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Environmentally responsible inventory models: Non-classical models for a non-classical era

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ABSTRACT

Mathematical models of inventory typically include the three inventory associated costs of surplus, shortage and ordering. These classic inventory models are then analysed so as to choose inventory parameters that usually minimise the total cost of operating the inventory system being investigated.

Unfortunately, classic inventory models do not provide a meaningful basis for analysing many real and increasingly important practical inventory problems and situations. It is therefore not surprising that over recent years, several authors have discussed these issues in broad terms and suggested that a new paradigm needs to be developed.

This paper develops some specific aspects of this discussion. In particular, the paper identifies a range of inventory problems that are not covered appropriately by traditional inventory analysis. One of these is to design responsible inventory systems, i.e. systems that reflect the needs of the environment. The paper then examines the importance of inventory planning to the environment in greater detail. For example, packaging is important, not only because of its costs and the protection that it provides to the inventory items, but also because of its eventual effects on the environment in terms of the use of resources and potential landfill. For similar reasons, waste, which can result from poor inventory management, is highly important. The location of stores is important because location affects transport costs. Thus the influence of the secondary aspects of most inventory models; packaging, waste and location are important but, even more important are the inter-relations with the total system. In particular, the location of the manufacturing plants and the effect that inventory planning has on the logistics chain, potentially have considerable environmental implications. Inventory is part of a wider system.

However, until the cost charged for an activity reflects the true environmental cost of that activity, it is likely that decisions will be made on the basis of erroneous data. In that situation, we are faced with either determining the environmental cost of specific actions or to use environmental costs that are somewhat contrived; in which case it may be more sensible to use very different performance measures and models. The paper discusses these ideas and ways in which inventory policies may reassure us with our environmental concerns.

1. Introduction and context

Man has dealt with inventory issues ever since he started to utilise the resources of the planet. However, inventory arises in many different situations and so it is unlikely that the same inventory planning and control considerations will apply equally to all categories.

Inventory management has been a focal research area in operations research/management science, production and operations management, and industrial engineering for many years. The first mathematical treatment of inventory systems was the economic order quantity (EOQ) model developed by Harris in the 1920s (Harris, 1913/1990). Interestingly, almost a century after its introduction, the EOQ is still being studied and extended by academicians. Major advances in understanding inventory problems took place in the 1950's and 1960's (e.g., Whitin, 1953; Arrow et al., 1962; Hadley and Whitin, 1963) with the emphasis on satisfying the needs of manufacture, logistics, etc. These classic inventory models include mathematical models that take account of surplus, shortage and ordering costs and are used to determine inventory parameters such as the re-order level (ROL) and re-order quantity (ROQ). The models are particularly applicable to operational planning for retailing, wholesaling and manufacturing stocks. However, as markets became competitive, dynamic and complex, inventory management also became more complex (Bonney, 1994) and market conditions have been changing more

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quickly than researchers could respond. Most inventory models are still confined to the classical cost analysis approach but the accuracy of the input parameters for these models is frequently uncertain. Some researchers (e.g., Bonney et al., 2003) examined some of the variables that are being affected by the dynamic environment in which companies operate and suggested that inventory models need more development and that parameter values are likely to change as a result. Recently, other researchers (e.g., Chikán, 2007) have moved away from classical inventory management by thinking that inventory should have an active rather than a passive role.

In addition to stocks that are needed for manufacturing, logistics, etc., inventory is needed for constructs such as health systems, military systems and organisations for humanitarian relief. Inventory planning of items such as decontamination units and medical supplies may be needed to deal with the potential consequences of terrorism. For health, of course there are many predictable problems but there is also the risk of new diseases and pandemics that could lead to great difficulties about what to do. For example, if, as many people predict, we may soon be hit by a new virulent strain of influenza then, even with the know-how and production facilities, how would one estimate how much vaccine should be made and then managed, to protect against the uncertain risk? With even more uncertainty, how does one plan to provide humanitarian relief for other rare but devastating situations arising, say, from an earthquake, a tsunami, or a military conflict? In some of the above situations, there will be a low but unknown probability that a specific event will occur. There will also be uncertainty about the timing. The risk levels are difficult to ascertain and the potential consequences may be severe.

Environmental problems are an area of steadily increasing concern and this paper examines the relation of inventory to the environment and, in particular, whether it is possible to create environmentally responsible inventory planning systems. It is suggested that in order to understand how to create such systems it is likely that further theoretical developments will be required and that there may be a need to develop methods that will determine inventory levels based on measures other than cost. Realistic costs are difficult to calculate even with the classic models (Jaber, 2009) but are virtually impossible with unusual and potentially catastrophic events. Also, and more importantly, models based on unreliable costs can be very misleading (e.g., Woolsey, 1990; Jones, 1991). However, potentially the most misleading aspect is that many of the model assumptions may not be realistic. Additionally, using cost minimisation as a performance measure is unlikely to give sufficient importance to meeting users' and society's requirements. Generalising to consider models in terms of utility may be intellectually satisfying but leads to equally difficult problems of measurement.

In order to derive their inventory parameters, stock items are generally considered independently. Frequently however, because there are interactions, the overall performance of an inventory system may not be the sum of the performance of individual items. For example, ordering some items may reduce the cost of ordering other items from the same supplier. Also, if an ordered item is manufactured using the same resources as other items, then the lead times chosen for some items may affect other lead times by changing queue priorities. Interactions arise also when several items of stock are needed at the same time e.g. for certain assembly operations. In that case, what is the shortage cost of a single item and is it the same if two items are short? Partial solutions, almost certainly non-optimal, to some of these problems are provided by Murdock's coverage analysis (e.g., Lewis, 1970), scheduling by load control (Wiendahl, 1995), and other production planning methods such as JIT, MRP, MRP II, OPT and period batch control (Burbidge, 1996). However, each planning method affects the ordering quantities (e.g., Johnson, 1986; Ptak, 1991; Voss, 1995; Miltenburg, 1997) but the quantities are generally unrelated to cost modelling.

Ideally, the OPT principle of using operational measures that are consistent with the strategic needs of the overall systems should be used. As an example, some studies suggest that the operational measures of throughput, inventory and operating expense are consistent with the strategic measures of profit, return on investment and cash flow (e.g., Fox, 1982; Kaplan, 1983; Gupta et al., 2002). Unfortunately however, many organisations appear to display little consistency between operational performance measures and strategic measures and so the system performance (the strategic measure) is not the sum of the parts (the operational actions). As Sprague (2002) mentions, even if valid models are derived, the different parameters in inventory models are not usually under the control of the same manager and so other inconsistencies can arise.

If there are these difficulties with situations that are not too far removed from the underlying classic model assumptions, it may be that there would be advantages in deriving inventory models based on metrics other than cost. This paper suggests that performance measures should encourage the positive aspects of holding inventory, such as providing flexibility, providing resources that allow things to be made, acting as a buffer and satisfying demand immediately but, at the same time, should act to reduce the negative implications of holding stock. Hence, to give inventory planning an environmental emphasis requires that performance measures should encourage 'environmentally good' activities and discourage 'environmentally bad' activities. Some possible ways of doing this are now examined.

2. Some current environmental problems

The world faces many environmental legacies. These include how to deal with greenhouse gases that have already been emitted into the atmosphere, how to reduce emissions that are still occurring and what to do with resources and waste products that have been used and then dispersed into landfill sites or just left to decay (or not). There are also many potential problems in the pipeline. The world has been using rain forests to supply wood and changing land use to produce soya for feeding animals. Large amounts of heavy metals such as lead have been released and dispersed into the environment from industrial processes, from using lead based paints (now mainly stopped) and from driving cars with anti-knock lead additives (now also mainly stopped). Mercury entered the fish food chain in Japan (e.g., Vallee and Ulmer, 1972; Gårdfeldt et al., 2003). Agricultural procedures have become much more intensive and depend on the use of large quantities of fertilisers for plants and antibiotics for rearing animals. A new disease; mad cow disease (BSE), resulted from changing feeding methods without considering the possible implications (e.g., Uzogara, 2000; Lindgreen and Hingley, 2003). Large amounts of chemicals and long lasting pesticides including organo-phosphates (e.g., Pimentel et al., 1992) have been released into the environment and may create long term problems (e.g., Levine, 2007).

From other causes (testing of atomic weapons and from the peaceful use of atomic energy) we have released long lasting radioactive waste into the environment. Nuclear power plants have created radioactive waste that will last thousands of years and we do not know where to put it (e.g., Krauskopf, 1988; Ringius, 1997; Dijkgraaf and Vollebergh, 2004). Non-radioactive but equally pernicious is dioxin, a chemical that has been released and still is, but to a lesser extent, from some industrial processes