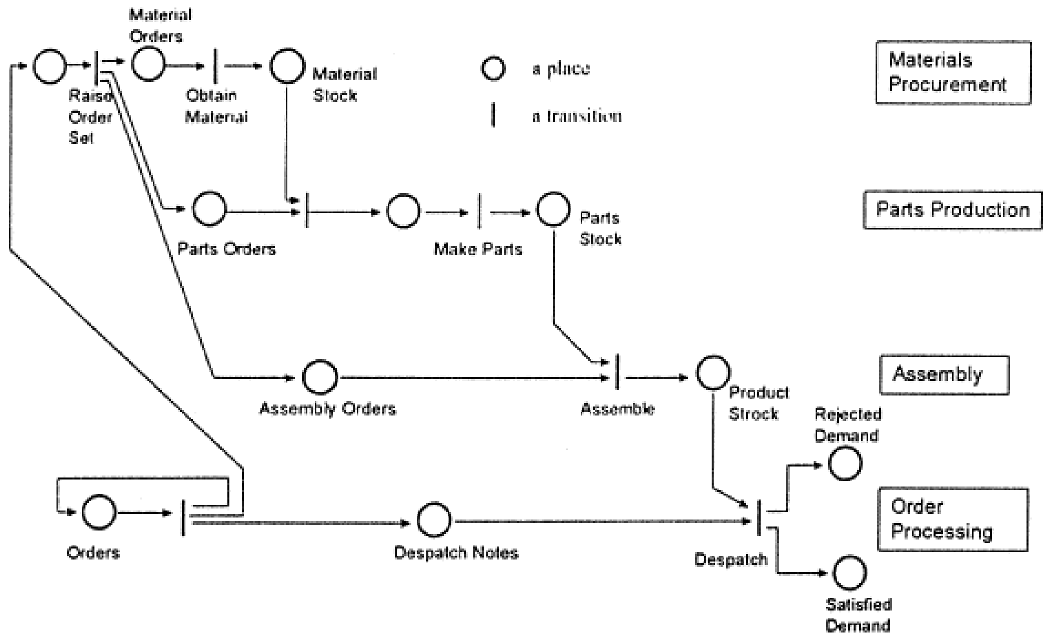


Fig 2.5: UNISON Petri-net model of the push system (Bonney et al., 1999)

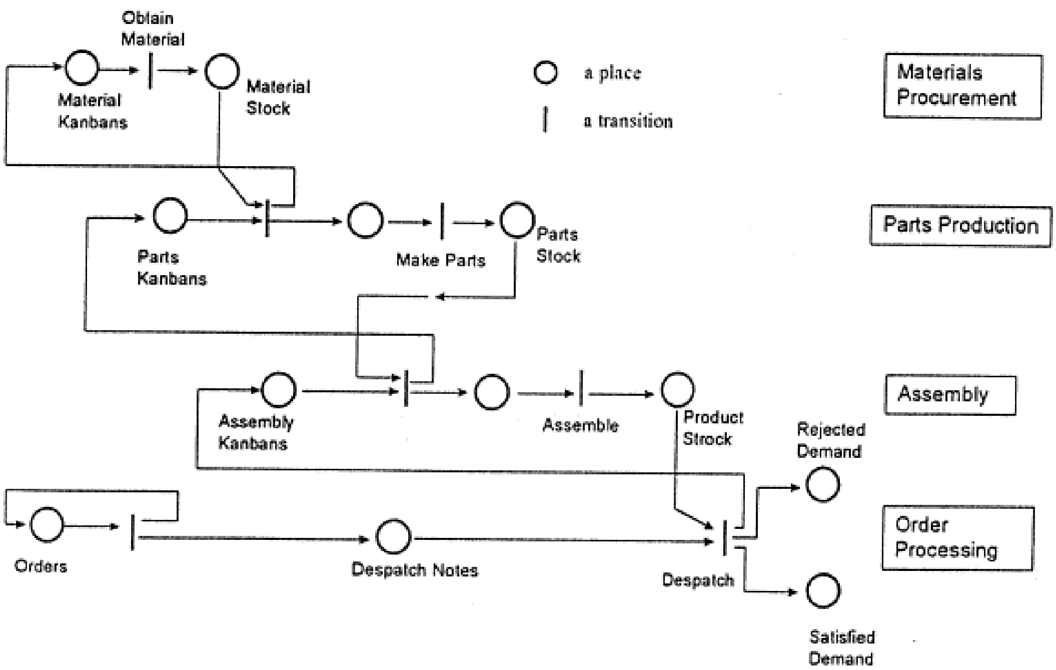


Fig 2.6: UNISON Petri-net model of the pull system (Bonney et al., 1999)

2.4.3 Takt Time

Takt time control is an important and powerful design principle in Lean manufacturing (Linck and Cochran, 1999; Miltenburg, 2001).

Takt time can be defined as the time between units of production output in the case that output is geared to customer demand. It can thus be calculated by dividing the net available production time per period by the demand for that period.

According to Bokhorst et al. (2008), time control requires a balanced division of work. Important advantages of takt time control are the realization of short and reliable throughput times.

Takt time control may also have motivational benefits due to the immediate feedback on performance (Hopp and Spearman, 2001).

Takt time control is predominantly found in high volume assembly environments. Here, products are often produced in one-piece flow, meaning that single products move from operation to operation in a (relatively) fixed order. The operations are divided in stages which all have to produce according takt time. The product variety is usually limited with respect to the number of required routings. Variety in the mix of product types and in the required processing times may ask for advanced methods to determine the assembly stages and to distribute tasks and workers to these stages such that each stage is able to produce efficiently according takt time (Bokhorst et al. 2008).

2.4.4 SMED, Single-Minute Exchange of Die

According to Shingo (1985) Single-Minute Exchange of Die (SMED) is one of the many lean production methods for reducing waste in a manufacturing process. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. This rapid changeover is key to reducing production lot sizes and thereby improving flow and reducing lead times.

The phrase *single minute* does not mean that all changeovers and startups should take only one minute, but that they should take less than 10 minutes (in other words, *single-digit minute*).

Shingo also recognized eight fundamental techniques in order to correctly apply the SMED process. In particular:

- Separate internal from external setup operations
- Convert internal to external setup
- Standardize function, not shape
- Use functional clamps or eliminate fasteners altogether
- Use intermediate jigs
- Adopt parallel operations
- Eliminate adjustments
- Mechanization

Shingo also suggested that SMED improvement should pass through four conceptual stages:

- ensure that external setup actions are performed while the machine is still running
- separate external and internal setup actions, ensure that the parts all function and implement efficient ways of transporting the die and other parts
- convert internal setup actions to external

- improve all setup actions.

2.4.5 Kanban

Kanban is a subsystem of the Toyota Production System (TPS), which was created to control inventory levels, the production and supply of components, and in some cases, raw material (Muris, 2010).

According to Graves et al. (1995), kanban is defined as a Material Flow Control mechanism (MFC) and it controls the proper quantity and proper time of the production of necessary products. It has been used worldwide with the meaning of card because it utilizes cards to manage the delivery and/or production of parts, items, or raw material.

However, if the interpretation of the kanban system is so narrowly restricted, it can be said that most companies use a system like this since the shop floor materials are controlled using cards of some kind, for example production order, schedule sheets, material list, or product structure. There are a number of works in which the term kanban is used indiscriminately meaning both ‘‘card’’ and ‘‘the system’’ itself.

According to many different literature sources (Ohno, 1982; Monden, 1984; Aggarwal, 1985; Grünwald et al., 1989; Sipper and Bulfin, 1997), kanban methodology works effectively only under specific production and market conditions.

This means that this system do not fit with these surrounding conditions:

- unstable market demand
- processing time instability
- non-standardized operations
- long setup time
- great variety of items
- uncertain raw material supply

The above list represents a sort of summary of the most relevant features both of today market demand and the current production systems challenges. This means that in a lot of industrial applications a kanban's evolution has to be adopted and used.

Muris et.al (2010) summarized the key features of the "standard" kanban system as follows:

- use of two communication signals (dual card kanban system):according to Sipper and Bulfin (1997), the dual card kanban system uses production signals (authorizes a process to produce a fixed amount of product) and transportation signals (authorizes transporting a fxed amount of product downstream)
- pulled production: the production is pulled based on the inventory level or the scheduling of the last station
- decentralized control: the control of the production flow is performed through visual control by the employees of each step of the production process
- limited WIP (Work in Process): the inventory level is limited in each workstation, which means, limited buffer capacity, depending on the number of signals.

In the market and industrial contexts where this *pull* tool can be adopted, the most important advantages are:

- Inventory reduction: only the demanded goods are produced, in the demanded quantity and at the right time
- Productions scheduling simplification
- Errors minimization during the production cycle or product flow

In order to better understand how the kanban system operatively works is interesting to introduce a Toyota diagram:

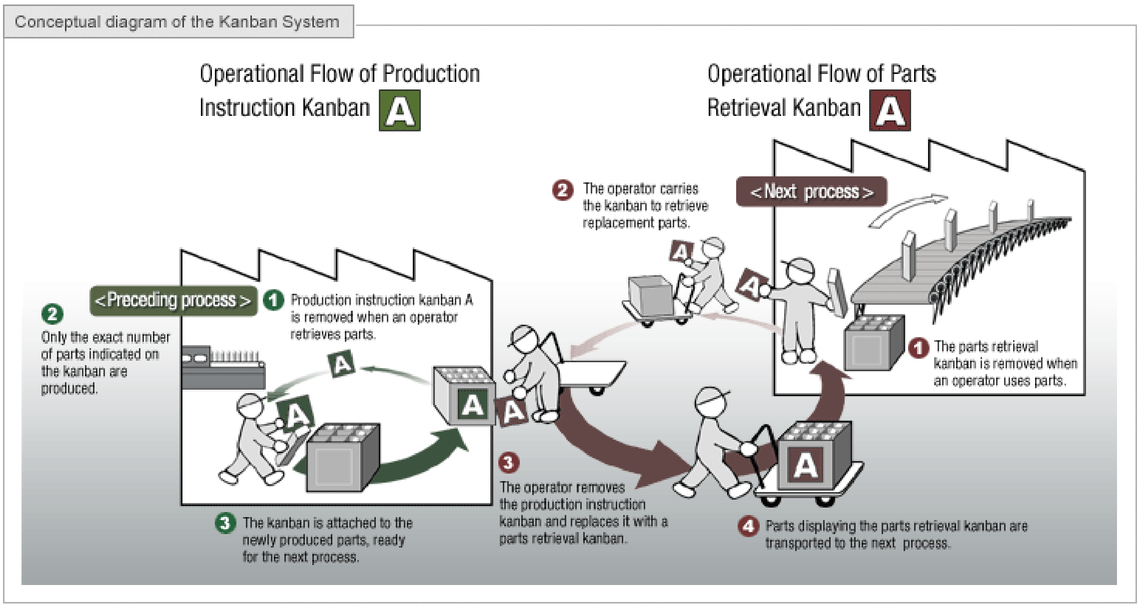


Fig 2.7: Two kinds of kanban (the production instruction kanban and the parts retrieval kanban) are used for managing parts (Toyota official website, *Vision* section, 2010)

2.5 *Jidoka*

According to Osono (2008), Jidoka is the practice of stopping the process when a problem occurs.

Adopting Grout (2009) approach, the Jidoka methodology's five steps are:

i. detect the problem
ii. stop the process
iii. restore the process to proper function
iv. investigate the root cause of the problem
v. install countermeasures

However, Ohno (1988) found that stopping the line and solving problems actually led to better performance in the long run. Initially, lines where workers can stop the process will exhibit lower output. As stoppages lead to problem solving, the line will have fewer stoppages and better quality compared with a line where workers are not empowered to create stoppages. With Jidoka in place, the process may be stopped either by a machine using sensors or by a worker pulling on a cord that hangs down in his or her workspace.

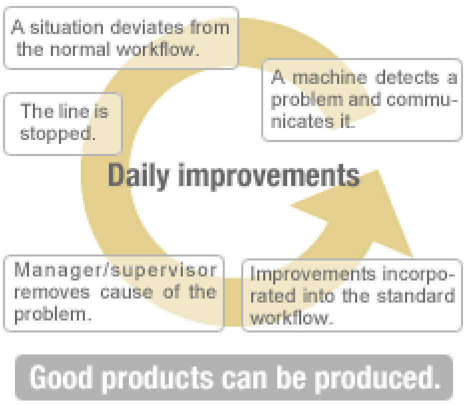


Fig 2.8: Jidoka real deployment in an organization (Toyota official website, *Vision* section, 2010)

2.5.1 Six Sigma

Six Sigma is a concept that was originated by Motorola Inc. in the USA in about 1985. At the time, they were facing the threat of Japanese competition in the electronics industry and needed to make drastic improvements in their quality levels (Harry and Schroeder, 2000).

Six Sigma was a way for Motorola to express its quality goal of 3.4 DPMO (Defects per million opportunities) where a defect opportunity is a process failure that is critical to the customer.

This goal was far beyond normal quality levels and required very aggressive improvement efforts. For example, 3 sigma results in a 66,810 DPMO or 93.3% process yield, while Six Sigma is only 3.4 DPMO and 99.99966% process yield.

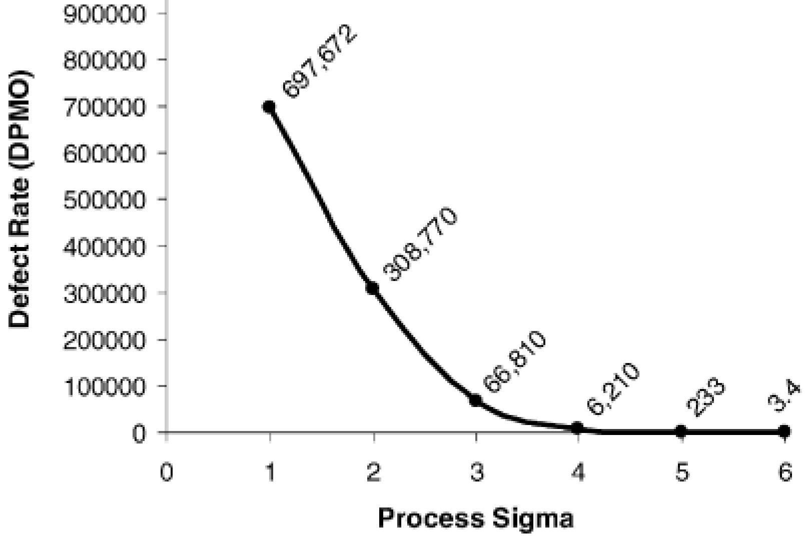


Fig 2.9: Defect rate (DPMO) versus Process Sigma Level (Linderman et al., 2002)

To try to give an holistic definition of Six Sigma methodology the definition of Linderman (2002) can be adopted:

Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.
Analyzing the above definition two are the most innovative aspects within this new approach to the quality management practice:

- the quality of a product (and then of a process) is defined starting from the customer's point of view. Defects mean defects for customer.
- Process features can be fine tuned directly on market requirements' proxy

The fundamental difference between Six Sigma and all the other process improvements is related to the ability of Six Sigma in providing an organizational context that facilitates problem solving and exploration across the organization. Six Sigma programs have their roots in the quality movement and they are different from other quality programs due to their limited time-frame, measurable and quantifiable goals and the project structure. (Andersson et al., 2006).

2.5.2 TQM, Total Quality Management

According to Reed et al. (1996), TQM is a business level strategy with components of process and content.
The content, or what the strategy does, can include improving product quality to help increase sales and revenues (Reed et al., 1996), or reduce risk (Kroll et al., 1999).
According to Reed et al. (2000), literature almost universally recognizes about the purpose of the quality and then the main goal of TQM.

- Quality creates customer satisfaction which leads to an improved competitive position.
- The costs of waste and rework are high and should be eliminated

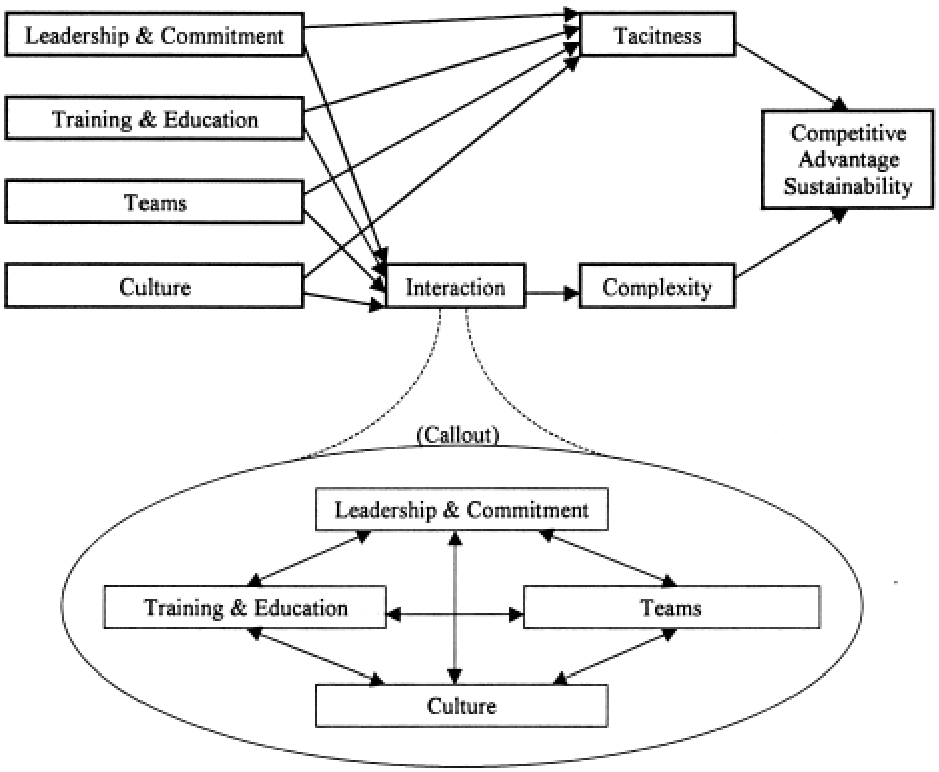


Fig 2.10: TQM process activities, tacitness, complexity and sustainability of advantage (Reed et al., 2000)

2.5.3 Andon

According to Neese (2007) another aspect peculiar of the Visual Management is the production *andon*, which simply means to signal an abnormal or undesired condition. In early Japanese assembly lines, if an operator recognized he was falling behind and was not going to finish his work in the allotted time, he pulled an *andon* chord which actuated a switch and lighted a bulb.

This action prompted immediate action from the line supervisor in order to:

- Help the operator to complete the operation in time
- Help the operator to figure out why he was late and how to prevent the defect at that station in all subsequent operations

2.5.4 Poka Yoke

Poka-Yoke or Mistake-Proofing, developed by Shigeo Shingo in the early 1960s, is a quality improvement methodology to prevent mistakes from happening to minimize the negative consequences (Krajewski, Ritzman, & Malhotra, 2007).

According to Shingo (1985) defects are avoidable if errors are detected and eliminated beforehand.

According to Al-Araida et al. (2010), the Poka-Yoke approach utilizes automatic devices or methods to detect problems before or as they occur using a Poka-Yoke device to minimize the negative consequences. Human unintentionally make mistakes due to absentmindedness; misunderstanding because of the lack of knowledge with a process or procedures; and delays in judgment.

According to the Poka-Yoke approach, occasional errors may warrant warnings whereas frequent errors, or those with large negative consequences, may call for a control Poka-Yoke.

The system aims at setting limits on how an activity is performed in order to force the correct completion of the operation.

In industry, Zero Quality Control (ZQC) Poka-Yoke takes a variety of forms

- 100% inspection
- identifying defects as close to the source of the defect as possible
- taking corrective actions upon detecting a defect to avoid repeating that defect
- designing the processes to avoid producing defects

2.5.5 5 Whys

According to Sakichi Toyoda, a typical example is used in order to explain the concept of the *5* Whys.

My car will not start. (the problem)

Why? - The battery is dead. (first why)

Why? - The alternator is not functioning. (second why)
Why? - The alternator belt has broken. (third why)
Why? - The alternator belt was well beyond its useful service life and has never been replaced. (fourth why)
Why? - I have not been maintaining my car according to the recommended service schedule. (fifth why, a root cause)
This technique belonging to the field of problem solving allows to deeply investigate the cause and effect relationships about a problem, just asking the question “Why?”.
The real key is to encourage the trouble-shooter to avoid assumptions and logic traps and instead to trace the chain of causality in direct increments from the effect through any layers of abstraction to a root cause that still has some connection to the original problem.

2.6 Kaizen

Kaizen, Japanese for "improvement" or "change for the better", refers to philosophy or practices that focus upon continuous improvement of processes in manufacturing, engineering, supporting business processes, and management. It

Kaizen deployment means a sequence of continuous and sustainable progresses gained and deserved by a wide set of organization's employees.

The cycle of kaizen activity can be defined as the respect of different objectives:

- Standardize an operation
- Measure the standardized operation (find cycle time and amount of in-process inventory)
- Gauge measurements against requirements
- Innovate to meet requirements and increase productivity
- Standardize the new, improved operations
- Continue cycle ad infinitum

According to Deming (1986) the kaizen deployment is often linked to PDCA (plan–do–check–act) framework:

PLAN: Establish the objectives and processes necessary to deliver results in accordance with the expected output. By making the expected output the focus, it differs from other techniques in that the completeness and accuracy of the specification is also part of the improvement.

DO: Implement the new processes. Often on a small scale if possible.

CHECK: Measure the new processes and compare the results against the expected results to ascertain any differences.

ACT: Analyze the differences to determine their cause. Each will be part of either one or more of the P-D-C-A steps. Determine where to apply changes that will include improvement. When a pass through these four steps does not result in the need to improve, refine the scope to which PDCA is applied until there is a plan that involves improvement.

3 Innovation in the distribution

3.1 Lean Distribution

Lean Distribution concept was born, as its precursor *Lean Production*, in the automotive industry, as an approach to manage large and complex networks of suppliers with the interdependent goal of reducing costs and ensuring high quality (Lamming, 1993; Womack and Jones, 1996; Cagliano et al., 2004).

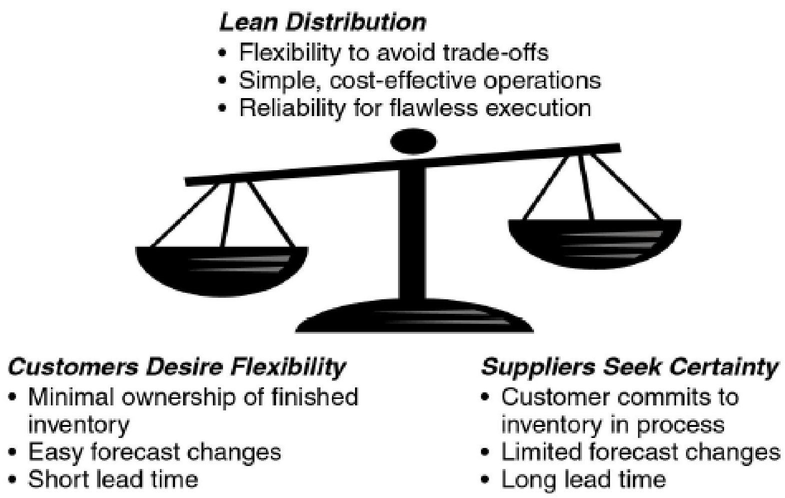


Fig 3.1: Lean Distribution objectives in the Supply Chain Management (Zylstra, 2006)

The above figure shows as Lean Distribution is the key answer in order to effectively manage the modern complex networks, dramatically changed due to new trends of supply chains enlargement (globalization effects) and mutated competition.

Lean Distribution brings a new way on managing a network, offering new angles for each of every Supply Chain degree of freedom.

In the below scheme it's possible understanding how this new approach manages different logistic dimensions.

Dimension	Traditional Approach	Lean Distribution
Customer Service	Collaborate to forecast, then ship to firm orders/releases	Manage flow as customer consumes, "owns" replenishment
Forecast	Are accurate enough, but should strive to make more accurate	Limited accuracy, use for longer-term and aggregate planning only
Inventory	Is an asset and should be close to the customer to meet lead time demands	Consolidate at the source and redirect flow quickly for changing replenishment needs
Variability	Not explicitly used in planning , but measured in operations if Lean and Six Sigma are embraced	Operational, customer demand, and supply chain variability factors used in Lean processes
Transportation	Changing with forecasts and orders; seek to reduce	Replenishment cycle driven; stabilize lanes to reduce
Optimization	Reduce each component of cost while filling forecasted demand	Streamline distribution total cost to replenish actual demand
Assumptions	Forecasts are sufficiently accurate and stable for planning . All cost reductions add to net profit . Inventory costs less than labor	Pull reduces variation and improves service. Only *total cost* reduction adds to profit. Inventory, handling and storage costs are understated

Fig 3.2: Lean Distribution approach in the Supply Chain Management (Zylstra, 2006)

Lean distribution in order to deploy this approach on the reality founds on a set of enablers, directly imported by the Lean Production environment.
In particular (Zylstra, 2006) they are:

- *Formal Service Policies* (close to *standard* Lean Production concept): creating standardized processes than could offer a standard level of quality, based on simple and repeatable activities, to optimize the entire supply chain. An organization can achieve this goal continuously matching customer's needs with their key internal capabilities.
- *Pull Approach*: every stimulus about goods' distribution starts always from a downward request and the customer are use to allow suppliers more latitude and responsibility.
- *Isolate variability*: variability is a condition of the real life and then you can find it in a distribution network management. The only way to manage variability, both in a manufacturing and in a distributive

environment, is creating buffers. The goal will be creating a buffer only in the location where it does make sense. A typical example of buffer's creation in a distribution network is placing a Cross Docking warehouse closed to the customers in order to maximize the service level and the quality dedicated to a certain set of customers, and to minimize at the same time the distribution costs.

- *Cost trade-offs*: in order to effectively minimize the costs related to the distribution, or more in general the whole distribution network, an holistic approach is requested. These means that the focus has to be directed not a specific cost driver, but more in general, to the cost function covering all the interdependent cost drivers.
- *Lead times reduction*: in a *pull* environment and with the current competition level, *lead time* often represents a crucial enabler to well perform in the market. Lean helps reduce lead times, improving flexibility and responsiveness. Optimized lead times bring cost reduction and service improvements.
- *Reduced lot sizes*: one of the most important trade-offs in the holistic supply chain management is linked to the lot size definition and optimization. It's mandatory considering at the same time the manufacturing side of the matter, but at the same time also the impacts on storage and transportation.

3.1.1 Optimizing distribution through maximizing asset utilization

In Chapter 1 the distribution network optimization has been discussed with a strong focus on the logistic side of the problem. This part of the thesis aims to cover more deeply the economics' side of the matter.

According to Zylstra (2006), production and manufacturing investments are usually viewed as strategic assets finalized to generate revenues or reduce

costs. At the same time distribution network investments are viewed as net cost increases and should be avoided wherever possible.
There are three different way to maximize the return of investment in distribution assets:

- *Reduce network assets:* the main purpose of optimizing a distribution network should be the starting point to deeply understand the profitability and the productivity in terms of customer order outbound or supply-related inbound logistics. As analyzed in the Chapter 1, the distribution network cost structure is based on *multivariable* trade-off among transportation costs, facilities and handling costs, IT costs and service level costs. This means that also in the exercise of network assets (costs) reduction you need to adopt a holistic approach in order to consider all the different cost drivers. In the reality this means that there is the need for designing optimization models considering all the above network elements and cost because once again the single reduction of a certain asset can easily bring to an increase of the total distribution network costs. Moreover, in the current environment (characterized by an high costs variability and low margins) the assumptions setting and comprehension play a strategic role in the distribution network optimizing model / business plan.
- *Variable and fixed assets trade off*: the topic of variable and fixed assets comes from the debate between *make* or *buy* options. Basically when this discussion is deployed in a distribution network discussion the main dimensions to be considered are in the below scheme.

Dimension	*Make*	*Buy*
Quality	The origins of any quality problems usually to trace in –house and improvement can be more immediate but can be some risk of compliance	Suppliers may have specialized knowledge and more experience , also may be motivated through market pressures, but communication more difficult
Speed	Can mean synchronized schedules which speeds throughput of materials and information, but if the operation has external customers, internal customers may be low priority	Speed of response can be built into the supply contract where commercial pressures will encourage good performance, but there may be significant transport/delivery delays
Dependability	Easier communications can help dependability, but if the operation also has external customers, internal customers may receive low priority	Late delivery penalties in the supply contract can encourage good delivery performance, but organizational barriers may inhibit in communication
Flexibility	Closeness to the real needs of a business can alert the in-house operation to required changes, but the ability to respond may be limited by the scale and scope of internal operations	Outsource suppliers may be larger, with wider capabilities than in-house suppliers and more ability to respond to changes, but may have to balance conflicting needs of different customers
Cost	In-house operations do not have to make the margin required by outside suppliers so the business can capture the profits which would otherwise be given to the supplier, but relatively low volumes may mean that it is difficult to gain economies of scale or the benefits of process innovation	Probably the main reason why outsourcing is so popular. Outsourced companies can achieve economies of scale and they are motivated to reduce their own costs because it directly impacts on their profits, but costs of communication and coordination with supplier need to be taken into account

Fig 3.3: Outsourcing Pros and cons comparison (Slack, 2007)

– *Utilization*: another aspect to be taken into consideration is the utilization of the adopted resources. Again this concept is linked both the interdependent optimization of the assets (transportation assets, storage & handling assets, ICT assets, etc.) and to the difference between owned resources and contracted ones. This means that every organization should aim to maximize all the owned resources utilization, minimizing the total cost of the distribution network management.

3.1.2 Lean Distribution differences with the traditional distribution approaches

According to Zylstra (2006) the benefits linked to Lean approach in the distribution are lower total costs, lower working capital and improved customer service.

Reorder Point (ROP) vs. Lean Pull

Apparently the ROP and Lean Pull approaches can be considered very similar because of in both cases the distribution flow is trigged by a downward signal. In reality, deeply analyzed, the two techniques present, as showed in the below figure, huge differences in some distribution dimensions.

The most important difference is the presence of a *kanban* between the demand and the replenishment.

Usually the Lean pull approach drives to a management of the total flow of material and goods; the ROP approach is instead focused on the single SKU management.

The optimization suggested by the Lean approach holistically covers all the aspect of the distribution process, ROP is more focused on the transportation optimization.

Triggers to reorder are dramatically different in the two approaches. In a ROP environment a reorder will be placed only when the inventory level will move below the reorder point level, regardless of the time dimension. The Lean approach suggests investigating on a reorder placement on regular basis: in this way a company is continuously aligned to market situation and it can easily and effectively meets the customers' requests.

Another important differentiating element to be considered is the management of the goods' flows through cross docking warehouses: on the on hand Lean distribution manages the entire flow of similar products across different stages of a distribution network, ROP approach considers each stage independently.

Dimension	*Reorder Point (ROP)*	*Lean Pull*
Inventory Level	Based on average usage, order quantity, lead time and safety stock	Based on average usage, demand variation, replenishment frequency
Trigger to reorder	When inventory falls below the reorder point level	Every replenishment cycle (time)
Reorder quantity	Fixed reorder quantity	Actual demand during last replenishment cycle
Connection across Cross Docking	Each level managed independently	Same replenishment cycle for groups of items
Key stability assumptions	Replenishment lead time Forecast continuity	Replenishment cycle Surge capability

Fig 3.4: ROP and Lean Pull comparison (Zylstra, 2006)

Distribution Requirements Planning (DRP) vs. Lean Pull

According to Wang (2009), in the same spirit as MRP logic, DRP (Distribution Requirements Planning) framework is a rolling horizon echelon-by-echelon approach that bases procurement decisions on time-phased projected future node requirements.

According to Zylstra (2006), basically for DRP the starting point is the forecast, customer orders, inventories and planning parameters. The idea is to plan into the future when replenishment orders should be created and then seek ways to optimize shipments and processing. With DRP replenishment orders are planned, created, and released in anticipation of customer orders being shipped.

The approach has several advantages (Martin, 1994). It can deal with any number of echelons, it takes the dependent nature of the demand into account, it manages lead times effectively, it can take economies of scale in transportation into account through the choice of appropriate lot-sizing algorithms, it can take any resource constraints into account indirectly through the intervention of a “master scheduler”, notwithstanding the fact that it has been implemented in several commercial software packages also supporting other needs of distribution/supply organizations (demand and order management, warehousing, transportation, personnel productivity, accounting, …).

The main drawback of the DRP approach is that it was fundamentally designed to support deterministic time-varying demands. Several mechanisms, such as safety stocks, safety times and freeze periods were introduced to “manage” demand uncertainty, but they are often used arbitrarily.

The basic difference with a Lean approach is to link replenishments directly to shipment of customer orders using Pull. When orders are received, the correspondent demanded goods are communicated back to the plant or supplier for replenishment. If no customer orders are shipped, then the plant or supplier does not replenish. In essence, Lean is creating a linkage to pull inventory through the distribution network.

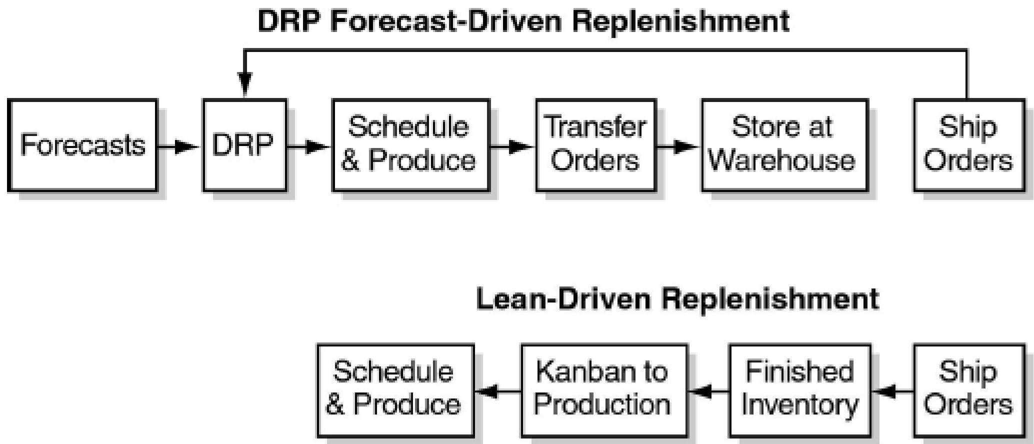


Fig 3.5: DRP and Lean Pull comparison in terms of replenishment approach (Zylstra, 2006)

Dimension	*Distribution Requirements Planning (DRP)*	*Lean Distribution*
Buffer Inventory	Close to each shipping point → high	Consolidated at one point → low
Reliance on forecast	High, at least as long as total lead time	Low, use for longer-term planning
Changes to forecast	Requires re-planning for all products and orders	Consider adjustments to target levels
Transportation Plan	Changes with forecasts and orders; variable	Replenishment cycle driven; stable
Optimization	Cost reduction within constraints	Product flow to daily customer demand
Key Assumptions	Forecasts are accurate and stable. Transportation cost must be reduced. Manage detail orders to a "perfect plan"	Demand variation can be effectively buffered and pulled. Inventory, handling and storage costs are understated. Manage within boundaries of variation

Fig 3.6: DRP and Lean Pull comparison (Zylstra, 2006)

3.2 Agile Distribution

According to Li et al. (2008), *Agility* is the result of integrating alertness to changes (opportunities/challenges) – both internal and environmental – with a capability to use resources in responding (proactively/reactively) to such changes, all in a timely and flexible manner.

In order to better review the literature about this topic below are indicated the most important contributions to the broad definition of *Agile*, broken down (Li et al., 2008) in four different categories: Manufacturing – Logistics Management and Supply Chain Management – Knowledge Management – Information Systems.

<u>3.2.1 Agile Manufacturing definitions timeline</u>

1995

Author Goldman et al.

Definition A construct having the following strategic dimensions: enriching the customer, cooperating both internally and externally to enhance competitiveness, organizing to both adapt to and thrive on change and uncertainty, and leveraging the impact of people and information

Author Kumar and Motwani

Definition A firm's ability to accelerate the activities on the critical path

Metrics A composite value of the strategic agility position of a firm, on a percentage scale, is computed based on the weighted sum of the firm's performance on each element of a matrix. The matrix represents all combinations of time-segments and agility determinants (material and information flow, state of technology, specialized functions, human resource factors, quality and flexibility)

1997

Author DeVor et al.

Definition The ability of a producer of goods and services to operate profitably in a competitive environment of continuous and unpredictable change

Author Quinn et al.

Definition The ability to accomplish rapid changeover from the assembly of one product to the assembly of a different product

1999

Author Dove

Definition The ability of an organization to thrive in a continuously changing, unpredictable business environment

Metrics Cost, time, robustness, and scope

Author Yusuf et al.

Definition The successful exploration of competitive bases (speed, flexibility, innovation, pro-activity, quality, profitability) through integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast-changing market environment

2000

Author Zhang and Sharifi

Definition A combination of three elements:

1) agility drivers, which are the changes/pressures from the business environment that necessitate search for new ways of running a business in order to maintain competitive advantage;

2) agility capabilities, which are the essential capabilities that a firm needs in order to positively respond to and take advantage of the changes;

3) agility providers, which are the means whereby the so-called capabilities could be obtained

Metrics Assessment model for agility: assessment of the organization's need for agility; assessment of the organization's current level of agility

2001

Author Sarkis

Definition Agility is the ability to thrive in environment of continuous and often unanticipated change

3.2.2 Agile Logistics Management & Supply Chain Management timeline

1995

Author Global Logistics Research Team

Definition Addresses how well a firm responds to customers' changing needs and is marked by the abilities to meet unique customer requests and adapt to unexpected circumstances

Metrics Relevancy, accommodation, flexibility

1999

Author Naylor et al.

Definition Use of marketing knowledge and virtual organization to exploit profitable opportunities in a volatile environment

2001

Author van Hoek et al

Definition A management concept centered around responsiveness to dynamic and turbulent markets and customer demand

2006

Author Swafford et al.

Definition Supply chain agility refers to the supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment

Metrics Procurement/sourcing flexibility, manufacturing flexibility, distribution/logistics flexibility

3.2.3 Agile Knowledge Management timeline

2006

Author Swafford et al.

Definition Supply chain agility refers to the supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment

Metrics Procurement/sourcing flexibility, manufacturing flexibility, distribution/logistics flexibility

3.2.4 Agile Information System timeline

Author Sambamurthy et al.

Definition The ability to detect and seize competitive market opportunities by assembling requisite assets, knowledge, and relationships with speed and surprise. Agility is comprised of three interrelated capabilities:

1) Customer agility: ability to co-opt customers in the exploration and exploitation of opportunities for innovation and competitive action moves;
2) Partnering agility: ability to leverage the assets, knowledge, and competences of suppliers, distributors, contact manufactures, and logistics providers through alliances, partnerships, and joint ventures.
3) Operational agility: ability of firms' business processes to accomplish speed, accuracy, and cost of economy in the exploitation of opportunities for innovation and competitive action

3.3 Leagility Distribution

According to Naylor et al. (1999) two of the most important paradigms of the modern Operations Management are *Lean Thinking* and *Agile Manufacturing*. Previously both Lean and Agile distribution are discussed in parallel.

This paragraph is dedicated to a new approach called *Leagility* aiming to merge the two different approaches.

In particular,

> *Leanness* means developing a value stream to eliminate all waste, including time, and to ensure a level schedule.
>
> *Agility* means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place.

The below figure represents the most important metrics describing a supply chain, focus upon the end-user.

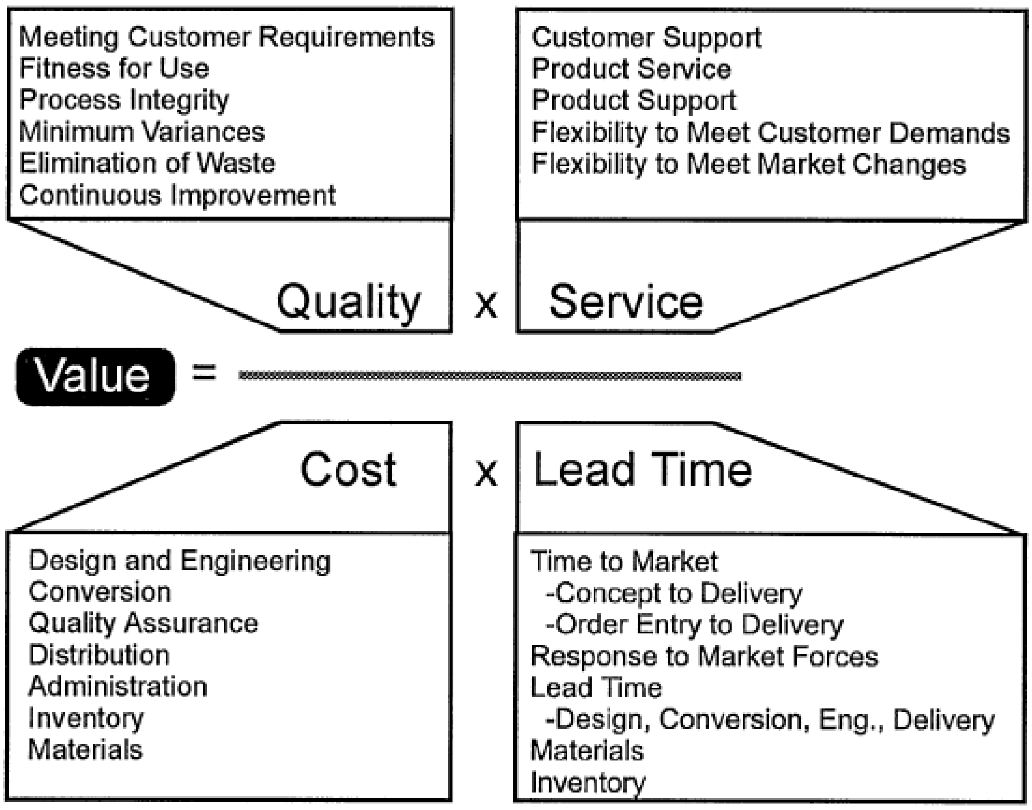


Fig 3.7: Supply Chain key metrics (Naylor et al., 1999)

The starting point of this approach is mapping the most important characteristics of a distribution network. Then rate the importance of the same characteristics in terms of *leanness* and *agility* with three values: essential, desirable and arbitrary.
Finally the table is broken down into three clusters of comparison: same, similar and different.

Keyword	Lean	Agile
Use of market knowledge	○ ○ ○	○ ○ ○
Virtual corporation/Value stream/ Integrated supply chain	○ ○ ○	○ ○ ○
Lead time compression	○ ○ ○	○ ○ ○
Eliminate muda	○ ○ ○	○ ○
Rapid reconfiguration	○ ○	○ ○ ○
Robustness	○	○ ○ ○
Smooth demand/Level scheduling	○ ○ ○	○

Note: ○ ○ ○ = essential. ○ ○ = desirable. ○ = arbitrary.

Fig 3.8: Rating the importance of different characteristics of leanness and agility (Naylor et al., 1999)

3.3.1 Characteristics of equal importance

Use of market knowledge

For both the paradigms the focus on the end-customers is crucial and essential: every action, each decision taken has to be aligned with what it is happening downward.

Integrated supply chain / value stream / virtual corporation

Despite of the adopted paradigm, businesses must work together to form an integrated supply chain focusing on meeting the demands of the end-user or final customer of the supply chain.

The final goal of each supply chain is ease the flow of material, cash, resources and information. With the integrated supply chain both the information and material flows will be simplified, streamlined and optimized reducing waste and lead times.

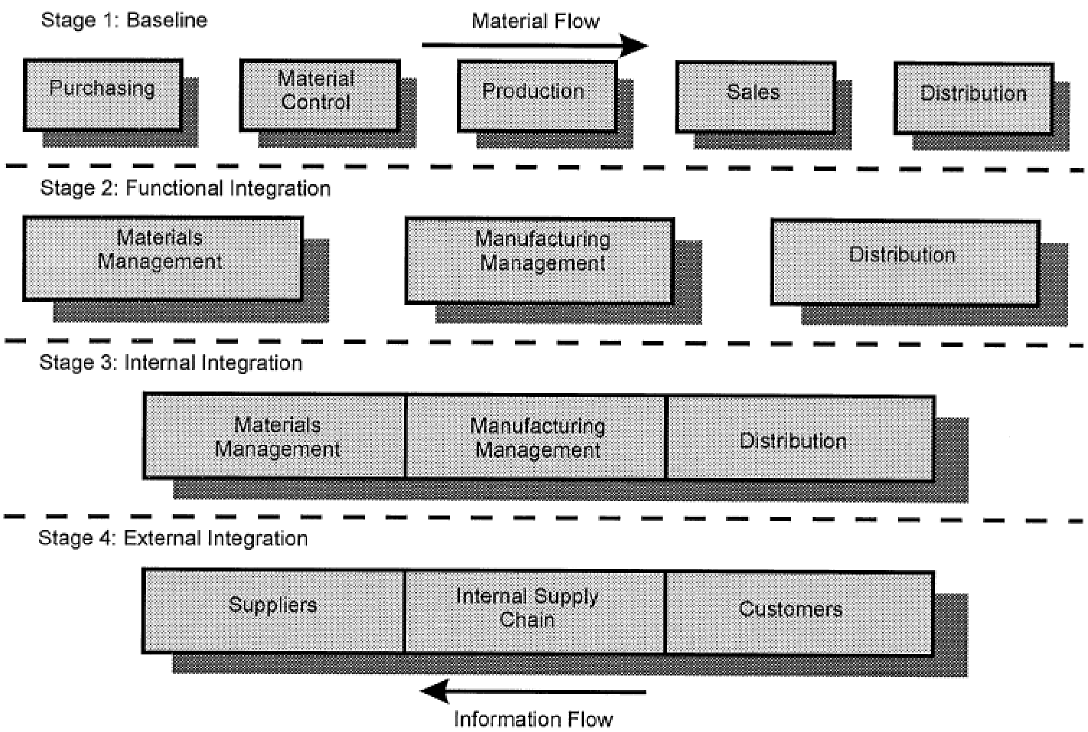


Fig 3.9: Integrated supply chain / value stream / virtual corporation (Naylor et al., 1999)

Lead time compression

For both the paradigms lead time compression is a final goal.

Leanness aims to the elimination of all wastes (*muda*) and the anything is not adding value to a process. Waste time does not structurally add value to a process.

Agility aims to create a responsive supply chain and to achieve this objective minimization of the lead times is crucial.

3.3.2 Characteristics of similar importance

Eliminate muda

Lean manufacturing is called lean as it uses less, or the minimum, of everything required to produce a product or perform a service. In a pure *lean* supply chain inventories are supposed to be eliminated, even if in the reality a small buffer is allowed (MRI concept, Minimum Reasonable Inventory).

On the other from an *agile* perspective a certain stock is the basis to build a robust to changes supply chain.

Rapid reconfiguration

Agile manufacturing means that the production process must be able to respond quickly to changes in information from the market. In a lean environment the rapid reconfiguration is important but it comes after having eliminated all the *muda*.

The below figure then shows how the perfect supply chain should be that supply chain merging the characteristics of both the paradigms.

Metric	Agile	Lean
Lead time	○ ○ ○	○ ○ ○
Service	○ ○ ○	○ ○
Costs	○ ○	○ ○ ○
Quality	○ ○ ○	○ ○ ○

Note: ○ ○ ○ = key metric. ○ ○ = secondary metric. ○ = arbitrary metric.

Fig 3.10: The *perfect* supply chain merges aspects from the two different paradigms (Naylor et al., 1999)

3.3.3 Characteristics of different importance

Robustness

To be effectively flexible and responsive on managing strong fluctuations it's mandatory having built a robust supply chain.

Smooth demand/level scheduling

Lean manufacturing by its very nature tends to reduce demand variation by simplifying, optimizing and streamlining the supply chain. At the same time, if the end-user demand is beyond the control of the supply chain it will not be possible to implement lean manufacturing at the interface with the end-use.

The below chart shows on which dimensions the two paradigms are very different in terms of supply chain management.

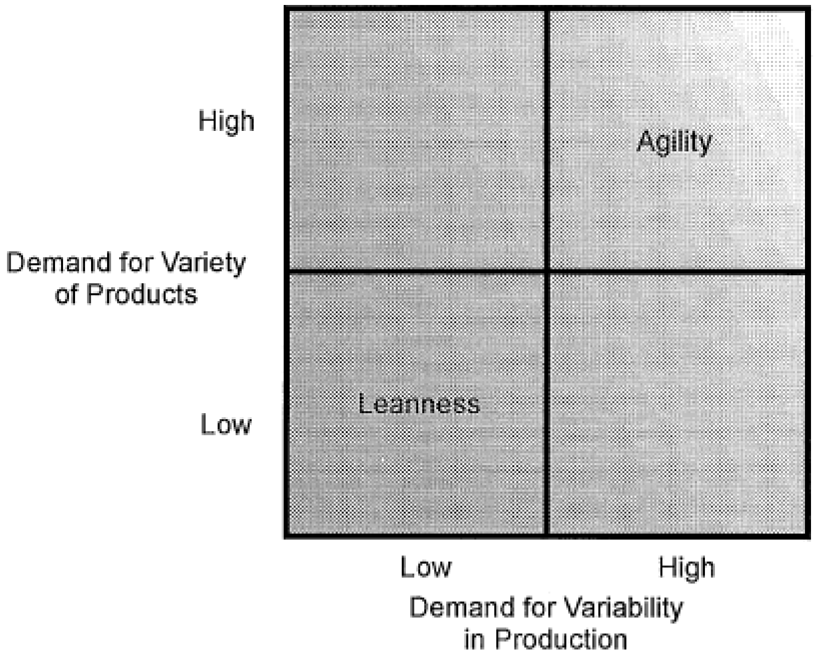
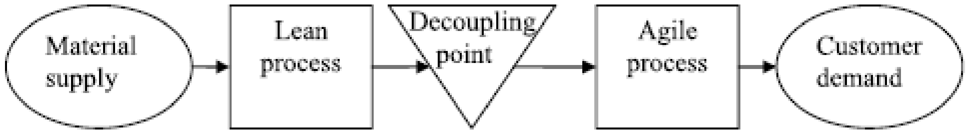


Fig 3.11: Paradigms differentiation (Naylor et al., 1999)

Finally, according to Mason-Jones et al. (2000) the *leagile* model is a supply chain archetype in which lean and agile systems operate at different points in a manufacturing supply chain. A key element of this model is a ‘‘decoupling point’’, which separates the lean processes from the agile processes in the supply chain.

The position of the decoupling point has an effect on determining the structures of the supply chains, and hence one could decide when and where to adopt leanness or agility



3.12: The decoupling point is a kind of cardan joint between lean operations and agile ones (Mason-Jones et al., 2000).

3.4 *Lean* distribution principles application: food logistics case study

3.4.1 Lean principles applied to a food Supply Chain management

The basic concept of lean philosophy is the *Value Maximization*. As introduced in the previous section, the process necessary to implement this concept can be explained by the following five steps (Womack and Jones, 1996):

1) Specify value from end customer's standpoint at the product family level.
2) Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
3) Make the value-creating steps occur in tight sequence, so the product will flow smoothly toward the customer.
4) As flow is introduced, let customers pull value from the next upstream activity.
5) As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

From a Supply Chain Management (SCM) point of view it is possible to identify customer's value as the possibility to get the products in the expected quantity, mix, quality, availability and safety. From this point of view it is indispensible that the Supply Chain (SC) follows the customers demand in terms of quantity, mix and quality with a pull philosophy, eliminating waste.

The food SC is a unique reality, when compared to other industries' SCs which are usually characterized by high difference of managed products in terms of value, physical characteristics, demand pattern, suppliers, safety risk, etc.

From this point of view the proposed model merges the critical aspect of the food SC with the key principles of the lean distribution in a linear programming model, specific to the food SC management.

Its output will be:

- How lean can a certain product category be managed?
- Is it really always true that lean means efficient for the entire food SC products category?
- What happens if the lean concept for one considered product category is stressed to the logistic activities and to its related costs?
- What happens if the lean concept for one considered product category is stressed to the distribution policy within the SC (Distributor Centres and Wholesaler-Manufacturers)?

Chart in Figure 3.13 reports the main dimension of a food SC (products, customers, suppliers) and the impacts on the logistic activities of its specifications. The related lean principles and how the proposed model merges them with the SC specification are reported in the relative row.

Distribution network angle	*Food industry supply chain features*	*Lean supply chain principles*	*Model features*
Products	• Great variety of PC managed • High differentiation on physical characteristics	• Pull philosophy focused on the market requirements • Customers' expectation on product quality, availability and safety • Focalisation on the	• Different products means different distribution strategies, the model focuses on the products category's peculiar features
Customers	• Great variety of customers' typology with different demand pattern • High sensitivity/elasticity of customers for product attributes as quality, safety and complete availability	• Rapidness in demand response • Flexibility to operate with fluctuations	• Demand response flexible for quantity and mix • Model considers different delivery policies (direct and indirect), using DCs or directly from manufacturer–wholesaler to customer
Suppliers	• Competition between supply chains • Focus on the total competitiveness of a value stream vs. the limited efficiency of the single part of the SC	• Supplier is a partner. Data interchange and interaction • Production principles (JIT production, high rotation indexes, high physical and information flows)	• The model considers that the demand is pulled by retailers and visible inside to all SC actors. This is the reason why supplier can delivery directly to the retailers
Network Operations	• Necessity of high rotation indexes and different management for different products category • Dedicated way of transportation (e.g. refrigerators) • High variability mix/quantity/frequency of deliveries. Necessity to small lot delivered in multi-product pallet	• All the actors of the SC have to follow the market demand for quantity, frequency and mix • Deliveries pulled by final demand in mix/quantity/ frequency	The model works for products category minimising the total costs. Lean KPIs are: • the rotation index balance level through the SC • the feasibility to manage direct deliveries from manufacturers–wholesalers using multi-product pallets

Figure 3.13: Food SC specification, lean principles and model integration

In order to link the lean principles to the food SC specification:

- Each product category (PC) is considered once in the model, and all its specification are considered as input data.
- The complete integration with suppliers and the complete data interchange is considered, with the possibility to optimize deliveries using direct or indirect shipments from manufacturers/wholesalers.

Moreover for each product category two main lean KPIs are also considered:

- *Rotation Indices Balance.* Pull philosophy from a demand quantity point of view: how convenient it is to have the same rotation index of Retailers at all the other levels of the SC (Distribution Centres - Manufacturers/Wholesalers), for a certain product category analysed. This assumption implies that the product category physical flow is directly pulled from a quantity point of view by the final demand within all the food SC (*high rotation indices balance*), versus the possibility to have lower rotation indices at the first levels of SC with a higher level of storage (*low level of rotation indices balance*).
- *Upstream multi products pallet feasibility*. Pull philosophy from a demand variety point of view: what is the impact of direct deliveries from the Manufacturer/Wholesaler level to Retailer with different types of pallets, for a certain products category analysed (according its real feasibility). This assumption implies that the product category physical flow is directly pulled from a variety point of view by the final demand within the SC with multiproduct pallet composition since the first level of SC (*high upstream multi products pallet feasibility*), versus the typical single product pallet composition (*low upstream multi products pallet feasibility*).

These two KPIs are the fundamental inputs of the model and summarize the basic lean concept of pull philosophy (both for quantity and variety point of view) allowing a value stream maximization within the SC. The KPIs variation, and their impact on total costs and on distribution policy, gives the answer to the questions if and how it is ideally convenient to manage a certain product category with a lean approach.

The real constrains for the application of such approach define the feasible solution. Figure 3.14 shows the lean SCM model.

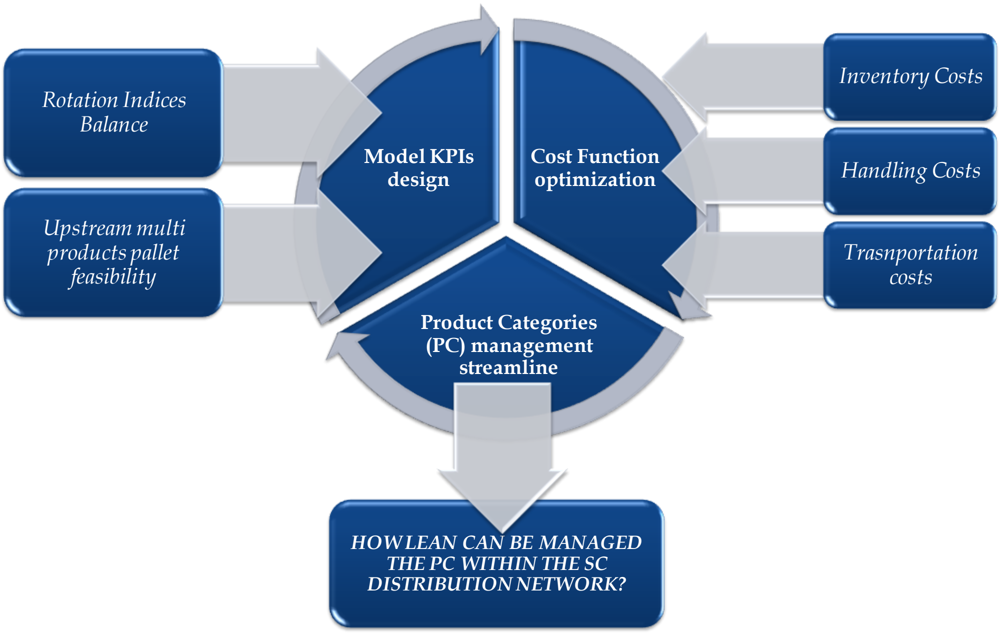


Fig 3.14: Lean SCM model flow chart

According with the two identified lean KPIs, and respecting the cost function optimization value (especially for the rotation index), and the real constrains (especially for multi products pallets feasibility at Manufacturer/Wholesaler level) each product category considered can be placed in one of the 4 different zones defined in Figure 3.15. The top-right part of the matrix represents a pure lean distribution philosophy, where demand pulls directly all the levels of SC for quantity and variety.

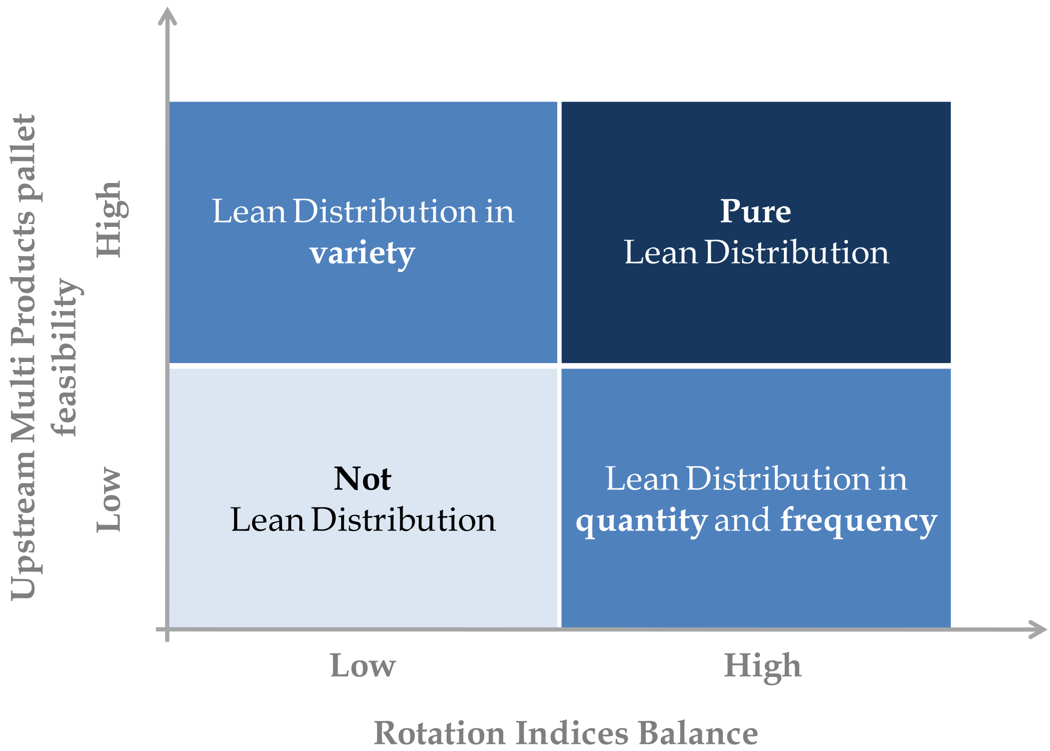


Fig. 3.15: Lean Matrix: lean model KPIs and lean distribution feasibility

3.4.2 The food Supply Chain lean model definition

The proposed model considers a three-stage distribution network: first level, the Manufacturers-Wholesales (M), second level, the Distribution Centers (DC) that can be used to deliver goods, and third level, the Retailers (R).

All the data refer to a certain planned period (i.e. year).

Figure 3.16 shows the considered Supply Chain structure.

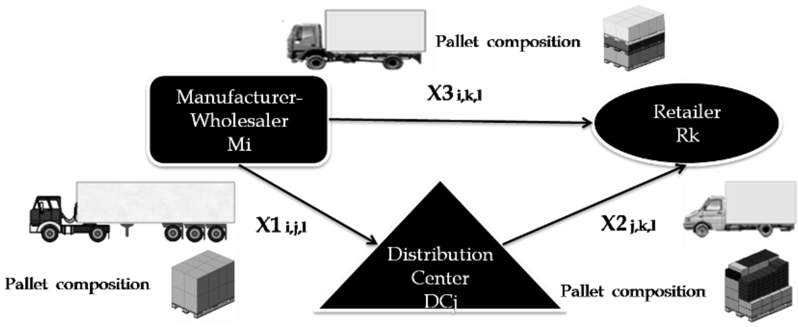


Fig 3.16: Considered food Supply Chain

Indices

i: Manufacturer/wholesaler (*M*); $i = 1, \ldots, I$

j: Distributor Center (*DC*); $j = 1, \ldots, J$

k: Retailer (*R*); $k = 1, \ldots, K$

l: Product category (*PC*); $l = 1, \ldots, L$

Decision Variables

$X1i,j,l$: quantity of product category delivered PC_l from M_i to DC_j (m^3).

$X2j,k,l$: quantity of product category delivered PC_l from DC_j to R_k (m^3).

$X3i,k,l$: quantity of product category delivered PC_l from M_i to R_k (m^3).

Assumptions

- The demand is pulled by Retailers, the SC actors have direct contact with end customers.

- Inventory costs at each SC stage depend on inventory cost rate, on safety stock level and on the average level of stocks, by the quantity delivered and by the rotation index of each product category.
- The inventory cost rate depends on the capital costs and on the product category features like storage space costs, inventory risk costs, including obsolescence, deterioration and pilferage.
- The transports are executed by three different types of trucks, T_1, T_2 and T_3:
  - T_1 truck in use on the routes from M_i to DC_j ; *volume* capacity, 90 m^3, *weight* capacity, 22 tons;
  - T_2 truck in use on the routes from DC_j to R_k ; *volume* capacity, 15 m^3, *weight* capacity, 3.5 tons;
  - T_3 truck in use on the routes from M_i to R_k ; *volume* capacity, 45 m^3, *weight* capacity, 9 tons;

Their capacity limits in weight and volume are considered in order to estimate the specific transportation cost for each products category.

- In the planned period (year) the total quantity of different products category demanded is equal to the quantity produced/sold at the manufacturers/wholesalers.
- DC_j receives goods from M_i and processes them for reshipment to customers with handling costs (depending on product's families) and inventory costs (depending on product's quantity). Other handling costs are not considered because they are always present.
- The rotation index at the R_k level depends on the product category considered. The relative rotation index at DC_j and *Mi* is considered minor or equal.

– The service level considered is equal to100%. Safety stock will be dimensioned consequently.

Input Data

H_l: handling cost per cubic meter of product's category PC_l (€/m^3).

C_l: cost per cubic meter of product's category PC_l (€/m^3).

$s1_i$: inventory cost rate at M_i.

$s2_j$: inventory cost rate at DC_j.

$s3_k$: inventory cost rate at R_k.

$TL1_{i,j}$: transportation limited capacity from M_i to DC_j in a trip (m^3/truck).

$TL2_{j,k}$: transportation limited capacity from DC_j to R_k in a trip (m^3/truck).

$TL3_{i,k}$: transportation limited capacity from M_i to R_k in a trip (m^3/truck).

CT:* specific transportation cost, depending on the specific truck used (€/m^3)

MLF_l: maximum load factor or volume saturation level, function of the product category and of the truck used (%).

For each couple *i,j; j,k; i,k* is possible to define:

$$CT_l = \frac{CT^*}{MLF_l \times TL} \quad (1)$$

Obtaining:

$CT1_l$: transportation cost of a cubic meter of product's category PC_l using the truck type 1 (€/km m^3) from M_i to DC_j.

$CT2_l$: transportation cost of a cubic meter cubic meter of product's category PC_l using the truck type 2 (€/km m^3) from DC_j to R_k.

$CT3_l$: transportation cost of a cubic meter cubic meter of product's category PC_l using the truck type 3 (€/km m^3) from M_i to R_k

$MC_{k,l}$: total demand matrix of product's category PC_l ordered by retailer R_k (m^3/year).

$MD1_{i,j}$: distance matrix from M_i to DC_j, (km).

$MD2_{j,k}$: distance matrix from DC_j to R_k (km).

$MD3_{i,k}$: distance matrix from M_i to R_k (km).

$R1_{i,l}$: rotation index target for product's category PC_l at M_i (/year).

$R2_{j,l}$: rotation index target for product's category PC_l at DC_j (/year).

$R3_{k,l}$: rotation index target for product's category PC_l at R_k (/year).

This set of parameters models the *rotation indices balance* KPI.

$SS1_{i,l}$: safety stock in M_i of product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS1_{i,l} = K1_{i,l} \cdot \sigma 1\%_{i,l} \cdot F1_{i,l} \cdot \sqrt{LT1_{i,l}} \quad (2)$$

$SS2_{j,l}$: safety stock in DC_j of product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS2_{j,l} = K2_{j,l} \cdot \sigma 2\%_{j,l} \cdot F2_{j,l} \cdot \sqrt{LT2_{j,l}} \quad (3)$$

$SS3_{i,l}$: safety stock in R_k for the product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS3_{k,l} = K3_{k,l} \cdot \sigma 3\%_{k,l} \cdot F3_{k,l} \cdot \sqrt{LT3_{k,l}} \quad (4)$$

Where related to the nodes *i,j,k:*

k: adjusting parameter for customer service level.

SL_l: service level of the product category *l*.

σ : standard percentage demand deviation of the product's family PC_l

LT: supply lead time (weeks).

F: forecasted annual demand of the product's category PC_l directly delivered to the DC_j (m^3).

The model assumes that the forecasted annual demand of the product's category PC_l derives from the historical annual demand.

$$F1_{i,l} = \sum_j X1_{i,j,l} + \sum_k X3_{i,k,l} \quad (5)$$

$$F2_{j,l} = \sum_k X2_{i,k,l} \quad (6)$$

$$F3_{k,l} = \sum_j X2_{j,k,l} + \sum_i X3_{i,k,l} \quad (7)$$

NPC1$_{i,j}$: average number of type of products category delivered from M_i to DC_j in a trip.

NPC2$_{j,k}$: average number of type of products category delivered from DC_j to R_k in a trip.

NPC3$_{i,k}$: average number of type of products category delivered from M_i to R_k in a trip.

NPC parameters model mathematically the concept of *upstream multi products pallet feasibility* KPI.

<u>*Cost functions*</u>

Minimize the total cost for product category PC_l using:

$$TotC_l = IC_l + HC_l + TC_l \tag{8}$$

Where:

IC_l : Inventory cost for product category PC_l.

It represents costs incurred by warehousing and storage activities. Usually, direct delivery reduces safety stock inventories, while the presence of intermediate warehouses increases safety stocks. The formula calculated the inventory costs as a function of the safety stock installed at the considered point (retailer or distribution center) and as the average level of stock.

$$IC_l = (\sum_i \sum_j \frac{X1_{i,j,l}}{R1_{i,l}} \cdot s1_i + \sum_i \sum_k \frac{X3_{i,k,l}}{R1_{i,l}} \cdot s1_i) \cdot c_l + \sum_j \sum_k \frac{X2_{j,k,l}}{R2_{j,l}} \cdot s2_j \cdot c_l + (\sum_j \sum_k \frac{X2_{j,k,l}}{R3_{k,l}} \cdot s3_k + \sum_i \sum_k \frac{X3_{i,k,l}}{R3_{k,l}} \cdot s3_k) \cdot c_l + \sum_i SS1_{i,l} \cdot c_l \cdot s1_i + \sum_j SS2_{j,l} \cdot c_l \cdot s2_j + \sum_k SS3_{k,l} \cdot c_l \cdot s3_k \tag{9}$$

HC_l : Handling Cost for product category PC_l

When products are moved from plant to trucks, from truck to customers, from truck to intermediate warehouse and from warehouse to trucks again, handling costs are inevitable. In this model, handling costs at manufacturer plants and at customers' sites are always generated, so they can be omitted in the calculation. The model considers only handling costs due to the transit of products through distribution centres, which is a direct function of the volume moved and depends on the characteristics of the product category.

$$HC_l = \sum_i \sum_j X1_{i,j,l} \cdot H_l \tag{10}$$

TC_l: Transportation cost for product category PC_l

Transportation costs include all costs involved in the movement or transportation of a shipment, but vary considerably with volume, weight of shipment, distances, transport mode, etc. Different correlated factors make up the transportation costs considered in this model: distance, goods delivery quantities, physical characteristics of goods, transportation policy and transportation route, and saturation at the truck level in function of the type of transportation. The specific transportation costs (€/km m^3) have been calculated estimating the cost for kilometre in function of the type of truck, and dividing it for the maximum possible quantity of cubic meter of the considered product category loaded. The model developed is based on specific transportation cost data, obtained by combining the different factors described above and expressed in Euro per cubic meter of goods.

$$TC_l = \sum_i \sum_j \frac{R2_{j,l} \cdot X1_{i,j,l} \cdot CT1_l \cdot MD1_{i,j}}{NPC1_{i,j}} + \sum_j \sum_k \frac{R3_{k,l} \cdot X2_{j,k,l} \cdot CT2_l \cdot MD2_{j,k}}{NPC2_{j,k}} + \sum_i \sum_k \frac{R3_{k,l} \cdot X3_{i,k,l} \cdot CT3_l \cdot MD3_{i,k}}{NPC3_{i,k}} \tag{11}$$

Subject to:

$$\sum_i X3_{i,k,l} + \sum_j X2_{j,k,l} = MC_{k,l\cdot} \cdot (1 - SL_l) \tag{12}$$

$$\sum_i X1_{i,j,l} = \sum_k X2_{j,l,k} \tag{13}$$

$$\sum_k X3_{i,k,l} + \sum_j X1_{j,k,l} \le MW_{i,l\cdot} \tag{14}$$

The first constraint ensures that all the goods delivered to the retailer are consumed in the planned period; the second ensures that all the goods received by each DC_j are delivered to the retailers in the planned period, and the third constraint ensures that the production capacity of each product category at each M_i is greater than the demand.

3.4.3 Applicative case

The following industrial application aims to explain how lean distribution can deal with food supply chain features and problem, and to investigate how different product categories should be managed within a food distribution network and how the different distributive policies can be supported by Lean concepts.

The considered network (as shown in Figure 3.17) is a three level supply chain, with a subset of a bigger distribution network managed by a mid-size Italian supermarket chain. At the first level there are six manufacturers or large wholesalers, producing or selling, different food product categories, indexed from M_1 to M_6.Then at the second level we considered two different distribution centres, DC_1 and DC_2. Finally, downstream the distribution is handled by twelve different retailers (i.e.: supermarkets), indexed from R_1 to R_{12}. The location of each point in the network is reported in Figure 3.18, while Figure 3.19 shows the distances among the different points.

We considered six different product categories, indexed from PC_1 to PC_6: three of them belong to the *packed food* cluster, basically food not perishable in the short term, one belongs to the *fresh products* cluster, another one to the *fruits and vegetable* cluster and the last one to the *frozen foods* cluster.

Figure 3.20 shows the average value for each product category, the related rotation index requested at the retailer/supermarket level, the specific handling cost and the inventory cost rate. Figure 3.22 and Figure 3.23, respectively show *demand* matrix and *delivery* matrix of quantities related to the flow of materials on a yearly basis.

Transportation constraints and its related costs have been modelled considered the following aspects, as shown in Table 3.24:

- For each of the network main routes ($x1_{i,j}$ $x2_{j,k}$ $x3_{i,k}$) only one truck category is available: as shown, both the maximum capacity in *volume*

(VTC, Volume Track Capacity) and in *weight* (WTC, Weight Truck Capacity) have been calculated.

- Each type of truck has a specific transportation cost.

Furthermore, considering that a different product category presents different features in terms of volume, weight and perishability, a matrix has been designed to model the transportations costs both on the truck dimension and on the product category dimension.

For each product category the inventory cost rate has been estimated.

In addition, in order to respect the lean principles it has been considered a service level parameter of 100%.

Other data from the applicative case are:

- Planned period equal to one year
- Lead time equal to five working days

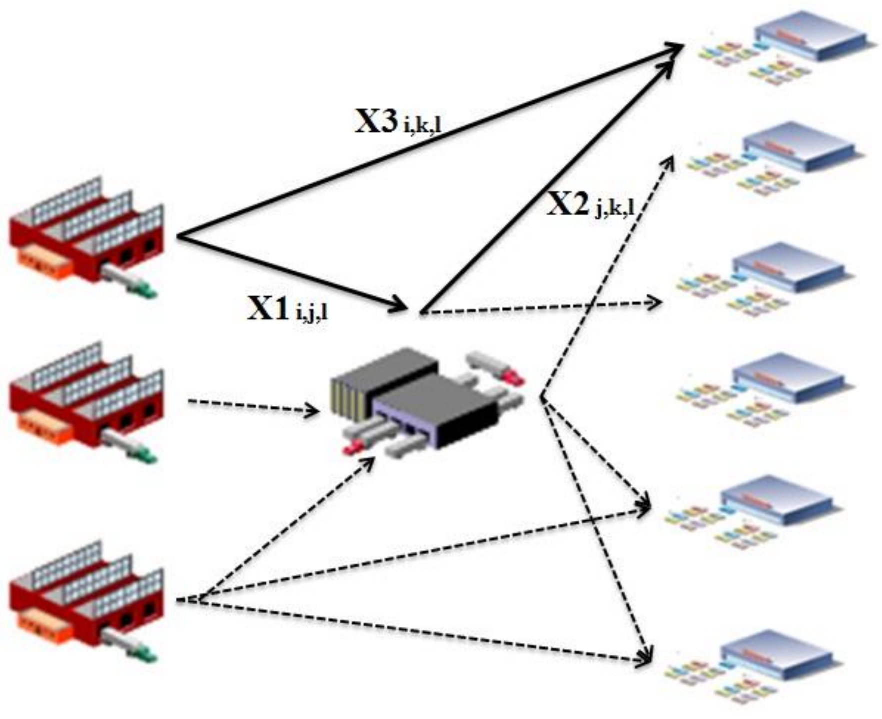


Figure 3.17: Applicative case distribution network

	Supply Chain Actor	*Location*	*Region*
W1	Manufacturer/Wholesaler 1	Turin	Piedmont
W2	Manufacturer/Wholesaler 2	Parma	Emilia Romagna
W3	Manufacturer/Wholesaler 3	Milan	Lombardy
W4	Manufacturer/Wholesaler 4	Brescia	Lombardy
W5	Manufacturer/Wholesaler 5	Verona	Veneto
W6	Manufacturer/Wholesaler 6	Treviso	Veneto
DC1	Distribution Center 1	Milan	Lombardy
DC2	Distribution Center 2	Vicenza	Veneto
R1	Retailer 1	Alessandria	Piedmont
R2	Retailer 2	Turin	Piedmont
R3	Retailer 3	Vercelli	Piedmont
R4	Retailer 4	Bergamo	Lombardy
R5	Retailer 5	Brescia	Lombardy
R6	Retailer 6	Milan	Lombardy
R7	Retailer 7	Pavia	Lombardy
R8	Retailer 8	Padua	Veneto
R9	Retailer 9	Venice	Veneto
R10	Retailer 10	Verona	Veneto
R11	Retailer 11	Bolzano	Trentino Alto Adige
R12	Retailer 12	Udine	Friuli Venezia Giulia

Figure 3.18: Food network actors and their location

Distance (Km)	*DC1*	*DC2*	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*R8*	*R9*	*R10*	*R11*	*R12*
W1	142	339	95	12	82	182	230	155	167	373	413	295	442	520
W2	125	192	164	243	209	162	117	125	113	210	250	144	282	360
W3	15	216	97	141	86	60	107	23	41	247	284	171	307	398
W4	101	120	184	230	174	55	11	100	135	152	188	73	210	299
W5	161	60	242	291	236	116	72	161	194	90	126	8	154	236
W6	297	94	377	426	370	251	205	297	328	71	45	144	291	129
DC1	0	0	99	142	87	60	110	13	41	247	284	170	311	395
DC2	0	0	293	343	287	168	125	211	244	45	83	60	207	192

Figure 3.19: Distance matrix

	Cluster	*Description*	*Average value* (€/cubic meter)	*Average Retailer Rotation Index* (/year)	*Handling cost* (€/cubic meter)	*Inventory Cost Rate* (%)
PC1	Packed Food	Bottled water	50	10	5	20%
PC2	Packed Food	Pasta	1,200	15	5	20%
PC3	Packed Food	Canned Food	2,500	7	5	30%
PC4	Fresh Products	Parmesan Cheese	20,000	30	10	40%
PC5	Fruits & Vegetables	Carots	2,000	300	10	90%
PC6	Frozen Food	Ice-cream	4,000	50	15	70%

Figure 3.20: Product Categories main features

(cubic meter)	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	TOT.
PC1	1,000	862	936	993	939	972	1,184	1,007	855	811	824	1,152	11,535
PC2	200	228	201	183	200	217	189	202	205	237	211	180	2,453
PC3	40	35	32	36	40	38	32	40	47	34	32	43	449
PC4	20	23	18	18	21	24	19	23	21	22	23	24	256
PC5	7	8	6	6	7	8	7	8	7	10	6	5	85
PC6	15	13	14	16	12	15	16	18	18	14	14	13	178
TOT.	1,282	1,169	1,207	1,252	1,219	1,274	1,447	1,298	1,153	1,128	1,110	1,417	

Figure 3.21: Demand matrix

(cubic meter)	W1	W2	W3	W4	W5	W6	TOT.
PC1			8,000			6,000	14,000
PC2		3,000					
PC3			1,000				
PC4		1,000					
PC5	50				60		
PC6	100				150		
TOT.	150	4,000	9,000	-	210	6,000	

Figure 3.22: Delivery matrix

Truck	*From*	*To*	*VTC* (cubic meter /truck,trip)	*WTC* (kg x 1000/truck,trip)	*Average Specific Trasportation Cost* (€/Km)
Type 1	Wi	DCj	90	22	1.5
Type 2	DCj	Rk	15	3.5	0.7
Type 3	Wi	Rk	45	9	1.1

Figure 3.23: Transportation features

	Cluster	*Description*	*Specific Trasportation Cost, Type 1 Truck* (€/Km x cubic meter)	*Specific Trasportation Cost, Type 2 Truck* (€/Km x cubic meter)	*Specific Trasportation Cost, Type 3 Truck* (€/Km x cubic meter)
PC1	Packed Food	Bottled water	0.076	0.272	0.118
PC2	Packed Food	Pasta	0.056	0.196	0.086
PC3	Packed Food	Canned Food	0.208	0.817	0.324
PC4	Fresh Products	Parmesan Cheese	0.125	0.490	0.194
PC5	Fruits & Vegetables	Carots	0.067	0.245	0.104
PC6	Frozen Food	Ice-cream	0.097	0.327	0.151

Figure 3.24: Transportation costs

The following tables show the key input data for each product category. In order to facilitate a general comparison between the different product categories presented, a 1-5 rating according to product category logistic attributes is presented in the last column of the table.

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	•
H	Handling cost	(€/cubic meter)	• •
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	• • •
R3	Retailer Rotation index	(/year)	• • •
s	Inventory Cost Rate	(%)	•
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	•

Figure 3.25: Bottled water input data

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	• •
H	Handling cost	(€/cubic meter)	• •
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	• •
R	Retailer Rotation index	(/year)	• • •
s	Inventory Cost Rate	(%)	•
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	• •

Figure 3.26: Pasta input data

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	• • •
H	Handling cost	(€/cubic meter)	• •
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	• • • • •
R	Retailer Rotation index	(/year)	• •
s	Inventory Cost Rate	(%)	• •
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	• •

Figure 3.27: Canned food input data

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	• • • • •
H	Handling cost	(€/cubic meter)	• • •
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	• • •
R	Retailer Rotation index	(/year)	• • • •
s	Inventory Cost Rate	(%)	• • •
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	• • •

Figure 3.28: Parmesan Cheese input data

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	● ● ●
H	Handling cost	(€/cubic meter)	● ● ● ●
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	● ●
R	Retailer Rotation index	(/year)	● ● ● ● ●
s	Inventory Cost Rate	(%)	● ● ● ● ●
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	● ● ● ● ●

Figure 3.29: Carrots input data

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/cubic meter)	● ● ● ●
H	Handling cost	(€/cubic meter)	● ● ● ● ●
CT	Average Specific Trasportation Cost	(€/Km x cubic meter)	● ● ●
R	Retailer Rotation index	(/year)	● ● ●
s	Inventory Cost Rate	(%)	● ● ● ●
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	● ● ● ●

Figure 3.30: Ice-cream input data

For each product category, the total cost has been calculated as the sum of different factors: transportation costs, inventory costs and handling cost. Every product category total cost has been repeated changing the value of the *lean* KPIs (*Rotation Indices Balance, Upstream multi products pallet feasibility)* in order to perform a reliable sensitive analysis that permit to define the best possible lean distribution strategy for the considered product category.

The optimal solution for each product category will be the one minimizing the overall costs, still respecting the constraints of that peculiar supply chain.

In the following table showing the solutions reached in the study, the spectrum of potential optimal solutions has been highlighted in light grey, the optimal solution in dark grey.

Bottled water

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	2	7	22	1	20	3	157,000	90,084	-	66,911	-	11,535	11,535	0	100
2	8	13	22	1	20	3	276,940	202,630	42,620	31,697	8,524	3,011	11,535	74	26
3	22	22	22	1	20	3	403,600	324,210	57,675	21,718	11,535	-	11,535	100	0
4	2	7	22	1	20	8	100,690	33,781	-	66,911	-	11,535	11,535	0	100
5	8	13	22	1	20	8	158,420	129,950	4,055	24,419	811	10,724	11,535	7	93
6	22	22	22	1	20	8	341,190	311,840	13,210	16,137	2,642	8,893	11,535	23	77
7	2	7	22	1	20	20	80,423	13,512	-	66,911	-	11,535	11,535	0	100
8	8	13	22	1	20	20	77,705	54,050	-	23,654	-	11,535	11,535	0	100
9	22	22	22	1	20	20	163,120	148,640	-	14,479	-	11,535	11,535	0	100

Figure 3.31: Bottled water output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, only very low NPC_3 are considered feasible: beverage manufacturers/wholesalers will never compose a pallet dedicated to the specific retailer’s requirements.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution is setting different values at the different stages of the food SC.

Positioning on Lean Matrix

For the above considerations this approach does not suggest at all to adopt the lean distribution to optimize the distribution network for bottled water product category.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

Pasta

	Input Data						Output Data								
Run	r1	r2	r3	NPC1	NPC2	NPC3	TotC	TC	HC	IC	X2	X3	X TOT	X2 %	X3 %
1	2	5	18	1	20	3	375,190	27,740	-	347,450	-	2,453	2,453	0	100
2	7	11	18	1	20	3	234,280	97,091	-	137,190	-	2,453	2,453	0	100
3	18	18	18	1	20	3	328,530	229,040	3,045	96,441	609	1,844	2,453	25	75
4	2	5	18	1	20	8	357,850	10,402	-	347,450	-	2,453	2,453	0	100
5	7	11	18	1	20	8	173,600	36,409	-	137,190	-	2,453	2,453	0	100
6	18	18	18	1	20	8	179,420	93,623	-	85,792	-	2,453	2,453	0	100
7	2	5	18	1	20	20	351,610	4,161	-	347,450	-	2,453	2,453	0	100
8	7	11	18	1	20	20	151,750	14,563	-	137,190	-	2,453	2,453	0	100
9	18	18	18	1	20	20	123,240	37,450	-	85,792	-	2,453	2,453	0	100

Figure 3.32: Pasta output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, only very low NPC_3 are considered feasible: beverage manufacturers/wholesalers will never compose a pallet dedicated to the specific retailer’s requirements.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution should be setting rotation indices along the SC partially pulled from downstream.

Positioning on Lean Matrix

For the above considerations this approach suggests to move toward the lean distribution archetype only, and partially, in terms of *Rotation Indices Balance*.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

Canned Food

	Input Data						Output Data									
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	1	4	12	1	20	3	384,700	8,226	-	376,470	-	449	449	0	100
2	4	7	12	1	20	3	156,810	32,906	-	123,910	-	449	449	0	100
3	12	12	12	1	20	3	119,500	29,909	1,355	88,237	271	178	449	60	40
4	1	4	12	1	20	8	379,550	3,085	-	376,470	-	449	449	0	100
5	4	7	12	1	20	8	136,250	12,340	-	123,910	-	449	449	0	100
6	12	12	12	1	20	8	102,500	24,255	650	77,594	130	319	449	29	71
7	1	4	12	1	20	20	377,700	1,234	-	376,470	-	449	449	0	100
8	4	7	12	1	20	20	128,840	4,936	-	123,910	-	449	449	0	100
9	12	12	12	1	20	20	82,589	14,808	-	67,782	-	449	449	0	100

Figure 3.33: Canned Food output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, higher NPC_3 values are allowed in comparison to *mass* product categories such as beverage and pasta.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order for the upstream flow of material to be perfectly pulled by the end customer' demand.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of rotation indices balance and partially in terms of upstream multi products pallet feasibility: in other words a lean distribution in quantity and frequency.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides both direct deliveries, mainly, from the manufacturers/wholesalers M_i to the retailers R_k (~70% in volumes), but also deliveries by distribution centers (DC_j).

Parmesan Cheese

	Input Data						*Output Data*								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	3	9	30	1	20	3	831,820	9,996	-	821,830	-	256	256	0	100
2	11	18	30	1	20	3	361,990	36,651	-	325,340	-	256	256	0	100
3	30	30	30	1	20	3	307,380	99,958	-	207,430	-	256	256	0	100
4	3	9	30	1	20	8	825,570	3,748	-	821,830	-	256	256	0	100
5	11	18	30	1	20	8	339,090	13,744	-	325,340	-	256	256	0	100
6	30	30	30	1	20	8	244,910	37,484	-	207,430	-	256	256	0	100
7	3	9	30	1	20	20	823,330	1,499	-	821,830	-	256	256	0	100
8	11	18	30	1	20	20	330,840	5,497	-	325,340	-	256	256	0	100
9	30	30	30	1	20	20	222,420	14,994	-	207,430	-	256	256	0	100

Figure 3.34: Parmesan Cheese output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, higher NPC_3 values are allowed in comparison to *mass* product categories.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order the upstream flow of material is perfectly pulled by the end customer' demand.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of rotation indices balance and partially in terms of upstream multi products pallet feasibility: in other words a lean distribution in quantity and frequency.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

Carrots

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	29	96	320	1	20	3	18,819	7,210	110	11,599	11	74	85	13	87
2	115	192	320	1	20	3	28,037	18,759	430	8,847	43	42	85	51	49
3	320	320	320	1	20	3	48,335	39,744	500	8,091	50	35	85	59	41
4	29	96	320	1	20	8	14,310	3,261	-	11,050	-	85	85	0	100
5	115	192	320	1	20	8	18,504	10,642	150	7,713	15	70	85	18	82
6	320	320	320	1	20	8	31,952	23,969	370	7,613	37	48	85	44	56
7	29	96	320	1	20	20	12,354	1,304	-	11,050	-	85	85	0	100
8	115	192	320	1	20	20	12,184	4,675	80	7,429	8	77	85	9	91
9	320	320	320	1	20	20	19,150	12,383	110	6,657	11	74	85	13	87

Figure 3.35: Carrots output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, the top NPC_3 values are allowed in this fresh food supply chain.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution should be setting rotation indices along the SC partially pulled from downstream.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of upstream multi products pallet feasibility and partially in terms of rotation indices balance: in other words a lean distribution in variety.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides mostly direct delivery (~90% in volumes) from the manufacturers/wholesalers M_i to the retailers R_k.

Ice-cream

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	1	4	12	1	20	3	558,180	990	-	557,190	-	178	178	0	100
2	4	7	12	1	20	3	187,350	3,960	-	183,390	-	178	178	0	100
3	12	12	12	1	20	3	112,200	11,881	-	100,320	-	178	178	0	100
4	1	4	12	1	20	8	557,560	371	-	557,190	-	178	178	0	100
5	4	7	12	1	20	8	184,870	1,485	-	183,390	-	178	178	0	100
6	12	12	12	1	20	8	104,770	4,455	-	100,320	-	178	178	0	100
7	1	4	12	1	20	20	557,330	149	-	557,190	-	178	178	0	100
8	4	7	12	1	20	20	183,980	594	-	183,390	-	178	178	0	100
9	12	12	12	1	20	20	102,100	1,782	-	100,320	-	178	178	0	100

Figure 3.36: Ice-cream output data

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, the top NPC_3 values are allowed within the frozen food supply chain.

Rotation Indices Balance

In terms of rotation indices balance it was observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order for the upstream flow of material to be perfectly pulled by the end customer' demand.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the pure lean distribution.

Distribution strategy

The distribution strategy suggested, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

In Figure 3.37, which reports the summary of different lean distribution approaches for the different product categories, it is made clear how, as results of the application of the proposed Supply Chain model, the different product categories are differently positioned in the lean matrix and how they require different distribution strategies in function of their different KPIs..

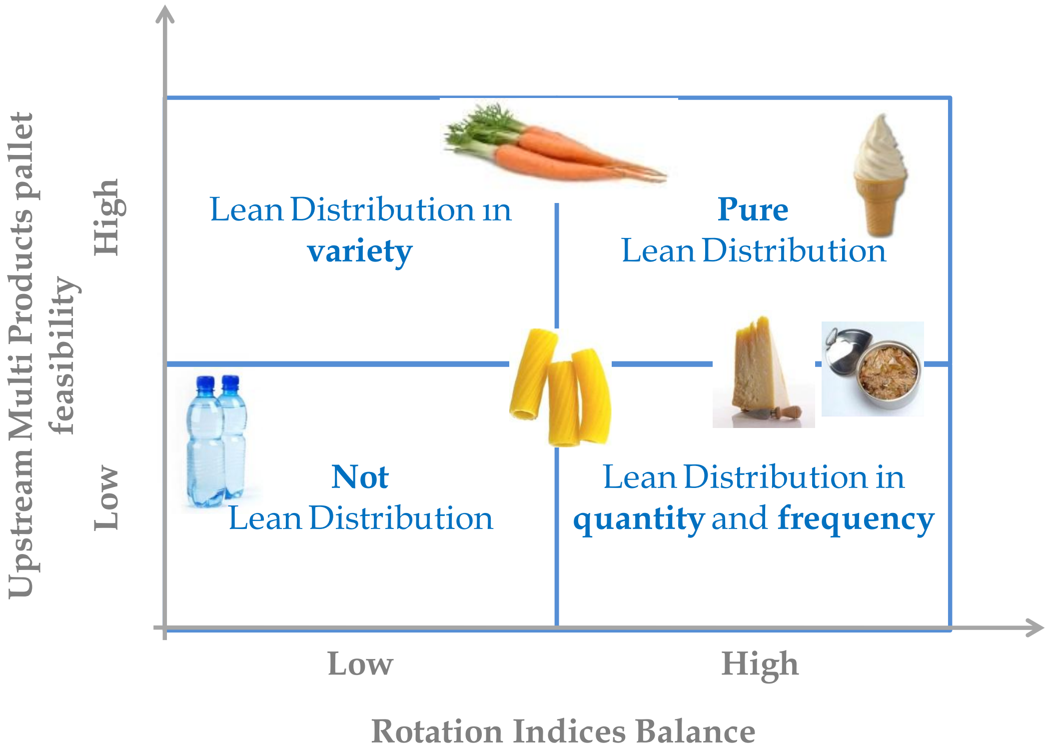


Figure 3.37: The different product categories mapped into the Lean Matrix

3.4.4 What's the innovation behind this approach

The study on hand presents an innovative Supply Chain Management model based on linear programming techniques that take into account the lean principles by key performance indicators and the specific characteristics of the food sector.

The main results are:

- The food SC specifications are different and more critical than those of other SC. For these reasons the application of lean principles to the different logistics activities (storage, transportation, handling, etc.) within a food SC, can potentially bring relevant benefits.
- According to the lean principle of value maximization applied to the SCM, it is possible to identify customer's value as the possibility to get products in the expected quantity, mix, quality, availability and safety. From this point of view it is indispensible that the SC follows the customers demand in terms of quantity, mix and quality with a pull philosophy, eliminating waste.
- The proposed model introduces two main lean KPIs: the *Rotation Indices Balance and the Upstream multi products pallet feasibility.* These two parameters define, from a quantity and variety point of view, how lean a SCM can possibly be, with respect to the final customer demand. The proposed approach minimizes the total distribution, changing the value of the lean KPIs. This way it is possible to define the best lean distribution strategy to implement for each considered product category.
- These two KPIs dimension are strictly related to the specific logistic characteristics of the products category and to the food SC features considered. For this reason a *product category approach is to be preferred in order to define the lean distribution strategy inside a food SC.*

- The applicative cases demonstrate how different product categories (evidenced also by the rating of their logistic attributes) need different level of lean distribution in order both to minimize the total distribution costs and to respect Manufacturers/Wholesalers constrains.

The proposed approach offers then a valid decision making tool able to define whether or not and how to implement a lean approach for a considered products category.

The limitations of this approach are that although it focuses on two important food SC KPIs such as *rotation indices balance* and the *upstream multi-products pallet feasibility*, it does not consider other important products category attributes typical of food SC, such as product shelf life or product perishability. These dimensions have an important impact on the distribution strategy optimisation, especially for some category of products, which will be the aim of future research in the attempt to integrate the lean matrix with other important dimensions of the product

4 Conclusions

The research has been developed and addressed in order to understand how and under which conditions a distribution network can be effectively optimized by the *lean* principles adoption and implementation.

The first research branch has been dedicated to the deep understanding of how a distribution network works. Key research goals have been:

- Critically assess and analyze the existing scientific literature related to the distribution network topic.
- Define the most critical variables for a distribution study with a strong focus to the cost functions.
- Understand how optimize the distribution management within a batch production environment, by developing an innovative model.

The second branch has been driven by the investigation of the lean production approach. Here the scientific activity has been deployed to fully understand the features of the Lean Production and the most important differences with the conventional productions systems.

On the one hand, the decision to investigate this discipline has been taken because *lean* objectives are often much closed to a modern distribution network's objectives: minimizing the overall costs and lead times and concurrently maximizing the customer satisfaction and the service quality.

On the other hand, the goal has been to understand in which environment and under which conditions the *lean production* perspective can be considered the right choice.

Finally the third branch has been addressed to merge the two main topics of the research work, the distribution and the lean approach.

In particular, after having reviewed the existing literature, an innovative model has been proposed to test and measure the effectiveness and the efficiency of

the adoption of the lean approach to manage distribution networks, under different conditions.
The results are clear and they show how, not always, but only under specific distribution network features (e.g. network structure, type of product categories, industry) the application of lean principles to the distribution represent the right choice.
The considered applicative case, for example, once defined a particular distribution network (e.g. food related), provides the features that the different product categories have to present (e.g. value, rotation, physical dimensions) in order to be effectively and efficiently distributed adopting the lean approach or a more “conventional” policy.

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6 Enclosed Papers

- ✓ Daria Battini, Maurizio Faccio, Pietro Vecchiato, Alessandro Persona, Goods delivery optimization in distribution networks with batch production , *The International Journal of Electronic Customer Relationship Management*, 2007, Vol. 1, No.2, pp. 200-230.
- ✓ Maurizio Faccio, Emilio Ferrari, Alessandro Persona, Pietro Vecchiato, Lean Distribution Principles to Food Logistics: A Product Category Approach, *International Journal of Operational Research (IJOR)*. <u>This paper has been accepted for the publication in IJOR scheduled in early 2013</u>