Financial Evaluation in Supply Chain Design using Enterprise Simulation

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Abstract
Supply chains will typically evolve through independent enterprises linking together to fulfil the needs of the end customer. Many argue that the unit of competition is not the single enterprise but the supply chain showing the importance of supply chain performance and the design that gives rise to it. This paper argues that supply chain designs and improvements should incorporate financial evaluation as well as cost evaluation. Evaluation of the financial performance, including the generation of profit and loss statements, could be considered the overriding measure of the appropriateness of supply chain configuration. Financial evaluation should take into account the operational and dynamic aspects in order to capture the detailed financial drivers and take account of the real-world operation of the supply chain. Importantly the evaluation would be holistic rather than of partial performance. The paper demonstrates the ability to incorporate the financial evaluation through the use of simulation modelling.

Keywords
Financial evaluation, Supply chain management, enterprise simulation, design methodology

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Introduction

Companies such as Dell and HP who have focused on their supply chain design and operation are performing significantly better than their competitors (eg. Davies 1993, Lee & Billington 1992). Frohlich and Westbrook (2002) state: “the most admired (and feared) competitors today are companies that link their customers and suppliers into tightly integrated networks”. There is as growing recognition that it is supply chains and extended enterprises that form the unit of competition rather than individual enterprises. Whilst Christopher (1992), Bhattacharya et al. (1995) and others refer to supply chains competing there appears to be insufficient measurement of supply chain design and operation to judge how effective competition is.

The overall complexity of supply chains can be enormous (Kotzab et al., 2003), especially given that any one enterprise is likely to be a member of several supply chains. Complexity arises as a result of the numerous interrelationships within the supply chain sub-processes, the time-based effects resulting from changes in demand and performance and the level of uncertainty that exists. Complexity will obviously exist with each single enterprise but this is compounded by events in one enterprise causing knock-on effects on others in the chain. Despite the complexity, significant results have been reported in supply chain improvement projects through the reduction of waste (e.g. Hammel et al, 2002) and improvements in lead-time and cost (e.g. Aitken, 2000).

Bhattacharya et al, (1995) see the effective design of supply chains as critical to competitiveness, however, analysis of instances of reported practice of supply chain development and measurement do not suggest it is commonplace. The design and operation must be optimised from the holistic perspective of the performance of the whole supply chain, not just the individual enterprise (Kehoe & Boughton, 2001). Whilst the inherent complexity of the supply chains may be high, this complexity can be captured and managed by the use of the appropriate methods and tools. A supply chain will typically evolve as a chain of independent enterprises coming together, rather than being the subject of an explicit, holistic and rigorous design process. As a result, their operational, financial and customer-service performance is likely to be far from optimal.

Any approach to designing or modifying a supply chain should assess improvement to the performance of the whole supply chain rather than the performance of an individual enterprise. This global approach should apply not just for supply chain design but for tactical and operational decisions as well, e.g. evaluating the impact of policy decisions on other members of the supply chain (Holweg and Bicheno, 2002). Impacts of changes across the supply chain can be assessed through metrics such as lead-time, work-in-progress, flexibility, etc. but should be measured in monetary terms as well.

Cost measurement is important in the evaluation of changes but can suffer from considering the effects locally rather than at enterprise or supply chain level. Financial evaluation by assessing the impact on the profit and loss account is far more powerful as it captures the overall effect rather than immediate local effects. Measuring financial impacts can be difficult due to the need to capture a sufficient number of the financial drivers within an enterprise. Measurement of financial impact
at an enterprise level is rare (e.g. Love & Barton, 1996) and those reported instances have been found of such measurement in a supply chain context are at a more abstract level (e.g. Guillen et al., 2007).

Assessing the financial impact of changes in supply chain performance is a challenging and complex task (Anderson et al., 2003). However, the right supporting methodology could provide tools to achieve this type of financial analysis. The methodology would have to define the major stages of the design process and the necessary tools and techniques. Importantly it would have to detail the methods and tools for evaluation, especially of financial performance. This paper reviews supply chain design methodologies and focuses on the evaluation of supply chains. A review of supply chain performance assessment fails to uncover instances of financial, “bottom line” assessment of impact on profit and loss. The paper argues that such financial evaluation is an important contribution to supply chain measurement and proposes a model by which this can be carried out.

Supply chain methodologies

This section introduces the need for methodologies to support the supply chain design process. It presents the need for methodologies in general and looks at the specific attributes of methodologies that have been developed. The focus of the discussion is on performance evaluation, in particular the “bottom-line” financial evaluation that would show the overall business impact.

Scope and detail of methodologies

Methodologies are of great importance in the design process. They guide the designer from the business goals and strategy through to defining the boundary of the problem and then through a series of structured processes typically incorporating tools to help evaluate the design options and allow an informed selection. Methodologies suggest to the designer the stages necessary for completeness and prompt for the level of detail required. Parnaby (1979) illustrated the power of design methodologies for manufacturing systems, demonstrating the stages of analysis and the inputs and outputs of these stages required for robust design. Later, work in manufacturing system design two works demonstrated how tools such as simulation could be integrated into a methodology (Love & Bridge, 1987; Popplewell & Bell, 1995).

A number of different types of methodologies have been developed with wider scope to guide the supply chain design process. These methodologies vary in the style, depth and breadth and range from high-level models based around flow charts to highly developed detailed approaches supported by analysis software. Some of these methodologies are introduced here before focusing in on the performance measurement features of methodologies.

The framework outlined by Davis & O’Sullivan (1999) provides a road map for the design of the information infrastructure. It has supply chain scope and detail to the level of departments and functions. It identifies the key areas of consideration and the type of data that would be managed by the information infrastructure. The approach would benefit from the process by which tools can be used in the way that
some manufacturing system design methodologies do and the way customers’
requirements are explicitly captured in Hines et al. (1998).

Christopher & Towill (2001) suggest a framework for integrated design of agile supply
chains. It captures the key features for dealing with supply chain dynamics and
suggests activities and approaches that contribute to agile design. The framework,
however, lacks detail of the process, tools and evaluation for the detailed design
stages.

Performance evaluation
Assessment of performance of supply chain design is essential, whether or not a
methodology has been used to guide the process. Performance measurement will
be used to assess the internal efficiency of the design as well as the overall
effectiveness (e.g. measure stock levels, lead-times, cost, etc as well as ability to
deliver on time, the flexibility to respond to changes in requirements, etc).

Persson & Olhager (2002) present a case study on evaluating the performance of
supply chain designs. Although they exclude planning and control from the design
evaluation they include metrics such as cost and lead-time as means by which to
evaluate overall performance across two companies. Other design methodologies
show performance evaluation, e.g. Korpela et al, (2002) with the analytical hierarchy
process (AHP) that links enablers through to critical success factors to goals.
Agarwal & Shankar (2002) also use AHP to prioritise improvements based on a
number of factors including cost, service level and lead-time. Peterson et al., (2005)
examine the impact of early supplier involvement in the product development and
supply chain design process. Whatever evaluation is used it is important that it
includes dynamic evaluation such as that demonstrated by Childerhouse et al (2002)
to ensure that the designs can cope with the operational effects.

Huang et al. (2002) introduce a SC selection approach based on product. Through a
series of questions their approach can guide the high-level selection of the supply
chain for a product based on factors such as demand characteristics, competition,
product life-cycle, etc. The approach guides the selection of lean, agile or hybrid
structures but does not evaluate performance or deal with the intricacies of everyday
manufacturing.

Financial evaluation
A comprehensive supply chain design methodology needs the relevant scope and
detail to be meaningful for implementation across the supply chain as well as
evaluation to assess the performance of the design. Whilst there are a number of
supply chain metrics that can be used, the financial performance is the most
powerful; financial measures take a global, all inclusive view of the business rather
than selective, localised measurement. Balanced scorecards can be used to provide
assessment through finance, customers, processes and learning and growth areas.
However, taking a hierarchical perspective the finance is at the top resulting from
market performance enabled by the business processes and sustained by learning
and growth. It is argued here that whilst operational/business process measures are
vital they should be complemented by financial assessment.
Riddalls et al. (2000) note the lack of cost-based analysis and that contemporary discrete event simulation packages may provide a more accurate simulation capability. They also make other criticisms such as the lack of stockouts and the lack of influence each echelon in the SC possesses over the next higher echelon.

The distinction of financial measures (including profit and loss) is often blurred by the use of cost measures (direct labour cost, efficiency, etc.). Cost measures are useful in their ability to identify focussed improvements but lack the power to indicate the overall impact on the operation of the whole company. Cost calculations often include coarse allocations of indirect costs, assume linear relationships with production volumes and concentrate too much on labour costs. Kosior & Strong (2006) provide an interesting discussion on different approaches to modelling costs and financial measures and the limitations of modelling methods and implementations. In a review of supply chain modelling Beamon (1999) noted single supply chain performance measures, such as cost, presented weaknesses when applying criteria such as inclusiveness, universality, measurability and consistency. Measuring the impact on the profit and loss account is a far more powerful and much more inclusive approach.

Baiman et al (2001) analytically model the costs in the supply chain. Guiffrida & Nagi (2006) use financial measures to assess supply chain configuration and variability of process. Guillen et al. (2007) look at mathematical modelling of a supply chain incorporating financial analysis. Persson & Olhager (2002) calculate cost, although the detail of how this is done is not presented. The industrial dynamics based methodology of Towill (1996) focuses on tools and contains both qualitative and quantitative phases but the inputs and outputs of each stage could be more explicitly defined and financial evaluation is not conducted at each phase. Likewise the VALSAT methodology developed by Hines et al (1998) does not assess the impact on profit and loss.

Kotzab et al (2003) present a model for strategy optimisation and examine the detail of transaction cost analysis. This type of analysis is more powerful as it can highlight the cost drivers more clearly. Wilhelm et al. (2005) examine international supply chain design with the aim of maximising profit with consideration to a range of logistical and financial issues. Chandra & Kumar (2000) introduce a methodology to analyse an existing supply chain design using mapping and modelling tools. The work incorporates Activity Based Costing (ABC) as well as simulation. Cost drivers are incorporated into the analysis to assess overall impact. Benjamin et al. (2001) present an IDEF and simulation based toolkit for supporting supply chain design using ABC for part of the analysis. Whilst the ABC approach offers greater granularity and is potentially more accurate through the detailed allocation of costs, inaccuracies can arise in the allocation to products. A more accurate approach would be to have a complete financial view covering cost drivers as well as investments and revenue. Such an approach should look at the transactions (such as works orders and purchase orders) that are typically averaged for costing purposes and model them in such a way that more accurate assessment of actual cost can be obtained.

Beamon (1998) lists measures used for supply chain analysis and shows cost and customer responsiveness as the most common with other measures such as profit
infrequently used. Some work (e.g. Fowler 1998) goes further to promote the need to model to evaluate profit but it is unclear how the management accounting function would be represented though it does detail the variables that would be involved including payment of salaries, suppliers, maintenance, etc.

These approaches will give a valuable insight in the local implications of change but the lack of financial or “bottom-line” evaluation prevents the global impact being assessed effectively. By developing a supply chain methodology that supported comprehensive financial evaluation then universal and inclusive performance evaluation could be carried out. However, such financial evaluation is rarely reported in a supply chain design context and, as such, would be a major, novel contribution of any proposed tool or methodology. Thus as the design progresses, each stage will be comprehensively evaluated against the operational and financial performance requirements whilst ensuring the original design objectives are retained as a core thread of the design process.

Financial analysis through simulation modelling

In order to evaluate the performance of a supply chain a powerful analysis technique is required. The technique needs to be able to capture the complexity of supply chains, the time varying (dynamic) interaction between the enterprises and the random effects that appear within them. A candidate technique for this is simulation.

Many evaluation techniques do not account for the time varying, dynamic behaviour of systems and supply chains in particular. Many techniques assume average, steady-state conditions to simplify the analysis. Such static analysis is often quick to perform and whilst this may be appropriate at certain stages of a design process, neglecting the dynamic effects can lead to designs not able to meet the operational requirements. Importantly, Fowler (1998) argues that steady state could be unobtainable and identifies the inherent compatibility between the behaviour of supply chain processes and the capabilities of simulation.

Simulation is a technique that can be used to model the dynamic behaviour of a system. For example, it could be used to model the flow of stock through a supply chain or the sequence of events of a product being kitted prior to assembly. It can therefore capture the variations in stock and shortages that prevent assembly taking place. Simulation is typically seen as a detailed, operational technique for modelling the detailed activities of a shop-floor but it can be used at any level, including abstract or detailed modelling of supply chains. Manzini et al. (2005) present a discussion of case studies of the use of simulation to optimise supply chain performance. They conclude that simulation is a versatile, flexible and effective analysis tool for supply chains. Simulation is able to model events and movements and can therefore model the movement of physical stock as well as transactions, e.g. the release of a production order or the change in a stock record. The ability of simulation to capture time varying effects, complex interactions and random events makes it an ideal candidate for modelling supply chains in which lead times for products are affected by queuing, competition for shared resources and delays in movement. In particular the ability to model transactions makes simulation well suited to modelling the financial drivers in an enterprise.
Terzi & Cavalieri (2004) provide a comprehensive survey of the use of simulation in supply chains and categorise the use by scope, technology and stage of development. They observe that there is a general lack of clarity of the detail of the supply chain configurations simulated. Smith (2003) uses spreadsheets for analysing a number of supply chain scenarios. The work shows that spreadsheets, typically used for static, average analysis can be used to capture coarse time varying conditions by modelling time across a limited number of worksheet cells. Beamon (1998) examines the use of performance measures in supply chain design and analysis and promotes the use of simulation as an appropriate tool to support the necessary evaluation identified. A large number of applications have been reported that use simulation to study the behaviour of supply chains. These applications focus on logistics (Chan et al., 2002; Lee et al., 2002, Owens & Levary, 2002) or selected functions of the supply chain (Phelps et al., 2001; Hieta, 1998; Strader et al., 1998). Chatfield et al. (2005) present a supply chain simulation system that is able to model the operations of a supply chain but, taking advantage of the object-oriented principles, has the potential to model a lot more.

Ng et al. (2003) describe a multi-echelon simulation workbench that models the key performance drivers across a number of companies in the supply chain. It is able to capture a significant amount of detail but does not derive profit and loss or have a supporting supply chain design methodology. Biswas & Narahiri (2004) present their decision support system, DESSCOM, that makes a clear distinction between non-financial and financial performance measures, however, the measures appear only to relate to cost. Crespo Marquez et al. (2004) developed a systems dynamics model to analyse financial effectiveness of a supply chain and modelled accounts receivable and accounts payable. This model shows how the financial drivers can be incorporated into supply chain modelling, however, the use of systems dynamics precludes the detailed modelling of the financial transactions to the profit and loss account. Similarly the mathematical approach of Guillen et al. (2007) of modelling supply chains provides overall financial indications but lacks the detailed transactions argued here.

Only two types of simulator were found to have a more comprehensive approach, those based on SCOR (e.g. Gensym, 2007) and the IBM Supply Chain Analyser (Bagchi et al., 1998) The latter lists customer, manufacturing, distribution, transportation, inventory planning, forecasting, supply planning, and financial reports among its components (the financial reports are based on Activity Based Costing (ABC) and not in actual financial transactions carried out in the system).

The approach developed by Jain et al (2001) is based on a virtual factory containing simulation models. Its scope covers the major sub-systems of an enterprise (planning, finance, human resources, manufacturing, etc) and provides assessment of the impact of design and policy decisions. Whilst there is comprehensive scope shown at an enterprise level the approach is enterprise based and yet to cover a supply chain. They identify financial drivers such as invoicing process but there are no apparent financial measures used for evaluation.

Love & Barton (1996) developed a Whole Business Simulator (WBS) to assess the financial impacts of engineering decisions. The system was used to evaluate changes to product design and changes to the manufacturing system (see Barton et
al 2001, for an example). The work modelled product manufacture and assembly along with the associated financial transactions at a single enterprise level. The WBS concept was developed to evaluate the performance of a single enterprise and although lacking the SC scope it modelled in detail the key financial drivers and resulting impact on profit and loss.

With the papers that have been reviewed there are varying degrees of detail (or fidelity) of the financial analysis such as whether simple costing or ABC is used. Similarly there are varying degrees of fidelity of the operations analysis such as whether the production systems are represented in great detail or as a "black box". By mapping the instances of simulations reported to the degree of financial and operational fidelity the levels of sophistication of the analysis tools can be illustrated. Figure 1 shows analysis tools plotted against financial and operational fidelity. It shows that generally speaking tools are either strong on financial analysis or on operational modelling but rarely both. The Whole Business Simulator (WBS) (Love & Barton, 1996) discussed later has been shown as having the ability to model detailed financial transactions as well as modelling the detailed operations that give rise to those transactions.

This review of the analysis tools can be complemented by a review of the financial and operational analysis needs of typically business problems. For example, sequencing of batches in production does not require much financial or operational analysis. On the other hand design activities would require significant operational analysis and increasing levels of financial justification as the scope of the design increases. A range of typical business issues has been plotted onto the same financial and operational fidelity scales used earlier and is shown in Figure 2. It shows that activities such as new product introduction and supply chain design require significant financial and operational impact analysis. Such strategically important activities also occupy the area of figure 1 which shows there to be few candidates for analysis.
Insight into selected issues positioned at the extremes of the scales in Figure 2 is shown in table 1. The table illustrates the issues for Vendor Managed Inventory (VMI), sequencing, budget setting, line design and Supply Chain Design (SCD) for the operational and financial fidelity required.
<table>
<thead>
<tr>
<th><strong>Scope</strong></th>
<th><strong>Sequencing</strong></th>
<th><strong>Budgets</strong></th>
<th><strong>VMI</strong></th>
<th><strong>Line design</strong></th>
<th><strong>SCD</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational fidelity</strong></td>
<td>Localised, short term decision making in operations</td>
<td>Strategic planning of operating boundaries and targets.</td>
<td>Interface between two tiers of supply chain</td>
<td>Local reconfiguration of resources</td>
<td>Elements of at least three tiers of supply chain</td>
</tr>
<tr>
<td><strong>Operational fidelity</strong></td>
<td>Impact on delivery performance of orders considered as well as resource utilisation.</td>
<td>High level view of resource capacity, flexibility and availability as well as inventory management.</td>
<td>Logistics flow and signals between tiers. Stores and dispatch changes. Support resources, purchasing and planning</td>
<td>Detailed analysis of capacity, tact time, flexibility and reliability.</td>
<td>Extremely wide covering, production system, logistics, purchasing, planning, accounts, etc.</td>
</tr>
<tr>
<td><strong>Financial fidelity</strong></td>
<td>Consideration given to penalties and transportation costs.</td>
<td>Detailed view of revenue, expenditure cash flow and risk.</td>
<td>Changes to purchasing activity and resources, changes to stock transactions and cash flow.</td>
<td>Typically limited to calculation of equipment investment and labour requirements</td>
<td>Extremely wide covering changes to timing, scope and origin of the financial drivers.</td>
</tr>
<tr>
<td><strong>Key issues</strong></td>
<td>Often driven by the necessity to deliver rather than cost minimisation analysis.</td>
<td>Will model scenarios and identify weaknesses in the plans.</td>
<td>Operational benefits are often easier to identify than true financial benefit of reduced transactions, time saved, etc.</td>
<td>Work on operational impact dominates the activity.</td>
<td>Benchmarking shows typical cost of just managing the supply chain is around 10% of revenue and design will have a critical impact on this and customer metrics.</td>
</tr>
</tbody>
</table>

Table 1. Scope of operational and financial fidelity of typical business issues

**Enterprise simulation**

Models can be created to represent small parts of a business or have significant scope. Models that have considerable scope and cover the business information flows as well as the production operations can be described as “enterprise models”. Such models cover more than just production areas but include inventory and links to the raw material supply as well as delivery to customer. These models could be represented diagrammatically to show the logic of the information and product flows or could be developed in simulation software as “enterprise simulation models” in order to be able to analyse the performance from specific designs and operating policies. When taken in the context of Figures 1 and 2 such tools would tend to be positioned towards the high end of operational and financial fidelity to analyse problems that would be placed in such space.

One example of an enterprise simulation is the work of Mujtaba (1994) for the analysis of a manufacturing model to examine the effects of demand variation on inventory and delivery performance. The model incorporates forecast sales and raw material supply as well as product structure information to drive the core production
model. It has proposed extensions to include modelling cash flows and R&D functions.

The Whole Business Simulator (WBS) (Love & Barton, 1996) introduced earlier was able to assess the financial impacts of changes at a single enterprise level, see Figure 3. This extended the concept of enterprise simulation to more accurate reflect the core business transactions and incorporate true financial modelling. The work demonstrated the power of simulation to support financial evaluation through the generation of profit and loss statements through modelling the detailed financial drivers such as purchase orders, invoices, direct and indirect salaries, stock transactions, etc.

![Figure 3. The Whole Business Simulator architecture (Love & Barton, 1996).](image)

The WBS concept was developed to evaluate the performance of a single enterprise. Given its scope to cover the wide range of processes including the purchasing, invoicing and stock transactions, then the concepts and the architecture have potential to be replicated to create multiple instances of enterprises and joined to form a supply chain.

**Modelling financial performance in a supply chain**

**Requirements for a methodology**

A review of existing supply chain design methodologies reveals that no one methodology has the scope and detail to provide the financial assessment of enterprises within a supply chain. Whilst this paper does not set out to present such
a design methodology it is important to state what is required in a methodology to support financial evaluation.

Firstly the financial evaluation should not be a final check on the performance of a design, it should be used to select between design options and to guide the refinement of the chosen option. It is therefore an iterative process that may start with vague or high-level design data that is progressively detailed over time. The evaluation of performance is therefore continuous and becomes more accurate allowing greater confidence in decisions made.

Secondly, financial evaluation should not be used in isolation. A methodology should guide the evaluation of operational performance as well. The balance of measures ensures that a detailed understanding of the behaviour of a design is gained and that the reasons for a particular set of financial results can be explained and verified.

To enable financial performance to be truly measured and seen as separate from cost analysis the methodology should guide the evaluation of the whole enterprise whether or not all parts are being evaluated. These wider areas could include IT, maintenance, product design and other production areas. Whilst these areas may not change they allow the bigger picture to be seen and enable all financial drivers to be captured and included. An example of where this is important is cost analysis associated with outsourcing where the local benefits may be significant but the overall financial performance may not be as positive due to the inclusion of the extra costs associated with running the outsourcing process, the effects of late deliveries and unchanged overheads for production support functions.

It was argued earlier that it is the transactions that give the important contribution to the financial behaviour. A methodology should therefore guide the capture of the important transactions (works orders, purchase orders, returns, invoices, stock transactions, consumables use, etc) and provide a mechanism by which their impact can be evaluated.

Finally the methodology must guide the financial evaluation (as well as operational and cost evaluation) that needs to be carried out such as calculation of return on investment (ROI) and the profit and loss account generation.

**Modelling the financial drivers**

A business is made up of a number of business processes, sometimes classified into operate, support and manage processes. The operate, value-adding processes will include getting the order, developing the product and fulfilling the order. Each of these processes will have associated transactions such as the receipt of orders, payment of invoices, stock movements, etc. In the design or redesign of a supply chain these processes could be reconfigured or affected by changes to other processes. One way of representing the configuration of the processes is by the use of the Supply Chain Operations Reference (SCOR) model (Supply Chain Council, 2007). The use of SCOR allows easy of communication through an accepted standard as well as easing model building through reference to standard process definitions and metrics. The SCOR model makes use of plan, source, make, deliver and return processes to represent the activities of each of the enterprises of a supply
chain, see Figure 4. Each of these processes can be progressively broken down into more and more detailed sub-processes.

Figure 4. The SCOR process model (Supply Chain Council, 2007)

The SCOR model has obvious strengths in representing many companies in a supply chain using an easy to replicate structure. The WBS model from Figure 3 could be mapped across to the SCOR model with existing processes to model the Plan (Material planning), Source (Supply side), Make (Manufacturing operations) and Deliver (Customer facing). Additionally, it has the enhancement of Design, Production Engineering and Accounts to represent the engineering and financial processes. By selectively combining the SCOR and WBS model activities and transactions, Figure 5 can be derived. The SCOR planning hierarchy is simplified for the purposes of illustration by presenting a single planning function and excluding the supply chain and detailed planning processes.

Figure 5. High level transactions for financial modelling (adapted from Love & Barton, 1996 and Supply Chain Council, 2007)
The combination of the two concepts will enable powerful models to be created. By utilising the SCOR supply chain representation multiple enterprises can be modelled. By building such models using simulation software the performance can be evaluated to ascertain measures such as lead-time, inventory, on-time delivery, etc. By using the WBS concepts the evaluation would be novel and unique in that the performance evaluation could not just be based on cost results but importantly on the financial performance as a result of transactions through the profit and loss account.

The activities within the processes and the transactions will affect the operational and in particular the financial performance of those processes and the enterprise as a whole. Operational as well as financial drivers and measures are illustrated in figure 6.

Figure 6. Overview of key financial drivers and transactions

The diagrams are simplified and show selective areas of an enterprise. By incorporating more of the activities of an enterprise at an appropriate level of detail more accurate assessments of the overall performance can be gained. In particular there will be sufficient activities and associated transactions to be able to generate a profit and loss account. The profit and loss figures would be used for an overall judgement of the performance of the enterprise and supply chain and the reasons for the underlying behaviour could be investigated by drilling down to the more detailed operational measures.

These diagrams show the performance of one enterprise. By linking these models (of appropriate levels of detail) together the wider supply chain can be modelled and financial evaluation of each enterprise made, see figure 7. From this, changes to areas of the supply chain can be viewed in the individual enterprises or across the extended enterprise or supply chain.
Example of modelling the financial drivers

To illustrate the benefits from the modelling approach presented and example of Vendor Managed Inventory (VMI) will be used. The benefits to customer for VMI are claimed to be better service and, possibly, lower costs.

Simulation is able to model the service levels by modelling the actual stock policies needed to sustain desired service level in the face of typical demand patterns. Traditional approaches to modelling ordering costs usually assume a cost per order. This may be calculated by dividing the total cost of the order processing function by the number of orders and then assuming that savings will equal the cost per order multiplied by the number of orders saved.

The direct savings that will be made actually depend on the extent to which the direct costs of ordering function (i.e. people and some minor operating expenses) can be reduced. If VMI is to be applied to only part of the component range then the simulation of the complete process will allow both the residual number of transactions to be determined and level of manning required to service them. All the people in the model generate wage transactions so that any reduction in people will be reflected by corresponding changes in the accounts. Similar changes would be triggered by any changes in expenses. Simulating the account transactions allows the actual changes in the companies finances to be judged more accurately (it is all real money, not 'notional' savings) and also for the time phasing of the changes to be determined from the simulation.

If operators are required to monitor stock levels and trigger replenishment actions then these activities may also lead to a reduction in productivity and the subsequent need to revise work practices or manning will again be reflected in the consequential impact on the related financial transactions.

From the supplier's viewpoint the costs of running a VMI system on the client's premises may be difficult to determine in advance. Again simple cost calculations may be misleading. Actual costs will depend on stock holding and monitoring costs as well as transport and handling. Stock holding costs are usually assessed through assumptions of a notional cost/item/year, frequently related to the item cost or price. In practice space-related costs can only be saved if the space is released for sale or utilised for new revenue-generating activities. The simulation and practical considerations will determine whether that is possible and the savings or extra revenue will appear in the accounts as a by-product of the way the simulation
operates. The cost of obsolescent stock would be included in the normal operating expenses at the time the items were originally made or (for VMI) purchased and would appear as addition part of the cost of sales in the accounts. Stock that goes out of shelf-life will have to be replaced and, again, the cost of this will appear through operating expenses when the new items are acquired. Interest charges would accrue as a result of any increases in borrowing required to finance the manufacture or purchase of the items concerned.

Better service should yield operational benefits that in turn should lead to financial benefits in improvements in downstream operations. These are very difficult to determine with traditional costing techniques. With this approach the model would allow the financial impact of those improvements to be seen through the changes in the financial transactions that are triggered by the operational changes that better upstream service allowed. For example less stock may be needed downstream (interest), manning levels (wages) could be reduced, less scrap or higher yields (material purchases) could occur. More complex effects, such as on the amount of capacity (investment) required to run the plant could also be evaluated.

In all these cases the model requires that consequent decisions or actions are required to implement the benefits from some change in the operation - it is those changes that trigger alterations in the financial accounts of the simulated businesses. Thus to compare policy A with policy B all that is required is to run the simulation with each policy and compare the standard financial reports that would have been produced by the real companies.

A simulator for financial evaluation

To be able to support financial evaluation tools are required, one of which is simulation. Simulation has been applied to supply chains (e.g. Towill, 1996) and is able to model the behaviour of systems over time. It can be used to assess the time based operational measures such as work-in-progress, lead-time and on-time delivery. Simulation has the ability to capture the complexity of the supply chain environment and importantly discrete event simulation is able to model transactions (such as orders and stock movements) which are key to capturing the financial performance.

Love & Barton’s (1996) work on the Whole Business Simulator (WBS) demonstrates the potential to be extended to supply chain work – the work modelled a substantial portion of the enterprise, the external transactions of invoices, sales and purchase orders as well as the accounting system. The simulator incorporated an accounts package, thereby allowing capture and presentation of financial data in the same way that an enterprise would of an implemented design. The simulator was not applied to the supply chain environment and therefore did not link enterprises together or model the logistics functions (although an MRP system was used internally).

A simulator for supply chain design analysis would need to provide relatively fast model creation due to the size of the data that would make up the model. It would need to support the supply chain process as well as provide the financial drivers for input to an accounts system. eSCOR and now webSCOR.com (Gensym, 2007) has the necessary foundations to provide this and integration with an accounts package
could be achieved by developing drivers within the underlying programming language. The ability to model a supply chain in detail with financial evaluation based on the transactions arising from the supply chain operation and wider parts of each enterprise would present a major novel contribution to supply chain performance evaluation. The simulation system is represented conceptually in figure 8. The figure shows one enterprise in detail for which models and metrics would be replicated at appropriate levels of detail up and down the supply chain. The SCOR representation of plan, source, make, deliver is shown as high level and would include all planning functions as well as the return cycle. Mapped onto this figure are the software packages that would be used to model each enterprise and the groups of metrics that would be captured for evaluation. Multiple enterprises could be used on the supplier and customer sides.

Figure 8. A simulation system supporting financial evaluation

The initial experience with e-SCOR indicates that the system has the capability of carrying out the analysis required for the financial evaluation described above. E-SCOR includes traditional SCOR performance metrics, which can be collected for the different actors of the supply chain, as well as at an aggregate level for the whole network. Additionally, e-SCOR provides the following advantages:

- e-SCOR uses several drag-and-drop blocks based on the SCOR framework to construct models at both the scope and depth of SCOR
- e-SCOR allows the entire network and organisational role performance to be evaluated based upon SCOR resource, output and flexibility measures
- e-SCOR using G2 programming language provides the opportunity to model more operational detail (e.g. machinery, people etc.), as well as to create additional financial and non-financial metrics.

Problems and future research

In developing the architecture of the supply chain simulation system that supports financial evaluation a number of issues arise. These issues relate the scope of supply chains rather than existing issues relating current modelling of the scope of a single enterprise.
Firstly, the speed of model development and model execution could appear as major obstacles to the use of such an approach to modelling supply chains. Supply chains have a wider scope than ‘traditional’ simulations and therefore the model build time will take longer. Developments in simulation software to allow a more data-driven approach to creating simulation models and the on-going increase in computing power will contain this to some extent. Additionally, model building methodologies and concepts such as multi-level modelling will help guide model builders to create models of appropriate scope and detail and not necessarily jump to the lowest level of detail possible from available data.

Secondly, supply chain models of such scope will contain significant amounts of data and potential for rich analysis of the supply chain leading to problems of modelling scope and confidentiality. The modelling scope will be an issue as when attempting to model companies in one supply chain, each company will also be members of other supply chains and therefore it is impractical to model the entire operation of each company fully. Techniques need to be taken from detailed manufacturing systems to be able to abstract and account for sharing of resources so that the relevant elements of, say, a supplier company can be modelled but not the parts that relate to other supply chains. So thirdly, the development of models may have to be distributed to ensure that confidential operational and financial performance of one company in the supply chain is not inadvertently made accessible to others in the supply chain.

Summary
This paper has reviewed developments in the areas of supply chain design, supply chain modelling and supply chain metrics. It has developed an agenda for supply chain performance research by arguing that the current evaluation of supply chains, whether or not it is driven by a design methodology, is insufficient as there is a failure to assess the overall performance of each enterprise.

The paper has argued that it is essential to model the financial performance of each enterprise as well as the operation performance. The paper has distinguished cost evaluation from financial evaluation and indicated the importance of capturing the key transactions as a basis for effective financial evaluation. It has shown a range of business issues that can be faced and how these can be mapped to the available tools in terms of the operational and financial fidelity.

The paper makes its contribution by proposing the development of a supply chain modelling architecture but adapting the enterprise focused Whole Business Simulator (WBS) and the Supply Chain Operations Reference (SCOR) model. The combination provides a supply chain analysis tool with true financial evaluation at its core. The software for modelling with such scope requires a combination of existing supply chain focused modelling tools that have potential for extension to support the generation and analysis of the financial drivers. The detail of the contribution is made by demonstrating how the WBS concepts, the SCOR model and the identification of the financial drivers can be combined to create a power simulation system for modelling the financial performance of enterprises in a supply chain.
References


