Cost Management in the Supply Chain: 
an integrated approach

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Abstract
We present an analytical tool to identify the optimal supply chain design and resource allocation that integrates supply chain planning with information from management accounting. Using costing data based on Time-Driven Activity Based Costing techniques, an optimization model determines the most beneficial route to market (i.e., with the lowest cost-to-serve) given the resource constraints in the supply chain. Since Time-Driven Activity Based Costing expresses costs in units of time spent on a resource, it can be combined with supply chain capacity planning, thus integrating supply chain optimization and costing. Based on a validation with practitioners in retail companies and their suppliers, we discuss the insights that the model can provide for practical use.

Keywords: supply chain optimization, Time-Driven Activity Based Costing, route to market, cost to serve

Introduction
In order to stay competitive in today’s global business world, manufacturing and distribution companies increasingly experience the need to manage the performance along the total supply chain. The goal of supply chain management is to link the market, distribution channel, operations process and supplier base such that customers’ needs are better met at lower costs (Hill and Hill, 2009). This requires an optimal design of the supply chain, as well as an efficient planning and execution of the existing supply chain.

Companies with several production plants and distribution centers have various optional routes to market. A central question in supply chain optimization is to determine which quantities of product should be produced in which plant and routed through which central and/or local distribution center to the end customers, such that demand requirements are met and total supply chain activity costs are minimized. At the same time, resource capacities need to be taken into account throughout the different phases in the supply chain, for instance in the warehouse, in production or in
transportation. Also, if products are supplied from external suppliers, the question is which supplier should deliver which quantities of products to which distribution center.

As a consequence, instead of trying to better manage costs at the level of individual departments or phases in the supply chain, companies increasingly pay attention to the total cost to serve their customers and manage the total supply chain costs in an integrated way. Integrated supply chain cost management is seen as an important source of improvement of the overall company performance.

However, for this to be possible, planning and costing data are required, and supply chain planning and management accounting are to be considered in combination. The role of supply chain planning is to provide managers with data on the volume and the timing of the logistic flows in the supply chain. The role of management accounting for supply chain management is to provide managers with relevant information of total supply chain activity costs (direct material and activity costs as well as driven overhead costs) related to the different possible routes to market.

Whilst the above may seem obvious, many companies still have functionally fragmented supply chains. Costs are only reported per individual supply chain phase (e.g. purchasing costs, warehouse costs, logistics costs) per legal entity and managers are unable to get an integrated view of the total costs at the level of a complete supply chain. In order to get such a view, management accounting systems should be able to measure costs at the level of the individual activities and calculate total costs along activity chains, across the different responsibility centers and legal entities. Activity Based Costing can be used for measuring costs at the level of the individual logistics activities. However, research has shown that, when activity complexity increases, companies may need to implement time-driven Activity Based Costing (ABC) to improve cost measurement accuracy (Kaplan and Anderson, 2004; Everaert and Bruggeman, 2007; Hoozeé, Vermeire and Bruggeman, 2012).

The objective of this paper is to explore how effective management accounting systems can provide managers with the relevant information for their supply chain design and planning, and more specifically, how time-driven ABC provides the information needed for the optimization of the supply chain design. The applicability of integrated supply chain cost management and the insights this generates are illustrated for the optimization of a simplified, generic retail supply chain. The approach has been presented to managers in retail companies and in the producers supplying to the retail companies. This has allowed us to validate the applicability of supply chain optimization tools for the retail sector. In doing so we hope to bridge the gap between management accounting and supply chain planning to optimize the integrated supply chain.

Supply chain planning
A typical supply chain configuration consists of suppliers, factories, warehouses, distribution centers and retail outlets: raw materials are procured, products are produced at one or more factories and shipped to warehouses, from where they are shipped to retailers or final customers. Most supply chains are complex networks that cross organizational boundaries and that are subject to uncertainties (e.g., demand may not entirely be known in advance, processes may be unreliable, transportation delays may vary, the quality of the raw material may fluctuate). Optimizing the chain to cope with this complexity and uncertainty is a challenging task; it requires decision making at the strategic, tactical as well as operational level.
Supply chain planning decisions at the strategic level include the design and configuration of the supply chain. Typical questions are how many factories and warehouses to run, how much capacity to install in each of these factories and warehouses, where to locate them, which products to assign to which factory, which customer to serve from which warehouse, etc. The choices that are made on these variables have a long-lasting impact on the cost and service level of the supply chain, and consequently on the performance of the company. Such decisions are typically made with a planning horizon of a couple of years and are revised only occasionally, with an annual or lower frequency (Simchi-Levi et al., 2008). A revision of the supply chain design can be triggered by some events, such as the termination of a contract with a logistic provider, the introduction of a new product group, or the growth or decline of a regional market.

At the tactical level, a supply chain master plan is required that allocates production, inventory and transportation resources, within the constraints of the existing supply chain configuration. The overall goal of this master planning is to optimize the utilization of the resources, thus minimizing cost for a required service level. This planning process departs from the demand forecast for the planning horizon (for example a month, a quarter, or a year) and generates plans for production, inventory and transportation. Traditionally, such plans are produced by each function, independent of the other function, and are coordinated in sequence. Ideally, however, the planning takes into account the interaction between the different functions and generates an integrated plan that minimizes the total supply chain cost rather than the production, warehousing and transportation cost separately. Such an integrative planning requires an integrative dataset and a decision support system that captures the complexity and the dynamics of the supply chain (Simchi-Levi et al., 2008).

At the operational level (which is beyond the scope of this paper), day-to-day decisions are made such as production scheduling, order planning, transportation routing or truck loading (Simchi-Levi et al., 2008).

Supply chain optimization data
Both the strategic design and tactical planning of the supply chain require a detailed and comprehensive map of the supply chain as a starting point. This involves a large amount of data, describing the supply chain configuration, the volume of the flows through the chain, and the cost of each of the flows and nodes in the chain.

The level of detail at which data is to be collected varies depending on the purpose of the exercise. In general, it is fair to state that a strategic network design exercise requires data at a less detailed level compared to a tactical supply chain planning exercise, it has a longer planning horizon and it has a lower frequency of re-planning (Simchi-Levi et al., 2008). We refer to Table 1 for some guidelines on level of aggregation, planning horizon and re-planning frequency taken from Simchi-Levi et al (2008).

<table>
<thead>
<tr>
<th>Level of aggregation</th>
<th>Strategic supply chain design</th>
<th>Tactical supply chain planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning horizon</td>
<td>years</td>
<td>Months</td>
</tr>
<tr>
<td>Re-planning frequency</td>
<td>yearly</td>
<td>Monthly/weekly</td>
</tr>
</tbody>
</table>

Table 1 Level of detail of strategic and tactical supply chain planning
Whilst the above are useful rules of thumb, one also needs to take into account the complexity and the dynamics of the supply chain. The volatility of the demand, the innovativeness of the product, the structure of the market, the structure of the supply side, the variety of products offered, are parameters that have an impact on the complexity and/or uncertainty of the supply chain. In deciding on how detailed and fine-grained to carry out the exercise, a trade-off has to be made: the more detailed one goes, the more the supply chain model reflects reality; on the other hand, the complexity of the model increases, and it may become difficult to have good data to feed the system. Effective management accounting systems therefore play a crucial role in the success of such an optimization exercise.

### Integrated supply chain cost management

Consider, for example, a company that purchases and delivers consumer packaged goods through retail distribution. In optimizing its supply chain, the company has several options. Products could be shipped from the supplier to the central distribution center (CDC) and from here to the local distribution centers (LDC) and to the retail stores. Alternatively, some nodes can be skipped in this network.

The managerial question is two-fold. At the tactical level, the question is to find the most cost-efficient routing through the supply chain (see Figure 1): is this the route going directly from the production site of the supplier to the retail store (dotted line); the route going from the production site to a local DC and from here to the retail store (straight line); or is it the route going from the production site of the supplier to the central DC, from the central DC to a local DC and from the local DC to the retailer store (dashed line)? At the strategic level, questions arise such as: should we add or eliminate a local DC? Should we increase or decrease the capacity of the central DC?

![Figure 1 Possible routes to market](image)

To answer these questions we need to implement a planning system that can provide information about (1) the total supply chain activity costs related to the different routings in order to determine the optimal replenishment flow, and (2) the capacity needed versus the capacity available to carry the corresponding flows in the DC’s.

To do so, we should get an integrated view of the total activity costs at all levels in the supply chain. Management accounting systems should therefore be able to measure costs at the level of the individual activities (e.g. inbound transport, putting away of goods in a warehouse, storage of goods, order picking in a warehouse, outbound staging, truck loading, outbound transport) and calculate total costs along activity chains, across the different responsibility centers and legal entities. Moreover, we need
to be able to combine supply chain cost optimization with supply chain capacity planning. This is exactly where time-driven ABC can be of help.

Costing complex logistics activities: the role of Time-Driven ABC

For measuring costs at the level of the individual logistics activities companies may use traditional ABC or the Time-Driven version of ABC.

Traditional ABC is a costing method that first assigns indirect costs to activities and then to products, orders or customers, based on their consumption of the different activities (Kaplan and Cooper, 1998). For example, consider the activity ‘receiving products from a supplier’s factory warehouse’. Assume that the total cost per week (payroll, depreciation and other supplies) assigned to this activity is equal to €14,400. When the number of pallets is the activity driver and 160 pallets can be received per week, ABC will come up with an activity driver rate of €90 per pallet per week. In calculating order profitability in traditional ABC each order will be assigned an amount equal to €90 x the number of pallets.

However distribution and logistics activities can be very complex. For example, activities may be driven by more than one cost driver. The receiving cost of a delivery of products from a supplier’s factory warehouse may depend not only on the number of pallets but also on the type of product (cool stored products, dangerous goods, …) or the type of supplier (own production site or external supplier). Traditional (rate-based) ABC calculates one single driver rate for each activity, which makes it difficult to model multi-driver activities. When for example the costs of receiving products from a supplier’s factory warehouse depend not only on the number of pallets but also on the type of product or the type of supplier, working with an average cost per order of €90 is inaccurate. This problem can be dealt with by splitting the activity in different types of activities: ‘order reception for product type 1’, … , ‘order reception for product type n’. However this method inflates the number of activities and makes the ABC model complex and difficult to maintain.

In order to overcome the implementation difficulties related to traditional ABC in complex environments, Kaplan and Anderson (2004, 2007) developed a new approach to ABC, called time-driven ABC. The new approach does not assign resources and costs to the specific activities. It identifies the different resource groups (departments) in the company (for example the inbound logistics department), their costs and their practical capacity (expressed in units of time). Based on this information the cost per time unit is calculated. Through interviews, the company’s activities are identified and data are collected on the time needed to perform each activity. The activity cost assigned to the cost object is then calculated by multiplying the cost per time unit of the resources by the time needed to perform the activity.

In complex environments where the time needed to perform an activity is driven by different drivers depending on the situation, it is no longer possible to specify one single standard time for each activity. The breakthrough idea behind time-driven ABC, lies in the fact that the time needed to perform an activity is modeled by using time equations. These equations are mathematical functions expressing the relationship between the time needed for the activity and the different drivers. Using time equations, the time required for performing an activity is expressed in function of the different characteristics of the context in which the activity takes place. These characteristics are called time-drivers, because they “drive” the time required for an activity.
We illustrate the method by giving two examples.

**Example 1 receiving products from a supplier**

Consider the activity ‘receiving products from a supplier’s factory warehouse’. Assume now that the department ‘inbound logistics’ with a total resource cost of €14,400 (payroll, depreciation, other supplies) per week has a practical time capacity of 5,760 minutes per week (80 per cent of the theoretical capacity of 40 hours per week for 3 employees). So, the cost for this resource group is €2,50 per minute.

Assume interviews with operational employees and analyses of process descriptions reveal the following timing information about incoming pallets:

- 30 minutes per incoming pallet if the product is of the type “cool”
- 25 minutes per incoming pallet if it concerns an ambient product that can be stored under normal temperature
- 40 minutes for each incoming pallet if the pallet contains dangerous goods
- An additional 10 minutes if the product is not an internally produced/own product, but a product coming from a third-party supplier

The time equation of the receiving activity can be written as:

$$\text{Reception time (in minutes) of an incoming delivery line} = \text{number of received pallets} \times (25 + 5\text{if ptype=}\text{cool} + 15\text{if pcategory=}\text{dangerous} + 10\text{if third party item})$$

The reception cost of a delivery line can then be calculated by:

$$\text{Reception cost of a delivery line} = \text{reception time of delivery line} \times €2,50$$

So, receiving an incoming delivery of one pallet of an ambient product produced by one of our own manufacturing plants costs 25 x €2,50 = €62,50 while the cost of receiving a delivery of one pallet of cooled products supplied by an external supplier is 40 x €2,50 = €100.

**Example 2: picking a shipment line**

When analyzing the activity ‘picking a shipment line’ one frequently finds that picking times depend on the type of product and the type of packaging format, and the time effect of packaging formats may depend on the type of product. This interactive effect on the activity time can also be modeled by the time equation of the activity.

Assume the interviews reveal the following information about picking products:

- 0.06 minutes per piece for putting products in a box if the product is of the type “cool”; 0.03 minutes if “ambient”
- 0.5 minutes per box for placing boxes on a pallet if the product is of the type “cool”; 0.35 minutes if “ambient”
- 10 minutes for picking a pallet with boxes if the product is of the type “cool”; 7 minutes if “ambient”

The time equation of the picking activity can be written as:

$$\text{Picking time of a shipment line} = (\text{nr of pieces} \times 0.06 + \text{nr of full boxes} \times 0.5 + \text{nr of full pallets} \times 10)\text{if ptype=}\text{cool} + (\text{nr of pieces} \times 0.03 + \text{nr of full boxes} \times 0.35 + \text{nr of full pallets} \times 7)\text{if ptype=}\text{ambient}$$
The picking cost of a shipment line (assuming the same cost of €2.50 per minute of this resource group) can then be calculated by:

Picking cost of a shipment line = Picking time of shipment line x €2.50

So, the picking activity for a shipment of one pallet of a cooled product, with on each pallet 4 boxes filled with 8 products per box, costs \((32 \times 0.06 + 4 \times 0.5 + 1 \times 10) \times 2.5 \, € = 13.92 \times €2.50 = €34.80\) per shipment line.

These examples illustrate that the use of time equations makes it possible to cost logistics activities, taking into account all the relevant cost drivers.

Time-driven ABC only assigns the consumed resource costs to the cost objects. The difference between the available (and thus paid) resources and the resources that are effectively used is reported as a cost of unused capacity. As such, shipping line and product costs are no longer influenced by the capacity utilization rate. When the complexity of the order flow through the supply chain increases, time-driven ABC will also signal which resource pools become a bottleneck. When volume or complexity goes down, the system reports the unused capacities.

A time-driven ABC system is able to cost each shipment line, the lowest level of granularity. In each phase of the supply chain, costs of the different supply chain activities are calculated per shipment line by multiplying the calculated activity times by the cost rate of the department executing the activity. The total cost of a supply chain routing is calculated by taking the sum of the costs across all activities in the routing.

Costs of shipment lines can easily be aggregated into costs of higher level cost objects. Each shipment line is related to a shipment which is characterized by an origin and a destination (reflecting the routing of the transaction) and is related to a responsible node (a factory or a warehouse) in the chain (see Figure 2). As such the time-driven ABC system can provide information on the cost per activity in each step of the supply chain per facility, the cost per product for each activity in each factory or warehouse, the cost per product from each origin to each destination, the cost for each customer for each activity, the cost per product per warehouse from each supplier, etc. The system also allows calculating the total supply chain cost of product volumes shipped through mixed routings (e.g. 80% from the supplier’s factory warehouse to the central distribution center and then to the customer and 20% from the supplier’s factory warehouse via the local distribution centers to the customer).

Figure 2  Cost information aggregation structure
The time-driven ABC system is appropriate to capture the full complexity of the supply chain activity costs of each shipment line in each phase of the supply chain. Based on these costs, the optimal supply chain routing can be determined that leads to the lowest total end-to-end supply chain cost. Moreover, since the time-driven ABC system expresses the costs in units of time spent on a resource, we are able to combine it with the resource capacity constraints across shipment lines (e.g., production, transportation or storage capacity) that are fundamental in supply chain planning. This allows us to combine both the planning and costing criteria into one integrated supply chain optimization model.

Supply chain optimization
To determine the route to market per shipment line with the lowest total supply chain cost, while taking the capacity constraints in the supply chain into account, we model the supply chain as a constrained network diagram. A network consists of a collection of nodes joined by a collection of arcs:

- The nodes represent the different entities in the supply chain (e.g., suppliers, importers, manufacturers, warehouses, depots, wholesalers, shops, etc.). These nodes may have limited capacities (e.g., in storage and/or production).
- The arcs connect nodes and represent the routes in the supply chain network to convey shipments (flows). Each arc has a cost per unit shipped: this cost is the total activity cost of a shipment line when it makes use of that route, and is measured by the time-driven ABC costing system described above. The arc may also have a capacity constraint on the shipment lines that use that route (e.g., minimum or maximum shipment quantity).

The objective is to find the flow through each arc in the network that minimizes the total cost in the network, meets the customer demand using the supply at supply nodes and takes into account the capacity constraints on the arcs and nodes.

Supply chain optimization methods
In order to identify the optimal supply chain configuration (at the strategic level) or the optimal allocation of supply chain resources given a supply chain configuration (tactical planning), one can choose between mathematical optimization techniques (such as linear programming and integer programming) and simulation models. Both sets of techniques have strengths and limitations. The mathematical optimization techniques - by definition - will provide an optimal, lowest cost solution. In addition, linear programming requires a short computation time and provides insights in the gap of a proposed scenario with the optimum. However, their limitation is that they optimize a deterministic model that is not taking into account the uncertainty in the chain. The strength of simulation models, on the other hand, is that they are designed to take the real-life complexity and uncertainty into account. Their limitation, however, is that they assess the performance of a pre-defined scenario, rather than propose the optimal solution. As such, they support the user to evaluate a set of scenarios that does not necessarily include the optimal one, which makes it very time consuming for optimization purposes. Hax and Candea (1984) suggest a two-stage approach where an optimization model first generates a set of optimal scenarios based on deterministic data; followed by a simulation model to evaluate the scenarios including uncertainty. In
the discussion that follows, we will focus on the optimization of the supply chain model using linear programming techniques.

The mathematical description of the network programming problem with \( n \) supply chain nodes, \( a \) supply chain routes (arcs), and \( k \) (capacity) constraints is as follows:

\[
\begin{align*}
\text{minimize} & \quad c^T x \\
\text{subject to} & \quad Fx = b \\
& \quad Hx \geq, =, \leq r \\
& \quad l \leq x \leq u
\end{align*}
\]

where

- The decision variable \( x \) is an \( a \times 1 \) flow vector, denoting how many shipment lines of a particular product are shipped through a given route (arc) between two supply chain nodes.
- Its corresponding \( a \times 1 \) cost vector \( c \) represents the costs of the different supply chain activities per shipment line that makes use of a given supply chain arc-node combination (e.g., production costs, storage costs, transportation costs).
- The constraints \( Fx = b \) are the flow conservation constraints in the network and algebraically state that what is shipped from a supply chain node, must also be supplied to that supply chain node (note that we can additionally define a dummy variable to denote inventory build-up when the supply temporarily exceeds demand in a supply chain node). \( F \) is then an \( n \times a \) node-arc matrix, where
  \[
  F_{i,j} = \begin{cases} 
  1, & \text{if the arc } j \text{ ships from node } i \\
  -1, & \text{if arc } j \text{ supplies to node } i \\
  0, & \text{otherwise}
  \end{cases}
  \]
  and \( b \) is an \( n \times 1 \) node supply/demand vector, where
  \[
  b_i = \begin{cases} 
  s, & \text{if node } i \text{ supplies } s \text{ units} \\
  -d, & \text{if node } i \text{ has demand of } d \text{ units} \\
  0, & \text{if node } i \text{ is a trans-shipment mode}
  \end{cases}
  \]
- \( Hx \geq, =, \leq r \) represent the capacity constraints of the resources that apply to all shipment lines that make use of a given route (e.g., capacity constraints in production, storage, transportation). \( H \) is the \( k \times a \) constraint coefficient matrix for arc variables, i.e., \( H_{i,j} \) denotes the (time-driven) capacity usage on resource \( i \) when a shipment line makes use of route \( j \). The \( k \times 1 \) vector \( r \) contains the available capacities of the resources. Finally, \( l \) and \( u \) are \( a \times 1 \) arc lower and upper flow bound vectors denoting either minimum or maximum (capacity) levels on the flow quantities per route.

At the strategic level, when the model is used to make supply chain planning decisions such as whether (and where) to install factories or distribution centres, the model can be run without capacity constraints, since these capacities are variable in the long term. When making supply chain planning decisions at the tactical level, the model is used with the capacity constraints, since production, inventory and transportation constraints are fixed in the short term. By adapting the boundaries of the optimization
problem, extensive scenario-analyses can be done to analyse the impact of sensitivities in the model.

A simple simplex algorithm is used to solve this model. However, to reduce the computation time one can use the primal simplex network algorithm and primal partitioning algorithm, which exploit the network structure by representing the network component of the basis with a spanning tree. We refer to Winston (2004) or Helbaek and McLellan (2010) for more details on solution methods for linear programming and network models.

Illustration
We illustrate our integrated approach to optimize the total supply chain cost based on time-driven ABC through a simple example with two suppliers SP1 and SP2, supplying respectively Product P1 and Product P2 to two customers C1 and C2. The supply chain consists of a central distribution center CDC and two local distribution centers LDC1 and LDC2, located in the proximity of respectively customer C1 and customer C2. These supply chain entities represent the nodes in the network. The arcs represent the routes for both products that connect one location in the network to another. The supply chain manager needs to determine the best end-to-end route to supply both products from the suppliers to the market, i.e., how many units $x_j$ of each product make use of a given route $j$ between two supply chain entities.

Each possible route between two supply chain entities has a cost $c_j$ per unit. These costs are derived from the time-driven ABC exercise described above, and include transportation, inbound handling, outbound handling,.... These costs depend on the supply chain route in the network, and can differ per product (based on the characteristics of the product) or even per time period (if these costs evolve over time). For instance, let’s assume that Product 1 is a product of the type “cool” and supplier 1 is an external supplier. The cost of the inbound receiving activities for Product 1 is therefore €100 per pallet (see above). The cost of the arc going from Supplier 1 to the central distribution center, is found by adding up the relevant costs; Let’s assume that, in addition to the inbound receiving activities, the cost of transportation is incurred:

- €20,00 per pallet for transportation from the supplier to CDC
- €100,00 per pallet for inbound activities at CDC

This gives a total cost of €120 per pallet for receiving at CDC.

For the calculation of the cost of the arc going from the central distribution center to a local distribution center, we assume the following costs are derived from the time-driven ABC exercise:

- €34,80 for picking at CDC (as calculated earlier – see above)
- €2,20 for customer specific conditioning at CDC
- €5,00 for loading at CDC
- €10,00 for transportation from CDC to LDC
- €28,00 for inbound activities at LDC

This gives a total cost per pallet of €80 for shipping product P1 from the CDC to LDC1.

Let’s assume that - using the same approach for all arcs in the network – we derive the costs for the flow of one unit of product P1 (resp. P2, between brackets) from one supply chain unit to another as shown in Figure 3.
Suppose supply chain planning provides the demand and supply data listed in Table 2. We provide data on a quarterly basis, but the analysis can be done on a different time frequency (e.g., monthly or yearly), based on the complexity of the exercise and the availability of the data. Demand in a demand node (end user, the store) is denoted negative; the idea here is that these nodes consume demand and hence take units from the network (vice versa for supply nodes).

<table>
<thead>
<tr>
<th>Node</th>
<th>Product</th>
<th>Quantity per quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>P1</td>
<td>500</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>P2</td>
<td>1700</td>
</tr>
<tr>
<td>Customer 1</td>
<td>P1</td>
<td>-250</td>
</tr>
<tr>
<td>Customer 1</td>
<td>P2</td>
<td>-1200</td>
</tr>
<tr>
<td>Customer 2</td>
<td>P1</td>
<td>-250</td>
</tr>
<tr>
<td>Customer 2</td>
<td>P2</td>
<td>-500</td>
</tr>
</tbody>
</table>

Table 2 Supply and demand data

The goal of the optimization is to find the cheapest route to market. The objective function therefore minimizes the total cost of the supply chain whilst meeting demand in the different demand nodes. The outcome of the optimization will thus be an optimal (cheapest) route to market for each product in every period. In our example, the optimal route to market for product P1 (and P2, between brackets) is shown in Figure 4. The total cost for this route is €6.575 per period (SAS Institute, 2010).
So far we did not consider any capacity constraints in the supply chain entities. In reality however, distribution centers or transportation modes have limited capacity, certainly on the short to mid-term. These constraints result in upper bounds on the arcs and are often valid across products (in theory, also lower bounds can be added to the network, but that rarely happens in practice).

Suppose the local distribution center LDC1 has a limited capacity of 1,000 units per period. In that case, some volume of P1 and/or P2 has to be rerouted as the current load for LDC1 is 1,450 units. For the supply chain manager, it is not obvious which product to reroute and what this new route then should be: via LDC2, direct from CDC, or direct from the supplier. The outcome of the constrained optimization model shows that the entire 250 units of P1 and 200 units of P2 need to be rerouted from CDC to customer 1. The resulting cost for this new route is then €6,765 per period (SAS Institute, 2010).

**Insights of the integrated supply chain costing approach**

We validated the value and applicability of our integrated supply chain costing approach in the retail sector, based on a focused workshop and several individual discussions with retail companies and producers supplying to retail companies.

One of the retail companies used the time-driven ABC analysis, which provided them new insights into the drivers of supply chain costs, and helped them identify potential cost reductions. For example:

- Analysis of the activity times of the store personnel revealed that their productivity had gone down due to the increase of the number of trips through the stores for collecting and preparing orders placed by e-customers. To prevent further productivity reductions, the company considered organizing an internet orders collection DC, where e-logistics employees collect the internet orders per customer without disturbing the activities of the store personnel. The time driven analysis allowed the company to quantify the cost gains from the productivity improvement, the cost of order collection in the internet order collection DC and the additional cost of transportation from the DC to the stores.
The time-driven analysis revealed that the time needed to put the products on the shelves depended on the type of packaging material used by the supplier. Employees knew that when a certain packaging material was used, a percentage of the packs were damaged and had to be repackaged in the store. The downstream additional supply chain cost driven by the choice of this lower-quality packaging material could be estimated based on the additional time per damaged pack, the total number of packs per months, the damage percentage, and the cost per unit time of the store employees. This led to a discussion with the suppliers to urge them to use higher quality packaging material.

These examples illustrate how insightful time-driven ABC is for managing (and reducing) supply chain costs. However, such analyses only capture (local) parts of the supply chain, independent of the other flows in the network, and they don’t explicitly take available resource capacities into account. The value of the network optimization exercise is that it captures the total end-to-end cost, taking into account the cost of all routes to market in the supply chain simultaneously. For example, a reduction in cost of a route to market may lead to a shift of volumes of products from more costly routes to this route. However, for the manager it may not be obvious which products in what volumes to shift to this route, given the impact the shift may have on the use of capacity constraints and on the flows of other products in the network. Such insights cannot be deducted the time-driven ABC analysis, unless it is integrated with a supply chain optimization exercise. Since both the costing analysis and the capacity planning are time-driven, they can be combined into one integrated approach. This helps the supply chain manager to take better supply chain decisions.

The techniques and the tools for an integrated supply chain costing and optimization approach are available. Technically speaking, it is possible to draw activity–based costing data and demand data from the ERP-system. Analytical tools are available that facilitate the use of linear programming. That is, both tactical planning and strategic design of the supply chain can be supported by linking transactional data systems and state-of-the-art analytical tools. However, the applications are still scarce. We tested the feasibility of our supply chain optimization tool and its challenges for implementation in the retail sector. The opinion of practitioners has been collected through a focused workshop and several individual discussions in the sector.

There was general consensus that this type of supply chain optimization exercise gives very valuable insights, both at the strategic and the tactical level. In general, it seems that more priority is given to the upstream optimization of the production and the supply network, than to the downstream optimization towards the customers. However, the level of sophistication at which such an exercise is carried out today is still rather low. The availability of good quality data is still an issue: the problem is not to get data out of the ERP systems, but to get it at the right level of detail, in a uniform format at each phase in the supply chain. It is expected that the evolution in technology will improve the data collection hence the data accuracy, which in turn will improve the reliability of the conclusions drawn from the optimization exercise.

An annual frequency for this exercise is considered ideal. Clearly, a trade-off is to be made between the complexity of the exercise and the benefits that can be gained. In complex supply chains, the effort required to build the optimization model is high; on the other hand, especially in complex supply chains, the insights to be gained from an optimization model can be very valuable, compared to what can be learned from spreadsheet-based supply chain planning. Also, if the supply chain activity costs are
relatively low in the total product cost, it may not be worth going through such a complex exercise.

Ideally, the strategic and tactical supply chain optimization spans the entire supply chain, starting upstream at (or before) the producer, and ending at the retailer (or even the final customer). Such an end-to-end supply chain optimization has proven to be feasible for a section of the overall supply chain with a well-defined scope. An interviewed food producer, for example, reported an optimization project for the distribution network from its two slicing factories to its customers. Nevertheless, in most cases, carrying out an end-to-end supply chain optimization including both the upstream and the downstream supply chains was perceived as too ambitious. Often, there is still a lack of goal alignment between the producers and the retailers. Although anecdotal, the following quote made by one of the retailers illustrates our point: “If we would embark on a joint project with one of our suppliers to reduce logistic costs, I doubt this producer will grant us a bigger discount than he would towards his other customers.” On the other hand, some producers - reporting on logistic cost improvements that had been identified by joint teams of their supply chain department and the retailer’s supply chain department - stated that “at the end of the day, the retailer’s purchaser and the supplier’s sales person are the ones closing the deal. Consequently, a logistic improvement always turns into a commercial negotiation on discounts.” For total supply chain cost improvements to really work across the supply chain, it is important to stimulate collaboration between the different supply chain departments and to leave the typical commercial negotiations (between purchasers and sales representatives) out of the discussion. Or rather, to lift the negotiations from a discussion on prices and discounts to a discussion on total cost reduction and gain sharing.

Conclusion
Management accounting systems, in particular ABC and its time-driven version, offer insights to the manager who wants to control and reduce costs in the supply chain. These systems can thus trigger cost improvements in the routes to the market. However, the real strength of such systems lies in their potential to be integrated with the supply chain planning system. Since Time-driven ABC expresses cost in terms of time spent on resources, which is the critical parameter for supply chain planning, it is an interesting management accounting technique for this purpose.

Our study shows that the integration of management accounting, supply chain planning through analytical tools offers insights that go beyond the understanding of the cost of each route to market. Rather, the integrated approach, which takes into account the capacities and costs of all routes to market simultaneously, can be the basis for an overall supply chain optimization at tactical and strategic level.

The techniques are available, the benefits they can offer are valued highly by managers, yet the applications are still scarce. Our study highlighted some of the barriers for implementation that will need to be managed for the approach to reach its full set of benefits. Access to accurate and uniform data is still an issue. More important is the lack of goal alignment between producers and retailers, which is a barrier for collaborative optimization of the overall supply chain. Small-scale pilot projects for optimizing sections of an inter-company supply chain, using our integrative supply chain optimization approach, can be a valuable step in opening the discussion and bridging the gap between producers and retailers.
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