CARRIER-MODE SUPPLY-CHAIN OPTIMIZATION FOR INBOUND GARMENT DISTRIBUTION IN UK

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Introduction

The UK fashion retail industry is highly reliant upon the efficiency of inbound supply chain networks from off-shore garment manufacturers (Christopher2009). Typically, off-shore suppliers and domestic retailers employ third party logistics (3PL) providers for transportation, warehousing, and garment processing services. Choosing the most cost-efficient provider, or carrier-mode option, is a complex optimization task which has a significant impact on a company's profit margins and, significantly with respect to current corporate policies (Cullinane2010), the CO_2 footprint of each imported garment.

The inbound shipping and distribution choices available to an off-shore supplier, or domestic retailer, to manage operational efficiencies are: container size and configuration, choice of packaging (box or hanging), and choice of whether or not to contract other value-added services, such as garment processing, to the 3PL. These issues need to be addressed, at some level by all global third party logistics service managers (Cochran 2006). The complexity of the carrier-mode problem is that these decisions are not independent of each other; the decision to process garments at origin, for example, affects downstream distribution decisions, such as the need to ship the garments on hangers in specialist containers. The employment of specialist containers limits the opportunities for back loading and shipment consolidation when distributing the merchandise to retailers in the UK, which, in turn, increases each garment's CO_2 footprint.

This paper will attempt to define a modeling framework and evaluation scheme by which carrier-mode efficiency comparisons can be made. The modeling framework structures the carrier-mode problem so that an analyst can determine the best combination of carrier options for each garment type. The framework will be the basis for a decision support tool that will allow a retailer, or supplier, to evaluate the total, end-to-end supply chain, efficiency implications (including impact of CO_2 emissions) of different combinations of carrier-mode options on a garment order.

The Carrier-Mode Problem

The global economy offers fashion retailers flexibility in their choice of suppliers and logistics service providers in their response to market opportunities and demand risk management. Fashion retailers respond to consumer demand uncertainty by maintaining low distribution center inventories and ensuring high levels of consumer satisfaction by providing frequent replenishment of merchandise via the inbound supply chain. The strategic emphasis on low inventories and frequent stock replenishment offers opportunities for retailers to exploit the distribution network that supports the supply chain through the optimal utilization of carrier resources. However, while a low inventory and frequent stock replenishment strategy enables a retailer to reduce costs by avoiding excessive obsolete stock, it is a strategy that places heavy environmental costs on the transportation network. Logistics managers are confronted with the problem of how to balance the demands of retailers with other stake holders in the global supply chain. For each movement of merchandise the logistics manager needs to evaluate, and satisfy, several conflicting decision criteria before an optimal carrier mode is identified.

For example, a freight forwarding company responsible for shipping an order of garments from Shanghai in China to a retail distribution center in the North West of England would need to identify a carrier mode that optimizes the movement of goods at several discrete levels: shipping cost, lead-times, corporate compliance regulations, and maximization of company resources (to take advantage of any opportunities for back-loading, cross-docking or consolidation). Historically, logistics service managers have employed decision analysis techniques from Operations Research (OR) (Simachi-Levi2005) to address such problems. For example, Cochran and Ramanujam (2006) describe a mixed integer programming model (Williams2006) for optimizing inbound supply chains for electronics manufacturing. The problem with such formal models is that they are typically highly abstract, with only a tentative mapping to the real-world problem. The various dimensions of real-world problems, such as the carrier-mode problem, cannot easily be reduced to a single evaluation metric, such as money or time, to combine their contribution to a total cost that can be either maximized or minimized to obtain an optimal solution. The orthodox approach is to employ a *single valued weighted sum objective function.*

The weighted sum objective function is the summation of *m single cost functions*, f_i, $i=1,\ldots m$. These single cost functions are defined for each *objective* and return a value that is *normalized* by a *total cost function* $F(x)$.

$$F(x)=\sum_{i=1}^{m} w_i f_i(x)$$

Such formal mathematical models do not lend themselves easily to communication between logistics planners and operations managers; operations managers tend to think in heuristic terms, influenced by past experience that is generally encoded in simple spreadsheet models.

There are a number of technical issues with the formal mathematical models beloved by the OR community as well as their lack of clarity:

- The individual parameter weight values of the objective function need to be determined somehow. This is something of a 'black art', usually achieved through long and painful discussions between problem owners and problem solvers and repeated experimentation.
- The individual cost functions f_i, i = 1…*m* typically employ different metrics to measure the worth of a solution. Shipping costs may be evaluated in currency (normalized to account for exchange rates), lead-times in shipping days, corporate compliance in boolean rules. These different dimensions of the problem need to somehow be combined in an overall *objective* value $F(x)$.
- Mathematical functions while they convey the semblance of scientific rigour are not that intuitive to the majority of industrial practitioners and therefore are subject to misunderstanding.
- It is technically difficult to fit specific business requirements to theoretical models by adjusting weighting values without a system that allows the business user, or operations manager, to 'visualize' the impact of each adjustment on the total performance of the enterprise.

While operations research techniques have dominated retail logistics practice and literature (Agrawal & Smith 2009) since the 1980s, researchers are now beginning to explore the possibility of employing Artificial Intelligence (AI) models to better represent the conflicting dynamics of real-world problems and the management concerns of the business environment (Min2010). Michalewicz and Fogel's (2004) *Valuated State Space* model employs an alternative approach, influenced by AI research, to weighted sum functions that is highly applicable to carrier-mode optimization of inbound garment distribution in the UK.

Valuated State Space Model

Objective functions simply employ 'objective criteria' to distinguish between alternative decisions made by an operations manager, or automated management system. It is important that objective criteria are derived from operations managers and business people with knowledge of, and authority over, the problem domain. The *Valuated State Space* model (Michalewicz2004) allows an analyst to take an alternative approach to reconciling the multi-criteria aspects of identifying the appropriate carrier-mode for shipping an order of garments into the UK. It does so by recognizing that 'solutions' typically map onto a landscape of possible solutions whose terrain is partly defined by the environment that determines shipment cost, currency exchange rates, and container capacity; and partly by the priorities of the business.

For example, let us imagine that a fashion retailer in the UK has hired a freight forwarding company to move an order of 7000 heavyweight chino trousers from Shanghai in China to its Distribution Centre (DC) in the North West of England via the port of Felixstowe. There are a number of dimensions to this problem, that are not easily represented by a single weighted cost function:

1. Capacity
2. Cost
3. Lead-times
4. Corporate compliance
5. Opportunities to maximise resource utilization

Before these parameters of the problem can be evaluated to understand their contribution to an overall carrier-mode solution they need to be explicated into sub-parameters, and possibly even sub-sub-parameters until a level of detail can be reached that allows the parameters to be measured. This is the role of the valuated state space that provides a solution landscape that competing solutions (ship boxed vs ship hanging) can be judged against.

Example 1 depicts an expanded valuated state space model for the movement of 7000 heavy weighted chino trousers from Shanghai to the United Kingdom. The values on the right, associated with the lowest levels of the state space are *achievements* and reflect the importance of this outcome to the operation of the business. The notion of *achievement* replaces the concept of *cost* which is the criteria for weighted sum functions. Achievement values range over 1 to 10 (in this example), 10 being the highest level of *achievement* for a solution. An *achievement* value of zero for any parameter indicates that the solution is not acceptable to the business. For example, in the valuated state space depicted in Example 1 any solution that suggests employing a pallet network will not be accepted. Likewise any solution that generates a CO_2 footprint above the target threshold for the company will not be accepted.

The values to the left of the parameter indicate the *weighting* for the parameter. They reflect the relative importance of the parameter to the business. Again, the values range over 1 to 10, 1 indicating that the parameter is of little importance to the business, while 10 indicates that the parameter is of high importance to the business.

The weightings of the valuated state space model depicted in Example 1 suggests that the main driver of the business is cost, with a 10 weighting; however capacity utilization is also highly valued with a weight of 8. The company also seeks to maximise its opportunities to utilize resources by consolidating shipments, cross-docking, and back-loading when possible.

The symbol � against an *achievement* in Example 1 indicates that that *achievement* is part of a solution identified by the operations management system. That solution now needs to be evaluated to see if it is better or worse than competing solutions. The solutions to be evaluated advocates that the garments are carried in a 40ft container in 'hanging cartons' to exploit 44% of the capacity of the container. By employing a standard container; which doesn't need to be configured with bars and curtains to hang garments; the company has opportunities to consolidate this order with other orders that might not be garments. However, the solution does require that the garments are processed once they enter the UK before they are distributed to the retailer. This will incur a cost: the garments will need to be removed from their boxes, steamed tunnelled, put on hangers with a plastic cover, and loaded onto a trailer for distribution from the processing centre to the retailer's distribution centre or store. The valuated state space model can evaluate whether this is more acceptable to the business than having the processing done off-shore (taking advantage of lower labour costs) and shipping the garments in specialist hanging container.

The valuated state space model offers a number of advantages over the weighted function model for a business user:

1. The multi-criteria components of the cost function are structured hierarchically so that the operations manager can better ‘visualise’ the problem parameters and their relationships and therefore better communicate requirements to other supply chain stake holders.

2. By discarding *continuous values* (required for mathematical functions) in favour of discrete interval values we better model business user’s notions of acceptable thresholds and boundaries.

3. The model’s diverse units of measurement – *capacity*, *time*, *boolean rules* - are natural conceptual metrics for business users and do not require complicated mathematics to normalise across categories. (The arithmetic mean based normalisation function used for evaluation in this scheme is described below).

4. The scheme supports the notion of a *critical* parameter. A parameter is critical when failure to gain any degree of *achievement* with respect to that parameter negates the contributions of all other parameters. This is what the zero parameter score indicates. It provides a natural mechanism for a business user to specify what is unacceptable to the business.

Evaluation of a valuated state space is achieved by employing a *normalisation* function that aggregates the impact of each measurable parameter starting at the lowest level of the state space hierarchy. The normalisation function is a simple arithmetic mean in the case of non-critical parameters. Where critical zero scores are involved, the solution state is rejected without further evaluation.

8 1 ***Capacity***

10 1.1 ***Shipping***

10 **1.1.1** ***40ft Container***

8 1.1.1.1 ***Boxed***

60 %: Boxed trousers without hangers, 650 boxes per container, 18 single trouser per box, Box Dimension (CM): 18 * 116 * 42 **8**

� **44 %**: Boxed men's trousers with hangers in 'hanging carton'. 1,575 boxes per container. Box Dimensions (CM): 11 * 77 * 43 **9**

40 %: Boxed trousers without hangers, 900 boxes per container, 20 heavyweight Chino trousers per box. Box Dimension (CM): 22 *64 * 44 **4**

6 1.1.1.2 ***Hanging***

54%: Casual trousers – Half folded. Stack height 3. Average number of bars 81, Average Trailer capacity 13000. **4**

100%: Trousers – Full length. Stack height 2, Average number of bars 54. Average Trailer Capacity 6933. **7**

5 1.2 ***Air Freight***

3 **1.2.1** ***Pallet Network***

120 trousers per pallet. 58 pallets **0**

10 2 ***Cost***

9 2.1 ***Shipment***

8 **2.1.1** ***To UK Port*** (per unit)

Less than £0.050 **10**

Between £0.050 and £0.100 **9**

Between £0.100 and £0.150 **8**

� Between £0.150 and £0.200 **7**

Between £0.200 and £0.250 **6**

Greater than £0.250 **3**

7 **2.1.2** ***Container to 1st Warehouse*** (per unit)

		Less than £0.020	**10**
		Between £0.020 and £0.030	**9**
		Between £0.030 and £0.040	**8**
		Between £0.040 and £0.050	**7**
�		Between £0.050 and £0.060	**6**
		Greater than £0.060	**1**
	6	**2.1.3 *Warehouse to warehouse*** (per unit)	
		Less than £0.020	**10**
�		Between £0.020 and £0.030	**9**
		Between £0.030 and £0.040	**8**
		Between £0.040 and £0.050	**4**
		Greater than £0.050	**1**
	8	**2.1.4 *Bag charges*** (per unit)	
�		Less than £0.040	**10**
		Between £0.040 and £0.060	**8**
		Greater than £0.060	**3**
	8	**2.1.5 *Hanger charge*** (per 10 units)	
�		Less than £0.10	**10**
		Between £0.10 and £0.15	**5**
		Greater than £0.15	**1**
	10	2.2 ***Exchange Rate***	
		Less than 1 → 2	**2**
�		Between 1 → 1 and 1 → 2	**8**
		Greater than 1 → 2	**10**
	7	2.2 ***Garment Processing*** (per unit)	
		Less than £0.10	**10**

� Between £0.10 and £0.30 **8**

Greater than £0.30 **2**

10 2.3 ***Recycling***

10 **2.3.1** ***Boxes*** (per unit)

Less than £0.01 **9**

� Between £0.01 and £0.05 **7**

Greater than £0.05 **3**

7 **2.3.2** ***Hangers*** (per 10 units)

Less than £0.05 **8**

� Between £0.05 and £0.10 **6**

Greater than £0.10 **1**

5 3 ***Lead Time***

Less than 20 Days **8**

20 to 35 Days **6**

� Greater than 35 Days **3**

8 4 ***Corporate Compliance***

8 4.1 ***CO_2 Emissions Targets***

Less than target **0**

0% to 5% greater than target **2**

� 5% to 10% greater than target **5**

Greater than 10% of target **10**

10 5 ***Opportunities***

7 5.1 ***Consolidation***

� Yes **10**

No **3**

2 5.2 ***Cross docking***

Yes	**5**
No	**3**

3 5.3 ***Back Loading***

Yes	**5**
No	**2**

***Example** 1:* Valuated state space model for movement of 7000 chino trousers.

The lowest level of the state space in Example 1 is level 1.1.1.1. This represents the choice of shipping the garments in boxes in a 40ft container. The solution recommends shipping the garments in hanging cartons with an *achievement* value of 9. The contribution of this *achievement* to the *capacity* parameter is determined by calculating the ratio of the degree of *achievement* attained (which is 9) to the maximum possible degree of *achievement* (which is 10) in each parameter and weighting that by the relative importance *weights*.

- (9/10) * (8 / (8+6)) = 0.514

The *weightings* 8 and 6 being the *weightings* for shipping boxed and shipping hanging respectively. These weights are summed to calculate what proportion the weighting 8 is of the total weighting of the 40ft container parameter. Therefore, 5.14 (re-scaled to 10) is the contribution of shipping the garments in hanging boxes to the 40ft container parameter. We aggregate this value to the next levels up the hierarchy to establish the contribution of this *achievement* to the *Capacity* parameter at level 1.

- (5.14/10) * (10/15) = 0.342 = 3.42

Therefore, 3.42 is the total contribution to the *Capacity* parameter. We turn now to what C*ost achievement* the solution provides. We calculate the contribution to *Shipment* at level 2.1:. The solution has achieved a shipment cost to a UK port between the interval £0.150 and £0.200 per garment with an associated *achievement* value of 7, a container movement cost to the first warehouse between £0.050 and £0.60 per unit with an associated *achievement* value of 6, and a warehouse to warehouse cost between £0.020 and £0.030 per unit with an associated *achievement* value of 9. Because the shipping movement is in hanging boxes we also need to bear the cost of cover bags and hangers. We have *achievement* values of 10 and 10 respectively associated with these costs. The calculation at this level is therefore:

- ((7/10) * (8/37)) + ((6/10) * (7/37))+((9/10) * (6/37)) + ((10/10) * (8/37)) + ((10/10) * (8/37)) = 0.843 = 8.43

Next we include the contribution of *Recycling* achievement to the *Garment Processing* level:

- ((7/10) * (10/17)) + ((6/10) * (7/17)) = 0.658 = 6.58

This value is next aggregated with values up the hierarchy:

- ((8/10) * (10/27)) + ((8/10) * (7/27)) + ((6.58/10) * (10/27)) = 0.747 = 7.47

Note the achievement value of 7.47 also includes the *Exchange Rate* component ((8/10) * (10/27)) of the *Cost* parameter which is at the same level of the hierarchy as *Garment Processing*.

Next we calculate the contribution of *Corporate Compliance* and CO_2 *Reduction* T*argets* to the solution:

- ((5/10) * (8/8)) = 0.5 = 5

Next we calculate the contributions of *Opportunities* to the overall *achievement* of the solution:

- ((10/10) * (7/12)) = 0.583 = 5.83

Finally we aggregate these lower level achievements at the top level to obtain an overall achievement valuation for the solution proposed:

- ((3.42/10) * (8/41)) + ((4.18/10) * (10/41)) + ((0.36/10) * (5/41)) + ((5/10) * (8/41)) + ((5.83/10) * (10/41)) = 0.412 = 4.12

According to the valuated state space scheme, the solution mapped onto the valuated state space example depicted in Example 1 has an aggregated *achievement* of 4.12. That value can then be compared with the aggregated *achievement* scores of other solutions, solutions that may have explored the use of hanging containers or shipping without hangers, to identify the best solution based on operational management priorities, environment conditions, and the business drivers of the company.

Conclusion

The valuated state space model has previously been used by the author as an alternative to a weighted sum function for evaluating local neighbourhood search algorithms (Hoos and Stutzle 2005) that address mobile resource scheduling problems in the utilities industry. The experience gained in developing that application convinced the author that the scheme is also appropriate for solving logistics planning problems. The carrier-mode problem has conflicting *objectives,* which lend themselves to a valuated state space formulation, where monetary costs need to be balanced against other factors, such as corporate compliance and business opportunities, that cannot naturally be translated into monetary terms.

There are of course criticisms associated with employing valuated state space technique. For example, associating *achievements* with *interval values* rather than *continuous values* is considered by some managers to be too crude a measure of system performance. This was a criticism levelled against the use of the scheme for evaluating good routes for mobile resources during stochastic search. To overcome this criticism the author employed a fuzzy set function (Buckley and Esfandia 2002) to determine if the evaluation of the solution generated by the solver that mapped onto an *achievement* interval in the valuated state space was closer to the lower value of the interval or the higher value of the interval. This translation of the state space does not seem necessary for the carrier-mode problem where precision is not that critical.

The positive aspects of the valuated state space scheme is that it works at the human level: it provides a framework for evaluating problems, and problem solutions, that map onto the way operations managers and human problem solvers construct a solution space. It structures the various components of the problem into a hierarchy of *achievement* values that can be simply aggregated into a single value that represents the proportional contribution of each parameter of the problem.

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