**Global Supply Chain Design: Understanding Costs through Dynamic Modelling**

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**ABSTRACT**

We study the economics of the outsourcing decision from a supply chain dynamics perspective. Production can be either in the UK, where products are delivered on trucks to a UK warehouse, or in China where product is shipped via a container liner to a UK warehouse. We show that the traditional “landed cost” approach of purchase price plus transport costs overestimates the benefit from outsourcing products to China. However, the dynamic costs associated with the pipeline inventory, the UK inventory & the UK warehousing capacity costs associated with unloading the containers is not large enough to change the outsourcing decision.

*Key words*: Outsourcing, globalisation, Order-up-to policy, inventory & capacity costs.

**INTRODUCTION**

Industrialisation of less developed countries, the emergence of new markets & improvements in transportation are increasing the options for sourcing & supply chain design. Supply chain costs are, to a large degree, determined by the structure of the supply network, & dynamic (bullwhip related) costs tend to increase with distance & lead time. Supply chain modelling can be used to understand the cost behaviour of alternative network designs, & to help choose the best solution. However, it can be difficult to decide which variables to model & which approaches to employ? Sophisticated models can help to explain the trade-offs, but may be too complex to communicate insights to key decision makers. Simple models can be persuasive, but there is a risk that key variables may be overlooked, leading to sub-optimal solutions. These dilemmas are explored via two overseas outsourcing case studies for double beds & a sample of 4 high-tech industrial products, using real data for demand processes, manufacturing cost, weight, volume, & associated transportation costs. The products have been chosen to explore the impact of different value densities (£ per Kg) on cost behaviour & model efficacy, where beds represent low value density & with the industrial products ranging from medium, high, very high to super value densities.

**REVIEW OF SELECTED LITERATURE**

A review of academic literature in the field of supply chain design reveals three possible supply chain modelling & design methodologies, which may be broadly classified as: *deterministic*, where a constant or average demand (e.g. Cohen & Lee, 1989) is assumed (as in Linear Programming based approaches employed in most commercially available software); *stochastic*, where probability density functions are employed to represent uncertainty (e.g. Lee & Billington, 1993); & *dynamic*, where demand & other variables are modelled evolving over time & particular attention is given to feedback loops, (e.g. Forrester, 1961 & Berry & Towill, 1995). In practice, both stochastic & dynamic approaches are employed once the physical supply network has been decided. *Dynamic* supply chain design employs control theory to understand the effect of time delays & feedback paths on system behaviour. However, as both stochastic & dynamic approaches are normally applied *after* the physical network has been decided, the potential of these methods is constrained. Ratanachote & Disney (2008) have developed a modelling technique which incorporates stochastic & dynamic analysis to model the inventory & capacity variances & costs associated with alternative network designs. Dynamic analysis adds some complexity to the modelling procedure, & it would be useful to develop some criteria to help identify the circumstances in which it should be applied.

Supply chain scenarios are inherently complex & there are many different variables that can be incorporated into a model. However, if too many variables are considered the model becomes unwieldy & difficult to communicate to managers. If the model is too simple, then key insights can be missed. According to Pidd (2006) in any modelling exercise it is important to ensure that a valuable result is delivered without being dragged into too much detail. Selecting which variables to model & which techniques to employ is therefore a critical decision.

Supply chain segmentation reveals a similar problem. According to Fuller et al. (1993) many companies attempt to deliver dissimilar products through the same supply pipeline with sub-optimal results, arguing instead for *logistically distinct pipelines*. This concept now appears in the literature as ‘supply chain segmentation’ (Lovell et al., 2005) & ‘value stream classification’ (Christopher et al., 2008) & is closely related to supply chain design, as pipelines must be designed for groups of ‘similar’ products. However, there are many different criteria by which a company’s products can potentially be grouped, including: stage in lifecycle, handling characteristics, shelf life, physical size & weight, value, demand location, demand level, demand variability, service expectations, lead time, transport mode availability & customs duties. Just as supply chain modellers must decide which variables to model, supply chain analysts must choose the most appropriate bases for segmentation. In both cases, it is necessary to choose the variables which exert the biggest influence on supply chain performance, either for the purposes of effective modelling or optimal pipeline design.

Lovell et al. identify the key segmentation variables as demand variability, throughput (volume) & product value density, exploring their impact on pipeline design choices, including transportation mode (speed) & degree of inventory centralisation. In relation to the supply chain modelling dilemma, the authors developed an initial view that product value density should guide the choice of modelling technique (McCullen & Disney, 2008), as high product value density would be associated costly pipeline inventories. The is leads to our *Hypothesis*: Where product value density (PVD) is high, pipeline inventory & bullwhip costs are dominant, & dynamic-stochastic modelling is appropriate. Where product value density is low, transportation costs are dominant, & static modelling is ‘good enough’ to select an optimal solution.

Two case studies are employed to explore the hypothesis. Case Study 1 involves an outsourcing decision for a furniture manufacturer (a low value density scenario). Case Study 2 involves the same outsourcing scenario, but considering high tech industrial products (a high value density scenario). Both cases are analysed using dynamic-stochastic modelling, with both static & dynamic costs separately identified. The two cases are compared & the efficacy of dynamic-stochastic modelling discussed in relation to the hypothesis.

**THE SUPPLY CHAIN SCENARIOS**

In both cases, UK or outsourced Chinese manufacture are compared. Both case studies employ the same supply chain scenarios. For UK manufacture, products are delivered directly to a warehouse, unloaded & ‘put away’, with the company incurring 2 weeks of pipeline cost, unloading cost & inventory cost. In the case of Chinese manufacture, the factory gate product costs are substantially lower, but goods must be paid for before they leave the factory, & the company incurs 8 weeks of lead-time with the associated pipeline cost, unloading cost & inventory cost. When shipping from China, high cube 40ft containers are used for the beds as they are relatively lightweight & volume constrained. For the industrial products, a normal 40ft container is used as they are payload rather than volume constrained.

The demand *d* in week *t* in all cases was deemed to follow an AR(1) model,

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where  is a normally distributed, i.i.d. random process with a mean of zero & a standard deviation which we matched to the real-life demand pattern. The mean demand  & the auto-regressive parameter of  were also matched to the real life demand pattern, see Table 2 for numerical values. Product value densities (PVD), on the basis of UK manufactured costs, are also shown in terms of cube & weight. The AR(1) demand process has a variance of

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The companies employed an ‘order-up-to’ (periodic review) replenishment system which involves regular shipments & variable order quantities. The order-up-to policy requires two forecasts. One of these forecasts is the demand over the lead-time. The other is a forecast of demand in the period after the lead-time. We use conditional expectation to create these forecasts (details omitted for brevity, but details can be found in Hosoda and Disney (2006). It then follows that the variance of the replenishment order placed on the Chinese supplier or UK factory is given by,

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where  is the replenishment lead-time, = 8 for China supply, = 2 for UK supply. The inventory variance (Disney & Hosoda, 2006) is likewise given by

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The order & inventory variances produce dynamic costs in supply chains. The inventory variance creates a need to hold inventory in the UK warehouse. The ordering variance creates a

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| Case | Product | Mean demand | Standard deviation  | Autoregressive co-efficient  | PVD(£/m3) | PVD(£/Kg) |
| Beds 4 You | Double beds | 5400 | 250 | 0.7 | 141.36 | 1.50 |
| IndustrialProducts | IP1 | 32 | 13.53 | 0.242 | 1,7122.62 | 26.02 |
| IP2 | 26 | 12.9 | -0.02 | 25,103.54 | 68.28 |
| IP3 | 8 | 10.64 | 0.258 | 38,879.49 | 120.66 |
| IP4 | 14 | 14.46 | -0.17 | 339,439.05 | 284.08 |

Table 2. Characteristics of the demand process & PVD

variable workload in the UK warehouse associated with unloading the products & putting it away. There is also a cost associated with the inventory owned in the pipeline. We will now briefly describe how each cost is calculated.

**Inventory costs**

Inventory costs are driven by the value of the inventory, the interest rate charged, the standard deviation of the inventory levels & the service level (availability) required. We will assume that inventory holding & shortage costs exist & can be described in the time domain by

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Here *ns* is the net stock at the UK warehouse at time *t*.  is the maximum operator, that is,  if , otherwise . *H* is a holding cost per unit per week & *B* is a backlog cost per unit per week. The inventory holding cost is set to be equal to the unit cost plus freight charges, pipeline inventory costs, & unloading costs, all multiplied by the weekly interest rate, 0.5%. The backlog cost is set to ensure the 95% of weeks end in a positive inventory (to meet the target inventory availability target).

Both companies offer products for immediate collection & delivery. They both target 95% inventory availability. The cost of holding an item in inventory for one week, *H*, can be obtained by multiplying the product’s cost by the cost of capital (0.5% per week). The backlog costs are obtained using that ensures that 95% availability also minimises the expected per period inventory cost,

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In order to ensure the sum of the expected inventory holding & backlog costs is minimised then the Target Net Stock (*TNS\**), the safety stock at the UK warehouse, needs to be set to . We can see that it is a linear function of the standard deviation of the net stock levels. This is safety stock level can be obtained via standard newsvendor techniques.

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The average amount of inventory held at any moment of time is  & the expected costs associated with the safety stock is given by,

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**Capacity costs**

The supply chain lead-time & demand process also create a capacity cost in the UK warehouse. Specifically it is associated with the order variance & it creates a variable workload in the warehouse associated with unloading products from trucks & putting them away in the warehouse. UK staff, in both cases, are guaranteed a standard (40 hour) working week & offered overtime at “time & a half” during evenings & weekends. These “unloading & putting away” capacity costs are given (Disney et al.,2012) by

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Note that, here we are ignoring the fact that labour could be used to manage other products in the warehouse. So the capacity costs should be taken to be a worst case scenario. Thus the following unload cost function exists. *U* is the cost of unloading a bed. *W* is the cost of over-time work per bed per week, *W*=1.5*U*. *ot-Tp-1*is the order placed in week *t-Tp-1,*  is the mean demand & *S* is the slack labour capacity above (or below when *S* is negative) the mean demand. Thus  is the unloading capacity of the normal working week. The optimal slack capacity is given by

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and the minimised unloading & putting away cost in the UK warehouse is given by

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**Pipeline costs**

Many Chinese factories require goods to be paid for before they leave the factory, Beds For You have 8 weeks of inventory in the supply pipeline that has to be financed in the Chinese option. There is often no similar cost for the UK accounts, as goods are paid for when they are delivered. The expected number of products in the pipeline can be easily obtained via Little’s law, .

**CASE STUDY 1: THE BEDS FOR YOU SCENARIO**

A UK supplier of double beds charges £30 per bed. The UK supplier incurs costs of £6 for materials & energy, £21 for labour & £3 for other costs & profit. It is delivered free to the Beds For You warehouse in on pallets. The cost of unloading the truck with warehouse truck is £0.25 per bed in normal working hours (£0.375 in over-time). An order that is placed in one week, will arrive in the week after next, thus the physical lead-time is one week with a review period of one week.

The Chinese supplier of double beds charges £9 per bed. Beds For You suspects that the Chinese supplier incurs costs of £5 for materials & energy, £3 for labour & £1 for other costs & profit. It is delivered FOB in a 40ft High Cube container to a Cargo Liner that leaves from Shenzhen Port in China for the UK. The container capacity details were shown in Table 1. The Chinese supplier will pack the 40ft High Cube container by hand & they can fit up to 360 double beds into the container, as a cost of £3350 delivered to the UK warehouse. These freight charges are paid for when the product is delivered. The replenishment lead-time is 8 weeks. This is made up of 6 weeks on board the Cargo Liner, one week for the factory to deliver to the port & one week for the shipping company to deliver the container from the UK port to the warehouse.

As the container is not palletized (to put palletized beds in a container would waste too much space) it has to be unloaded manually. The shipping company require a container to be unloaded within 3 hours (or a charge of £50 per hour will be levied). The warehouse manager estimates that it will cost £1.50 per bed to unload the container & palletize the beds at warehouse (3 hrs to unload with 5 people @ £12 per hour per person divided by 360 beds = £1.50) in normal working hours. In over-time working this unloading cost increases to £2.25.

Both static & dynamic elements of cost are analysed to estimate the total cost per bed for both options, to be obtained from the: Unit product cost & freight cost (static); Expected pipeline inventory costs (dynamic); Expected unloading capacity required & unloading costs (dynamic); Inventory costs, consisting of safety stock & cycle stock (dynamic); Total costs (static & dynamic). Let’s first consider the obvious costs, the unit “landed” costs. Collecting together the information described above we have Table 3. Therefore the freight charges per bed will be  per bed. So, at first sight the unit cost of beds from China is only 57.5% of that from the UK supplier.

Dynamic costs will be present because of the differences in the lead-times. We will need to use our knowledge of the order rate & net stock variance amplification ratios (equations & ) to calculate the impact of the lead-time, demand, forecasts & replenishment rules on these dynamic costs. We note that both the order & the inventory variances are much smaller for the UK supply. The inventory related costs are linear in the standard deviation of the net stock levels & this is influenced by the lead-time. The inventory costs are also influenced by the value of the inventory, which is much higher for the UK supply than for the Chinese supply. However, the difference between the two scenarios in terms of inventory related costs is very small compared to the impact of the labour cost. More interesting is the fact that, on the average, 70% more stock has to be held in the Beds For You warehouse with Chinese supply when compared with UK supply. This could have implications for warehouse requirements or product range offering in Beds For You.

**CASE STUDY 2: INDUSTRIAL PRODUCTS (HIGH VALUE DENSITY)**

The Industrial Products Company has a UK supplier, & would like to explore the economics of outsourcing to China. Four representative products, from their broad product range, have been chosen for the purposes of comparison. The products are made from CNC machined components & include an electric motor. Materials represent 70% of factory gate costs, & these costs are unaltered by outsourcing to China. The remaining 30% of costs are labour costs, which are 37% lower in China, resulting in an overall 26% reduction in unit purchased costs. Selling prices are considerably higher, & the sales margin includes the contribution to overheads & profit.

The individual products have much lower mean weekly demand than the beds, & containers are filled with a variety of different products. The company uses standard 40ft containers which are packed with a variety of different sized packages, the maximum container utilisation by volume is only 80%. Product size, volume & associated transportation costs are shown in 2 on the basis of a China to UK container shipping cost of £3350. Products IP1, 2 & 4 can be unloaded by hand, & the unloading costs have been estimated on the basis of the average hourly rate, giving normal unloading costs of £0.8, £0.8 & £0.4, with overtime rates at time & a half. Product IP3 is heavy & must be unloaded by fork-lift truck, giving normal unloading cost of £5, & £7.50 in overtime.

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| Product | Weight (Kg) | Volume (m3) | No. per payload | No. for 80% of the payload | Unit freight costs (£) |
| IP1 | 30 | 0.046 | 886 | 1188 | 3.78 |
| IP2 | 31 | 0.084 | 863 | 647 | 5.18 |
| IP3 | 54 | 0.166 | 497 | 326 | 10.27 |
| IP4 | 6 | 0.005 | 4430 | 10786 | 0.76 |

Table 2. Shipping characteristics for Industrial Products

**NUMERICAL ANALYSIS**

We have calculated the following cost comparisons shown in Table 4.

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| Company | Beds For You | Industrial Products Co. |
| Product | Double Bed | IP1 | IP2 | IP3 | IP4 |
| Country of manufacture | UK | China | UK | China | UK | China | UK | China | UK | China |
| Unit purchase cost (£) | 30.00 | 9.00 | 780.50 | 579.80 | 2,103.00 | 1,562.23 | 6,455.50 | 4,795.52 | 1,704.50 | 1,266.20 |
| Unit freight charges (£) | 0 | 9.62 | 0.00 | 3.78 | 0.00 | 5.18 | 0.00 | 10.27 | 0.00 | 0.76 |
| **Landed cost** | 30 | 17.24 | 780.50 | 583.58 | 2103 | 1567 | 6455 | 4805 | 1704 | 1267 |
| *Percentage change in landed costs* |  | *-43%* |  | *-25%* |  | *-25%* |  | *-26%* |  | *-26%* |
| Average number of units in pipeline | **0** | 43200 | 64 | 256 | 52 | 208 | 16 | 64 | 28 | 112 |
| Value of goods in pipeline (£) | 0 | 388800 | 49952 | 148429 | 109356 | 324944 | 103288 | 306913 | 47726 | 141814 |
| Cost of pipeline inventory per week (£) | 0 | 1944 | 250 | 742 | 547 | 1625 | 516 | 1535 | 239 | 709 |
| **Pipeline cost per unit (£)** | **0.00** | **0.36** | **7.81** | **23.19** | **21.0** | **62.5** | **64.6** | **191** | **17.0** | **50.65** |
| Normal unloading costs, *U* | 0.25 | 1.5 | 0.8 | 0.8 | 0.8 | 0.8 | 5 | 5 | 0.4 | 0.4 |
| Overtime unloading costs, *W* | 0.375 | 2.25 | 1.2 | 1.2 | 1.2 | 1.2 | 7.5 | 7.5 | 0.6 | 0.6 |
| Order standard deviation, *σo* | 561 | 810 | 17.79 | 17.85 | 12.65 | 12.65 | 14.28 | 14.34 | 12.35 | 12.36 |
| Slack capacity at warehouse, *S\** | -241 | -349 | -7.66 | -7.69 | -5.45 | -5.45 | -6.15 | -6.18 | -5.32 | -5.32 |
| Weekly capacity required, *S\*+µd* | 5159 | 5051 | 24.34 | 24.31 | 20.55 | 20.55 | 1.85 | 1.82 | 8.68 | 8.68 |
| Unloading (labour) costs per week, *C* | 1426.43 | 8762.54 | 33.36 | 33.39 | 26.32 | 26.32 | 78.93 | 79.10 | 8.29 | 8.30 |
| **Unit unloading cost** | **0.26** | **1.62** | **1.04** | **1.04** | **1.01** | **1.01** | **9.87** | **9.89** | **0.59** | **0.59** |
| *Percentage change in unloading costs* |  | *514%* |  | *0%* |  | *0%* |  | *0%* |  | *0%* |
| Net stock standard deviation, *σNS* | 493 | 1951 | 27.84 | 51.81 | 22.05 | 38.02 | 22.16 | 41.50 | 22.53 | 37.73 |
| Unit cost | 30.26 | 20.60 | 789 | 608 | 2125 | 1631 | 6530 | 5007 | 1722 | 1318 |
| Inventory holding cost, *H* | 0.15 | 0.01 | 3.95 | 3.04 | 10.63 | 8.15 | 32.65 | 25.04 | 8.61 | 6.59 |
| Backlog costs, *B* | 2.88 | 0.20 | 75 | 58 | 202 | 155 | 620 | 476 | 164 | 125 |
| Safety stock at warehouse, *TNS* | 811 | 3209 | 46 | 85 | 36 | 63 | 36 | 68 | 37 | 62 |
| Average stock in warehouse, *TNS+µ/2* | 3511 | 5909 | 62 | 101 | 49 | 76 | 40 | 72 | 44 | 69 |
| Inventory costs per week, *I* | 154 | 41.45 | 227 | 325 | 483 | 640 | 1492 | 2143 | 400 | 513 |
| **Inventory cost per unit** | **0.03** | **0.01** | **7.08** | **10.15** | **18.6** | **24.6** | **187** | **268** | **29** | **37** |
| *Percentage change in inventory costs* |  | *-75%* |  | *43%* |  | *32%* |  | *44%* |  | *28%* |
| Weekly landed costs | 162000 | 93096 | 24976 | 18675 | 54678 | 40753 | 51644 | 38446 | 23863 | 17737 |
| Weekly pipeline costs | 0 | 1944 | 250 | 742 | 547 | 1625 | 516 | 1535 | 239 | 709 |
| Weekly unloading costs | 1426 | 8763 | 33.36 | 33.39 | 26.32 | 26.32 | 78.93 | 79.10 | 8.29 | 8.30 |
| Weekly inventory costs | 154 | 41.45 | 227 | 325 | 483 | 640 | 1492 | 2143 | 400 | 513 |
| Total weekly costs | 163580 | 111,296 | 25486 | 19775 | 55734 | 43043 | 53732 | 42203 | 24510 | 18968 |
| **Total cost per unit** | **30.29** | **20.6** | **796** | **618** | **2143** | **1655** | **6716** | **5275** | **1751** | **1355** |
| *Percentage change* |  | *-32%* |  | *-22%* |  | *-23%* |  | *-21%* |  | *-23%* |

Table 3. Cost comparison of outsourcing to China

The ‘landed cost comparison’ arises from a static analysis of purchase cost & transportation cost. The greatest reduction of 43% is achieved for the beds, due to their higher labour content & local material cost savings. When dynamic costs are taken into account, the overall cost reduction is 32%. The largest component of dynamic cost is the unloading cost, which affected by bullwhip-induced under & over-utilisation of capacity. Inventory costs are negligible, as may be expected for such a low value density product. Here we can see that because the unit cost of unloading & palletizing the container manually, the warehouse unloading costs are quite high for Chinese supply option. But we can see that we need more unloading capacity, (above the average demand) for the UK option. This is because the unit of measurement is in number of beds. However, as with the inventory analysis, these unloading costs are rather small in comparison with the other unit costs.

For the industrial products, average landed cost savings of 25.5% are reduced to an average of 22% as a result of dynamic costs, & in these cases the pipeline & warehouse inventory costs are absorbing around 3% of the saving, with negligible unloading costs, as may be expected for these higher value density products. A better understanding of the overall cost composition could be obtained by analysing the percentage of total unit costs for all five products when outsourced.

**CONCLUSION**

On the basis of the five products analysed, the hypothesis is unsupported. However, significant differences in product handling characteristics & demand processes are also driving the dynamic element. The relatively high unloading cost for the beds is driving the dynamic costs, &, at nearly 10%, suggests than dynamic analysis *is* worthwhile even for this low PVD product. For the industrial products, it is useful to know that some 3% of total cost arises due to the bullwhip effects on inventory.

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