Munitions Supply Chain Modelling: A Top-Down Approach

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Abbreviations

Abbreviation	Definition
APF	Activity Profile Frequency
APG	Activity Profile Generator
ASTRID	Ammunition System Two Revised Interactive Development
CoA	Concept of Analysis
COEIA	Combined Operational Effectiveness and Investment Appraisal
DIDO	Demand in Deployed Operations
DLO	Defence Logistics Organisation
E2E	End-to-End
IA	Investment Appraisal
LARO	Logistics Analysis Research Organisation
LCM	Large Calibre Munitions
MASS	Munitions Acquisition, the Supply Solution
MCM	Medium Calibre Munitions
MD	Main Depot
MGBC	Main Gate Business Case
MOD	Ministry of Defence
MoE	Measure of Effectiveness
SAA	Small Arms Ammunition
SCM	Supply Chain Model

Abstract

Under Project MASS (Munitions Acquisition, the Supply Solution), the UK MOD is seeking to rationalise and outsource the supply chain management for dumb munitions. In support of the MASS Business Case, Advantage Technical Consulting Ltd is carrying out a Combined Operational Effectiveness and Investment Appraisal (COEIA), comparing a range of logistic supply chain configuration options.

Advantage has adopted a top-down process modelling approach to the COEIA, developing a suite of three models to address the problem:

- A Monte Carlo simulation to generate multi-year "activity profiles", containing multiple concurrent and sequential operational scenarios
- A supply chain model representing production, storage, distribution, consumption and disposal
- A whole life cost model that includes the cost of the supply chain activities

We describe the modelling and analysis process and discuss the advantages and limitations of the approach taken.

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Background

1.1 Introduction

1.1.1 In this paper we look at the supply chain modelling and analysis carried out by Advantage Technical Consulting Ltd in support of Project MASS (Munitions Acquisition, the Supply Solution). We describe the problem to be addressed, the top-down approach taken and some of the modelling and analysis techniques used. The issues raised are discussed.

1.2 The Munitions Supply Chain

1.2.1 For the purposes of this paper, we are considering only "dumb" munitions (for small arms, cannon, artillery shells and so on) used by UK armed forces, principally the Army. Figure 1-1 illustrates the current supply chain.

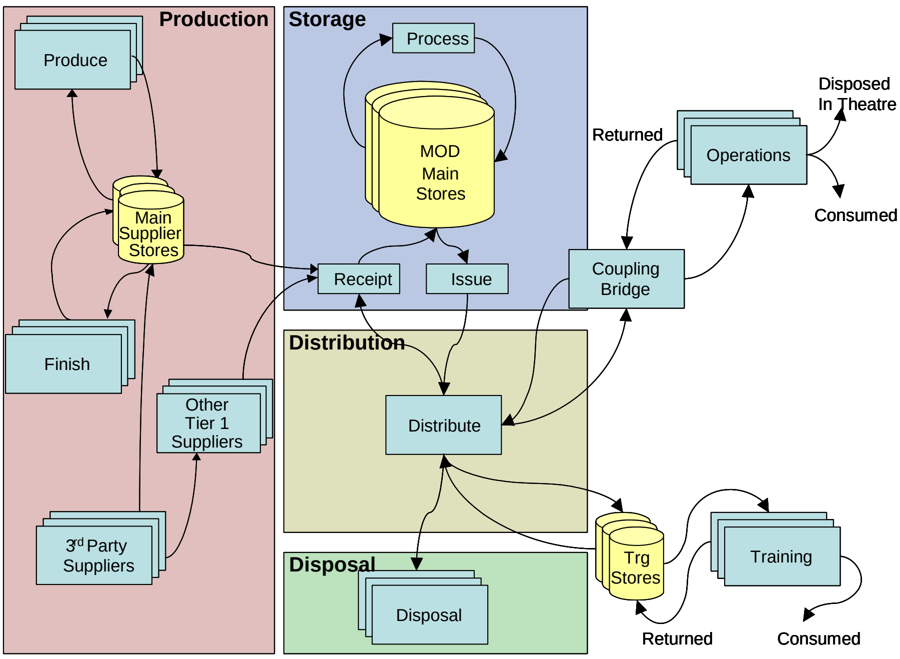

Figure 1-1: Current UK Munitions Supply Chain

1.2.2 The overwhelming majority of munition types are currently provided by a single main supplier, with a small number of munition types sourced directly from other suppliers. These "Tier 1" suppliers each have their own production supply chains, including production and finishing plants, storage and distribution and 3rd party "Tier 2" suppliers. The finished munitions are delivered to MOD stores.

1.2.3 Munitions are issued from MOD stores and distributed to training stores to meet training demands, and to the "Coupling Bridge" for outload to operational theatres. Any unused munitions are returned to MOD stores via the same routes. On receipt, returned munitions may be reconditioned and stored for future use or sent for disposal. While in storage, munitions are inspected and maintained, and lifed munitions are sent for disposal. The whole of this process is managed by MOD.

1.2.4 The current approach to munitions acquisition is centred on the concept of liabilities for each nature set by the Stockpile Planning Steering Group. The liabilities define the quantity of munitions and the lead time at which these should be available for out-load. These liabilities are derived from the most challenging combination of SAG scenarios and are adjusted for natures used heavily in other scenarios to cover "any eventuality". MOD then buys munitions to maintain the required stock levels.

1.2.5 The current supply chain configuration leads to a number of inefficiencies. The multiplicity of stores builds in delays and tends to cause overstocking at each store to compensate. The fact that it is not fully integrated, with full visibility throughout the supply chain, creates inefficiencies in resource allocation.

1.2.6 The current acquisition policy leads to training natures being stocked, with the older stock of dual use war and training natures being used in training to 'life' the stockpile. Earlier studies have shown that different management procedures could be applied to the training and training/war stock to achieve greater efficiencies.

1.2.7 While the current supply chain (mostly) meets operational and training requirements, there are strong reasons for believing that it could be done more cost effectively. This is a key driver for the MOD's Project MASS.

1.3 Project MASS

1.3.1 The Single Statement of User Need for MASS is:

To provide a munitions supply and support capability to Front Line Commands and Training Agencies within agreed time, cost and performance parameters.

1.3.2 The objective is to provide munitions at least as effectively as currently achieved, at lower cost, whilst ensuring long term security of supply.

1.3.3 The anticipated benefits are:

- MASS will deliver munitions demand fulfilment at lower cost by enabling optimisation of the supply chain.
- MASS will mitigate the risk to security of supply (supply chain 'vulnerability') to acceptable levels by either exploiting the UK supply base or holding adequate stock of supplies from other countries.

1.3.4 The scope and procurement strategy for project MASS are currently under review.

1.4 Structure of this Paper

1.4.1 Section 2 sets out the requirements for analysis to support Project MASS, including the scope of the supply chain options to be evaluated and the implications for how they should be modelled.

1.4.2 Section 3 describes the method of analysis. It covers the overall choice of approach, the steps involved in the analysis, and the models and data sources used.

1.4.3 Section 4 gives a selection of illustrative results. These are provided for the purpose of demonstrating the method in context; the values shown do not reflect the actual results of the study.

1.4.4 In Section 5 we discuss some of the methodological issues that arose during the study. These include the benefits of taking a top-down approach, the precise definition of the measure of effectiveness and the representation of a large number of sources of uncertainty in the method.

1.4.5 Brief conclusions are offered in Section 6.

Section 2
Requirement for Analysis

2.1 Introduction

2.1.1 MASS is currently in its Assessment phase, at the end of which there is a major decision (Main Gate) on whether or not to proceed with the project. The Main Gate Business Case (MGBC) is required to define the scope and costs of the proposed MASS solution, and a programme for its delivery.

2.1.2 A quantitative justification of the proposed solution in the form of a Combined Operational Effectiveness and Investment Appraisal (COEIA) is a mandated element of the MGBC. Modelling and analysis are required to support the COEIA.

2.2 Options

2.2.1 Previous work has explored a range of feasible options for Project MASS, looking at two main considerations: process and organisation.

2.2.2 The process axis encompasses a range of supply chain management philosophies, including:

- "Agile": ensure that the supply chain can meet all possible foreseen requirements. Essentially the supply chain management today is agile through the holding of munitions in stock, though this is not efficient;
- "Lean": deliver munitions demand fulfilment at lower cost by enabling optimisation of the supply chain (principally lower stockpiles). This is a key initiative across the MOD's Defence Logistics Organisation (DLO), and is the objective of MASS;
- "Just in Time": deliver munitions demand fulfilment without the need for stockpiles held by MOD. This would rely on suppliers to achieve the right balance between the stock they hold and their manufacturing capacity, and is considered too high risk for MASS.

2.2.3 The options vary in process through:

- Varying levels of capacity for surge, leading to a trade-off between manufacturing capacity and stockpile levels;
- Alternative distribution patterns, for example the delivery of some training ammunition directly to the point of use to provide a consequential reduction in storage, handling and transport costs;
- Rationalisation of storage facilities.

2.2.4 The organisation axis addresses changing from a resource level (stock pile focused) paradigm to a service level paradigm by altering the management and ownership of elements of the supply chain in order to achieve best value for money. The most far-reaching option foresees the MOD involvement changing from a "provider" of the service to a "decider" of the service level necessary to meet end user needs (i.e. the intelligent customer role). This option is intended to be consistent with the concept of an 'end-to-end' (E2E) logistics solution.

2.2.5 The options vary in organisation through:

- The extent to which distribution, disposal and munitions management are out-sourced (for example, the migration to a munitions supply service, optimised to deliver munitions at greatest efficiency);

- The management of munitions stores, to provide security of surge supply by offering an industry partner a source of income during periods of low manufacturing demand and to provide gain share savings by offering that industry partner the potential to optimise the combined manufacturing and MOD store capacity;

- The number of contractual interfaces (for example, reduce to a single Tier 1 supplier, with all other suppliers sub-contracted);

- The balance between competition and partnership, taking account of the UK's Defence Industrial Strategy[1].

2.2.6 For options which involve entering into a long term contract with a single Tier 1 supplier, 25 years has been identified as a likely timescale for any such contract.

2.3 Implications for Modelling and Analysis

2.3.1 The objectives of the analysis are:

a. To compare the operational capability of the COEIA Options under different operational conditions over a 25-year timescale;

b. To quantify the supply chain activities required for each Option to enable an Investment Appraisal (IA) to be carried out;

c. To carry out the IA, taking into account the costs and risks associated with the supply chain activities;

d. To achieve the above in a way that is fit for purpose to support the MGBC for a project of this size (£several billion over 25 years).

2.3.2 The greatest stress is placed on the supply chain by concurrent operations, and by the need to replenish stocks following a large outload. Thus it will not be sufficient to consider operational scenarios in isolation. Instead, the analysis will need to look at combinations of scenarios over the 25-year period – a "meta-scenario" approach.

[1] Defence Industrial Strategy: Defence White Paper, Cm 6697, 15 December 2005

2.3.3 There is a need to model a range of differently configured supply chains, while achieving this as simply as possible and in a way that ensures comparability of results. This will require a supply chain model that in sufficiently generic that it can be altered to represent any of these configurations simply through data changes. Figure 2-1 gives a generic picture that will form the basis for constructing such a model.

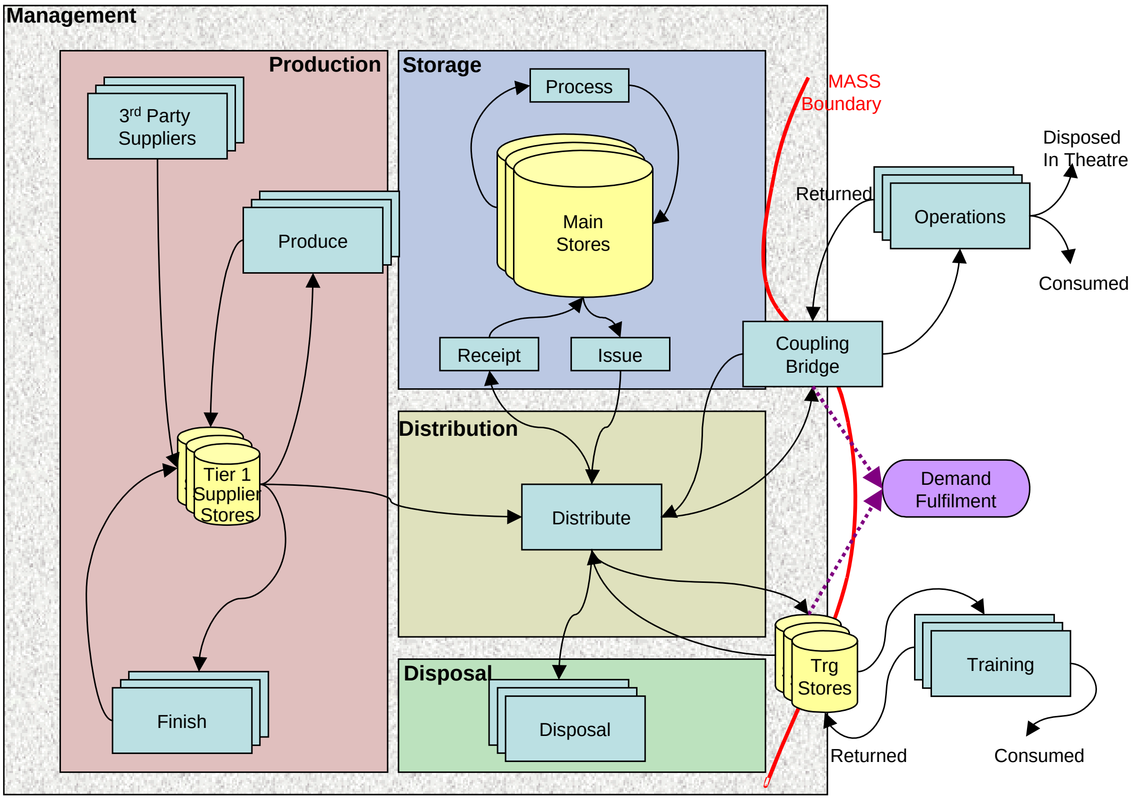

Figure 2-1: Generic Munitions Supply Chain

2.3.4 The key change from Figure 1-1 is in the integration of the distribution function with production. This enables distribution from and to any node within the MASS boundary. By changing the delivery flows, it is possible to represent direct distribution. Elements of the model can also be "turned off" (e.g. to represent rationalisation of stores) simply by setting the appropriate stocks and flows to zero. Organisation changes may be reflected by varying decision rules. This picture also simplifies the munitions production process and defines a Management Layer encompassing Production, Storage, Distribution and Disposal.

Section 3
Methodology

3.1 Basic approach

3.1.1 The method of analysis, formally known in MOD as a “Concept of Analysis” (CoA), should be fit for purpose to meet the requirement for analysis, as outlined in the previous section. For a COEIA, we must assess both the cost and effectiveness of each option with sufficient fidelity to discriminate between the options. Applying our top-down approach, we start with the following basic methodology questions:

- Given the range of options to be compared, what measure of effectiveness (MoE) should be used?
- Given the MoE and option definition, what is the most suitable approach to enable robust discrimination of options?
- A key choice: should the analysis be carried out on a constant cost or a constant effectiveness basis?

3.1.2 We may measure the impact of alternative supply chain configurations on an organisation’s performance at many points in the *value chain*[2]. For a munitions supply chain, we could in principle measure any of the following:

- Operational effectiveness: the effect of the supply chain on the ability of UK defence forces to achieve operational objectives, as traditionally assessed using combat modelling in one or more operational scenarios;
- Availability: the effectiveness of the supply chain in making munitions available to users to meet their demands;
- Supply: the effectiveness of the industrial supply chain in delivering munitions to MOD stores.

3.1.3 Measuring operational effectiveness would introduce issues well beyond the scope of MASS, and would be very difficult to do in a way that could reliably discriminate between the options.

3.1.4 A simple measure of supply is more suited to a stockpile-based supply system but inappropriate for an E2E service level supply chain paradigm. Although feasible, it would not be able to discriminate between the range of options under consideration.

[2] A *value chain* categorizes the generic value-adding activities of an organisation, e.g. operations, logistics, sales and marketing, and service (maintenance).

3.1.5 The most suitable MoE to use is a measure of availability, or "demand fulfilment". This measures the effectiveness of supply chains at the MASS Boundary, as shown in Figure 2-1. The particular MoE chosen was percentage of demand fulfilled, to be measured over time (consistent with the requirement for a "meta-scenario" approach) and for each type of operational and training requirement.

3.1.6 The choice between constant cost and constant effectiveness is a matter of modelling practicalities. A constant cost approach was deemed impractical because of the sheer number of contributors to cost in the supply chain (production, storage, distribution, etc.) and the non-linear relationships between them. Therefore a constant effectiveness approach was chosen. Discussion with the client revealed that the only acceptable target was 100% demand fulfilment; this was set as the constant effectiveness level.

3.1.7 In the previous section we noted that a "meta-scenario" approach was required, involving combinations of scenarios over the 25-year period. The implication was that we needed to pay some attention to representing the demand for munitions as well as the supply. The supply chain is a system (made up of interacting activities such as production and distribution) that provides munitions ready for use over time. Similarly, there is a "demand system", consisting of military operations and training activities, which also interact, for example due to concurrency constraints.

3.1.8 In order to provide a balanced comparison of the options, we would need to test how they performed against a range of different demand profiles over 25 years. We therefore concluded that, in addition to a supply chain model, a separate demand side model was required to produce the demand profiles against which each of the options could be evaluated.

3.2 Outline of the method and models

3.2.1 The method developed for the COEIA involves the following steps:

a. Generate a representative set of activity profiles based on defined frequencies of operational scenarios (including large scale exercises), using a model known as the Activity Profile Generator (APG);

b. Calculate the resulting demand profiles, taking into account the agreed munitions liabilities for each activity and the munitions required for ongoing training (these two steps effectively implement the required "meta-scenario" approach);

c. For each option and each demand profile, run a Supply Chain Model (SCM) with maximum stock to determine the target stock holding required for that option to achieve 100% demand fulfilment (constant effectiveness), identifying any options than are unable to achieve 100% demand fulfilment for any of the demand profiles. This provides the Operational Effectiveness (OE) input to the COEIA;

d. For each option and for selected demand profiles, run the SCM a second time, using the target stock holding and measuring the supply chain activities within the MASS Boundary (production, storage, distribution and disposal);

e. For each option and the selected demand profiles, use a Cost Model to cost the supply chain activities, incorporating investment and management costs and adjusting for risks. This provides the Investment Appraisal (IA) input to the COEIA;

f. Identify any other contributory factors (OCFs) that have a bearing on the decision between options but cannot be quantified in terms of cost or effectiveness. This provides the final input to the COEIA.

3.2.2 Figure 3-1 illustrates the interfaces between the three models involved, the inputs required and how they combine to produce the COEIA.

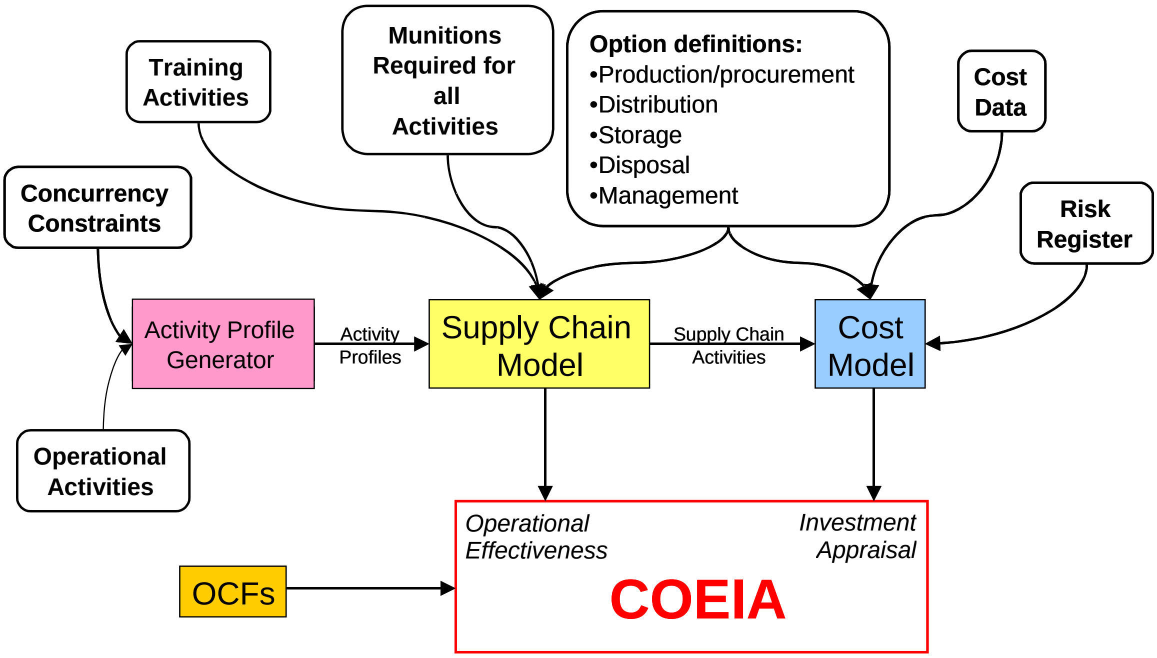

Figure 3-1: Relationship between the models and the COEIA

3.2.3 The method, models and data involved in steps (a) to (d) are described in the sections below. The cost analysis and identification of OCFs are still under way, and are not discussed further in this paper.

3.3 Generation of activity profiles using the APG

3.3.1 The APG produces "activity profiles" which determine the operational conditions under which the COEIA Options are tested in the SCM. The APG is constructed using the ARENA process modelling software package. It was developed in less than a month. Set up time is measured in minutes and run time in seconds.

3.3.2 Note that the generation of activity profiles is independent of the SCM, enabling the same activity profile inputs to be used when assessing each COEIA Option. Using this approach enables a clear and unambiguous comparison of the Options.

3.3.3 The APG creates activity profiles using Monte Carlo simulation, which reflect the intensity of the operational setting, by generating "events" at an Activity Profile Frequency (APF) commensurate with the intensity of the operational setting, as indicated below.

a. APF Low – Low intensity operational setting (small number of events, spaced far apart in time, few concurrent events)

b. APF Medium – Medium ("routine") intensity operational setting

c. APF High – High intensity operational setting (large number of events, spaced close together in time, many concurrent events)

3.3.4 An event can be any one of the following:

a. Large Scale Operation

b. Medium Scale Operation

c. Small Scale Operation

d. Large Scale Exercise

3.3.5 Frequencies were derived from a number of sources. These include the Defence Science and Technology Laboratory's Demand in Deployed Operations (DIDO) model, the data for which has come from analysis of UK operations during a recent eight year period (1996-2003). The probabilities of operations continuing after each 6-month period were also derived from this model. An example of activity frequencies for 25 years is shown in Table 3-1. Note that, as with all tables and graphs in this paper, these figures are illustrative only.

Event	Frequency (average occurrences over 25 years)		
	APF Low	APF Medium	APF High
Large Scale Op	1	2	3
Medium Scale Op	5	10	15
Small Scale Op	10	20	30
Large Scale Ex	5	5	5

Table 3-1: Illustrative Event Frequencies

3.3.6 The alternative APFs can be thought of as different assumptions about the likely levels of conflict in the world over the next 25 years, and the chances of UK forces being involved either as a combatant or in subsequent peace support operations. The consequences of making an incorrect assumption have been explored as sensitivity cases.

3.3.7 In addition, constraints on the numbers and types of concurrent operations possible and the minimum time interval between operations to allow for replenishment of stocks were applied, based on MOD policy.

3.3.8 The APG was used to generate a set of 25-year activity profiles, one set for each APF. Each set of activity profiles comprised 50 replications. This ensured that all the different viable combinations (concurrencies and sequences) of events were represented.

3.4 Calculation of demand profiles

3.4.1 Having generated activity profiles, the next step is to calculate the resulting profile of demand for munitions. The MOD's Logistics Analysis and Research Organisation provided munitions requirements for each type of event based on the number of vehicles/units expected to be deployed for an operation, using the Waymarker Model[3].

3.4.2 Munitions requirements for ongoing training activities were then added to produce the overall demand profile. ASTRID[4] demands for the period of April 2002-March 2004 were used to derive the volumes required for training. For the purposes of this analysis, munitions were grouped into 34 categories.

3.4.3 Figure 3-2 shows the shape of the profile of training and operational requirements over the period from April 2002 to March 2004 (but not the actual numbers). Note that this period covered OP TELIC, allowing analysis to be conducted of changes in training usage due to a large-scale operation.

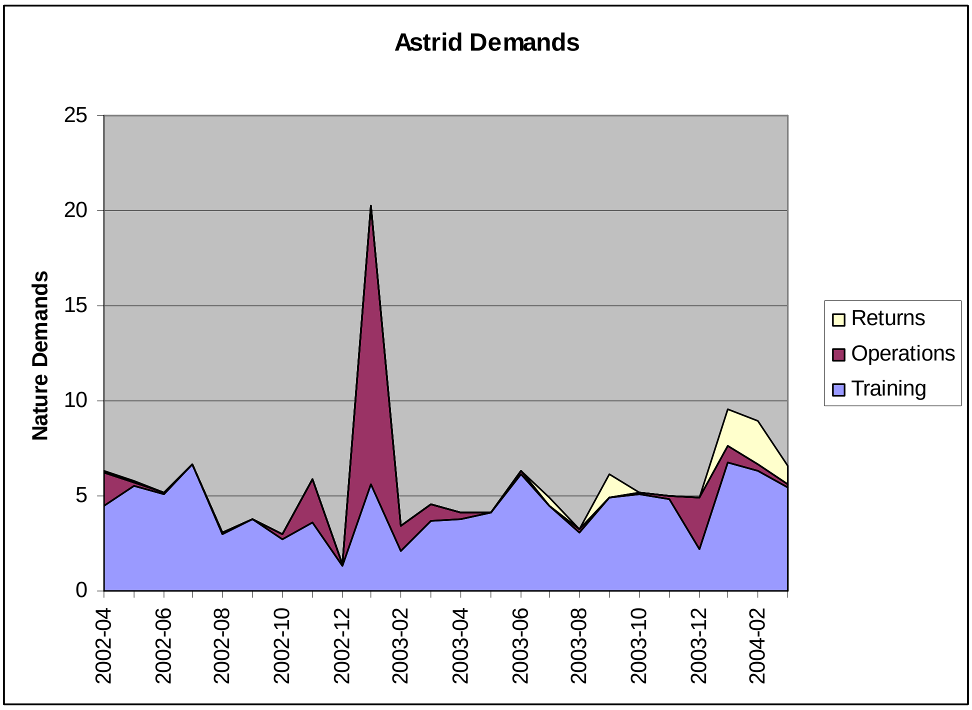

Figure 3-2: Demand Profile

3.4.4 The proportion and condition of munitions returned were derived using a combination of Waymarker and the returns recorded from OP TELIC.

[3] Waymarker is a method for deriving the liabilities for consumable items such as munitions from combat requirements by factoring in margins for logistic losses, maintenance and so on.
[4] ASTRID stands for Ammunition System Two Revised Interactive Development

3.5 The Supply Chain Model (SCM)

3.5.1 The SCM is a high level discrete event simulation model of the supply chain, constructed using the ARENA software package. Initially a base model was created based on a few key objects as shown in Figure 3-3.

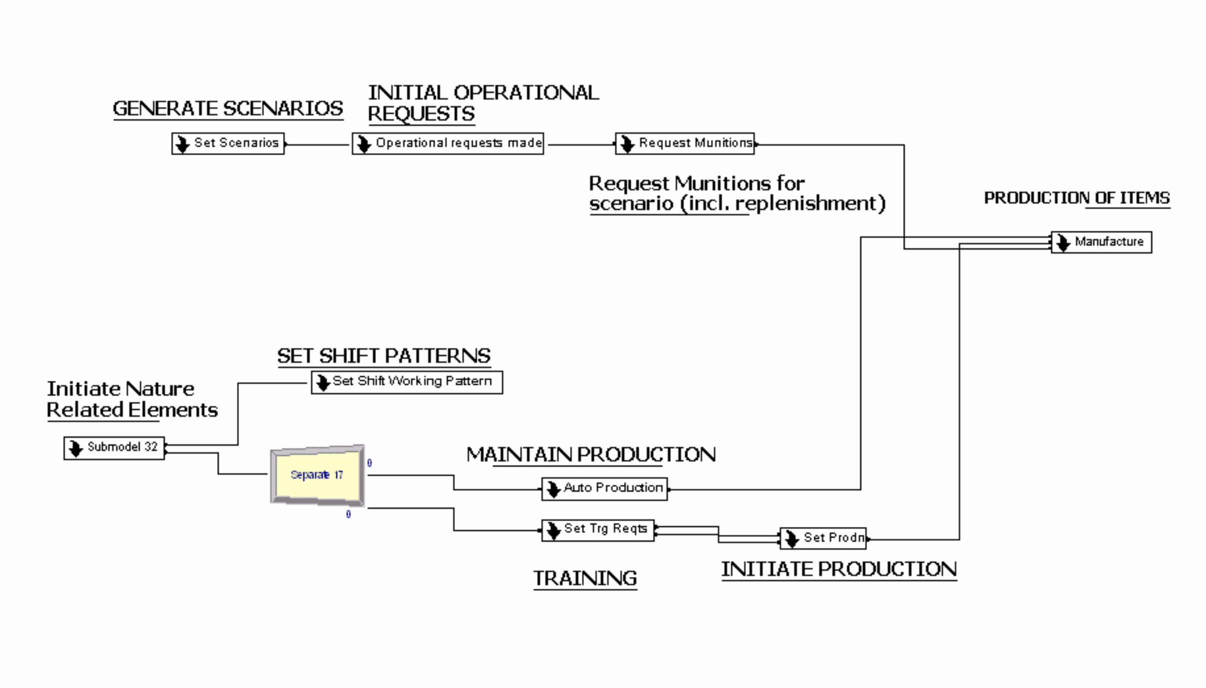

Figure 3-3: SCM Model Objects

3.5.2 Underlying each of these objects is more detailed model functionality. Figure 3-4 shows the sub-model for "Request Munitions".

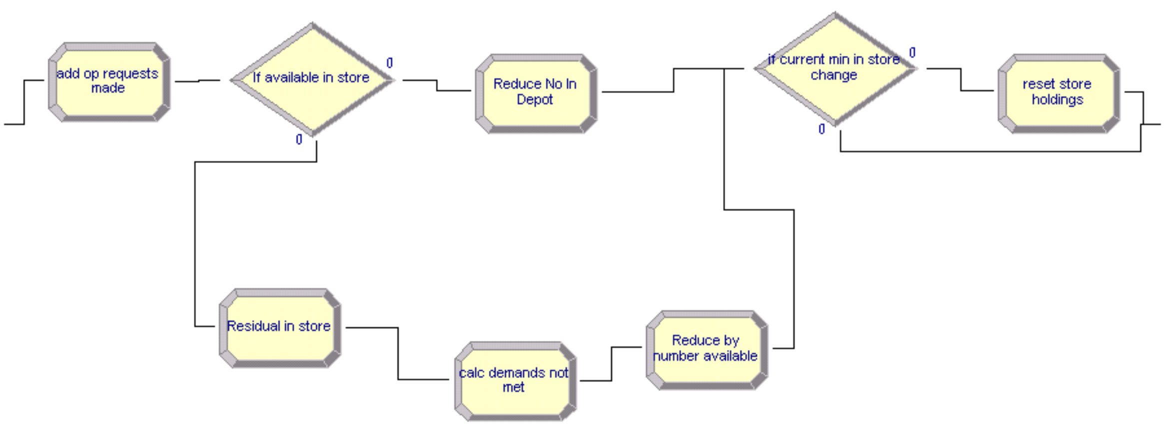

Figure 3-4: Detailed Model Construction

3.5.3 The SCM was designed so as to maximise the ability to vary supply chain functionality through changes to the input data. All variables are held within an Excel spreadsheet, including APG model outputs, shift patterns, munition type identifiers and number of items in store at the start of the run.

3.5.4 The SCM can be run in two different ways depending on the type of output required. The first option is used when calculating the target store holdings, as described in Section 3.6, for which the only outputs required are the minimum numbers of each type of munition held in store for each profile. This allows all 50 profiles generated by the APG to be run through the SCM in only 15 minutes. The second option is used to provide full details of the supply chain activities as described in Section 3.7. These runs take approximately 15 minutes per profile, but are only required for a small subset of the profiles.

3.5.5 The ability to produce different types of output reduces the total run time required, as to produce full results for all 50 profiles for each APF and every option would take several days.

3.5.6 Rates of production and information regarding the sharing of lines between different munition types were obtained from the current supplier. Shared resources, which have the potential to cause delays or backlogs in the production process, are represented in the SCM. An example of this is the process for large and medium calibre munitions, which is shown in Figure 3-5.

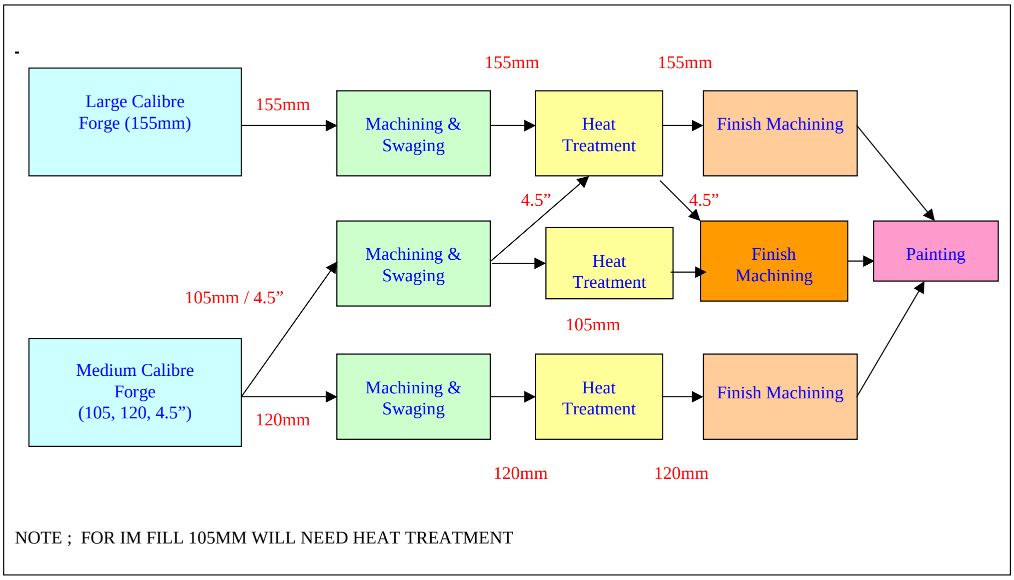

Figure 3-5: Large and Medium Calibre Munitions Manufacture

3.5.7 Options also consider the increased production potential from the working of additional shifts. The possible shift rates were obtained from the current supplier.

3.6 Determining the Target Stock Holding using the SCM

3.6.1 For each Option and each APF, the target stock holding required to maintain constant effectiveness is obtained by:

a. Running all the activity profiles through the SCM, whilst initially holding the maximum quantity of stock possible/allowed for the storage facilities associated with the option.

b. Calculating the target stock holding required consistent with meeting the set of demand profiles.

c. Adjusting the quantity of stock held down from the initial (maximum) value to the minimum level identified in the step above.

d. Verifying that the demand profile is still met after the adjustment, by running all the same activity profiles through the SCM again.

e. Applying any minimum levels required by policy.

3.7 Measuring the Supply Chain Activities

3.7.1 For each APF and for each Option, the supply chain activities from three activity profiles will measured and costed: a "representative" profile, containing the expected number of each type of activity for the APF; a profile at the upper end of the scale; and a profile at the lower end of the scale. This is done in order to check that the ranking of the Options does not change with the activity profile chosen for costing. Figure 3-6 illustrates the choice of one representative and two contrasting profiles from the populations of profiles generated.

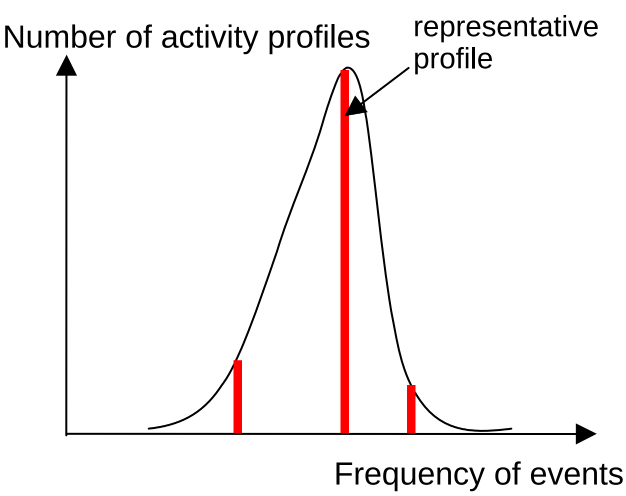

Figure 3-6: Selection of Activity Profiles

3.7.2 The choice of a representative profile requires care. Simply using an "average" would be inappropriate, as operations at average separations are probably the easiest for the supply chain to support. Rather, the representative profile should have the average number of each operation type, but with a time distribution that includes both short intervals between operations and longer gaps with lower levels of activity. Thus the representative profile for each frequency has been hand picked.

3.7.3 Table 3-2 below lists the outputs from the SCM that will be used as inputs to the Cost Model. The SCM records data on a monthly basis, e.g. the "Out Returns" output records the number of items returned to Main Depot stores following an operation each month, over a 25 year period, for each activity profile.

Name of SCM output	Purpose of output
Production	This output records the number (and type) of items produced by the Tier 1 supplier. It is used to calculate the cost of munitions to the MOD.
Shift Working	This output records the number of weeks spent working on the various shift patterns (defined within the SCM). It is used to calculate the manpower costs to the MOD of producing munitions working to those shift patterns. Note that items produced under surge conditions may be charged at a higher rate.
MD Stores	This output records the number of items in Main Depot (MD) stores over time. It is used to calculate storage costs of munitions. This OE output can also be processed to assess the number of times an item would have been inspected during its stay in store. This then enables the number of man-hours spent (and hence the cost to the MOD in) carrying out these processes to be calculated.
Supplier Stores	This output records the number of finished items in the Tier 1 Supplier stores over time. It is used to calculate storage costs of munitions.
Number Produced	Details the number of items produced each month by the Tier 1 Supplier. This profile will enable calculation of the cost of raw material provision and storage.
Transfers to Ops	This output records the number of items transferred from the MD stores to operations. It is used to calculate the distribution costs of munitions. This output can also be used to derive processing costs (issues) of munitions.
Transfers from Supplier	This output records the number of items transferred from the supplier to the MD stores. It is used to calculate the distribution costs of munitions. This output can also be used to derive processing costs (issues and receipts) of munitions from supplier and MD stores respectively.
Transfers from Supplier to Training	This output records the number of items transferred from the supplier to training compounds. It is used to calculate the (direct transfer) distribution costs of munitions for Options B and C (see section 4.1). This output can also be used to derive processing costs (issues) of munitions.
Transfers to Training	This output records the number of items transferred from the MD stores to training compounds. It is used to calculate the distribution costs of munitions. This output can also be used to derive processing costs (issues) of munitions.
Disposed	This output records the number of items disposed. It is used to calculate the disposal costs of munitions. This output can also be used to derive processing costs (issues) of munitions.
Returns	This output records the number of items returned to the MD stores following an operation. It is used to calculate the distribution costs of munitions. This output can also be used to derive processing costs (issues) of munitions.

Table 3-2: Outputs from the SCM that will be used as inputs to the Cost Model

Section 4
Illustrative Results

4.1 Introduction

4.1.1 In this section we present a selection of illustrative outputs from the analysis. The objective is to highlight the variety of ways in which the modelling approach adopted allows us to assess and compare alternative supply chain options. The "results" shown here are provided for the purpose of demonstrating the method in context; the values shown do not reflect the actual results of the study.

4.1.2 For the purposes of presenting the illustrative results, we will consider a representative sample of the options under consideration:

a. Option A is a traditional stockpile-based supply system. MOD manages the stockpile, issuing stock from its stores when requested and placing orders with industry to maintain the required stock.

b. Option B introduces an agreement with the main Tier 1 supplier that provides a surge capacity, thus reducing the stock holding requirement. It also introduces direct delivery of training munitions. MOD continues to manage the stockpile for operations.

c. Option C transfers responsibility for managing almost all aspects of the supply chain to an Industry Partner, including procurement from 3rd party suppliers. The Industry Partner is responsible for providing munitions to users, to meet requirements set by MOD.

4.2 Target Store Holdings

4.2.1 The SCM was initially run to identify the target store holdings required to fulfil all demands on the system for the Option/activity profile in question.

4.2.2 The typical impact of different levels of operations is shown in Figure 4-1. These indicate that for munitions with an operational requirement, the APF level can have a large influence on the target store level.

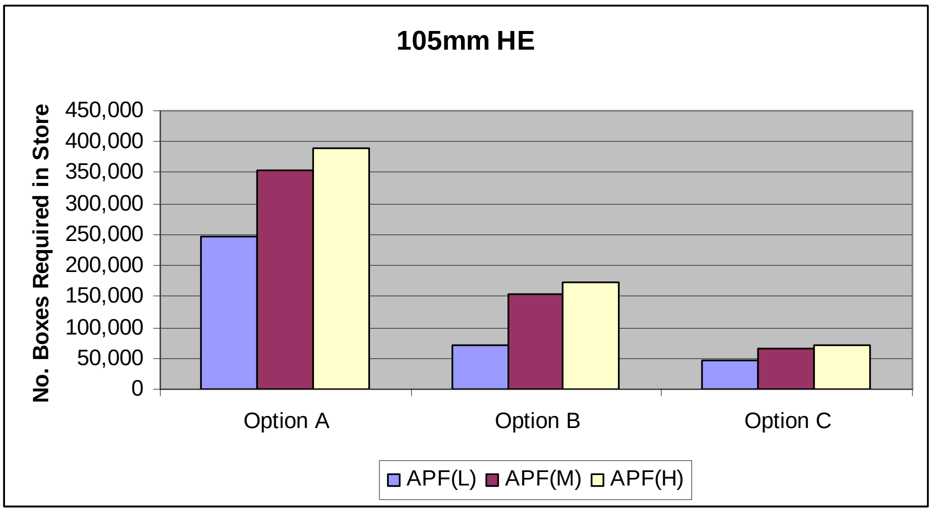

Figure 4-1: Target Holdings for 105mm HE

4.2.3 There is an increased requirement in Option A as the level of operations intensifies. This is due to the low production rate and two shift working. However, the difference is more significant between options than between activity levels. Increased production, surge capability and more rapid replenishment reduce store holding requirements between Option A and Option C.

4.3 Production

4.3.1 To enable an increased production capability and therefore reduce the number required in store, Options B and C have the option of working two shifts plus weekends or three shifts, depending on the workload, whilst Option A is restricted to a maximum of two shifts.

4.3.2 The model calculates the number of weeks where each shift pattern is worked.

4.3.3 A typical profile for small arms munitions is shown in Figure 4-2.

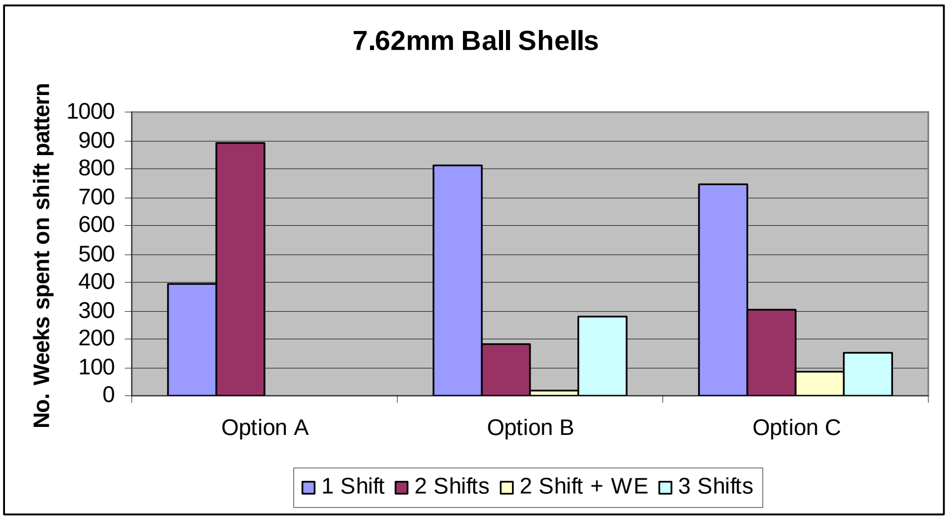

Figure 4-2: Typical Staff Shift Profile for Small Arms munitions

4.3.4 For Options B and C it may be possible in some cases to meet the required demand on two shifts over a slightly longer period rather than working three shifts or two shifts + weekend. In this case there is a trade-off between lower store levels and lower staff costs.

4.4 Storage

4.4.1 The average number in store is an indicator of storage space required by Project MASS for munitions storage under each option. The average number in store shows similar patterns to those observed for target holdings.

4.4.2 Figure 4-3 shows a typical profile of the average number in store for large calibre munitions.

Figure 4-3: 105mm HE Average Number in Store

4.4.3 The 105mm HE has a decreased number in store for Option C primarily due to the increased production rate available under this option (double that of Options A and B), but also partly due to the immediate replenishment of stocks after the deployment of an operation. The differences between Options A and B follow from the fact that Option B has surge production and three shifts available and can therefore recuperate more quickly, allowing a lower target store level.

4.4.4 In fact, Figure 4-4 shows that under Option A, given the particular set of assumptions used for these runs, 105mm HE store holdings cannot be sustained at the required levels in the long term.

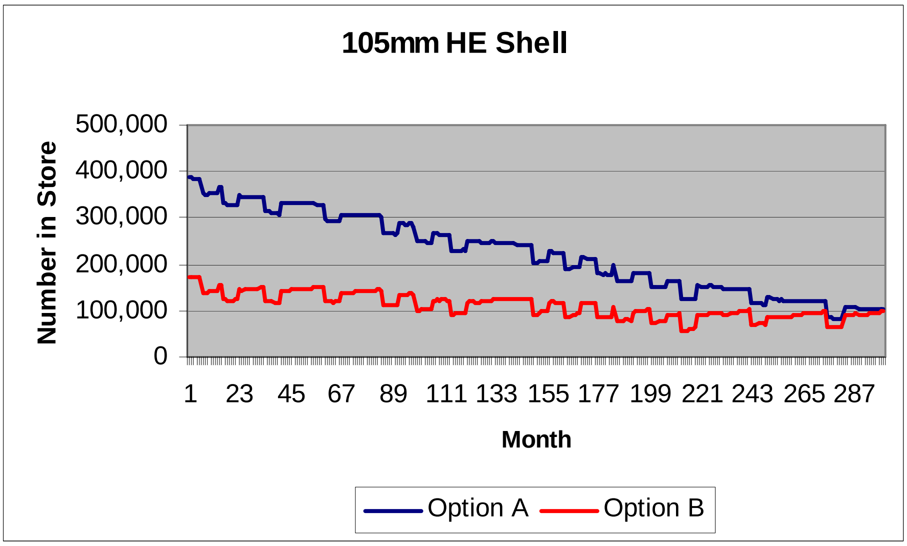

Figure 4-4: 105mm HE Store Holdings Over Time for APF(M)

4.4.5 The time in store of an item affects the amount of surveillance/maintenance carried out on it. This is usually carried out every three years. Given the high turnaround of Small Arms munitions, the majority currently spend less than three years in store. Results for some of the "slower moving" munitions are shown in Figure 4-5.

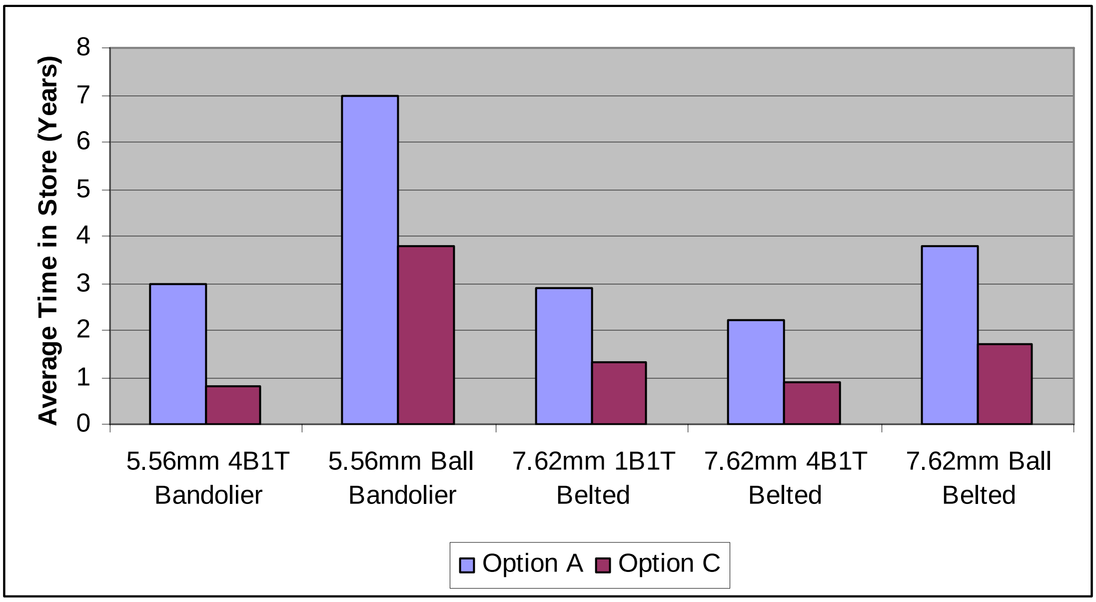

Figure 4-5: Selected Small Arms Munitions – Average Time in Store under APF(M)

4.4.6 5.56mm Ball Bandolier spends, on average, over twice as long in store as other small arms munitions. This is due to the fact that this munition is typically not used on peace support operations.

4.5 Distribution

4.5.1 As illustrated in Figure 4-6, the number of transfers generated by the activity profiles overlap. This indicates that the activity profiles test the options under a wide range of conditions.

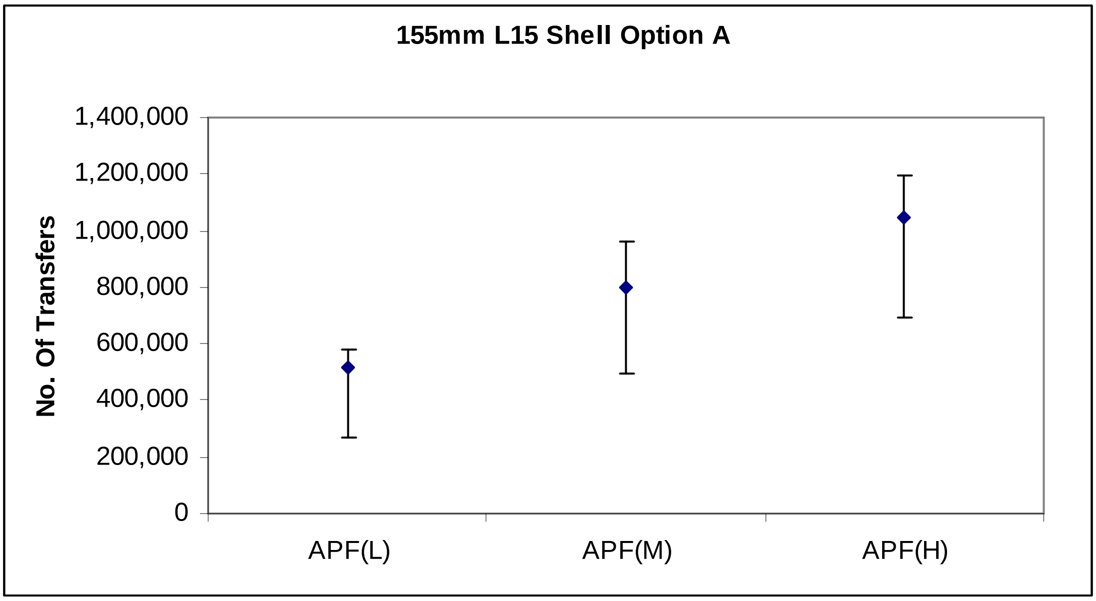

Figure 4-6: Variation in Number of Transfers across Activity Profiles

4.5.2 At present, all munitions are transferred to MOD stores before being distributed to training locations. Direct delivery enables them to be delivered from their production location direct to the training ground. This results in a reduction in the number of transfers. All Small Arms munitions show a similar pattern of reductions in the number of transfers between Option A and the remaining options (Figure 4-7).

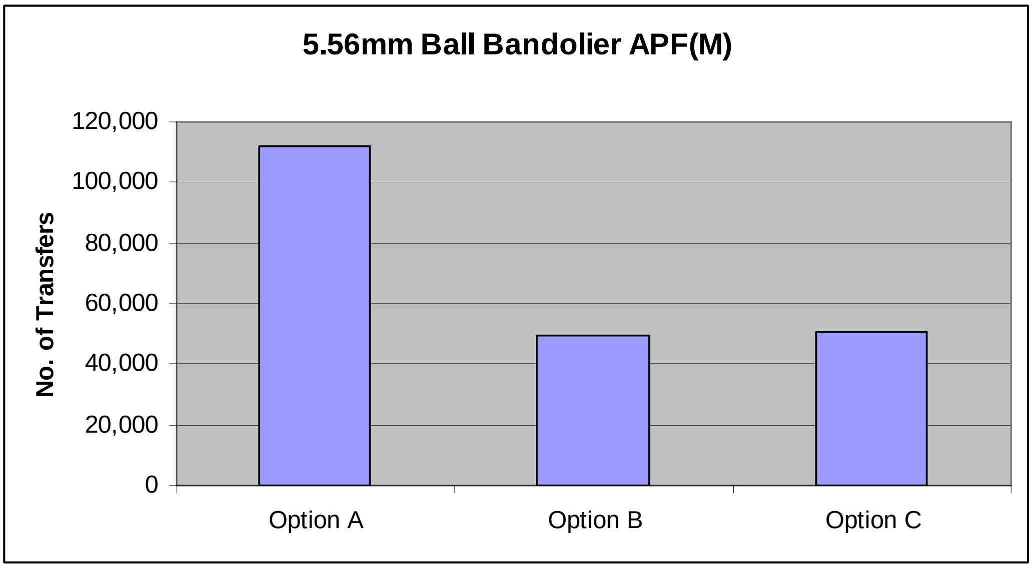

Figure 4-7: 5.56mm Ball Bandolier Number of Transfers

4.6 Operational Activity

4.6.1 As described in the previous section, target store holdings were set based on the individual activity profiles (i.e. APF(L), APF(M) and APF(H)). In reality, we do not know whether the coming 25 years will have a high, medium or low frequency of operations. Therefore there is an risk that the operational activity is higher than that for which the store holding was set and/or a financial risk that we are storing stocks which turn out not to be required.

4.6.2 In fact, the supply chain options turn out to be fairly robust to the operational risk, with only a small number of munitions suffering significant shortfalls. Figure 4-8 shows the requirements not met over a 25 year run with demands at APF(H) level but with store holdings optimised for APF(L).

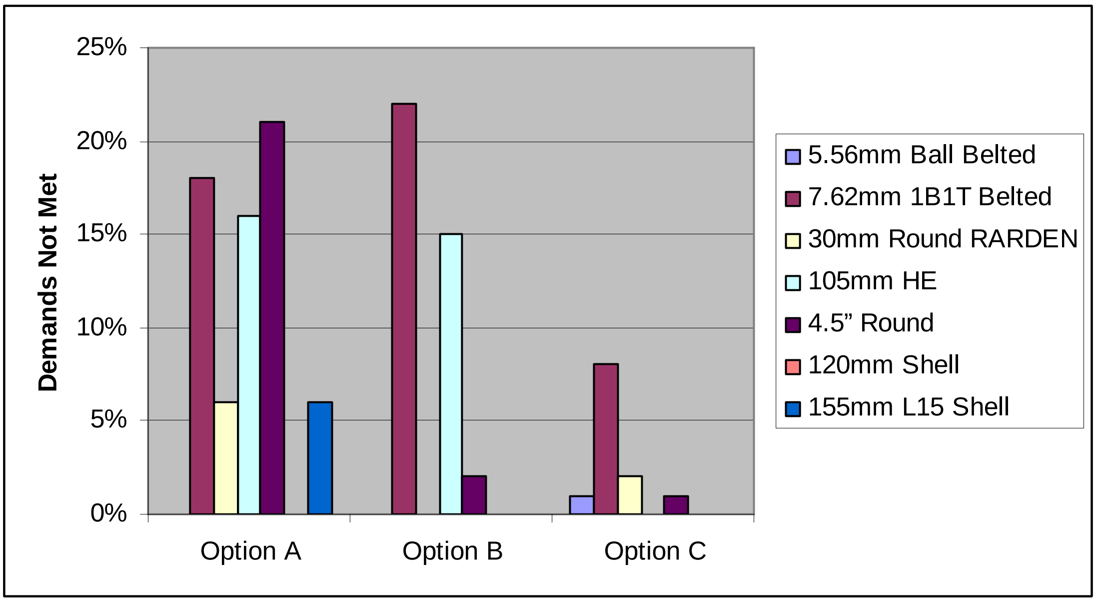

Figure 4-8: APF(H) Total Requirements not met with APF(L) Store Holdings

4.6.3 Overall the above results suggest that Option C is more resilient to setting the store levels below that which is required. This is principally due to the fact that this option replenishes store levels immediately on deployment.

Section 5
Discussion

5.1 Benefits of a top-down approach

5.1.1 When developing a model to examine a particular aspect of an organisation's business processes – in this case the UK MOD's munitions supply chain – there is a temptation to focus too quickly on that aspect without giving sufficient consideration to the context. The result can be a model that accurately reflects many of the differences in the detail of alternative options but risks missing some of the higher level (and often more important) issues and may not be good at discriminating between options.

5.1.2 In contrast, a top-down approach aims to identify the most significant issues and develop a method that incorporates them. Only then does the development of model(s) within that methodology framework begin. We believe that the top-down approach we have taken in this project has resulted in a number of benefits.

5.1.3 When Advantage Technical Consulting considered the requirement top-down, the key issues to resolve were choice of MoE (percentage demand satisfaction) and analysis approach (constant effectiveness). The design of the method then flowed from these two decisions.

5.1.4 The choice of demand satisfaction as the MoE made clear the importance of variation in the demand for munitions over time, which could potentially overwhelm any differences in supply chain configuration. The answer was to model the demand side as well as the supply side. The "meta-scenario" approach is not in itself new, but we believe that the use of the APG to generate activity profiles and demand profiles is a novel solution (at least, we have not heard of it previously being done this way).

5.1.5 The other main consequence was in the design of the SCM as a generic, high level model of the supply chain. In doing this we made sure it was relatively fast-running and sufficiently flexible to allow for alternative configurations to be represented simply by data changes. This ensured that it could be used to provide comparative evaluations of a wide range of options without the need for development of several models, with all that entails.

5.1.6 We made a number of simplifying assumptions in the SCM. For example, for distribution (usually seen as a key element of logistics), we set the time for every journey transferring stock from one location to another (within the UK) at one day, regardless of origin, destination or mode, and with no random variation. We knew we could safely do this from our initial analysis of the sources of uncertainty, which showed that any variation in distribution timescales (of hours or days) would be overwhelmed by variation in operational timescales (of weeks or months). In contrast, we modelled returns in some detail (including random variation), since they have a direct impact on stockpile, storage and production requirements.

5.1.7 The type of model developed (stochastic discrete-event simulation) is well suited to the "what if?" analysis required for comparing pre-defined options. While the outputs of such a model provide feedback that can inform the development of options, it is not appropriate for optimising the design of an option. Even "optimising" the value of a single parameter value (such as the target store holding) requires manual intervention.

5.2 Issues to be considered

5.2.1 Early on in the study, we wrestled with the problem of the definition of the MoE – specifically what was meant by demand satisfaction of less than 100%. For example, 100% demand satisfaction is in practice unachievable, for all kinds of reasons. So there might be an argument for setting the constant effectiveness level at, say, 95%. The problem is there are several ways of interpreting this figure:

a. On every occasion and for all munition types, deliver at least 95% of the required number of munitions on time.

b. On every occasion, deliver the required number of munitions on time, for at least 95% of munition types (possibly weighted by value?).

c. On at least 95% of occasions and for all munition types, deliver the required number of munitions on time.

d. A combination of two or more of the above interpretations, possibly involving some tolerance for the definition of "on time".

5.2.2 In practice, there was a desire not to "build in" a shortfall, so the constant effectiveness level was set at 100%, thus avoiding this problem. For the small number of instances where there has been a shortfall (e.g. in Figure 4-8), we have effectively used a formulation akin to (c). Although not likely to be important for this study, the choice of definition is still in principle an open question.

5.2.3 As mentioned above, a key part of the top-down approach was an analysis of the sources of uncertainty. Having identified some 15 types of uncertainty, we needed to work out how best to represent them. Table 5-1 shows the choices we made.

Area of Uncertainty	Description of Uncertainty	Source/Cause	Where Modelled	How Modelled
Activity Profile	Event Frequency	Long Term World Situation	APG	Parametric
	Event Occurrence	World Situation	APG	Stochastic
	Event Duration	World Situation	APG	Stochastic
	Event Concurrency	Mil Ops	APG	Parametric
	Operation cancelled/delayed/ brought forward	Mil Ops	APG	Parametric
Liabilities	Operational Liabilities	Mil Ops	SCM	Parametric

Area of Uncertainty	Description of Uncertainty	Source/Cause	Where Modelled	How Modelled
	Returns	Mil Ops	SCM	Stochastic
	Training Demand	Training	SCM	Stochastic
Production	Production Rate Variability	Productivity	SCM	Parametric
	Production Location Unavailability	Productivity	SCM	Parametric
Distribution	Logistic Variations	Distribution Capacity	Not Modelled	
Storage	Minimum Holding Requirement	MOD Policy	SCM	Parametric
Cost	Unit Costs	Estimates	Cost Model	Stochastic
	Risks (Financial)	Various	Cost Model	Stochastic
	Risks (Operational)	Various	Cost Model	Stochastic

Table 5-1: Representation of sources of uncertainty in the method

5.2.4 These choices are largely pragmatic, driven by the relative importance of the uncertainties and practical modelling considerations. For example, parameters that are represented as stochastic in one model become parametric in the next – this is essential to ensure a fair comparison of the options. There is also some weeding out as we move through the modelling process. For example, from the full set of activity profiles for each APF produced by the APG and modelled in the target-setting runs of the SCM, only three will be fed through for analysis in the Cost Model.

5.2.5 These choices are by no means definitive, and there are doubtless other valid ways in which this aspect of the problem could have been handled.

Section 6
Conclusions

6.1.1 Advantage Technical Consulting Ltd has adopted a top-down approach to supply chain modelling to support Project MASS in the evaluation of alternative supply chain options.

6.1.2 The outcome of this approach is a method that addresses both the demand and supply side of the equation. To implement the method we have developed three models:

a. The APG, a Monte Carlo simulation that generates multi-year activity profiles, containing multiple concurrent and sequential events;

b. The SCM, a high level Monte Carlo discrete event simulation representing the full supply chain: production, storage, distribution, consumption, returns and disposal;

c. A Cost Model that calculates the whole life cost of the options.

6.1.3 As a result of adopting the top-down approach, the method and models incorporate the most important sources of uncertainty, while leaving out immaterial details. Consequently they are fit for purpose: sufficiently flexible to represent the full range of supply chain configurations under consideration, while able to provide highly robust comparative evaluations of the options.

6.1.4 The models were developed in a short time frame and are relatively fast running.

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