Simulation in Supply Chains: An Arena basis

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Abstract

The quest for global competitiveness brought about new business approaches, of which the supply chain has become an important entity during the last few years. With even more complex decision structures, demand variation and the need for evaluating alternatives within this frame, simulation and simulation-optimization have been identified as key decision-making tools. This paper briefly reviews the basic characteristics of supply chains, and illustrates that existing software may be integrated towards a supply chain simulator.

Opsomming

Die strewe na globale mededingendheid vereis nuwe benaderings deur ondernemings, terwyl die toevoerketting 'n belangrike entiteit gedurende die afgelope paar jaar geword het. Toenemende kompleksiteit in besluitneming, variasie in vraag en die behoefte om alternatiewe binne hierdie komplekse raamwerk te evalueer, het tot gevolg dat simulasie en simulasie-optimering as sleutel-besluitneming gereedskap beskou word. Hierdie artikel gee 'n kort oorsig oor die basiese eienskappe van toevoerkettings, en dit word getoon dat bestaande programmatuur integreer kan word om 'n toevoerketting-simuleerder te ontwikkel.

1. Introduction

Globalisation contributed to the evolution of informed, demanding customers, which requires a new operational approach to satisfy them. This operational approach evolved into the supply chain and its management, and today the supply chain is a given in many enterprises. This brought about new management complexities that require understanding and analysis of the supply chain in order to stay competitive.

The modern customer profile includes the demand for quality products supplied in any quantity within a short time. Time, quality and cost are therefore basic, but important measures (Kaplan[1]). Time is a key weapon in today's competition, while quality has been a critical competitive dimension since the 1980s, and is still important today. Customers are always evaluating the price they pay for a product, and usually measure the complete package (lead time, product quality and service quality) against the price paid.

Enterprises are required to collaborate in both the design and production processes, while information must be shared. It is also required that coordination takes place on the strategic, tactical and operational planning levels, which impacts the business processes and the information system. While supply processes are becoming more and more important, their complexity and requirements pertaining to quick response times increase. An optimal design of the relations between deliverer and consumer is of essential importance, because today the time between ordering and availability may already be a matter of hours. Given these complexities and wide range of entities that must be integrated, simulation can be a powerful tool to analyse and eventually optimise the complete supply chain. The supply chain is dynamic due to variation of customer demand, as well as characteristics of its subcomponents. As short time-to-market has to be achieved without a decrease in income, it is essential to evaluate new products or new operational processes before production is started.

This paper outlines some of the basic characteristics of supply chain management, as well as the relationships among them. A supply chain simulator is proposed, using MS-Access and MS-Excel[1] files as data sources and targets for simulation reports, while the simulation kernel is implemented in Arena[2]. The simulator enables users to observe and analyse the dynamic behaviour of a supply chain with this new configuration.

2. Basic characteristics of supply chain management

Some of the basic characteristics of supply chain management are identified in this section.

2.1. Definition of supply chain management

Supply chain management (SCM) is defined by Umeda e.a.[2] as "the management of material and information flows both in and between facilities in the chain, such as vendors, manufacturing plants, and distribution centres".

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[1] Excel and Access are registered trademarks of Microsoft Corporation.

[2] Arena is a registered trademark of Systems Modeling Corporation.

2.2. *Time horizons*

Management and planning occur on three levels, while these three levels each has specific characteristics, as shown in figure 1 (Umeda[2], Ingalls[3]):

Strategic planning

- Longest time horizon (up to several years).
- Scope: Enterprise-wide management issues, given certain information.
- The future is uncertain, while options exist to open or close manufacturing sites, any required capital may be procured and product deployments are open.
- Large cost decisions are made on this level.

Tactical planning

- Intermediate time horizon (typically several months).
- Scope: Regional, on the aggregate level, typically for a family of products.
- The location of some facilities are fixed while capacities may be known.
- Many resources are open to adjustment.
- There is usually some certainty over the medium term.

Operational planning

- Short time horizon (typically one day).
- Scope: Limited, typically for one plant at the part number level.
- Resources are known and fixed, with planning aimed at the machining, dispatch, maintenance and material handling.

Figure 1 Planning horizons and their characteristics

2.3. *Supply chain management processes*

When considering the processes involved in supply chain management, it is useful to refer to the Supply Chain Operations Reference-model (SCOR) (SCC[4], Weyers[5]). This model describes a supply chain in terms of four modelling constructs or processes, which are:

- Plan
- Make
- Source
- Deliver

Using these four processes, the supply chain is modelled and described as shown in figure 2:

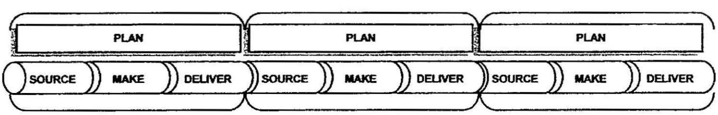

Figure 2 The SCOR Management Processes

It is evident from the previous figure that various enterprises can be integrated into the supply chain, with at least one interface between enterprises. The scope of these processes is briefly as follows (SCC [4]):

Plan (Demand/Supply planning)

- Assess supply resources, plan inventory, plan rough-cut capacity
- Manage planning infrastructure
- Make/buy decisions, business planning

Source (Sourcing/Material acquisition, Sourcing infrastructure)

- Obtain, receive, inspect, hold, issue material
- Sourcing quality, component engineering, vendor contracts and vendor payments

Make (Production execution, Manage (the) Make infrastructure)

- Request/receive material, manufacture and test product, package, release product
- Engineering changes, facilities and equipment, shop scheduling and sequencing, short-term capacity

Deliver (Order–, Warehouse–, Transport– and Installation management)

- Enter and maintain orders, generate quotations, create and maintain customer databases and product/price databases, invoicing etc.
- Pick, pack, configure and ship products
- Manage traffic, freight and product import/export
- Manage channel business rules, order rules, deliver inventories and deliver quality

3. Supply chain management Problem Solving tools and techniques

Some characteristics of the supply chain were outlined in the previous section and it should be clear that managing the supply chain is difficult due to its complexity. Industrial engineers are equipped to assess a system like a supply chain in its entirety, and they nearly always apply quantitative methods for improvement of and better decision making in a system. These methods include linear programming, integer/mixed-integer programming and network models (Hicks[6]). Supply chain issues are mainly of strategic and business planning nature, and problems are of diverse types such as:

- *Inbound-materials management*: Location, acquisition and preposition materials.
- *Finished-goods inventory management*: Inventory levels, Inventory location(s), Make to stock or make to order.
- *Logistics-network planning*: Facilities (what plants and distribution centres to open/close and where), Facility allocation (which facilities and channels serve which customers).
- *Transportation*: How and when to move what quantities of materials.
- *Supply chain strategy issues*: Make or source manufacturing process supplies.

The problems in supply chain management involve systems dynamics, while *variation* must be assumed as a given. Quantitative methods often fail to satisfactorily address complex problems where randomness is present, and in such cases simulation modelling and analysis is considered. A new dimension is, however, also part of the supply chain problem solution requirement, namely simulation-optimisation. This technique combines the capabilities of simulation (modelling complex systems with variance) while utilizing the strengths of various techniques (e.g. evolutionary algorithms) to evaluate different alternatives to find an optimal or near-optimal solution. The use of simulation in supply chain management will be discussed in the following section.

4. Supply chain management and Simulation

Supply chain management is required to develop the business activities for suppliers and customers, and to increase their benefits. Supply chain simulation is useful to speed up the integration of a supply chain, because it allows the evaluation of "what-if" scenarios, with various operational parameters.

In this section a simulator that is able to evaluate some scenarios is discussed. An overall view of the possible use of a virtual supply chain manager is also discussed.

The main elements of the simulator are:

- a simulation model (Arena model) which is the kernel of the system
- a Microsoft Access database (MS-Access) with the customer orders (which can be updated on account of the prior months order tendency, the prior year order level etc.)
- Microsoft Excel worksheets (MS-Excel) for input data (different simulation parameters) and output data (simulation report).

Although dedicated supply chain software exists (IBM's Supply Chain Simulator (Bagchi e.a.[7]), Promodel Corp.'s *Supply Chain Optimisation Suite* (Hicks[8])), it is illustrated here that simulation with an existing package like Arena is possible, while integrating it with a standard relational database system as well as a spreadsheet application. This is possible because Arena supports automation and is able to exchange data with Microsoft applications.

The subsequent paragraphs give details about a supply chain simulator that was developed by the authors.

4.1. The supply chain under study

The supply chain has six enterprises with two components suppliers (CS1 and CS2), one transformation factory (F), one assembly factory (AL) and one warehouse (W). CS1, CS2, F and the AL enterprises have their own carriers, respectively named C1, C2, C3 and C4. It is assumed that customers go to the warehouse by themselves, so there is no carrier for the warehouse.

Figure 3 shows the product flow and the order flow within the supply chain. Suppliers provide raw material to their downstream manufacturer, while, typically, the information flow is going upstream in the supply chain. With reference to the SCOR model terms, each entity has a Plan, Source, Make (manufacture, assembly or pack) and Deliver (carriers) process.

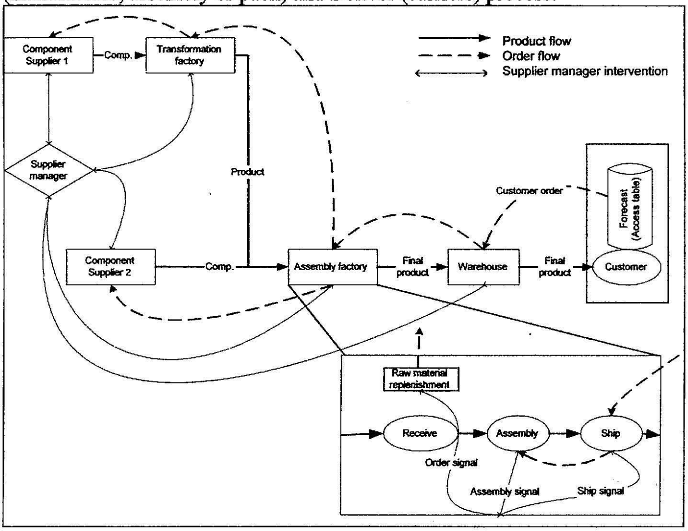

Figure 3 The supply chain under study (Guittet-Remaud[9])

4.2. *The supply chain simulator*

The simulator's architecture is based on three existing software applications. These applications exchange data and most of these exchanges are driven by Arena Visual Basic for Applications (VBA) procedures, while only one Microsoft Excel procedure is required to import some Access data (customer orders, order fulfilment lead time) when the simulation terminates. Figure 4 shows the conceptual exchange architecture between the applications through VBA for Arena and for MS-Excel.

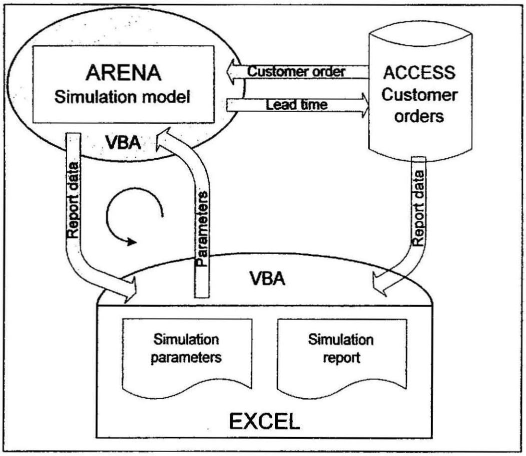

Figure 4 Conceptual application integration

A supplier manager is implemented in the Arena application. It is a dynamic element for the integration of these applications in simulating the supply chain. It is aimed at coordinating the supply chain activities, by informing other enterprises in the supply chain of a change in customer demand. Thus, these enterprises can react according to their stock levels and the increase in order level. They:

- order enough raw materials for the production,
- increase their finished goods stock level, and
- may deliver these products before the dispatch quantities are completely made up.

MS-Excel provides the user interface to the management system. Thus only a few MS-Excel worksheets are accessed from the user's point of view. These contain simulation parameters, a report and a few ActiveX® controls (command buttons). One of the sheets is used to run a process that:

- saves the MS-Excel data,
- opens the Arena model and runs it, and
- closes Arena and writes the simulation report in MS-Excel.

The kernel of this simulator, namely the Arena model, will now be discussed.

The "Factory" module

There are three role players in this module:

- the factory itself, with product and order flows,
- the carrier whose trucks deliver the finished products (product flow), and
- the initialisation section that fills the Finished Products stock when the simulation begins, with a level the user assigns.

Raw material arrives from CS1 to the factory (its SOURCE), where it waits for finished product replenishment orders. When an order is placed, the raw material entities are released to the factory's MAKE section where the raw material is processed. This process is realised via a global delay, but it is possible to design a complex model for this part. The process time is one of the parameters that can be altered in the MS-Excel worksheet. When the manufacturing process is completed, finished product entities are admitted to the finished product inventory. These products are thus buffered to wait for finished product orders from the Assembly line. When such an order is placed, the entities are released to the factory's DELIVER part.

The stock levels within the factory are also controlled: When the finished product level is lower than a minimum level assigned by the user, an order for finished product replenishment is placed. The order quantity of products is limited by a maximum level that the user has assigned. The finished product level can therefore not be higher than this maximum level.

Finished products are made available to the carrier and wait until:

- the carrier truck is full, or
- the carrier truck load reached a level the user assigned, or
- the last finished product loaded in the carrier truck is the last product in the order.

These decisions depend on variables that the user can assign before the simulation, and that the supplier manager can change when the model runs.

All the modules (CS1, CS2, Factory, Warehouse etc.) have exactly the same properties as the Factory module explained above. Differences come from the fact that some of them have none, one or two raw materials entrance point(s).

The "Replenishment" module

This module handles the raw material replenishment orders. It calculates the quantity of products the SOURCE needs to fulfil the production, according to the following rule:

$R = P_f - Q_r + S_M$

where

R = Required quantity of raw materials

P_f = Number of finished product orders waiting for raw material

Q_r = Raw material on hand

S_M = Safety margin (the user may assign its value)

The "Customer" module and the Supplier Manager

The module *Customer* is aimed at writing and reading data to and from MS-Access in order to create the customer orders, and to send them to the Warehouse module. The customer orders wait until the simulation time is equal to the user assigned lead time. The implementation of this module is included as an example, and is shown in figure 5:

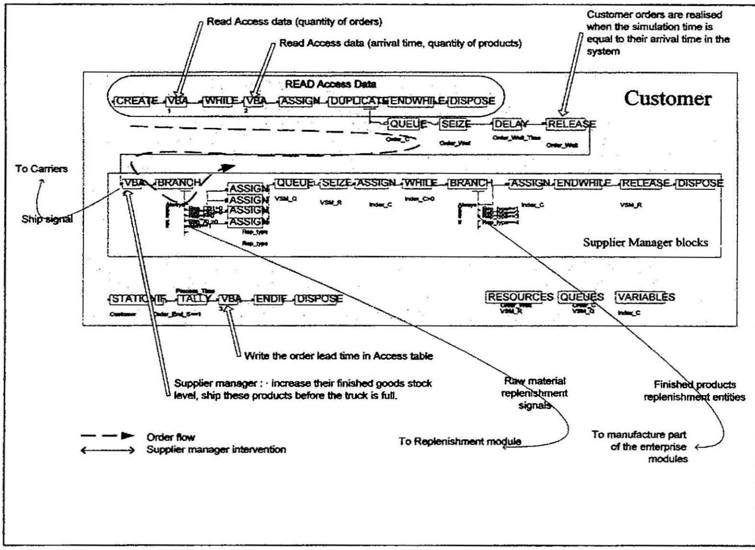

Figure 5 Flows in the "Customer" Arena module

The Supplier Manager is implemented in this module because it supports the upstream suppliers with the variation in customer demand. The Supplier Manager is aware of the quantities of the customer orders. If this quantity is higher than the average quantity, replenishment signals are sent upstream for finished products, and if needed, also for raw materials and assembly.

The Information support components

These components are implemented in MS-Access and MS-Excel.

The Microsoft Access component

This component contains business transaction information, for example data on orders, which may contain an order number, quantity required and the time the order is due. An example of a transaction table is shown in figure 6:

Order	Time	Quantity	Lead Time
1	100	60	0
2	200	60	23
(...)	(...)	(...)	(...)

Figure 6 Typical Order transaction table

The simulation kernel reads data from this component when orders are received.

The Microsoft Excel component

This component defines the user interface of the simulator, which includes a parameter specification area, as well as a reporting area. The latter is filled after a scenario is simulated. A typical interface is shown in figure 7, while a report is shown in figure 8:

Parameters

Simulation length		4000

☑ Batch Mode

☑ Supplier Manager

Input orders

Standard deviation for input orders	5

(Normal distribution)(0 for no deviation)

Simulation

Alert Threshold (%)	10

Save Data

Firms

		CS1	CS2	Factory	Assembly Line	Shop
Raw materials	MINImum Stock level			20	20 20	20
Finished products	MINImum Stock level	100	100	100	100	100
	MAXImum Stock level	150	150	150	150	150
	Initial Stock level	120	120	120	120	120
Process Time	Mean	0.6	0.6	0.85	0.4	0.2
N(Mean,S.D.)	Standard Deviation	0.1	0.1	0.15	0.05	0.02

Replenishment

	Time between each replenishment order	Time of the first replenishment order
Factory => CS1	100	103
AL => CS2	100	102
AL => Factory	100	102
W/house => AL	100	101

Transport

	Truck capacity	Option	Rate (%)	Duration
CS1 => Factory	50	0	100	10
CS2 => AL	50	0	100	10
Factory => AL	50	0	100	10
AL => W/house	50	0	100	10

Figure 7 A typical user interface with scenario specifications

Activity Cost Estimation

Orders

Lead time (customer orders)		
MINImum	Mean	MAXImum
0	0	0

Delay / product unit	1.6
Penality / product & time unit	20

Number of deliveries	0	
Number of late deliveries	0	(see sheet Deliveries for more details)
Order fulfilment rate	0	
Late deliveries penalities	0	(see sheet Deliveries for more details)

Firms

		CS1	CS2	Factory	Assembly Line		W/house
Raw materials	Stock cost / product unit			200	200	400	800
Finished products	Stock cost / product unit	200	200	400	800		1000
Work cost / time unit		R40.00	R40.00	R40.00	R40.00		R40.00

		CS1	CS2	Factory	Assembly Line		W/house
Raw materials	MINImum Stock level			0	0	0	0
	Average Stock Level			29.87	28.52	5.13	9.64
	MAXImum Stock level			50	60	50	51
Finished products	MINImum Stock level	0	0	0	0		0
	Average Stock Level	11.71	2.63	2.50	2.50		6.08
	MAXImum Stock level	120	120	120	120		120
Resources		0.78	0.95	0.95	0.95		0.95

	CS1	CS2	Factory	Assembly Line	W/house
Stock cost	R2,341.00	R526.00	R6,976.00	R9,758.00	R13,794.00
			Total		R33,395.00

Replication Length	4000

	CS1	CS2	Factory	Assembly Line	W/house
Work cost	R125,008.00	R152,000.00	R152,000.00	R152,000.00	R152,000.00
			Total		R733,008.00

Transport

	Delivered products	Shipments	Price / shipment	Transport cost
CS1 => Factory	200	5	R100.00	R500.00
CS2 => AL	200	5	R100.00	R500.00
Factory => AL	160	4	R200.00	R800.00
AL => Warehouse	201	5	R200.00	R1,000.00
			Total	R2,800.00

Income

Price / product unit	R500.00
products sold	242
Total	R121,000.00

Figure 8 A typical post-simulation report on a scenario

4.3. *Evaluation and Analysis*

Some aspects of the behaviour of the supply chain is illustrated in this section. Three specific aspects are:

- the effects of a large increase in customer demand,
- changing the global process time in the transformation factory, and
- fluctuating customer demand.

Many other aspects may be investigated, but it is sufficient for illustration to discuss only a few simplifications here. The process time of the Factory as well as the time between order arrivals were made deterministic for the purpose of this illustration.

Large increase in customer demand

A group of 20 orders equally spaced over time is placed on the Factory, each demanding 60 units of the product. At a point in time there is a sudden increase in customer demand – 500 units are required instead of the usual 60. The simulator was allowed to handle this situation with and without the Supplier Manager. The results are shown in figure 9:

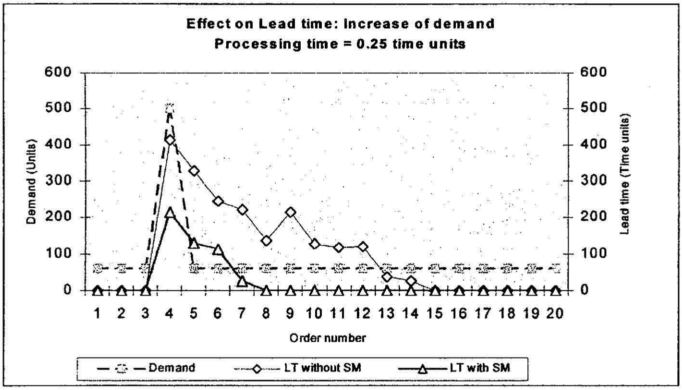

Figure 9 Effect of the SM on the lead time

For the given processing time, the supply chain recovers quicker with lower lead times when the Supplier Manager is active in the simulator. Note that the order data was imported from MS-Access, while the graph and its underlying data were created by MS-Excel after the data was exported by Arena.

Increase in process time of the transformation factory

The same situation described above can be re-evaluated with a longer processing time of the Factory. Suppose a different enterprise is introduced into the supply chain, with an overall processing time of 0.85 time units. This enterprise may be considered due to its lower product unit cost. If the same demand pattern is fed to the simulator, it yields the result as shown in figure 10:

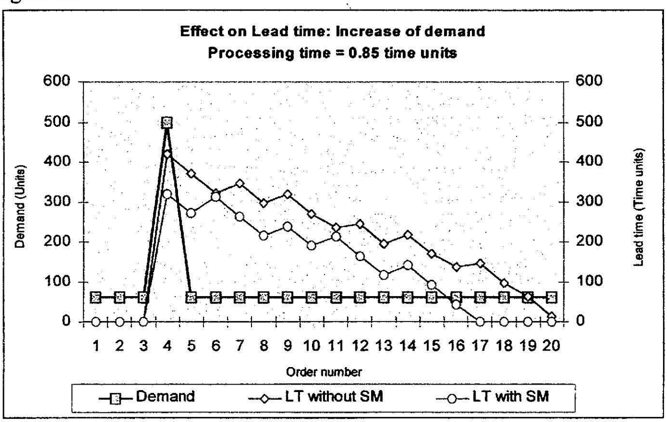

Figure 10 Effect of longer processing time

The longer processing time causes a longer recovery period, with longer lead times associated. The Supplier Manager still improves the lead time and recovery period. This example also confirms the complexity of decision-making in the supply chain. Although the lead times may be longer, this factory with the longer processing may be a feasible option if overall costs are considered. This would include the lower product unit cost of this factory, the possible higher inventory levels on the finished product, as well as raw materials upstream.

Fluctuating customer demand

The previous two examples considered the effects of a single upward increase of customer demand. The following example (figure 11) shows the effects of cyclic deterministic demand, for the original processing time of 0.25 time units:

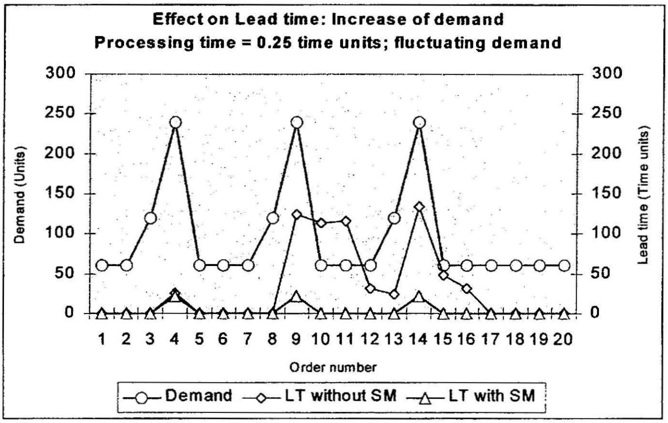

Figure 11 Effects of cyclic demand

The supply chain can again recover sooner when the Supply Manager is active, given that the resources are not overloaded.

Only specific aspects of the simulator were shown in the examples above. It is important to realise that the supply chain should be evaluated as a whole, and not by isolating some subcomponents of it. However, a subcomponent may be isolated for improvement after its target operational parameters' levels have been determined by the complete supply chain.

5. Conclusions

Supply Chains and its management pose new challenges through its complexity and dynamics. Existing problem-solving and –evaluation tools may be applied to various dimensions of the supply chain, while simulation-optimisation may become a fundamental tool in supply chain management.

Although dedicated software packages for supply chain management already exist while other similar products are still under development, it was illustrated that existing desktop applications may be integrated to supply a basic management tool. Further research and development will be focused on the flexibility of such a tool, with full information integration capabilities. It is, however, people that create and utilise systems and decision tools, and the industrial engineer is therefore expected to be the ideal user of such a tool.

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