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Reference report on the use of environmental life cycle methodologies in procurement in the Swedish defence

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FOI-R--2185--SE User report
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Weapons and protection

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Reference report on the use of environmental life cycle methodologies in procurement in the Swedish defence

Abstract

This report is a compilation of several years of work in the field of life cycle thinking, It should be used as a reference report and help users to choose how to use life cycle thinking and different methods such as life cycle assessment and simplified life cycle assessment in the procurement of military materiel.

The report is compiling information on how procurmenet can use a life cycle approach. We describe methods which exist and how they can be used when procuring military materiels. We describe which result you get from a Life cycle assessment. And how to modify simplified methods for life cycle assessment to function in the procurement of military materials?

The report is built like a reference report with distinct chapters in order to help the reader finding information.

Keywords

Life cycle, life cycle assessment, procurement, Swedish defence, Environment.

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Referens rapport för användandet av miljörelaterade livcykel metoder i anskaffning av försvarsmateriel i svenska försvaret

Sammanfattning

Detta är en sammanställning av flera års arbete inom området livscykelanalys. Rapporten är tänkt att kunna användas som en referens rapport och därigenom hjälpa användare att välja hur livs cykel tänkande och livscykelmetodiker såsom livscykelanalys och förenklade metoder av livscykelanalys används i anskaffandet av försvarsmateriel.

Rapporten sammanfattar information bl. a. om hur man i anskaffningen kan använda en livscykel inrikting. Vi beskriver v metoder som finns och hur dessa kan användas i anskaffning av försvarsmateriel. Vi beskriver också vilka reultat som en livscykelanalys ger Och hur förenklade metoder för livscykelanalyser kan modifieras för att bättre passa försvarsrelaterad upphandling.

Rapporten är byggd som ett referensverk med distinkta kapitel för att förenkla för läsaren att hitta den information som sökes.

Nyckelord

Livscykel analys, upphandling, Svenska försvaret, miljöfrågor

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Preface

This is the final report from a three-year project on Life-Cycle methodologies in the procurement of defence materiels. It summarises results from several reports. These are are described and referenced in later chapters. The project has been a co-operation between FOI (the Swedish Defence Research Agency) and its division for Weapons and Protection and KTH (the Royal Institute of Technology) and its division for Environmental Strategies Research – fms. Joakim Hägvall and Rolf Tryman work at FOI, Elisabeth Hochschorner, Liselott Roth and Göran Finnveden work at KTH.

The project has been funded by the Swedish Armed Forces.

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1 Introduction

In 1998, the Swedish Government decided that the Swedish Armed Forces (SAF) and the Defence Materiel Administration (FMV) should apply 'Guidelines for environmental supply of defence materiel', thereby taking environmental consideration in all phases of the acquisition process. The importance of taking environmental consideration in a life cycle perspective has also been stressed by both FMV and SAF, see for example FMV's environmental report (FMV 2002). There are a large number of tools that can be applied to assess environmental impacts of different systems (e.g. Ahlroth, Ekvall et al. 2003; Finnveden and Moberg 2005). These tools can be applied using different system boundaries depending of the system studied and questions asked. The choice of system boundaries and also method is crucial because it affects what information on environmental performance that actually can be obtained. Different tools could to some extent address different questions and consequently the outcome illustrates varied issues (cf. Roth and Eklund 2003; Roth and Eklund 2004). Searching for information on product related environmental interventions in a wide sense put the focus on life cycle assessment methods.

In order to further emphasis environmental concern in the acquisition process life cycle aspects are addressed, as these would raise the level of ambition. This is because life cycle thinking puts the focus on products and materiel in general and its environmental interventions throughout the entire life cycle. Applying a life cycle perspective in environmental management often implicates an extended experienced responsibility for upstream and downstream environmental impacts (cf. Heiskanen 2002). There is a discussion in this report as to how you could integrate appropriate tools, such as Life Cycle Assessments (LCA) and Life Cycle Costing (LCC), for environmental assessment of purchasing into the acquisition process of defence materiel.

Experiences from LCA of defence materials are limited, however it seems as though standard LCA methodology also could be appropriate for studies on defence materials (Hochschorner and Finnveden 2004). Nevertheless, there are some aspects that may include differences between military and non-military products. Firstly, concerning the type of materials and chemicals used, it could be difficult to find data for either the inventory analysis or the impact assessment steps. This is because the included substances and the total composition of, for example weapons, to some extent are confidential. Also the type of chemicals and materials may be different from non-military products. Secondly, another difference concerns the exposure situation, which may diverge from that of ordinary consumer products, as there exists two very different situations of use of munitions; peace and war. In peace, the main part is stored and the uses of munitions basically mean controlled tests of a small part. Generally, the main part of all purchased materiel is stored in case of a war situation or an international operation. Consequently, there are totally different options in the use and end-of-life phases between these situations. In peace, materiel can be handled to minimise environmental pressure, while a war situation could involve uncontrolled emissions and damages. Furthermore, the damages on land, materiel and humans associated with war situations are not very easily covered in the LCA methodology. Additionally, as the focus of the Swedish Armed Forces has changed to international operations also makes it difficult to assess how the munitions will be used in the future.

During the years the Swedish Defence Research Agency (FOI) has done research to understand and develop the possibilities to incorporate life cycle aspects into the acquisition process of defence materiel, the aim of this report is to deliver a reference work as a guide to how this can be acheived. This is the final report that encompasses informations from projects that have been active for about five years.

1.1 References

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Finnveden, G. and Å. Moberg (2005). "Environmental systems analysis tools - an overview." Journal of Cleaner Production **13**: 1165-1173.

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Roth, L. and M. Eklund (2003). "Environmental evaluation of reuse of by-products as road construction materials in Sweden." International Journal of Integrated Waste Management, Science and Technology **23**(2): 107-116.

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2 Background

Sweden was and is a predecessor concerning environmental thinking in different parts of the society. This has been an incitement for the armed forces to take environmental considerations in their activities. The armed forces started their work in this field with a few reports in the mid nineties. The Swedish Defence Research Agency (FOI) started to work with environmental considerations at about the same time and did a lot of environmental work for the armed forces in the late ninties.

The armed forces have had a unique situation in that they have bought materials for several billions SEK every year. This is to maintain a large body of armed soldiers in the case of an act of aggression from other nations against Sweden. This huge amount of material has not been under the constraint of normal Swedish laws due to the need to defend Sweden. Under the nineties this started to change and the armed forces made an effort to take environmental considerations when planning and working for the defence of Sweden.

The first studies that FOI made were mainly concerned about specific problems in the armed forces such as dumped munitions or other chemical related issues. But soon FOI started to look in a more strategically and societal point of view. This culminated in a few report to the armed forces and the Ministry of Defence (Eriksson, Moberg et al. 2000; Finnveden, Wadeskog et al. 2002; Johansson, Jonsson et al. 2004) concerning the defence sector's indirect environmental aspects. Up to that time and since then, FOI has been deeply involved in the international development on LCA and strategically environmental thinking in the defence sector.

The report on indirect environmental impacts from the defence sector (cf. Finnveden, Wadeskog et al. 2002) can be seen as a jump start for LCA thinking in and around the armed forces. It showed that a large part of the total environmental impact from decisions taken within the defence sector occurs in the production of defence materials. It also showed that another large part comes from the use of defence materials. Thus, there is a large potential to reduce direct and indirect environmental impacts for the Swedish Armed Forces. That is if the defence acquisitions process can be developed so that the environmental life-cycle perspective is considered when environmental impacts are specified in the different phases of the procurement of defence materials.

It was decided that a project should start 2002 to see how life cycle thinking could be used in the armed forces and in their procurement phase. A case study on munitions was executed and included in this study to show the possiblility to execute such a study on military material which hardly had been done before. The project was active for two years and ended in 2004. The results from this were the reports "the use of life cycle assessment in the acquisition process of defence material" Hochschorner and Finnveden (2003) and the case study "Life Cycle Assessment of a PFHE Shell Grenade" Hägvall et al. (2004). The case study showed unexpected results such as that metal were a major contributor to the environmental impact and that the expected impacts from explosives hardly showed at all.

There were several target groups for these reports; actors in the acquisition process of defence materiel and other individuals/groups interested in environmental aspects in public procurement, life cycle assessment, and use of life cycle assessment in procurement (for both public and private organisations). By actors we mean environmental and procurement units at the Swedish Armed Forces (SAF), the Swedish Defence Materiel Administration (FMV) and the Swedish Ministry of Defence, but also industries producing defence materiel, international organs and forms of co-operation. FMV is a target group of special importance due to their key role in the acquisition process.

A new project was started 2004 to continue on the previous research but with the goal to produce an output that could be more easily used by the end users. For this project it was decided to expand the case study into a database and add on more substances. Since it is very time consuming to gather data for the database, it was deemed necessary to make a time cut off and only what was gather to that point was included. It was also decided that all materials with no information were going to be calculated with a Swiss method for calculating LCI data for chemicals (Geisler, Hofstetter et al. 2004).

Parallel with the building of the database a part of the project tried to examine how to use of Life Cycle Costing (LCC) and if possible how to implement environmental considerations into this. LCC is a much more used method of life cycle thinking but does not usually incorporate environmental cost. It is a method to examine the total cost for a product containing the cost of all stages in its life cycle.

The amassed information from the Life Cycle Assessment projects has been compiled and resulted in this reference report for the use of life cycle thinking and similar principles and methods for defence materials. This reference report also includes the data gathered for this study.

2.1 References

Eriksson, N. B., Å. Moberg, et al. (2000). Försvarssektorns totala miljöpåverkan - inledande studier. Stockholm, Swedish Defence Research Agency (FOI).

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3 Public procurement

This part of the report gives a brief description of public procurement, regulations for environmentally preferable procurement, the acquisition process and regulatory documents used by the Swedish Armed Forces (SAF).

When procuring materiel that has not been developed especially for the customer, the development and production phases are not included in the process, and this is called direct procurement (Swedish Armed Forces 1997).

3.1 Procurement in public organisations

Authorities and organisations from the public sector in the European Union (EU) are obliged to follow the directives addressing public procurement (see 3.2.1. below) when they will purchase products and services over a certain economic value (decided by EU). The Swedish Defence is purchasing materiel that often reaches over this threshold value and therefore acquisition of defence materiel must follow the EU directives for public procurement. Procurement in public organisations is different from non-public organisations, depending on these regulations. Other differences apart from regulations are for example (Organisation for Economic Co-operation and Development 2000):

- Public procurement involves many participants in the decision.
- Considerable quantities or values may be involved in public procurement.
- Public procurement is a highly structured and formalised process to determine the characteristics of the products and services to be tendered.

Contracting should be a result of a competitive tendering procedure that starts with a ‘call for tender’. The call for tender includes specifications on bidders and products and can be open or restricted. The search for a contractor has to be announced in the Official Journal of the European Union. Requirements on the products or services are entered in the ‘tendering specifications’, which should also include criteria for selection and awarding of the contract. Selection criteria must be based on economic capability of the bidders and/ or technical specifications. These are used to screen bids in a first review process. Environmental requirements can be formulated as part of the technical requirements in the call for tenders (The European Green Purchasing Network 2003).

The Organisation for Economic Co-operation and Development (OECD) has defined the following public procurement process (Organisation for Economic Co-operation and Development 2000);

1. Specification: Definition of demand, market research, choice of product and volume analysis.
2. Selection: Setting criteria, publication, invitation and supplier selection, proposal or tender application and evaluation.
3. Contracting: Negotiation and definition of agreement.
4. Ordering.
5. Monitoring of contract, individual orders and invoice verification.
6. After-care: Claims, complaints, contract evaluation and new contract preparation.

3.2 Environmental consideration in public procurement

Different organisations have their own meaning of environmental consideration. Depending on the chosen perspective, different strategies and means are usable. The focus can be on one or several aspects, for example chemicals, waste, energy or legal requirements. In addition to environmental concerns, other important aspects to consider when procuring materiel are for example costs, legal requirements, policy and social aspects. Hence, the choice of supplier or product and the decision on requirements on these imply trade-off situations. The possible help from tools in trade-offs is discussed in Byggeth and Hochschorner (2004). Tools can be used in two different ways for procurement purposes, so-called supplier selection or product selection (Baumann and Tillman 2004). In supplier selection, suppliers are compared. In product selection, tools can be used to analyse and compare products and thereby choose supplier. In this work a product selection approach was assumed. If the former approach had been assumed, our suggestions would have been different.

In this report the focus is on tools with a life cycle perspective (Life Cycle Assessments (LCA) and Life Cycle Costing (LCC)). A lot of other tools for taking environmental consideration have been developed; for example guidelines with prescription on important aspects to consider (see for example Luttropp and Karlsson (2001)) or checklists of materials or chemicals that should not be used (see for example (2003a) and Nordkil (1998)). There are also tools including criteria or general requirements on products to procure; a Swedish tool for environmentally preferable procurement called the EKU-tool (see Swedish Environmental Management Council (AB Svenska Miljöstyrningsrådet) (2006) and the Swedish Defence Materiel Administration's (FMV) prescriptions for procurement). The EKU-tool is a database available on the Internet that mainly consists of criteria documents for commonly procured products and services. The criteria are principally ready to use as part of the inquiry in the public procurement process (EKU-delegationen 2002; Swedish Environmental Management Council (AB Svenska Miljöstyrningsrådet) 2006).

Other means for environmental consideration in procurement are to choose products with eco-labels, or to require that the suppliers have Environmental Management Systems (EMS). However, since EMS is a system for the company's environmental work, not addressing a specific product, it is not further discussed in this report. Nevertheless, three different types of eco-labels exist according to ISO 14020 series. Type 1 is voluntary multiple criteria-based eco-labels that are awarded to a product claming overall environmental preferability within a particular product category based on a life cycle perspective (ISO 14024:1999 1999). Examples of type 1 labels are the European Eco-label and the Nordic Swan. Type 2 labels are environmental claims without a third party certification (ISO 14021:1999 1999). Environmental Product Declaration (EPD) is the third type of eco-label. EPD is a declaration of quantified environmental data for a product with pre-set categories of parameters based on life cycle assessments (according to ISO 14040-series) without valuations or requirements to fulfil. The information in an EPD must be based on a life cycle inventory analysis (according to ISO 14041), an inventory analysis with complementary methods or a full LCA including an impact assessment (according to ISO 14042:2000, (2000)). The LCA information can be complemented with other relevant information (ISO TR 14025:2000 2000; Piper, Ryding et al. 2001).

Since acquisition of defence materiel can include the actual production of the materiel to be bought (the process is described below in section 3.3.4), it is important to use a tool that can give guidance for environmentally preferable production and that considers the whole life cycle of the product. LCAs have been used for procurement purposes in the building sector. The use of LCA for building materials is described in, for example, Baldo et al. (2002) and Lippiat and Boyles (2001) where Baldo et al. (2002) use LCA to find criteria for eco-labels and Lippiat and Boyles (2001) combines LCA and LCC in a tool for measuring environmental performance of building products.

3.2.1 Regulations for environmentally preferable public procurement

Laws and regulations control environmental consideration in public procurement, for example The Act on Public Procurement (Lag 1992:1528 om offentlig upphandling, (Sveriges Riksdag 1992b)) in Sweden. The Swedish Act on Public Procurement is based on EU-directives and GPA (Agreement on Public Procurement within WTO, to which Sweden is affiliated) and controls procurement in Swedish public organisations. The Commission of the European Communities has made an interpretative communication on the possibilities for integrating environmental considerations into public procurement (Commission of the European Communities 2001). The following description of environmental consideration in public procurement is mainly based on the Commission of the European Communities (2001).

The main possibilities for performing environmentally preferable public procurement are when deciding on the subject matter of a contract. These decisions are not covered by the rules of the public procurement directives, but are covered by Treaty rules and principles on the freedom of goods and services, notably the principles of non-discrimination and proportionality. How far this is effectively done depends on the awareness and knowledge of the procurement entity, and also environmental or other legislation (Commission of the European Communities 2001) .

The public procurement directives do not cover public procurement below certain economic threshold values (1.4 MSEK for authorities) or secret materiel (per. com. Falkendal 2002). Contracts that are not covered by public procurement directives have a considerable larger freedom to impose desirable requirements. In such cases, the procurement authorities are free to impose requirements and define conditions that go beyond what is possible under the public procurement directives.

For contracts that are covered by the directives, there are two options for awarding the contract: the lowest price and the 'most economically advantageous tender'. As a general rule, the public procurement directives impose two conditions with regard to the criteria applied for determining the most economically advantageous tender. First, the principle of non-discrimination has to be observed and second, the criteria applied must generate an economic advantage for the contracting authority. Awarding the contract is, of-course, also regulated by environmental or other legislation, either community legislation or national legislation compatible with European Community law (Commission of the European Communities 2001). Contracts that are covered by the directives also have to consider the following regulations when taking environmental consideration for procurement (Commission of the European Communities 2001):

- The technical specification of the article to be purchased must according to Directives be included in the general or contractual documents relating to each contract. Technical specifications include all characteristics required by the contracting authority in order to ensure that the product or service fulfils the use for which it is intended. It is possible to include prescriptions of primary materials, production processes, ECO-labels and use of variants in the technical specification, in cases where the subject matter of the contract may not be sufficiently precise and clear to all parties concerned. Such indications must be non-discriminatory and must always be accompanied by the term *'or equivalent'*. There are also some other restrictions, for example regarding production processes, see Commission of the European Communities (2001).

- The most economically advantageous tender must be evaluated in terms of criteria that the contracting authority has indicated beforehand, either in the contract notice or in the contract documents. It is possible to use criteria other than the examples given in the directives, but they must not be discriminatory and they must be economically advantageous for the procurement authority. Economic considerations can include aspects of environmental protection, such as the energy consumption of a product. The evaluation of the most economically advantageous offer implies complex trade-offs, even without consideration to environmental characteristics Commission of the European Communities. Factors that can give rise to trade-off situations are for example: competition, functionality and social aspects (Organisation for Economic Co-operation and Development 2000).
- Environmental considerations are not explicitly mentioned in the current public procurement legislation. However, it is possible to consider for example the consumption of natural resources, by 'translating' this environmental objective into specific, product-related and economically measurable criteria by requiring a rate of energy consumption.
- Costs incurred during the life cycle of a product, which will be borne by the contracting authority, may be taken into account for the assessment of the most economically advantageous tender. When evaluating tenders, a procurement organisation can also take account of costs for treatment of waste or recycling.
- As a general rule, externalities are not borne by the purchaser of a product or service, but by the society as a whole and therefore do not qualify as award criteria as defined above. The Commission notes in this respect that contracting authorities retain the possibility to define the subject matter of a contract or impose conditions relating to the execution of the contract and to integrate their environmental preferences linked to the eventual occurrence of external costs.

In addition to the interpretative communication, the Commission has produced a handbook on green public procurement with examples on how to draw up green calls for tender in conformity with Community law (Commission of the European Communities 2004; Europeiska kommissionen 2005)

.

The Committee for Ecologically Sustainable Procurement in Sweden has developed guidelines to help public sector organisations integrate environmental concerns into their procurement of goods, services and contracts (see EKU-delegationen 2002). This has been done in co-operation with representatives from government agencies, local authorities and county councils. The guidelines are Internet-based and include proposals for environmental requirements that can be applied to about 70 different product groups such as batteries, food, furniture and cleaning services.

The Commission has also made an interpretative communication on integrated product policy (Commission of the European Communities 2003). According to this, it is essential to have a life cycle perspective for products and currently life cycle assessments are the best available methodology to assess the environmental impact of products. A web page containing relevant rules and laws, a product database (with product criteria) and guidance for public procurement will be available at the end of 2004. More information on IPP can be found in (Commission of the European Communities 2003) and at the website http://ec.europa.eu/environment/ipp/ (access: 2006-11-07).

3.3 Acquisition in Swedish Defence

Since the end of the Cold War, Swedish Defence has been undergoing changes, as has the acquisition process. Processes described below may therefore change during coming years. Materiel acquired is used in the Swedish Armed Forces for education, practice and maintenance or stored for use in an emergency situation. It can also be used in international co-operation and for peacekeeping operations. Products include ammunition, aeroplanes, clothes, tools and cutlery. FMV's financial turnover was about 18 billion Swedish crowns in 2005 (http://www.fmv.se/WmTemplates/Page.aspx?id=213 (access: 2006-11-20))

3.3.1 Actors in the Swedish acquisition of defence materiel

The Swedish acquisition process for defence materiel engages actors from both the public and non-public sectors (Materielförsörjningsutredningen 2000), namely:

- The Swedish Parliament
- The Swedish Government
- Swedish Armed Forces (SAF)
- Swedish Defence Materiel Administration (FMV)
- Swedish Defence Research Agency (FOI)
- Industry
- International organs and forms of co-operation

There are a number of documents regulating the process. The connection between actors and these documents is illustrated in Figure 3-1 below. A brief description of each actor and the documents is presented after the figure.

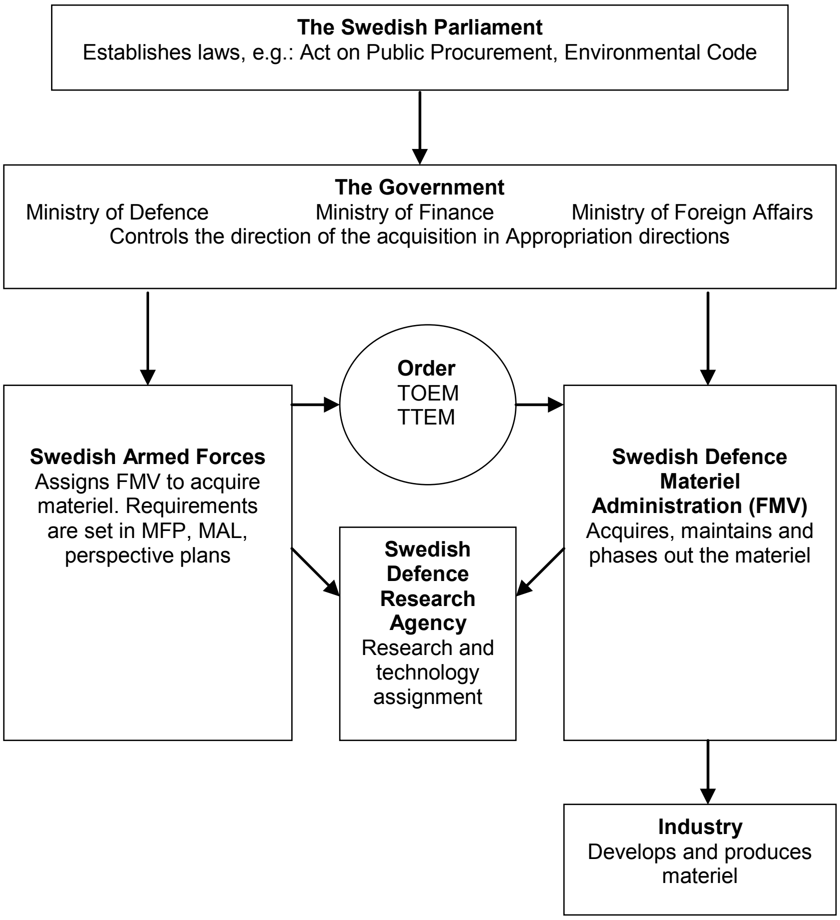

Figure 3-1, Actors in the acquisition process. Based on STYROM (2002).
The arrows indicate decisions; information for the decisions often goes in the opposite direction. Squares are Actors, circles are documents.

The Swedish Parliament's ('Riksdagen') responsibility concerning materiel acquisition is to establish laws. Laws in force regarding materiel acquisition are e.g. *The Act on War Equipment* (see Sveriges Riksdag 1992a) and *The Act on Public Procurement* (see Sveriges Riksdag 1992b) .

The Government informs and makes suggestions for the decisions of the Parliament. It controls the acquisition process by instructions, rules, general conditions, and formulation of assignments to the authorities. The Government strongly emphasises the need for international co-operation, especially when planning for new military systems.

The orientation of the acquisition-process is controlled in *The Appropriation Directions to the Armed Forces* ('regleringsbrevet till försvarsmakten'), where requirements on aims and results are stated. A long-term control of the acquisition process is also made by indication of the acquisitions alignment. The Act on Public Procurement controls the commercial activities (STYROM - Styrning och Organisation av Materielförsörjningen 2002).

Acquisition for the Armed Forces is made on the basis of *The Plan for Supply of Materiel* ('MFP, materielförsörjningsplanen'). In the *Appropriation Directions*, the Government gives directions regarding which systems in the MFP the Armed Forces should introduce to the

Ministry of Defence before ordering. This occurs, for example, when the total acquisition value for an individual system amounts to 50 million SEK or more.

The preparation of acquisition matters is a joint effort between the Ministry of Defence, the Ministry of Finance and the Ministry of Foreign Affairs. The preparation includes contacts with industry concerning, for example, the strategic conditions for production of military systems in the country and different aspects of the internationalisation of the industry.

The Ministry of Defence has regular dialogue with the Armed Forces and the Defence Materiel Administration concerning acquisition and planning of support of materiel. The Ministry of Defence also contributes to a large extent to the international co-operation of security and defence policy.

The Ministry of Foreign Affairs co-ordinates the Government Offices' security policy aspects within the international co-operation. The Ministry also co-ordinates matters of promotion and control of defence materiel export.

The Ministry of Finance co-ordinates aspects of economic policy of importance for the acquisition process. (Materielförsörjningsutredningen 2001)

The Swedish Armed Forces (SAF)
The Armed Forces place an order for the requirements of a research, development, or acquisition assignment with attendant funding to the Defence Materiel Administration (STYROM - Styrning och Organisation av Materielförsörjningen 2002).

Acquisition in the Armed Forces is made on the basis of the established terms of reference in *The Plan for Supply of Materiel (MFP)* and *The Plan for Supply of Land, Installations and Premises* ('MAL (mark, anläggning och lokaler)- försörjningsplanen'*)*. Acquisition can be made as step-by-step procurement or direct procurement (Materielförsörjningsutredningen 2001).

The fundamental analysis and planning activity is carried out within the *Perspective Plans.* The work with the plan is reported annually to the Ministry of Defence and is a basis for the Government's long-term decisions.

The Swedish Defence Materiel Administration (FMV)
From a systems perspective, the Swedish Defence Materiel Administration (FMV) is responsible for cost-effectively providing the Armed Forces with military materiel. FMV acquires, maintains and phases out materiel and supplies on assignment from principally the Armed Forces.

The National Fortification Administrations (Fortv)
The National Fortification Administration administers and rents out defence properties, and is responsible for management of these properties. It is a government agency under the Ministry of Finance. This report does not focus on the work done by the National Fortification Administration.

The Swedish Defence Research Agency (FOI)
The Armed Forces and the Defence Materiel Administration can get support for studies of the operational capabilities and structure of the materiel from FOI. The research carried out by

FOI can, for example, help FMV and SAF to specify performance of the materiel, which is important in order to reduce risks and environmental impacts.

Industry

Swedish-based contractors supplying systems to the Swedish Defence include: Alvis Hägglunds AB, Bofors Defence AB, Saab AB, Ericsson Microwave Systems AB and VOLVO Aero Corporation. A number of large contractors are also found in the European Union, in the US and elsewhere in the world.

International organs and forms of co-operation

Swedish Defence co-operates with many organisations within the area of defence materiel, for example the Western European Armaments Group (WEAG). The actor in charge of the co-operation is the Swedish Government, represented by the Swedish Defence Materiel Administration (Materielförsörjningsutredningen 2000)

3.3.2 Regulatory documents in the Swedish acquisition of defence materiel

The acquisition process is regulated by a number of documents, some of which are:

- Appropriation Directions ('Regleringsbrev')
- The Plan for Supply of Materiel ('MFP, materielförsörjningsplanen')
- The Plan for Supply of Land, Installations and Premises ('MAL-försörjningsplanen')
- The Perspective Plan ('perspektivplanen')
- The Objectives Handbook ('Handbok MÅL')
- Tactical Organisational Economic Goal (TOEM)
- Tactical Technical Economic Goal (TTEM)
- Agreement on Co-ordination ('Samordningsavtal') between the Swedish Armed Forces and the Defence Materiel Administration
- Environmental regulatory documents (listed separately below).

Appropriation Directions:

The Government controls the direction and funding of the acquisition process through the Appropriation Directions. Long-term control of the acquisition process is also achieved by indication of the acquisitions alignment (STYROM - Styrning och Organisation av Materielförsörjningen 2002). The Ministry of Defence prepares the Appropriation Directions.

The Plan for Supply of Materiel and the Plan for Supply of Land, Installations and Premises:

Acquisition for the Armed Forces is made on the basis of *the Plan for Supply of Materiel (MFP)*. In the Appropriation Directions, the Government gives directions regarding which orders in the MFP the Armed Forces should introduce to the Ministry of Defence before ordering. The Swedish Armed Forces establishes terms of reference for procurement in MFP and *the Plan for Supply of Land, Installations and Premises (MAL)* (Materielförsörjningsutredningen 2001).

The Perspective Plan:

The Perspective Plan is drawn up by the Swedish Armed Forces. Perspective studies cover a period of 15-20 years into the future and result in *Perspective Plans* with proposals for the future goals of the military defence and war organisation. The development of the Armed Forces over a maximum of 5+5 years is directed by *Programme Plans*. These are discussed annually and are elaborated on the basis of the existing war organisation and with a direction towards the long-term aim indicated.

The Objectives Handbook:

The Objectives handbook gives directions for the development of the military organization, on the basis of conditions and demands from the Armed Forces' operative planning and production in peace. It describes, among other things, goals for units, supplies and constructions, the process and co-ordination of the acquisition process and the work with TOEM and TTEM.

Tactical Organizational Economic Goal:
Type units should have a unit goal called the *Tactical Organizational Economic Goal (TOEM).* With TOEMs for units as a basis, the necessary *Tactical Technical Economic Goals (TTEM)* for supplies are prepared. TOEMs are written by the Swedish Armed Forces.

The process step-by-step is normally:
1. Draft goals (UTOEM)
2. Preliminary goals (PTOEM)
3. Final goals (TOEM)

Tactical Technical Economic Goal:
Tactical Technical Economic Goal (TTEM) is based on TOEM and a description of the aggressor, standardised for the object or system with tactical, technical, economic, combat and environment studies and investigations. The goal expresses the relationship between effect and costs of procurement, support and disposal respectively. It also serves as a basis for specification of performance characteristics; quality and capability to meet the units' needs and serves as a basis for contracts with suppliers (through FMV).

According to the Objectives Handbook (Swedish Armed Forces 1997) TTEM is used as a basis for:
- Specification of performance, quality and capacity to provide the needs of the units,
- Submitting a tender and ordering (from FMV, Fortv and others),
- Contract with suppliers (made by FMV, Fortv and others),
- Studies, investigations, projecting, development and production, and also liquidation of materiel and constructions.

TTEM is written by the Swedish Armed Forces in co-operation with FMV and should be available when a decision for investment is made and before the procurement is initiated (ibid.).

TTEM should be prepared and decided by a central production leader.
If necessary, co-operation is initiated with the authorities concerned outside the Armed Forces.

TTEM exists in three versions:
1. UTTEM (draft) indicates the direction for industrial studies and system plans.
2. PTTEM (preliminary) serves as a basis for investigation and development activities and long-term planning. PTTEM should be to hand when a decision for development is taken.
3. STTEM (approved) serves as the operational and tactical requirements in the assignment to FMV.

Agreement on co-ordination

This is an agreement to co-ordinate relations and routines between the Swedish Armed Forces and the Defence Materiel Administration, regarding research and technology development, acquisition of materiel and constructions, technical services, land and constructions. According to this agreement FMV should apply 'Guidelines for Environmental Supply of Defence Materiel' (for a description of the Guidelines, see below). Chemical substances must also be approved by the Swedish Armed Forces's chemical group.

Environmental documents to be considered during the acquisition process of defence materiel are:

- **The Environmental Code (Miljöbalk 1998:808)** (Sveriges Riksdag 1998)
- **The Defence Sector's Environmental Goal** ('Miljömål för försvarssektorn och arbetet för ekologisk hållbarhet' (Swedish Armed Forces 1999)).
- **Nordic Agenda 21 for the Defence Sector** (Swedsih Ministry of Defence 2002)
- **Guidelines for Environmental Acquisition of Defence Materiel:** (Swedsih Ministry of Defence 1998)
- **Guidelines on the Acquisition of Environmentally Sound Defence Procurement** (NATO/PFP 2001) should be considered in international co-operation-projects.
- **Environmental Policy of the Armed Forces,** (SAF) the policy is available at: http://www.mil.se/article.php?id=9643, acsess: 2006-11-20
- **Environmental Policy of the Defence Materiel Administration,** the policy is available at: http://www.fmv.se/WmTemplates/Page.aspx?id=1368, access 2006-11-20
- **System Safety Handbook by the Swedish Armed Forces** ('Försvarsmaktens handbok för Systemsäkerhet, H SystSäk' (Swedish Armed Forces 1996))
- **Environmental Handbook by the Swedish Armed Forces** ('Handbok miljö för Försvarsmakten, H Miljö' (Swedish Armed Forces 2003)).
- **FMV's Criteria for Chemical Substances,** (FMV 2003a)

The Environmental Code (Miljöbalk 1998:808)

The Swedish Environmental Code was adopted in 1998 and entered into force on 1 January 1999, bringing together 15 existing central environmental laws. The aim of the Environmental Code is to promote sustainable development based on the understanding that nature is worthy of protection in its own right, and that man's right to exploit nature carries with it a responsibility. The Environmental Code is further elaborated on and specified in the form of ordinances, regulations issued by public authorities and decisions taken in individual cases. (Sveriges Riksdag 1998)

The code is available in English at: http://miljo.regeringen.se/pressinfo/pdf/ds2000_61.pdf .

The Defence Sector's Environmental Goal

Based on the national environmental objectives, the Swedish Armed Forces has been assigned by the government to develop environmental objectives for the defence sector. According to this assignment, the economic consequences for society concerning benefits and costs caused by the measures must also be presented in relation to the measures and possible effects and scope of the objectives. (Swedish Armed Forces 1999)

Nordic Agenda 21 for the Defence Sector

The defence ministers in Denmark, Finland, Norway and Sweden have formulated an environmental policy with 21 superior objectives for authorities in the defence sector in Nordic countries. The objectives have been made with the intention of fulfilling Agenda 21, adopted at United Nations conference on environment and development in Rio de Janeiro 1992. One of the 21 objectives is to set up and implement environmental requirements in acquisition of materiel and buildings. The objectives can be found in full in (Swedish Ministry of Defence 2002).

Guidelines for Environmental Acquisition of Defence Materiel
The Swedish Government decided in 1998 that FMV and SAF should apply guidelines for environmentally sound procurement. The guidelines state, among other things, that FMV and SAF should stimulate the defence industry to develop environmentally preferable products and processes and that chemical products should be decreased and environmentally hazardous substances replaced with less hazardous substances (Regeringen 1998). The guidelines are available in Swedish at: http://www.fmv.se/WmTemplates/Page.aspx?id=723, access: 2006-11-20

Guidelines on the Acquisition of Environmentally Sound Defence Procurement
Guidelines developed for the armed forces of the North Atlantic Treaty Organization (NATO) and the Partnership for Peace (PfP) countries should be considered in international co-operation projects. The aim of the guidelines is to ensure that defence materiel complies with obligations in the field of environmental protection and has minimal environmental impacts throughout its entire life cycle (NATO/PFP 2001).

Environmental Policy of the Armed Forces
The overarching objective for the armed forces is to prevent war and thereby avoid the catastrophic environmental destruction a war causes. In peacetime the objective should be fulfilled within the environmental regulations and with the lowest possible environmental impact by taking environmental consideration during all planning and operation, minimising use and spread of substances that are unfamiliar for nature, minimising use of energy and non-renewable resources, using resources sparingly and minimising waste, striving for continual improvements in the environmental field, limiting the spread of noise, promoting biological variety, involving all personnel in the environmental work and assisting society in the event of an environmental catastrophe (SAF). The policy is available at: http://www.mil.se/article.php?id=9643, acsess: 2006-11-20

Environmental Policy of the Defence Materiel Administration
FMV´s environmental policy states that FMV should continuously achieve improved environmental performance and prevent pollution by: being the most knowledgeable on environmental defence materiel issues, considering environmental issues during the whole materiel supply process, demanding that suppliers and those submitting tenders have their own active environmental work and that they develop environmentally sound products and processes, making sure that environmental legislation is observed and contributing towards other legislation being favourably developed from an environmental point of view, improving internal activities and developing the defence sector's environmental activities in co-operation with the Armed Forces. The policy is available at:
http://www.fmv.se/WmTemplates/Page.aspx?id=1368, access 2006-11-20

System Safety Handbook by the Swedish Armed Forces ('Försvarsmaktens handbok för Systemsäkerhet, H SystSäk')

The System Safety Handbook contains SAF´s internal regulations and guidelines for safe operation of the defence system (Swedish Armed Forces 1996).

Environmental Handbook by the Swedish Armed Forces
The Environmental Handbook (Swedish Armed Forces 2003) is intended as a guideline for directors and environmental administrators within the Swedish Armed Forces. One section of this handbook is about environmentally preferable acquisition and environmental requirements. The handbook points out the importance of considering the whole life cycle of the materiel and of having relevant environmental requirements. Criteria should be established to evaluate the requirements. If a specific criterion is to be fulfilled, it has to be stated in the inquiry. Tools that can be used to set relevant environmental requirements are, according to the handbook: Environmental Product Declarations (EPD), Life Cycle Assessments, a tool made by the Committee for Ecologically Sustainable Procurement in Sweden and eco-labels (Swedish Armed Forces 2003). All these tools except for EPD are discussed in this report.

FMV's Criteria for Chemical Substances (FMV 2003a) are discussed in section 3.4.2.

3.3.3 Environmental requirements in the documents regulating the acquisition of defence materiel

The Swedish Government decided in 1998 that the Armed Forces and the Defence Materiel Administration should apply 'Guidelines for Environmental Supply of Defence Materiel'. Thereby environmental consideration is to be taken in all phases of the acquisition process (The phases concerned are studying, development, further development, procurement, maintenance and phasing out) (Swedish Armed Forces 2001). These guidelines, together with FMV's environmental policy, must be attached to all acquisitions over 75 000 SEK (FMV 2003b).

A working-group with participants from SAF and FMV has given the following suggestions to improve the work on environmental acquisition (Swedish Armed Forces 2001):

- Environmental requirements should be included in the TTEM,
- Relevant environmental requirements for operation of the materiel should be used for procurement.
- Requirements should be placed on the industry to give instructions for environmentally preferable dismantling of defence materiel.

A second working group, with participants from SAF, FMV, FOI, the Swedish Environmental Protection Agency and industry, has further specified these suggestions. This working group made a suggestion on environmental requirements to be incorporated in *The Objectives Handbook (HMÅL),* and thereby included in the TTEM. They suggest that the work in the study phase should be completed and adjusted so that a future objective for the outer environment is integrated in the work with the threatening picture and that it should be analysed if the requirements are to be incorporated in the agreement on co-ordination between SAF and FMV (Swedish Armed Forces 2001).

The work resulted in the following suggestions for environmental requirements. Requirements shall be formulated so that the materiel systems:

- Have **low resource use**, through low energy use, use of renewable sources of energy and effective material use during the whole life cycle of the system.

- Become **recyclable** by construction for future phase out, use of as few types of materials as possible, marking for facilitating separation of materials and also establishment of material specifications.
- Contain a **minimum of hazardous substances** by reducing the quantity of chemical products, by minimizing the use of environmentally hazardous chemicals, by minimizing the use of solvents and products with solvents, by eliminating the use of CFC, HCFC and Halon. New chemical products shall be reported to the Defence Chemical Group before introduction into service. All chemical products used shall be registered in the Defence Index of Hazardous Substances.
- Contain a **minimum of radioactive substances** by minimising or avoiding these forms of substances.
- Have **low levels of emissions** during operation, by reducing emissions of:
    - nitric oxides, hydrocarbons, sulphur oxides, carbon dioxide and particles to air.
    - hydrocarbons, nitrogen, phosphorous compounds and discharge to water from ships and boats, nitrogen and phosphorous compounds and also petroleum spill to ground.
- Have **low noise levels** while running ships, vehicles and aeroplanes and also while firing guns.
- **Minimise other environmental impacts** e.g. minimisation of damage to land, seashore and sea bed.

The requirements are intended to be discussed and balanced during the acquisition process, like the other requirements such as tactical, technical, and economic requirements. FMV are suggested to elucidate and develop the environmental requirements for each materiel system, where appropriate (Swedish Armed Forces 2001). The second working group also suggested that life cycle assessments (LCA) can be performed for some reference products in different materiel systems in order to identify considerable environmental aspects and facilitate the work with environmental requirements for specific materiel systems. The use of LCA in the acquisition process is further discussed in the next paragraph.

The manuals for use, maintenance and storage of a material system shall, according to the working group, include environmental information. As an example the manual for maintenance of an airplane should include environmental risks that can arise in a possible crash, for example dangerous gases in the event of fire. A risk assessment on the environmental impacts can be needed to complete the manual (Swedish Armed Forces 2001).

Environmental impacts in the disposal phase should, according to the working group, be observed when developing and designing the materiel system. If environmentally hazardous substances can not be avoided in some components, such components shall be marked and it should be possible to dismantle and take care of them separately. Specifications for the materiel systems should include materials and hazardous substances that are used in the materiel (Swedish Armed Forces 2001).

FMV has developed the following requirements on the supplier’s environmental work and on products to be purchased. The requirements on the supplier’s environmental work are within these areas (FMV 2003c):

- **Substances that are dangerous to environment and health;** the supplier shall account for the amounts and placing of environmentally hazardous substances within the product. Attention shall be paid to FMV's criteria for chemical substances (see section 2.3.4.). The supplier is responsible for replacing substances that are not allowed with substances allowed according to law and approved for the materiel system. The supplier shall draw up a plan on how to replace unwanted substances. When delivering chemical products, the supplier shall provide a safety data sheet that fulfils requirements by the Swedish Chemicals Inspectorate. When phasing out the materiel system, environmentally hazardous substances shall be dismantled and taken care of separately.

- **Batteries;** The supplier shall account for all batteries (even in-built) within the materiel system. This shall include information on the type of battery and placement in the system. The supplier is required to work actively with choice of batteries. This work shall be included with the tender. If the supplier is Swedish and imports batteries, the supplier is required to account for battery fees paid. Rejected batteries (separate or built-in) must not be stored in or together with other disposals. The handling of batteries shall be accounted for.
- **Electronics;** The supplier shall account for electronics within the materiel system and their choice of electronics. When phasing out the system, a deeper analysis of electronic products should be made to distinguish environmental and hazardous substances in order to suggest measures to reuse or recycle substances with profitable economic values.
- **Producer responsibility;** The suppliers, producers or importers shall take care of finished products. Today in Sweden, producer responsibility exists for packaging, waste paper, tyres, cars and electric and electronic products (only for offices and households). When procuring from a Swedish supplier, the supplier is required to account for the producer responsibility. When phasing out the system, requirements shall be set on materiel that is covered by producer responsibility to be sorted out and delivered to the producer's collecting system.
- **Protection against radiation;** When ionising radiation is included in the system permission according to the Radiation Protection Act (1988:220) (Sveriges Riksdag 1988) shall be presented. The supplier shall account for all sources of radiation and their placement in the system. Sources of radioactive radiation shall be handled as radioactive disposal, and shall be taken care of by a company approved by the National Institute for Radiation Protection. The requirements shall state that radiation sources be dismantled and taken care of by an approved company.
- **Energy consumption;** The supplier shall account for the system's energy consumption. They shall also show their systematic work to reduce the system's energy consumption.
- **Emissions and noise;** The supplier shall account for emissions (to air, ground, water and noise) that the system causes. They shall also show their systematic work to reduce emissions.
- **Education for users;** The supplier shall provide information on how to reduce the system's environmental impact.

In the technical specification of the product, the requirements shall guarantee that Swedish environmental and working environment laws are followed, that use of the products follows the permission for the place of use, that the goals for the sector can be achieved and that international agreements of co-operation can be followed (FMV 2003b). The technical specification shall include requirements on FMV (2003b):

- **Substances that are dangerous to environment and health;** Products shall not contain substances that are forbidden according to Swedish law or FMV's criteria for chemical substances. The requirements shall also state which substances should be avoided as far as possible according to FMV's criteria. A safety data sheet shall be included in the tender. This shall be made according to Chemicals Inspectorate Directions KIFS 1998:8. In international co-operations, the most restrictive laws shall be followed according to NATO/PFP and the Nordic Agenda 21.
- **Batteries;** Batteries containing mercury are not allowed, and batteries that contain cadmium and lead should be avoided.
- **Electronics;** The requirements shall state that electrical components follow FMV's criteria for chemical substances.
- **Choice of construction material;** When choosing a material, it shall use few resources, be recyclable/ reusable and not contain substances that are dangerous to the environment or health.
- **Energy consumption;** Components and systems that in general use little resources and energy in the phases from idea to phasing out shall be prioritised.
- **Emissions and noise;** Emissions and noise from the product shall be lower than the Swedish Defence current permission for environmentally hazardous activities. When replacing an old system with a new one, emissions from the new system shall be lower than those from the old.
- **Protection against radiation;** Ionising radiation shall be avoided as far as possible. If radiation sources consist within the system, is the aim that they should have as low activity as possible.
- **Requirements for future phasing out;** Systems, parts of systems and components shall be easy to identify and dismantle. It should be possible to reuse or recycle the materials to a high degree. To make recycling easier, the materiel should consist of few materials that are easy to separate from each other.

It can be noted that environmental requirements are not formulated on all products purchased by FMV. Currently approximately 50 % of the economic value of purchases includes some sort of environmental requirement (FMV 2002).

3.3.4 The acquisition process

The acquisition process in the Swedish Defence Material Acquisition Agency (FMV) is constantly under development. The two processes described below are thereby a construction taken direct from FMV. The process for acquisition in FMV is made out of two models, the commission and the product model. The commission model (Figure 3-2) describes how FMV works between the commissioner (Swedish Armed Forces) and the supplier (Industries). This is the working model in all acquisition processes for FMV. The purpose of the commision model (Figure 3-2) is to control with decision gates, plans and operation of a specific commission. The prospect is to take care of customers order and internal orders.
The commission model contains four phases in the case of procurement, these are planning, tender, procurement and end phase. The main purpose of this model is to ensure that the customer (SAF) receive the correct product/service at the end of the procurement.

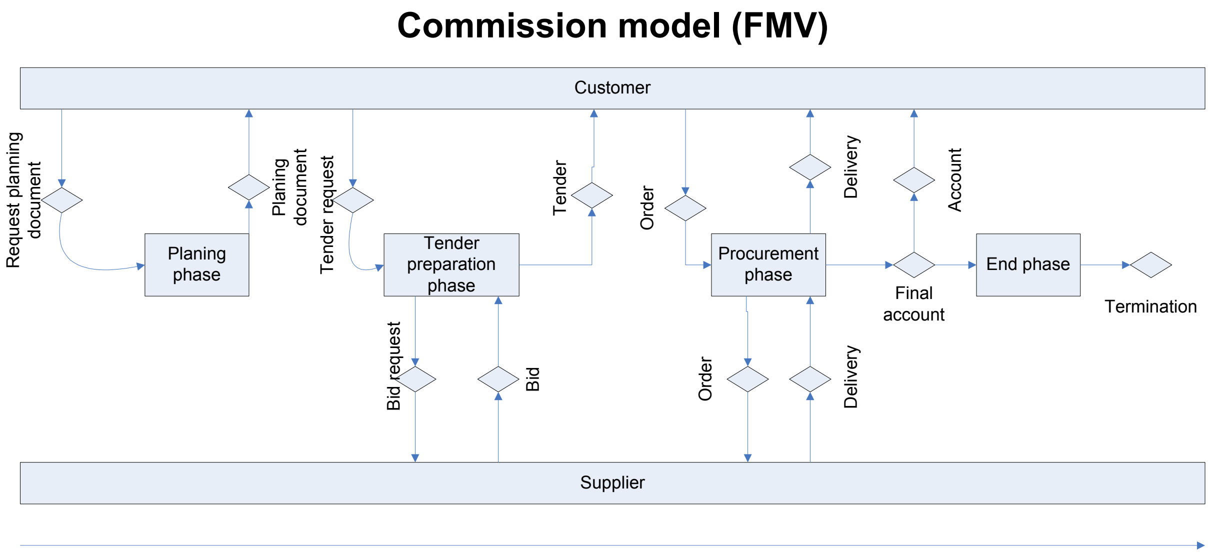

Figure 3-2, The Commission model that are used by FMV, with the different phases (squares) and different document transfers (rhomb).

The second model the product model describes how FMV works when the product is not already produced (Personal contact Joakim Thornéus 2006-04-25). The product model is the model for generating new products for the armed forces. The model has six different phases as can be seen in Figure 3-3. These phases are concept generating, concept evaluation, definition and demonstration, procurement, sustainment and, finally, phase out. Each of these is described in greater detail below.

Product model

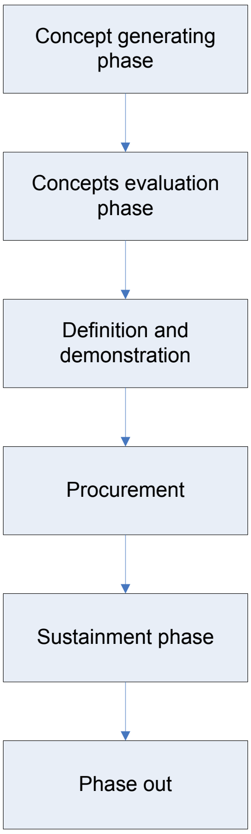

Figure 3-3, The product model, describes how FMV works with a new product from idea to end of life.

Firstly, the concept generation (Figure 3-3) is a stage with the purpose to identify a need or an idea of a new system or change of an existing system. One or several system solutions are examined through studies, analysis and examinations to be sure that the identified needs are met.
The result from this stage is:

- Identification of new system concept or maintenance concept
- Identification of interested parties demands and preliminary systems demands
- Identification of risk
- Identification of services that are needed from in support from support system during the whole systems life cycle
- Concept for execution of all following phases
- Plans for concept evaluation phase
- Approval to advance to evaluation phase

The phase concept generation includes deciding demands from interested parties, analyse these demands and to prepare suggestions of system solutions that are compared to the demands and the integration into architectures and or infrastructures.

Secondly, the concept evaluation phase (Figure 3-3) has the main purpose of the concept evaluation phase is to evaluate the previous developed system concept according to their implement, use, maintenance, and disposal in a life cycle perspective.

The outputs from this stage are:

- The declaration of interested parties demands
- Results from the evaluation on the system concept
- Preliminary systems demands
- Specific goals for coming stages
- Plans for the development phase
- Approval of continuing into the development phase

From the customers decided frames and demands evaluate the concepts from a number of perspective as for example implementation, economics, systems safety, technical, maintains and market possibilities and limitations, risk and adaptation to existing architectures and integration into the infrastructure.

Thirdly, the definition and demonstration phase (Figure 3-3) has the purpose to develop a system that meets the interested parties' demands and that it is possible to construct, verify, use and dispose of.

The output from this stage is:

- Decided system architecture
- Decided functional baseline
- Calculated life cycle cost (economical)
- Verification and validation plans
- Decided demands for support systems
- Approval to continue to procurement phase

Based on decided demands systems solutions and their interfaces and relations to cooperative systems and infrastructures including plans for verifications. Starting from demands and systems solution do maintenance analyses, develop plans for functionality growth and implementation and perhaps the disposal of the existing system, integration, verification and validation. In certain cases the customer demands that FMV shows the function as a demonstration. In such cases a demonstration is given to the customer and handled according to the procurement phase.

The definition and demonstration phase is initiated with a detailed enough specification of the systems demands and design solutions, that are altered to one ore more products that make it possible to provide a service throughout the use. The system can be a prototype during this stage.

Fourthly, the procurement phase (Figure 3-3) objective is to produce products that are verified and approved before use. In this phase the procurement, integration, verification/validation are performed, also the sustainment functions for the system are produced.

Fifthly, the sustainment phase (Figure 3-3) main objective to give logistics, maintenance and runtime support services
The following outputs are possible from this phase:

- Technical orders
- Status reports
- Runtime follow-up report
- Action plan

- Action decision

Finally, the disposal phase main objective is the disposal of a system/product, which has been decided to be removed from active duty, with related runtime and maintenance services.

The output from this stage is:

- The specified system is demilitarized, disposed, reused etc
- Plans to move services to another or new system

In this phase suggestions are made for disposals or decisions and also execution of or support to the customer in the actual disposal.

The disposal phase includes the disposal of a system or product. The phase is applicable when a system has reached the end of its life cycle and is initiated by a decision of for example:

- to replace a existing system with another or new system
- that the system is not cost effective to maintain, repair or modify
- that the system no longer is of use to the user

The plan for the disposal shall be done in previous phases, for example in the Procurement phase.

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4 Tools in life cycle management

This chapter gives examples of approaches and tools relevant in the area of life cycle management (LCM) and procurement.

4.1 Life cycle management and life cycle thinking

Life cycle management (LCM) is a framework and a practical but comprehensive approach aiming to bring product focus into environmental management. Currently, there are no consensus on a definition of LCM, but several attempts to descriptions. One example is provided by Hunkeler (2004) who describes LCM as corporate strategies to implement better environmental practice with the means to fit into the present organisation and with continuous improvement of environmental as well as economic aspects. Further, the UNEP Life Cycle Initiative provides a Guide to LCM and formulates it as "manage the total life cycle of an organization's products and services towards more sustainable consumption and production" (http://lcinitiative.unep.fr/, access 2006-12-01). LCM is also voluntary and flexible, why a key procedure for success in an organisation is to integrate LCM activities into existing structures and systems at all levels in the organisation (Hunkeler, Saur et al. 2004). In order to fulfilment of the ambition that LCM should be helpful in corporate decision making, it is important to use quantitative but also qualitative indicators that are validated and could communicate progress (Hunkeler, Saur et al. 2004). In the case studies briefly presented in Hunkeler (2004) several entry gates into an organisation and also drivers of LCM, were identified. One mentioned entry gate and additionally a driver for LCM is procurement (ibid.[1]). Other examples of entry gates were: the environmental, health and safety department, research and development, top management, production, and sales and marketing. While the drivers, mainly external environmental drivers, such as, global warming, waste generation, loss of biodiversity, protection of human health and the environment from persistent organic pollutants (POPs), market drivers, public and private procurement, society and legislation were presented.

In addition, applying LCM means to thinking in life cycles, i.e. gathering information on environmental aspects from cradle to grave, as a model when addressing environmental issues. This can be done using more or less accepted and standardised methods such as Life cycle assessments (LCA) or Life cycle costing (LCC). While LCA methods are constructed to address the entire (physical) life cycle of products and product systems (cf. ISO 14040:1997 1997), applying the underlying ideas of thinking of environmental issues in terms of consequences of activities in the product life cycle could be termed life cycle thinking (cf. Heiskanen 2002). Life cycle thinking is one way to address environmental issues without using a specific method and an approach to structure environmental consequences, concerns, responsibilities, environmental management et cetera (ibid.).

4.2 Life cycle assessment

Life cycle assessment (LCA) is the compilation and evaluation of data on inputs, outputs and potential environmental impacts of a product system throughout the life cycle. Life cycle includes mining of raw material, production, use and disposal of a product (ISO 1997). The term 'product' includes physical products as well as services. LCAs are often used as comparative studies. However, it is not the products that are compared, rather the function of the products. The assessment is standardised in the ISO 14040- series (ISO 14040:1997 1997;

[1] Ibid. (Ibidem) is a latin expreion that means "on the same place". It is used in papers, thesis etc as an acronym when several references from the same place exist two or more times after each other.

ISO 14041:1998 1998; ISO 14042: 2000 2000; ISO 14043: 2000 2000). A guide to the standards has been made by (Guinée, Gorrée et al. 2002).

The analysis is performed in four steps: i) *definition of goal and scope*, ii) *inventory analysis*, iii) *impact assessment*, iv) *interpretation* (Figure 1; Guinée et al. (2002).

Definition of goal and scope: The goal of the study should be explained, the intended use of the results, the initiator of the study, the practitioner, stakeholders and intended users of the results should be specified. A scope definition establishes the main characteristics of an intended LCA study, for example a technical or a geographical study. The function, functional unit alternatives and reference flows should be defined in this phase.

Inventory analysis: The product system is defined in the inventory analysis. The definition includes setting the system boundaries, designing the flow diagrams with unit processes, collecting data for each of these processes, performing allocation phases for multifunctional processes and completing the final calculations. The main result is an inventory table listing the quantified inputs and outputs to the environment associated with the functional unit, for example x kg carbon dioxide per studied unit.

Impact assessment: The results from the inventory analysis are further processed and interpreted in this Life Cycle Impact Assessment (LCIA). This phase includes classification, characterisation and the optional phases of normalisation, grouping and weighting. A list of impact categories is defined that is used to classify the results from the inventory analysis, on a purely qualitative basis. The actual modelling results are calculated in the characterisation phase. The optional normalisation serves to indicate the share of modelled results to a reference, e.g. a worldwide or regional total. The results can be grouped and weighted to include societal preferences of the various impact categories.

Interpretation: The results from the analysis, all choices and assumptions made in the analysis are evaluated, in the interpretation, in terms of soundness and robustness. Conclusions are drawn and recommendations are made.

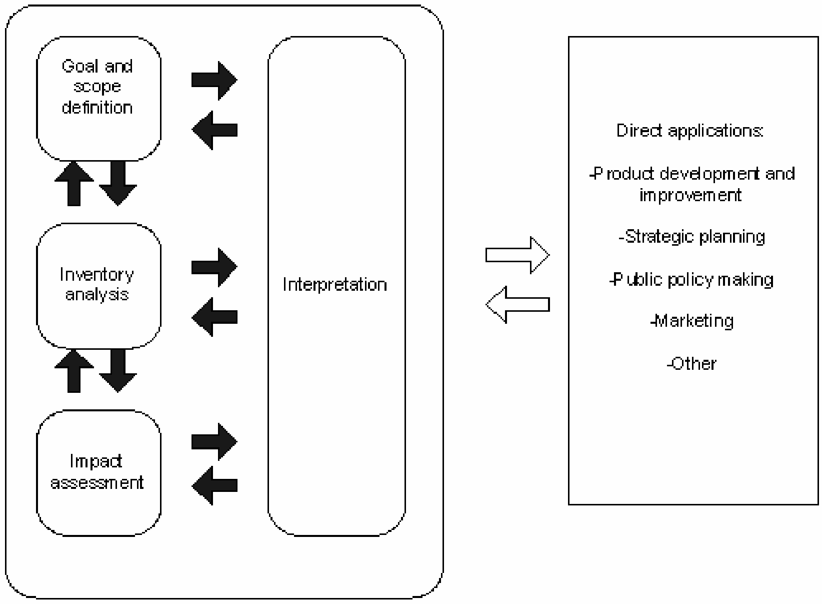


Figure 4. The framework for life cycle assessment based on the ISO standard 14040 (ISO 14040:1997 1997) and its possible applications.

A LCA can be qualitative, quantitative or semi-quantitative. LCA performed according to the ISO standards (Figure 1) is an iterative process and mainly based on quantitative data. However, it is often not possible to find as much quantitative data as required. Therefore, qualitative data and estimations are necessarily included to create a more comprehensive picture. It is also possible to consider quantitative information in a qualitative LCA when such is easily accessible (Johansson, Finnveden et al. 2001).

The step of *Impact assessment* briefly explained in the list above encloses parts of the procedure of LCIA that are compulsory such as classification and characterisation and parts that are voluntary according to the ISO 14040 standards, i.e. normalisation, grouping and weighting. Developing such methods for a quantitative LCA includes many processes and vast amounts of data on inputs and outputs. However, once they are developed their use is straight forward. In the computer-based programs available for performing LCAs there is characterisation methods and some weighing methods implemented. As an example we will refer to the impact assessment baseline approach that is recommended as characterisation method in the Operational guide to LCA produced by Guinée et al. (2001). This approach defines the impact categories at the midpoint on the cause effect chain of environmental problems, i.e. a problem-oriented approach, in contrast to the end-point approach, which refer to damage (ibid.). These baseline impact categories, into which the inventory result should be translated, are:

- depletion of abiotic resources,
- impact on land use,
- climate change,
- stratospheric ozone depletion,
- human toxicity,
- eco toxicity,

- photo oxidant formation,
- acidification and
- eutrophication.

Further, study-specific impact categories and other could be included if it is demanded according to the goal and scope of the LCA study. This could be loss of life support function, loss of biodiversity, freshwater sediment eco toxicity, marine sediment eco toxicity, odour and noise. Also Pennington et al. (2004) gives a brief overview of examples of commonly used impact categories, which all are represented in the text and the list above. In LCIA the impact categories could be summarized in four larger areas of protection (AoP) (cf. Udo de Haes and Lindeijer 2002), which are

- human health,
- natural environment (resources and life support function, climate regulation, soil fertility),
- natural resources, and
- man-made environment (monuments, forest plantations)

The aggregation of impact categories into AoPs can be used as a step in order to aggregate all impact categories into one single indicator, for example a monetary value.

As noted above, one of the first steps in the LCIA is to qualitatively classify all inventory data into the decided categories and thereafter transfer these into one and the same unit or equivalent for each impact category. This latter is done by using characterisation factors for midpoint (or the endpoint) approach, available in, for example, the Operational guide to LCA (see Guinée 2001). Furthermore, some LCIA methods including characterisation factors are implemented in LCA software (for example SimaPro). Additionally, these software implemented methods, such as EPS, Ecoindicator and Ecotax, also offer weighting approaches for LCIA. These weighting methods emphasising different values, for instance, while one emphasise climate change another may prioritise water quality, i.e. different methods weight environmental impact categories differently. They are also based on different methods for weighting. For example, EPS is based on willingness-to-pay studies; Ecoindicator, has a damage approach that relates to the areas of protection; and the Ecotax method weight the environmental issues based on the environmental related taxes on for example, nitrogen oxides and materials sent to landfill in Sweden. For prioritisation purposes, weighting are sometimes required by stakeholders. It is, however, not allowed according to the ISO standard for some applications. As there is no consensus concerning which weighting method to use, it is common to use several as a sort of triangulation, i.e. showing the validity of the result using several approaches or tools.

4.3 Simplified life cycle assessments

Ambitious LCAs enclosing many subsystems give raise to a vast life cycle inventory and together with the LCIA this procedure can be time-consuming. It is also unlikely that an absolutely complete, quantitative LCA will ever be performed (Graedel 1998). However, it could be practical to start with less detailed studies, such as simplified or streamlined LCAs, and work towards more detailed (Lindfors, Christiansen et al. 1995). A simplified LCA is a simplified variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 14040 standards and representative of studies typically requiring from 1 to 20 person-days of work (Guinée, Gorrée et al. 2002). A large number of simplified LCA methods have been developed, for examples see reviews in Christiansen (1997), Graedel and Allenby (1998), Todd and Curran (1999), Johansson et al. (2001) and Byggeth and Hochschorner

(2005). The simplifications in these methods are mainly focused on reducing the life cycle inventory phase and the collection of data that could be time-consuming to perform.

Many of these methods have been developed for a specific group of products and are not well documented. Two simplified LCAs have been evaluated by Hochschorner, Johansson and Finnveden (cf. Hochschorner, Finnveden et al. 2002; Hochschorner and Finnveden 2003). The methods studied were Environmentally Responsible Product Assessment matrix (cf. Graedel 1998) and MECO by Wenzel et al. (1997) and described in Pommer et al. (2001). These two methods were chosen since they are well documented and fundamentally different. The evaluation resulted in a recommendation to use the MECO principle as a parallel complement, and/or as a pre-study to a conventional LCA.

4.3.1 The MECO principle

MECO has its origin in Denmark and was intended to small and medium sized enterprises (cf. Wenzel, Hauschild et al. 1997; Pommer, Bech et al. 2001) and is a simplified life cycle assessment method. The analysis can be followed by a more detailed LCA, making a gradual evaluation of the product. To perform a simplified life cycle assessment according to the MECO principle differs in fact on two important ways from a conventional LCA. Firstly, the MECO principle is primarily an inventory of inflows, which limit the data collection. Secondly, the environmental assessment is gradually developed with increased information and knowledge. Even though, MECO sometimes is more of an environmental assessment with a life cycle perspective than a life cycle assessment, its basic core elements should always be in accordance to life cycle assessment basic elements (Hochschorner, Finnveden et al. 2002).

Performing a simplified life cycle assessment according to the MECO principle follows a flow chart where the studied product's life cycle is divided into phases, which were specified to the activities *Material*, *Manufacture*, *Use*, *Disposal* and *Transport* (Figure 2). These are further subdivided into four categories, which have given the MECO principle its name: *Materials*, *Energy*, *Chemicals* and *Others* (Figure 2; Wenzel, Hauschild er al. 1997). These categories are in accordance with the underlying causes of the product's environmental impacts. Information on inflows of materials, chemicals and energy and outflows of materials and emissions to air and water are then gathered and put into the MECO chart. When performing the assessment, one category at time is treated with respect to the chosen life length and the functional unit.

Table 4-1, MECO chart according to Pommer et al. (2001).

	Material	Manufacture	Use	Disposal	Transport
1.Materials a) quantity					
b) resource					
2. Energy a) primary					
b) resource					
3. Chemicals					
4. Others					

4.4 Life cycle costing

Life Cycle Costing (LCC) is a method for analysing the costs related to a production system or a product during its life cycle (Dahlén and Blomsjö 1996). LCC is a cost management method with the aim of estimating the costs associated with the existence of a product, and not a method for financial accounting (SETAC Working Group on Life Cycle Costing 2005). Even though, the procedure of making a LCC includes several estimates of different trustworthiness, it is utilized since it allows costs other than the actual price of the product to be taken into account. The final result from a LCC accounting can be used to support economic decision-making, e.g. in the production planning and the procurement processes. One example is the American defence organisation that, as early as the 1950-60s, started to use LCC in the procurement process (Huppes 2003). The finding that operation and support costs for typical weapon systems accounted for as much as 75% of the total cost of a production system stimulated the adoption of the method (Aseidu and Gu 1998).

Since the method is not standardised, the organisations using it often apply a version of LCC that is adapted for the case in focus (Hochschorner, manuscript). Therefore, the costs included are somewhat different depending on the description of the method. The analyzed life cycle is an economic lifetime for the system. This can be the time from development to procurement, use and disposal (Figure 3; Woodward 1997). It can also be the economic lifetime during only the use phase, for example, three years for a computer (Norris 2001).

According to SETAC Working Group on Life Cycle Costing (2005) there is a distinction between *Conventional*, *Environmental*, and *Societal LCC*. Firstly, *Conventional* LCC is based on a purely economic evaluation, and generally includes costs directly borne by a given actor, i.e. internal costs. Costs occurred as market prices and payment of taxes should be added. External costs, i.e. costs borne by other parties than the company, e.g. the society, are often neglected, these would only be considered if they were related to significant risks or costs. Conventional LCC involves discounted costs, where the lowest rate to be applied is the market interest rate corrected for inflation and the highest is the internal rate used by organisations for their intended return on investment (ibid.). The choice of discount rate affects results significantly; if the rate is high it will bias decisions with low capital costs on short time. On the other hand, if the rate is low it will bias future cost savings (Sterner 2000).

Common practice for conventional LCC is for internal business related cost assessment and controlling. The analysed product is usually complex with a long lifetime and has high life cycle costs. Secondly, *Environmental* LCC on the other hand, has according to the SETAC Working Group on Life Cycle Costing (2005), the same system boundaries and functional unit as LCA (compare to Figure 3 in the next chapter). All costs directly borne under the life cycle and those likely to be internalised during the relevant time for the decision are included. External costs that may turn up as real money flows for any actor would be of interest. Environmental LCCs are often performed for investigating environmental and economic impacts during a product's life, rather than providing inputs for tenders or for controlling reasons (ibid.). The analysed product in environmental LCC is typically less complex than in conventional LCC. Further, discounting is often not possible or easily done, since time is not normally specified for activities leading to inventory results (ibid.). Finally, *Societal* LCC is focused on social costs, with the aim of maximising social welfare. Costs associated with the life cycle of a product that are covered by the actors in the society are included. This LCC approach can be likened with a Cost-Benefit Analysis (CBA) for products combined with further societal aspects. Discounting is made with a social time preference. Payment of taxes should not be added in societal LCC, since these are already covered for.

From a survey on LCC case studies we can see that conventional LCCs seem to be the most commonly practised; more than 55% were conventional LCCs, 25% environmental and 10% social LCCs (SETAC Working Group on Life Cycle Costing 2005).

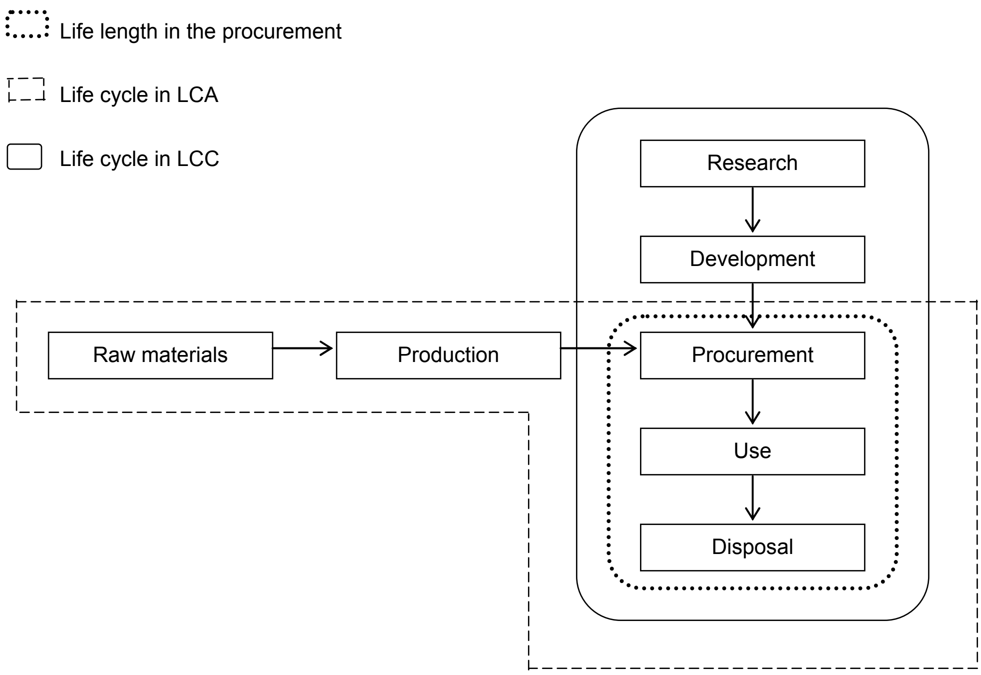
The term 'life cycle' is sometimes used with different meanings in LCA and LCC and when describing the life of a product in the acquisition process (Figure 3). In LCA the term life cycle includes mining of raw material, production, use and disposal of a product (ISO 14040:1997 1997), while the life cycle in LCC includes organisational processes such as research, development and procurement, additional to use and disposal. Furthermore, the term life length, as it is used by FMV, merely includes the steps procurement, use and disposal (Figure 3). Additionally, FMV use the terms life cycle and life cycle perspective to describe the life length of a *materiel system*. The term 'life cycle perspective' is used to describe development of products from idea to phasing out (FMV 2002).

Figure 3. Life cycles in LCA, LCC and life length in the procurement process are illustrated with different lines: the dashed line represents a life cycle in LCA; the dotted line represents life length in procurement; and the unbroken line exemplifies life cycle in LCC. The boxes show examples of simplified life cycle phases. The illustration is based on discussions with M. Overcash.

4.4.1 Environmental aspects of LCC

There exist different explanations of environmental costs and also different LCC approaches with environmental costs included. These do not necessarily have the same system boundaries as environmental LCC described earlier. In the SETAC Working Group on Life Cycle Costing (2005) environmental costs are defined as either environmental damage expressed in monetary terms, or as the market based cost of measures to prevent environmental damage. In Norris (2001) and Center for Waste Reduction Technologies (2000) environmental costs are presented as five different types:

- direct, e.g. costs for waste disposal and raw material,
- indirect e.g. costs for environmental management systems,
- contingent such as fines,
- intangible, for example goodwill or bad will, and finally



- external costs which are costs borne by other parties than the company, e.g. the society.

In contrary to external costs, direct, indirect, contingent, and intangible costs are borne by the company, i.e. internal costs. Hochschorner has reviewed the use of LCCs including environmental costs and conclude that of those who use such a method it seems that the applied LCC methods are adapted to the firm using it. Further, the costs included by all studied LCC methods are direct, indirect and contingent. Only, a few firms include intangible and external costs (ibid.).

Generally, the costs increase from conventional to environmental to societal LCC, due to expanded system boundaries and inclusion of externalities (SETAC Working Group on Life Cycle Costing 2005). However, trade-offs or win-win situations between environmental and economic aspects are likely to occur. These can be identified by analysing the final results from a LCC together with results from a parallel LCA study. The interest rate and system boundaries become more important in long-term complex estimates than in short-term. This is because estimates with a clear cause-effect line and on a short time may be expected to differ moderately compared to complex situations where estimations are more problematic. Due to the expanded system boundaries, it seems like the environmental LCC presented in the report by the SETAC working group is more like an LCA combined with LCC, than an LCC with additional environmental costs (Hochschorner, manuscript).

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5 Tools in the acquisition process

This chapter discusses how to implement life cycle management tools in the acquisition process; generally as well as the special case of the Swedish Defence. Environmental consideration in all phases of the acquisition process can be done with several perspectives using different approaches. It could, for example, be to demand that the supplier has environmental management systems (or equal) or to choose eco-labelled products, for example the Nordic Swan label (or equal). This product focus could be explored to enclose life cycle aspects in a wide sense. Our approach to environmental considerations in the acquisition process of defence materiel takes departure in such a life cycle perspective. We will discuss principles and tools that could facilitate enclosing environmental concern in the acquisition process and especially helpful for setting feasible requirements on products. There are, of course, a large variety of tools developed for environmental consideration in product development that can contribute in these situations. However, the focus here will be on product life cycles. In this context we will discuss life cycle management (LCM) and life cycle thinking, life cycle assessment (LCA), the MECO principle and Life Cycle Costing (LCC). A number of other simplified tools that can be used for trade-off situations in the procurement process and eco-design are discussed in a separate paper (Byggeth and Hochschorner 2005).

5.1 Life cycle management and life cycle thinking

Applying life cycle thinking into an organisation often leads to a new form of experienced responsibility of the environmental interventions from the organisations' products and services along their supply chain (Heiskanen 2002). Heiskanen (2002)shows that personnel at purchasing departments in companies that has applied a life cycle thinking were starting to ask questions about the origin and environmental interventions of purchased materials and also about what happens with their materials and how to dispose of it. This upstream and downstream focus could lead to the insight that together with the site- and organisation specific environmental impact, the material and services purchased do play a role in the overall environmental performance of the firm and its products and services. Another insight that often follows is that the company as a purchaser can, to some extent, affect these upstream and downstream environmental interventions.

Life cycle management (LCM) and green procurement are related in so that green procurement or at least purchasing can be an entry gate to LCM (Hunkeler, Saur et al. 2004). To apply LCM in the acquisition process could be to utilise the existing organisational structures in order to gather and structure the information that should be used to evaluate environmental performance. This can be realised by including a product focus and life cycle thinking in the existing environmental management system. Further, it could be to employ tools from the LCM toolbox, such as, LCA methods and LCC that additionally could produce new knowledge by including non-site specific and general data.

5.2 Life cycle assessment methods

In this section life cycle assessment (LCA) and the simplified LCA of MECO will simultaneously be described in the context of the acquisition process.

5.2.1 Methodology aspects

One of the major difficulties when performing environmental preferable purchasing is the lack of reliable information about the environmental performance of the product or service (Organisation for Economic Co-operation and Development 2000). To ask for information on environmental performance of the materiel in question in the acquisition process is a start. On the other hand, when quantified information is available different tools developed for environmental consideration in product development, such as LCA, MECO and guidelines and checklists, can be used during the acquisition process.

However, the choice of methodology to perform a study depends on economics, time, type of product, system studied and need of information. As the focus in this report is on products in the acquisition process we will discuss life cycle assessment methodology aspects and alternatives. The major difference between traditional LCAs and simplified LCAs such as MECO is that the former is more suitable when choosing between alternatives, while simplified LCAs can primarily be used for identifying critical aspects (Hochschorner and Finnveden 2003). This latter function is of relevance in the acquisition process since information on environmental hotspots in the complex web of a supply chain could be an initial step to address environmental concern. It is therefore suggested that MECO can be useful for identifying critical aspects and based on that setting requirements. Further, the MECO principle can generate more information on, for example, chemicals with toxic properties than the quantitative LCA. Therefore to employ a MECO analysis becomes even more relevant when coping with materiel that in a life cycle perspective generate flows of toxic substances. Another advantage with the MECO principle is that the data needed to perform the analysis are not production-specific.

5.2.2 Implementation into the acquisition process

LCA as well as the acquisition process focuses on products and services. Therefore, LCA is suitable as an environmental assessment method in the acquisition process. To turn focus onto environmental aspects of the materiel contributes to increasing the overall knowledge and also the level of ambition. There are several different reasons to perform a LCA, e.g.

i) to learn about environmental aspects of the product,
ii) to fulfil requirements from customers,
iii) to set environmental requirements and finally,
iv) to gather information that facilitate the choice between alternatives.

Consequently, LCA can be utilized in different ways in the acquisition process. We will here distinguish between two different ways of using LCA. One way is to actually perform an LCA within the acquisition process. The other way is to use the results from an LCA that has already been performed. This has consequences for learning and findings about the study object (Baumann 1998). For example, the performer of the study may learn the most about the product, its use and the methodology in the assessment and its strengths and limits. On the other hand, the part of the organization ordering the LCA may from the start know more about the use of the product and the organizational context, however, lacks information on overall environmental performance. Moreover, the users of the result from a LCA may have comprehensive knowledge of the product and partially deep knowledge of a few to them important aspects. Therefore, the use of LCAs is somewhat different for the purchaser and the producer. While the former may use the result as a guideline in purchasing, the latter could use LCA for improvement of the product during its life cycle.

We will here describe a suggestion on how to implement as well LCA as the MECO principle into the acquisition process that refer to FMV as a purchaser. In this context, the acquisition process is divided into the steps: *studies*, *development*, *procurement*, *production*, *operation*, *phasing out* and finally, *disposal* (Figure 4). This model can be compared with the FMV product model that is described in chapter 3.

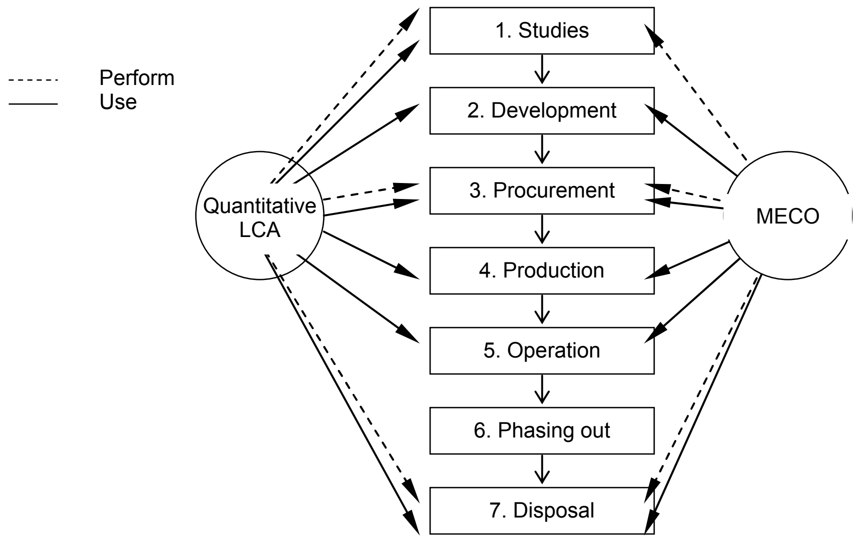

Figure 4. An example of integration of life cycle methodology into the acquisition process, which is illustrated with the boxes one to seven (Hochschorner and Finnveden 2004). The structure of and steps in the acquisition process presented here should not be confused with the description of different meanings of life cycles and life length illustrated in Figure 3.

In order to search for environmental hot spots it is preferable to perform a quantitative LCA or a MECO assessment in the acquisition process as early as possible, i.e. in the *study step* (Figure 4). Though, the product will often not be specified enough to allow a detailed LCA so early in the process, a simplified LCA can be performed as a pre-study (Hochschorner and Finnveden 2004). Even though, no specific data are available, an analysis performed with general data indicates a picture of environmental performance. Later in the process, e.g. in the *development step*, the pre-study could be enlarged and complemented using LCA or MECO methodologies. In cases when the MECO principle is used mainly as a complement to an existing quantitative LCA, the analysis should be made with harmonised life cycle phases (ibid.[2]). Data from quantitative LCAs can be used to facilitate a choice between different alternatives in development, for example, materials and processes. Further, the MECO assessment will identify environmental critical aspects in the product's life; which is useful product development.

Further, if relevant data is missing earlier in the acquisition process, a LCA can be complemented or performed in the *procurement step* (Figure 4). For this purpose, a distinction can be made between two phases:

- i) setting up requirements and
- ii) choosing between suppliers.

Information from LCA and MECO can be useful for setting up requirements. However, it is unlikely that the suppliers can provide the relevant information and therefore doubtfully that LCAs can be used for choosing between different suppliers in the procurement step. Simplified LCAs focusing on data for a limited number of easily accessible aspects could however be useful for the choice between different suppliers.

[2] Ibid. (Ibidem) is a latin expreion that means "on the same place". It is used in papers, thesis etc as an acronym when several references from the same place exist two or more times after each other

In addition, outcomes of LCA studies could be helpful in environmental management in the *operation step* (Figure 4) in the acquisition process. This step also encloses maintenance. Finally, a quantitative LCA or a MECO can also be performed in the *disposal step* (Figure 4), in order to gather information on the environmental impact the materiel system has had until this step. The knowledge produced here is useful, for example, when developing new products. It can, however, be difficult to gather data in this step, since it can be approximately 30 years since production (Hull 2003) or when planning new products disposal is 30 years ahead. All in all, data from LCAs can be used to facilitate a choice between different alternatives, for example materials and processes, but also to evaluate disposal plans or other plans in a life cycle perspective during the acquisition process.

In the situations when the procured material will be developed especially for the customer, we recommend making a conventional quantitative LCA to require knowledge of the product's environmental impact along the life cycle. Further, in cases when the new product resembles a product for which a LCA has been performed, the existing LCA can be adjusted for the new product. Alternatively, the LCA data on the original product can be used as input in a MECO analysis. For example, when the product already exists on the market it can be sufficient to perform a MECO analysis, preferably using data from an existing quantitative LCA or MECO.

Based on the research performed and especially the LCA of a pre fragmented high explosive grenade (see Hochschorner and Finnveden 2004) and also the study of simplified LCAs (Hochschorner, Finnveden et al. 2002)two major suggestions on how to incorporate life cycle considerations into the acquisition process in the Swedish Defence. The first refers to performing LCAs on reference products, strategically selected from representative product groups in the Swedish Defence. The reference products should, in some sense, consist of typical examples of products in different product groups, for example vehicles, ammunition and clothes. Definitions of product groups should be made by FMV and SAF in collaboration. Then, for each product group quantitative, conventional LCAs or simplified LCAs such as MECOs should be performed for the selected reference products. For one example see the LCA study of a pre-fragmented high explosives shell grenade, called 40/48 KULSGR 90 (the international name is 40 mm L/70 PFHE Mark two) (cf. Hägvall, Hochschorner et al. 2004). This study may serve as a demonstration case for future LCAs on defence materiel. The outcome and data from these studies could then be used in the entire acquisition process (Hochschorner, manuscript).

It is also preferable if reports on studies could be publicly available to allow reviews and discussions of results. This would increase the consistency of the outcome through filling data gaps and discussions on e.g. made assumptions, used data, system boundaries and characterisation methods. The results would be spread more widely in the organisation, which would raise the level of knowledge and therefore develop the acquisition process. Since it could be hard to compare defence materiel with materiel from other Swedish actors, for example concerning munitions, international co-operation could be a way to improve the study and thereby the environmental performance. Further, to make the work with life cycle studies cost-effective, international co-operation should be sought. In addition, it is preferable if LCAs can be performed as an integrated part of the acquisition process as early as possible and it should be the responsibility of either SAF or FMV that implementation of life cycle approaches in the acquisition process of defence materiel is accomplished (Hochschorner and Finnveden 2004).

The results from studies on reference products should be an identification of critical aspects in the life-cycles of these products. Since many parts of the products in the same product group can be the same or similar (e.g. the same metals in a group of vehicles) the results will form a database that can be used when making new analyses. The analyses should preferably be made with quantitative LCAs, in order to get an extensive database. The analysis can also be complemented with an MECO assessment. The database can then be used when performing a new LCA or an MECO assessment, when writing specifications of what to procure and when setting up environmental requirements.

The second suggestion is to make LCAs during the acquisition process. The advantage of doing this is that the information could be used directly. However, as it can be too time-consuming or too expensive to perform a quantitative LCA, it can be useful to use data from existing LCAs on, for example, reference products.

5.2.3 Life-cycle tools in the product development process

Ever since LCA and life-cycle thinking started to develop rapidly in the beginning of the 1990s, there has been an ongoing discussion on how LCA can be integrated in product development. Here we will only briefly mention to two papers which present interesting suggestions on how LCA has been integrated in the product development process in Denmark (Nielsen and Wenzel 2003) and at ABB (Tingström, Swanström et al. 2006).

The paper by Nielsen and Wenzel (2003) is based on experiences from a major Danish project on environmental design of industrial product involving several major companies. They developed a toolbox for LCA and also suggestions on how LCA methodology can be integrated in the product development process. One important part was the environmental diagnosis. In this step a comprehensive LCA on a reference product is performed. Based on learning from this study a number of key aspects of environmental concern are identified. The product development teams were then asked to work on these aspects and try to minimise the associated environmental impacts. When they have developed new concepts, the environmental performances of these were tested with new LCAs. These can be done much easier than the previous ones since they can build on the earlier study, and also since the LCA performers were more knowledgeable about the studied product system.

Our suggestion for integrating life-cycle methods in the acquisition process is much inspired by the Danish experiences. We also suggest that LCAs are performed on reference products. Based on the outcomes of these studies, requirements for procurement and further product development can be formulated. When new concepts are developed, new LCAs can be performed to make sure that the new products are indeed environmentally preferable.

Another recent paper by Tingström and Swanström et al. (2006) describes how LCA has been integrated in the gate model for product development at ABB. In this gate model, the product development is divided into a number of stages. Between each stage there is a decision gate which has to be passed. In the gate model at ABB, environmental aspectsand sustainability actions are included. In the different gates the sustainability requirements are identified, then a checklist is used to check some environmental aspects for example concerning the use of different hazardous chemicals and a simplified LCA is performed. A tool for such a simplified, quantitative LCA has been developed and is available for product developers online. In this tool they specify the materials in the product, energy requirements during the use phase and some other aspects. Based on this information the tool performs a simple LCA. Later, sustainability goals and a plan on how to achive these are set up, followed by communication of goals and the plan. Further, implementation of the actions in the sustainability plan and finally follow up to determine if the goals were met is done. Two key factors for success were identified as, firstly, the designers have to have access to sustainability expertise and, secondly, the management of the project must be truly interested in the sustainability goals and actions.

The ABB example is an interesting example of how LCA can be used in the product development. It could be interesting both for FMV and industry to work in similar ways. The gate model is similar to the models used at FMV and other industries. For FMV, the development of a simplified tool would be a great challenge since they procure such a large number of different products. It may be the case that different simplified tools need to be developed for different types of product groups. A first step in this process could be to learn more about the environmental impacts of different product groups in a life-cycle perspective in order to make sure that the simplified tool can handle the relevant aspects of the particular product group and also that data for the relevant steps are available.

5.2.4 Possible implications

Since conventional LCA on products could identify environmental significant aspects during a product's life cycle, the outcome of an assessment would point out both environmental strengths and areas of improvement. This could be beneficial for selection of products in several ways in the acquisition process. Some examples are:

- i) indicating which aspects should be prioritised when setting requirements for the procurement,
- ii) indicating which aspects should be prioritised in the product development,
- iii) indicating future environmental problems due to end-of-life treatment, which may be many years ahead,
- iv) identifying potential obstacles due to coming legislation,
- v) highlighting environmental issues defined as important by different actors in the acquisition process and
- vi) to identify non wanted materials/chemicals in upstream or downstream processes.

Information gathered from LCA and MECO studies, respectively, can also facilitate to further develop the environmental requirements stated by FMV (FMV 2003; FMV 2003) and especially requirements in a life cycle perspective. These requirements specified for procurement of defence materiel, should be a further development of the general requirements presented in the operational handbook (Swedish Armed Forces 2001). These must include noise; emissions to air, water and ground and also requirements on land use. Except for noise and land use, these environmental impacts are normally included in a conventional LCA. Principally, all of the impacts can be included in MECO. Further, SAF should make sure that environmental requirements, based on an environmental life cycle perspective, are included in the TTEM (Tactical Technical Economic Goals), which partly sets criteria for procurement (ibid.).

5.3 Life cycle costing

As life cycle costing (LCC) is occasionally used in procurement and according to Forsell (2005) LCC is currently used by FMV in the acquisition process. Further, LCC is a tool in the LCM framework, which altogether contributes to our interest and therefore will be discussed in this report.

5.3.1 Methodology aspects

All costs originating from environmental impacts caused in the life cycle of a product are not necessarily included in a LCC. This depends on the studied system boundaries, what the life cycle represents and whose costs are considered e.g. producer, customer, or society. In a conventional LCC only internal costs are considered.

Whether external costs should be included in LCC are still under discussion. If so, it is necessary to reflect upon what type of external values that are concerned and how to estimate them. Reasons to include external costs can be that the company wants to take responsibility for the society or that there is a risk that the costs will be laid on the company because of political decisions, i.e. that the external cost will be internalised (see for example Rebitzer and Hunkeler 2003). In that case, external costs are transformed to contingent. An approach for enclosing internalised external costs in the LCC-assessment could be to use methods that capture external costs. There are a large number of different methods available for estimating external costs (see for example Turner, Pearce et al. 1994; see for example Bocksteal, Freeman et al. 2000) that also correspond to different types of external costs. For example, it may be of specific relevance to use an approach estimating prevention costs, which could be a measure of future costs for abatement of pollutants. By including external costs, the LCC method will have similarities to Cost-Benefit Analysis (CBA) (e.g. Ahlroth, Ekvall et al. 2003).

Some LCC studies mainly consider environmental costs that are internal and then summarise these in a single measure of environmental costs (e.g. Bengtsson and Sjöberg 2004; Senthil, Ong et al. 2003). This means that proactive environmental activities are added to reactive ones. For example, costs for prevention of impacts can be added to costs for taking care of impacts. A reason for doing so can be the ambition to present all environmental related costs borne by the company as an example of goodwill. An alternative to this specific handling of environmental costs could be to compare or relate them to each other. Further, in the general LCC models disposal costs are included, however, not in the current models applied at FMV (Hochschorner, manuscript).

Yet, another question is how to allocate indirect environmental costs, such as costs for environmental management systems, to the product analysed. One suggestion here is to apply the same method used for allocating other costs for environmental costs as well.

5.3.2 Implementation into the acquisition process

Depending on the purpose of the LCC it can be performed and used in different steps in the acquisition process (compare with the use of LCA and MECO in Figure 4). Firstly, using LCC in the *study step* could, for example, be analysis of consequences of requirements as a base for choosing between different alternatives, i.e. to analyse cost consequences of requirements on reliability on the system. Secondly, LCC in the *procurement step* can be used for evaluating bidders. Further, in step-by-step procurement, i.e. when a product is developed especially for the Swedish Defence, LCC can be used for influencing the costs for operation, maintenance and construction (Forsell 2005). In contrary, purchasing when the product already exists on the market, i.e. direct procurement, LCC can be used for choosing supplier. In the latter case LCC is also relevant for evaluation of maintenance of the product. Thirdly, in the *operation step* LCC can be used to find out if cost requirements on operation and support are fulfilled and also as a basis for decisions on improving systems and to streamline maintenance considering changes (ibid.). Finally, in the *phasing out step* LCC can be used to decide when spare parts no longer should be procured, and how fast these should be phased out. Additionally, LCC can also be used to consider costs for recycling of used materiel.

As stated in Forsell (2005) it is preferable if LCC-activities are largest in the beginning of the acquisition process, i.e. if possible performed in the *study step* and with later complementation if required. To be able to compare alternatives in a fair way the present value of future costs or revenues needs to be calculated. This is done using a discount rate, which transforms future costs or revenues to current economic values. However, no discount rate is currently used in the LCC accounting by FMV (ibid.).

5.3.3 Possible implications

FMV has developed a handbook on LCC (see Swedish Defence Materiel Administration 2002) and the methods presented in the handbook can be characterised as *conventional* LCC, where LCC is defined as a measure of the total economic consequence of a materiel system over the system's life length, i.e. costs incurred during development, procurement, use, support and disposal (see Figure 3). Further, a materiel system is one or many materiel objects with complementary operation and maintenance and the life length refers to the number of years the materiel system is to be used (Swedish Defence Materiel Administration 2002). However, FMV does not necessarily include the total actual cost for the materiel system in their LCC. For example fixed costs and absorbed costs, i.e. costs that will not affect future decisions, are often excluded from the analysis (ibid.).

Based on Hochschorner's survey it can be concluded that no environmental costs are normally included in the LCC model used by the Swedish defence sector (Hochschorner, manuscript). Even though, FMVs general LCC models include the environmental related cost for disposal, it is unusual that this actually happens. However, Hochschorner's study shows an ambition from the Swedish Defence to include all types of environmental costs into the use of LCC. This could be realised when reliable coefficients can be set for the different types of costs. In contrast, external costs are not likely to be included at all since these are not in its nature borne by the organization itself (ibid.).

5.4 Concluding remarks and method recommendations

If it has been decided that some kind of life cycle method should be used, it is preferable to, as early as possible, perform quantitative LCA, MECO or LCC assessments in the acquisition process, i.e. in the *study step,* with later complements if required.

The major difference between traditional LCAs and simplified LCAs such as MECO is that the latter is less suitable when choosing between alternatives, while both approaches can be used for identifying critical aspects (Hochschorner and Finnveden 2003). This latter function is of relevance in the acquisition process since information on environmental hotspots in the complex web of a supply chain could be an initial step to address environmental concern. It is therefore suggested that MECO and/or traditional LCAs can be useful for identifying critical aspects and based on that setting requirements in the acquisition process. Further, the MECO principle generates more information on, for example, chemicals with toxic properties than the quantitative LCA. Therefore to employ a MECO analysis becomes even more relevant when coping with materiel that generates flows of toxic substances. Another advantage with the MECO principle is that the data needed to perform the analysis are general and not product specific. It is therefore suggested that the traditional LCA and the MECO can complement each other since they partly generate different types of information.

In situations when the procured material will be developed especially for the customer, we recommend making a conventional quantitative LCA to require knowledge of the product's environmental impact along the life cycle. Further, in cases when the new product resembles a product for which a LCA has been performed earlier, the existing LCA can be adjusted for the new product. Alternatively, the LCA data on the original product can be used as input in a MECO analysis. For example, when the product already exists on the market it can be sufficient to perform a MECO analysis, preferably using data from an existing quantitative LCA or MECO.

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6 Method recommendations

This chapter presents recommendations concerning the performing and adjustments of LCA, MECO and LCC to its use in the acquisition process in the Swedish Defence.

6.1 Life cycle assessments

As noted above, one of our suggestions is to systematically work through LCAs for reference products. This will form an extensive database that can be used when making new analyses. Supplementary studies applying LCA or MECO assessments, or others, could be based on data from the database. Using data from existing LCAs would shorten the time needed to perform an analysis. These new studies will also generate new data and the database will extend further. The database and the performed studies could then facilitate to set up environmental requirements in the acquisition process. Both the Swedish Armed Forces (SAF) and the Swedish Defence Materiel Administration (FMV) have the position to receive the responsibility and order that LCAs on reference products are performed. It is an advantage if the two organisations can co-operate in this matter.

The methodology for LCA could as far as possible follow the standard methodology as described in the ISO standards 14040. The recent Handbook on LCA (cf. Guinée, Gorrée et al. 2002) is useful and was one basis for our case study on ammunition (cf. Hägvall, Hochschorner et al. 2004).

For the characterization step of the Impact Assessment we recommend the baseline impact categories and characterization methods suggested by Guinée et al. (2002). However for one of the impact categories, the abiotic resources, there is still an ongoing debate on the advantages and disadvantages of the different approaches that are available (Pennington, Potting et al. 2004). Here we suggest that the Thermodynamic approach developed by Finnveden and Östlund (1997) is used. This approach is based on a thermodynamic description of resources where the loss of resources is described in terms of loss of useful energy and ordered matter, both aspects which can be described in terms of production of entropy or loss of exergy (useful energy). Further, when applying Life Cycle Impact Assessment methods it is important to keep up with research, since this still is a developing area. There could be aspects that may need updating and further specification.

The normalisation, grouping and weighting are optional phases in LCA as it is described in ISO 14040. If and how to weight between environmental aspects is discussed in the research area of LCA (cf. Finnveden, Hofstetter et al. 2002; Pennington, Potting et al. 2004), however, sometimes requested by the end user or customer to facilitate to prioritise environmental impacts and as a basis for decision-making. As there is no consensus on how to weigh environmental impact categories the common practice, if weighting is requested, is to run several of the available models, which in relation to each other prioritise differently. The result from these methods is to some extent complementary and all of these together may indicate environmental hotspots. Therefore, we recommend that in cases when weighting methods are used, it should be transparent in the reporting of the study which environmental aspects that are considered the most important and consequently which weighting methods that was chosen. In order to search for hotspots it is recommended to apply several different methods that complement each other. For example, in the study on ammunition (cf. Hägvall, Hochschorner et al. 2004) the Ecotax02, Ecoindicator 99 and EPS 2000 were applied as these are implemented in the LCA software tool, SimaPro, which was used for the LCA. As weighting, grouping and normalisation still is a developing area we also recommend to follow its development.

6.2 Adjustment of the MECO principle

In order to benefit as much as possible from the MECO principle we have to some extent adjusted it to better fit in to the acquisition process as it is applied in the Swedish Armed Forces.

The suggestion on how to modify the MECO principle for acquisition in the SAF refers to the categories and the MECO chart in Figure 2. Firstly, the category *Material* includes all the materials needed to produce, use and maintain the product. The use of materials is partly presented as quantity and partly as a characterised result. Materials that are reused in the disposal phase are entered in the Disposal box, marked with a minus sign. We suggest that the so-called 50/50 method (Lindfors, Christiansen et al. 1995) is applied as allocation method, in which the environmental impacts caused by recycling are allocated according to:

- 50% of the environmental impacts caused by primary material production and waste management are allocated in proportion to the amount of primary material in the product. The remaining 50% are allocated in proportion to the amount of material lost from the technosphere to the environment.
- In the case of environmental impacts caused by recycling processes, 50% are allocated in proportion to the amount of material delivered to the recycling processes. The remaining 50% are allocated in proportion to the amount of the recycled material in the product.

Secondly, the category *Energy* includes all energy used during the product’s life cycle, including the use of energy during the supply of materials. The use of energy should be indicated as primary energy (2a, Figure 2) and, in contrast to the original description in Pommer et al. (2001) where all energy resources were recommended to represent oil consumption (2b, Figure 2), we propose a characterised result by applying the Thermodynamic Approach (cf. Finnveden and Östlund 1997; Hochschorner and Finnveden 2004). In addition, there is no consensus concerning the best available practice regarding characterization of such abiotic resources, despite that there are methods available for characterization (Lindeijer, Müller-Wenk et al. 2002). Therefore, we recommend presenting renewable energy as renewable, when such is used. Instead of looking at the global reserves, the Thermodynamic Approach describes use of energy and material resources as either consumption of exergy or production of entropy (Finnveden and Östlund 1997). As exergy can be described as a measure of available energy we recommend that exergy values should be used for nonrenewable and renewable energy characterisation, instead of calculating all energy as use of oil resources. The inputs in this characterisation should be natural resources as found in nature.

Thirdly, the category *Chemicals* (3, Figure 2) should include all chemicals in the product’s life cycle. The chemicals are classified as type 1, 2, or 3 according to the environmental hazard level. This classification is made with help from the FMVs list ‘Restriktionslistan’ (Criteria for chemical substances) (FMV 2003), which purpose is to help setting environmental requirements for procurement. This list consists of two parts, where the first part contains chemicals that shall not be included in products that FMV procure. The second part contains substances that should be avoided as far as possible. Chemicals are divided in the two parts by using their Risk-phrases specified in the EU directives on marking of chemicals (European Commision 1967) and their application in products. For instance, lead is included in both part 1 (as lead in electrical components, finishing, metals and fuels) and in part 2 (as lead in batteries and glue). We recommend using the Risk-phrases and not the application of the chemicals to specify type 1-3 in a MECO assessment, where the Risk-phrases can be found in either the Swedish Klassificeringslistan (cf. Kemikalieinspektionen 2003) or the N-Class Database by the Nordic Council of Ministers . The criteria for the types are:

- *Type 1: Very problematic substances*. These substances should, according to (FMV 2003), not be included in products that FMV procure. Further valuation of these substances is needed, to find possible substitutes. Type 1 substances are substances with the Risk-phrases R26-28, 39, 45-46, 48-51, 53, 59-61 (as in part 1 in FMV 2003).

- *Type 2: Problematic substances.* Use of these substances should be avoided as far as possible, according to (FMV 2003). Further evaluation of these substances is needed, to find possible substitutes. Type 2 substances are substances with Risk-phrases R20-25, 29, 31-38, 40-43, 48, 52, 54, 55-58, 62-68 (as in part 2 in FMV 2003) and substances in the Swedish OBS-list (a list containing substances with serious environmental or health properties (Kemikalieinspektionen 2003). Substances that are difficult to assign a proper type, within reasonable time, should be classified as type 2.

- Type 3: Less problematic substances. Use of type 3 substances is not regulated in Restriktionslistan (Criteria for chemical substances). Type 3 substances are substances that do not fulfil the criteria for type 1 or 2.

When a MECO assessment is used with the purpose of complementing a quantitative LCA, (cf. Hägvall, Hochschorner et al. 2004), we suggest that the analysis focuses on the categories *Chemicals* and *Others*. Such a complementary study should, of course, follow an equal modelling of the life cycle as the one used in the existing quantitative LCA. Then it is not necessary to divide the category *Chemicals* into the life cycle stages presented in the MECO chart (Figure 2). The outcome will be a complement to a quantitative LCA by giving more information on the substances environmentally hazardous risks (by using the Risk-phrases) and by the possibility of including more qualitative information. Further, the chemicals studied should be classified according to the three types described above.

Finally, environmental impacts that do not fit into the categories described above should be included in the category *Other* (4, Figure 2). Information that should be included in the category *Other* depends on the use of the method. When the method is used in the acquisition process of defence materiel, we suggest that the following aspects should be considered:

- Components that are included in the product with unknown content, for example electronics
- The effect of use of the product in a war situation
- Noise
- A checklist on other environmental effects that cannot be quantified. This checklist can be based on environmental goals (Sweden's or the Defence sector's) and FMV's environmental requirements on the supplier.

6.3 Life cycle costing

FMV has worked out a handbook on life cycle costing (LCC) and this assessment method is incorporated in some parts of the Swedish Defence sector. We suggest that FMV should work with what was called conventional LCC in chapter 4, that means that all costs which are actually borne, or can be predicted to be borne, by the Swedish Defence should be included. This also includes some environmental costs. However, as noted above, environmental aspects are generally not included. This may to some extent depend on lack of data, and to some extent on lack of methodology. Both data and methodological aspects therefore need to be considered in the future work.

As noted in chapter 4, conventional LCC usually use a discount rate. However, the FMV handbook applies a discount rate of 0%, which means that an investment today equals the costs of an investment tomorrow. Further, which type of discount rate that should be used has been discussed in other reports, e.g. Nordlund et al (2005). The choice of the discount rate is complicated by the fact that it is difficult for the defence to save money from one fiscal year to another. This means that for the defence there is no intended return on investments (cf. chapter 4.4). That is one argument why the defence should not have a discount rate (Nordlund, Wickberg et al. 2005). On the other hand, the Swedish government, who has an important role in many decisions in the acquisition, has the possibility to save money between fiscal years, and from their perspective it would thus be relevant to use a discount rate. Clearly, this is an area, which need further research and discussions.

As noted in chapter 4.4.1, there are several types of environmental costs, and these will be briefly discussed here.

- direct costs, e.g. costs for waste disposal and raw materials should clearly be included in conventional LCCs. Normally market prices can be used to assess these costs. Some of these costs are already included today, e.g. costs for raw materials. However, it was noted in the study by Hochschorner that the costs for phasing out of defence materials were hardly ever included in LCCs. This is clearly surprising since they should. Obviously more work is needed in this area to make sure that these costs are properly included.
- Indirect costs, e.g. costs for environmental management systems (EMS). Also this type of costs should by definition be included in the conventional LCC just like other indirect (overhead) costs. Often market prices can be used to calculate the costs. The major methodological problem here is how to allocate the costs to the different products. For example, how much of the costs for local EMS should be allocated to new vehicles? This is a methodological issue that may need for attention.
- Contingent costs, such as fines. These types of costs should also in principle be included. They are often associated with future costs due to unexpected consequences of permitted or intentional releases and are best described by their expected value, their range and the probability. These numbers can of course be difficult to assess, but may nevertheless be very important. A special case of a contingent cost needs more attention. It concerns the risk that external costs will be internalised. This is further discussed below.
- Intangible costs for example goodwill and badwill. Also these types of costs should in principle be included in conventional LCCs. They are however difficult to assess and also in this area, further attention may be required.
- External costs which costs are borne by other parties. This type of costs should by definition not be included in a conventional LCC.

We will now turn to the special case of contingent costs. Many military products and systems have very long life times. That means that future costs need to be assessed using different types of scenarios. Many countries have different types of goals and ambitions in relation to environmental aspects. For example, Sweden has a system of national environmental quality objectives. Some of these are quite far reaching and may require significant changes. One example is the goal for reduced climate change that requires that the emissions of gases contributing to climate change should be reduced by 50 % to the year 2050 and decrease further after that. The objective for a Non-toxic environment requires that a large number of chemicals which are frequently used today should be phased out. If these goals are taken seriously they may thus require some major changes for many sectors in the society including the defence sector. Thus, these may be considered as contingent costs. If these changes are implemented, some costs may occur which could be considered together with a factor for the risk that the costs would occur. Alternatively the costs may be considered in a sensitivity analysis without a specific risk factor.

For estimating this type of contingent costs different approaches could be used. Of special relevance could be to estimate the avoidance costs. If the environmental impacts are to be reduced, and avoided to a certain level, what would be the costs for this. There are a number of such studies available for some environmental problems, and they need to be compiled and put together. Another approach could be to assume that the optimal level of environmental reductions would be required and the optimum level is the level where the avoidance costs equals the external costs. Thus estimates of the external costs could be made as proxy for the contingent costs. In any case, this is clearly an area that needs further research.

Considering LCC studies, these could depending on the purpose, be performed and used in different steps in the acquisition process. It is questionable if the current use of a discount rate that equals zero fairly represents the present value of future costs or revenues. Therefore, to continuous discuss and question the magnitude of the discount rate is essential in order to motivate this special case. Further, a discussion on inclusion of the risk of external costs that could be internalised in LCC studies could be important for ensuring a reasonable outcome.

6.4 References

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7 An example of LCA on munitions, PFHE shell grenade

During the earlier stages, when the LCA methodology was examined as a tool for procurement in the Armed forces, it was decided that there were a need to evaluate if it is possible to do a “complete” LCA on something like munitions. There were several worries of why this could prove to be impossible. The major concern was that collecting data would prove too difficult considering the amount of data for munitions that are classified.

The project group considered this and decided to try to perform a case study on a PFHE shell grenade. The main reason for this choice was that this shell grenade is fairly old, it has also been produced in very large quantities and is spread all over the world. This would hopefully give an advantage concerning the amount of available open information.

It was shown that given the right contact it is possible to perform a “complete” LCA on munitions items such as shell grenades. This is a description of the above mentioned case study and an example how it is possible to perform a “complete” LCA on munitions. For a more detailed description of the performed LCA please refer to the complete report (Hägvall, Hochschorner et al. 2004).

7.1 Description of the shell grenade

The studied shell grenade is an older type of ammunition that was chosen since the idea was that data would be easier to obtain. An older shell grenade does not differ much in construction from a newer one and during the last 30 years not much has changed in the construction on such a shell grenade. This means that choosing an older shell grenade gives almost the same data as a newer one but the data is hopefully more easily obtained. The main exception is the use of electronics in the shell grenade, which has changed considerably during the last ten years. Another positive effect from choosing an older shell grenade is that we know how the end of life and the disposal is handled.

The shell grenade in this study is a very common shell grenade manufactured by Bofors since 1975. It has been produced in about one million items and sold to over 30 nations. The model used in this study is called mark two and is from 1983.

The shell grenade has the calibre 40 mm and is used by both land and sea weapons. It is constructed with heavy metal alloyed balls. The shell grenade is used primarily against air targets. In Sweden it has the name 40/48 KULSGR 90 and the international name is 40 mm L/70 PFHE mark two (Bofors Defence AB, 2002; Gander and Cutshaw, 2000-2001).

7.2 The life cycle of the shell grenade

The life cycle of the shell grenade and its sub parts were divided into the life stages of manufacturing, storage, use and demilitarization(demilitarization is the military word for phasing out equipment). Each of these has according to LCA procedure been compiled for their total life cycle. We have done a distinction between two different life cycle scenarios that we compare. The two life cycles scenarios are “normal” usage of the shell grenade (total shell grenade scenario) and the war scenario (war scenario). These two scenarios differ in that the war scenario doesn’t have a demilitarization part and the storage time is reduced. Further, an increased amount of transport and explosion of the shell grenade outdoors is also included in the war scenario simulating the actual driving the combat vehicle in combat. We chose these two scenarios as the two opposites but also because we wanted to see the effect of reuse and different end of life scenarios. Simplified we estimate that the war scenario is a bad end of life and the normal scenario is the preferred end of life.

7.3 Manufacturing of the shell grenade

7.3.1 Cartridge

The shell grenade is cartridge-based ammunition, meaning that the shell grenade is mounted with a brass cartridge that contains the propellant. Simplified it could be said that it has the appearance of an over sized rifle round. The brass casing is made by Nammo in Finland and sold to Bofors who put it together (Edesgård and Eriksson 1999). The process for doing the brass casing is called extrusion moulding. Further, the case is extruded in three steps where the length of the case increased and the diameter and the wall thickness are decreased. The lengthening final stage is called first cutting of length and here excessive materials are cut off. After that the case base is pressed into shape. The last three steps are the conical pressing to match the size with the dimensions of the cartridge chamber, the machining of the base and the second cutting to length. The final finish of the cartridge is corrosion protection, the case is applied with a non-porous fine crystalline substance and then put in an oven at a high temperature(Demex Consulting Engineers 2000).

The propellant in the cartridge is gunpowder, the gunpowder is a single base NC-powder (NitroCellulose). This gunpowder was made by Nexplo in Sweden. Gunpowder is produced by nitrating the cellulose and adding stabilisators and plastiziser. The process for making gun powder is a well documented process. Cellulose is first nitrated with nitric acid, resulting in nitrated cellulose with a high amount of water. The water is exchanged to ethanol with the use of a centrifuge. This product is then kneaded with an ether/ethanol mixture until a gel is formed. When the material is being kneaded stabilizers and plastiziser are added. The resulting gel is pressed through specific tools to make the desired shape of the final gun powder. The gun powder is then pre dried and cut into appropriate sizes. After that the gun powder is dried in a vacuum drier. The final stage is to treat its surface with graphite and other chemicals. The shaped gun powder is put into cotton bags and put into the cartridge (Bofors Defence AB 2002).

7.3.2 Primer

At the bottom of the cartridge the primer is inserted. The function of the primer is to ignite the gunpowder in the cartridge. When the gunner wants to fire the shell grenade he/she pushes a button that sends an electric current through a metal thread. The metal thread works like a light bulb filament, gets hot, and ignites the energetic materials in the primer (Bofors Defence AB 2002).

The primer has three sub-parts: body, detonator and black powder. The body is made out of a brass casing just like the cartridge. It is shaped from a brass cylinder by turning. The detonator is the part that ignites when the metal thread gets hot. The detonator is about 1 mg of a mixture of antimony trisulphite, potassium perchlorate and zirconium. The detonator ignites the black powder which ignites the gun powder in the cartridge. The black powder is a mixture of charcoal, potassium nitrate and sulphur (ibid.).

7.3.3 Pre Fragmented High Explosive (PFHE) Shell grenade

This is the part of the weapon system that does the damage. It is made out of several metal parts. In the middle there is a core (bursting charge) of energetic material in this case Octol. Octol is made out of octogen and trinitrotoluene in a 70-30 mixture. Octogen is made from hexamine and a few other chemicals. Trinitrotoluene is toluene or ortho-toluene that is nitrated to trinitrotoluene with nitric acid. The Octol is melted and poured into the shell grenade (Bofors Defence AB 2002) .

Around the bursting charge there is a steel skeleton, the steel is special high fragmenting steel. This skeleton is made by turning a steel cylinder. The ball charge, containing 600 heavy metal alloy balls (in tungsten) in a rubber matrix, is placed outside the steel cylinder. Outside this there is another steel casing that holds the ball charge in place also in the same steel as the skeleton. At the bottom there is a cap made of steel that is a safety measure for the shell grenade so the gunpowder can not accidentally ignite the shell grenade (Bofors Defence AB 2002).

7.3.4 Fuse

At the top of the shell grenade there is a fuse. It is programmed to burst the shell grenade at the desired time. The fuse in this shell grenade is of proximity type and works according to the doppler principle. This is the most complex component in the shell grenade. We have divided it into four sub-parts: electric unit, S/A device, fuse detonator and fuse body.

The electric unit is a sonar, it is made out of electronics and has a battery. A detonator is connected to the electronics, it is all cased in a noryl casing (plastic). The battery is a glass bottle, in the glass bottle there is a water solution of boric acid and flouro boric acid, which is mixed under flight and gives a small amount of energy. The detonator in the electric unit ignites the fuse detonator. It is made of Graphite, lead azide, silver azide and Tetrazene in very small amounts (Bofors Defence AB, 2002).

The S/A device is a safety detail so the shell grenade can only burst after a specified time of flight. It is made in Switzerland and is in fact a small steel clock (Bofors Defence AB 2002).

Fuse detonator is the energetic material that makes the octol in the PFHE shell grenade to burst. This is first a small amount of trinitrophenylmethylnitramine (tetryl) and then a larger booster of cyclotrimethylene trinitramine (hexogen) (Bofors Defence AB 2002).

The S/A device and the fuse are fitted in an aluminium casing that is turned out from an aluminium rod.

7.4 Storage

The main part of a shell grenades life is in storage. This could be from 10 to over 30 years. The value estimated for this LCA sudy is 25 years. The storage facility has a climate and humidity control, which mainly use electricity (Fortifikationsverket 2002).

7.5 Use of the shell grenade

This shell grenade is used in combat vehicle 90 (CV 90) in the SAF. The use of the shell grenade include some transportation (driving the CV 90) and firing the shell grenade either in combat or practise which means that most of the materials in the shell grenade are spread into the environment. Propellant and explosives in the shell grenade are combusted and the produced gases are assumed to be according to the bang box experiment (Wilcox, Molenaar et al. 1996).

7.6 Demilitarization

This is the end of the shell grenade life cycle. Here two possible demilitarization processes are used. The first is Open Detonation (OD), where a large amount of shell grenades are detonated in the open on a firing range in the country. This is an older way of doing demilitarization, but it is still used (Hägvall 2002). The second method studied is a Swedish method where all the materials in the shell grenade have been reused as much as is possible. This means reclaiming explosive and propellants and reusing these and recycling all the material in the shell grenade such as steel and copper. Only a small amount of the explosive and propellant is not reused but are burned (Sjöberg 2003). In this study, the latter type of demilitarisation is used. The demilitarisation is a sort of an ideal process where everything is recycled as much as possible.

7.7 Process tree

Process trees for the studied shell grenade and the two selected life cycles can be seen in Figure 7-1 and Figure 7-2. The complete process tree can be seen in Hägvall et al. (2004).

Overview of the processtree

The Total Grenade Life Cycle

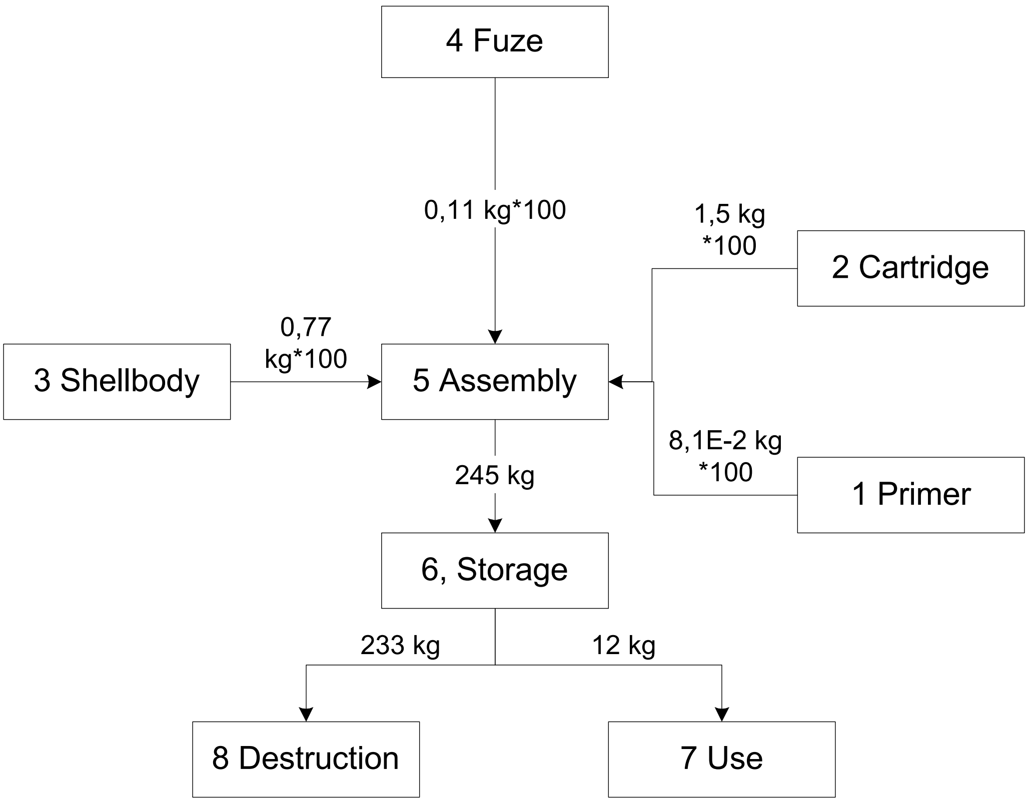

Figure 7-1, Overview of the process tree for total shell grenade scenario with the total massflow of each phase

Overview of the processtree

The War Life Cycle

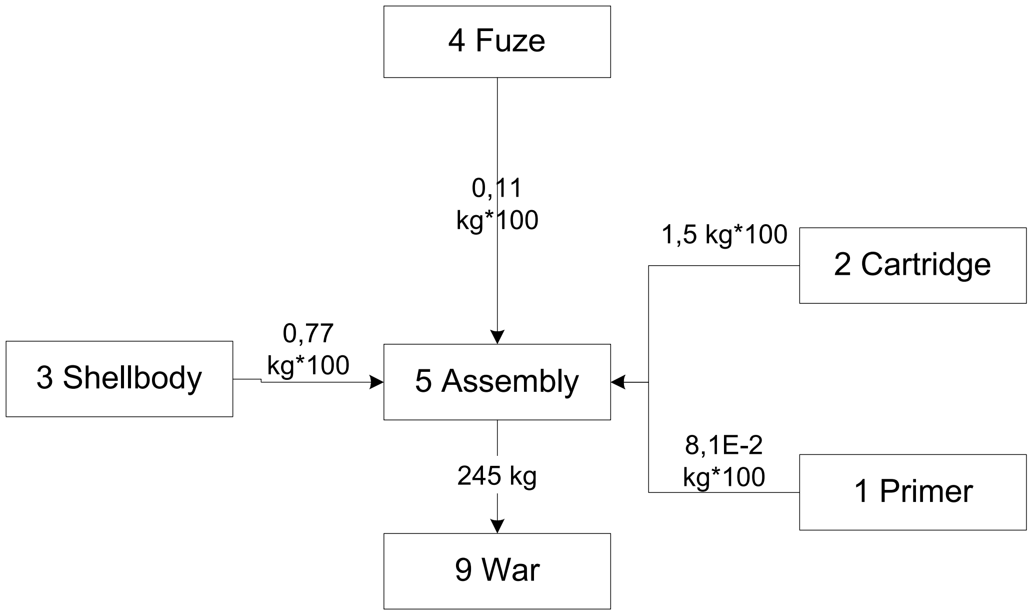

Figure 7-2, Overview of the process tree for the war scenario with the total massflow of each phase

7.8 Data quality

The quality of the data used in the study differs a lot and is dependent on the source of data. The quality of the references used varies and will be discussed here.

Data from Edesgård and Eriksson (1999) originates from a LCA produced as a master thesis, it is focused on the manufacturing of a similar shell grenade. It was made in close cooperation with Bofors Defence and its coverage of the "Bofors processes" is very good when it comes to energy usage and materials used. No chemical processes are included in the study and there is minor information on processes outside Sweden. .

Data from Bofors' development consent (Nexplo Bofors AB 2002) that is an application that Bofors filed for their production according to Swedish Environmental Code. It concentrates on the maximum production capability at this facility. Values from this reference were mostly used when no other source were available.

Data from Bofors Defence standards (Bofors Defence AB 2002) refers to the standards and drawings that Bofors Defence has provided for this research. The data were in the form of their standards and complete drawings of the shell grenade and all the containing parts. Data provided directly from Bofors Defence also have this reference.

Data from Wilcox et al. (1996) is a report from the U.S. Army. It includes tests on open burning/ open detonation of munitions materials. This is used when explosives or propellant is burned or detonated. Validity is unknown but these are the best available data.

In addition, data with varying quality have been drawn from the SimaPro databases.

7.9 Impact assessment

In the Life Cycle Impact Assessment (LCIA) the results from the inventory analysis are further processed and interpreted in terms of environmental impacts and societal preferences (Guinée, Gorrée et al. 2002). The impact assessment in this study includes a classification, characterisation and three different weighting methods, Ecotax 02, Ecoindicator-99 and EPS 2000. Each method is briefly described below. The selected impact categories and performance of characterisation are included in the description of the methods. Normalisation and grouping has not been included in this study.

7.9.1 Characterisation methods

The characterisation methods used in this study are baseline methods (see chapter 4.2; cf. Guinée, Gorrée 2002) as included in the SimaPro 5.0 program except abiotic resources, where a method based on exergy content (Finnveden and Östlund 1997) has been used.

7.9.2 Weighting methods

<u>Ecotax 02</u>

Ecotax 02 (Eldh 2003) is an upgraded version of Ecotax 98 developed by (Johansson 1999). Ecotax 98 is based on environmental taxes and fees in Sweden 1998. Ecotax 02 is updated with taxes and fees until the end of year 2002. The method links a tax or a fee to a relevant impact category. Even if a tax or a fee is only expressed for one substance, it is possible to get a reference equivalent weight by making a characterisation factor conversion.

In Ecotax 02 are both characterisation methods and tax bases updated compared to Ecotax 98, for more detailed description, see Table 7-1 and Eldh (2003).

Table 7-1, Weighting factors for Ecotax derived from environmental taxes and fees in Sweden 2002 (Björklund, Johansson et al. 2003; Eldh 2003).

Intervention	Weighting factor	Tax or fee base
Extraction		
Fossil energy	0-0.15 SEK / MJ	Tax on fossil energy
Biotic energy	0-0.069 SEK/MJ	Tax on biotic energy
Emission		
CO_2	0.63 SEK/kg	Tax on carbon content in fossil fuel
Ozone depleting substances	1200 SEK/kg	Fee for using prohibited ozone depleting substances
Nitrogen	12 SEK/kg	Tax on nitrogen content of fertiliser recalculated due to leakage of 15% (tax 1.80 SEK/kg)
HC	20-200 SEK/kg	Emission fee for air traffic
Sulphur	30 SEK/kg	Tax on sulphur content in fossil fuels
Toluene	17.65-36.07 SEK/kg	Tax differentiation on petrol qualities (unleaded petrol vs. alkylate petrol)
Cadmium	30 000 SEK/kg	Tax on content of cadmium exceeding 5 g/1000kg phosphorous in fertiliser
Pesticides / Copper	20 SEK/kg	Tax on active substance in pesticides

The weighting factors in Table 7-1 are combined with different impact categories in Table 7-2. Minimum and maximum values are used for some impact categories indicating uncertainties in the methods. The weights of reference in Table 7-2 indicate the value of the reference substance used in the different impact categories (Björklund, Johansson et al. 2003; Eldh 2003).

Table 7-2, Weights used in minimum and maximum combinations (Björklund, Johansson et al. 2003; Eldh 2003).

Impact category	Combination	Weighting factor	Reference of the characterisation method (eq)	Weight of reference
Abiotic resources	Min	0 SEK / MJ	MJ	0 SEK/MJ
	Max	0.15 SEK / MJ	MJ	0.15 SEK/MJ
Biotic resources	Min	0 SEK / MJ	MJ	0 SEK / MJ
	Max	0.069 SEK / MJ	MJ	0.069 SEK / MJ
Global warming	Min	0 SEK / kg CO_2	CO_2	0 SEK / kg CO_2
	Max	0.63 SEK / kg CO_2	CO_2	0.63 SEK/kg
Depletion of stratospheric ozone	Min/Max	1200 SEK / kg ozone depleting substance	CFC-11	1200 SEK/kg
Photochemical oxidation	Min	20 SEK / kg HC	C_2H_2	48 SEK/kg
	Max	200 SEK / kg HC	C_2H_2	480 SEK/kg
Acidification	Min/Max	30 SEK / kg Sulphur	1.2 SO_2	18 SEK/kg
Eutrophication	Min/Max	12 SEK / kg N	PO_4	28.57 SEK/kg
Fresh water aquatic ecotoxicity	Min	17.65 SEK/kg Toluene	1,4-dichlorobenzene emitted to freshwater	60.86 SEK/kg
	Max	36.07 SEK/kg Toluene		124.37 SEK/kg
Marine aquatic ecotoxicity	Min	20 SEK/kg Copper	1,4-dichlorobenzene emitted to seawater	$1.333*10^{-5}$ SEK/kg
	Max	20 SEK/kg Glyphosate		0.606 SEK/kg
Terrestrial ecotoxicity	Min/Max	30 000SEK/kg Cd	1,4-dichlorobenzene emitted to agr. Soil	176.47 SEK/kg
Human toxicity	Min/Max	30 000SEK/kg Cd	1,4-dichlorobenzene emitted to agr. Soil	1.50 SEK/kg

For further description of the method, see (Johansson 1999; Eldh 2003) (Finnveden 2000)).

<u>Ecoindicator-99</u>

Ecoindicator is developed by PRé consultants in the Netherlands. The methodology is described in Goedkoop and Spriensma (2000). Three different versions of the method are developed the egalitarian perspective, the hierarchist perspective and the individualist perspective. In this LCA we have used the hierarchist perspective, which is based on inclusion of substances if there is consensus among scientists regarding the effect. For example, all carcinogenic substances in IARC (International Agency for Research on Cancer) class 1, 2a and 2b are included, while class 3 has deliberately been excluded. In the hierarchist perspective, damages are assumed to be avoidable by good management. As an example the damage from fleeing people that flees from their home because of rising water levels is not included since it can be reduced by good management. Further, in the case of fossil fuels the assumption is made that fossil fuels cannot easily be substituted, which means that oil and gas are to be replaced by shale, while coal is replaced by brown coal.

Weighting is performed for the three damage categories; Human health, Ecosystem quality and Resources. The impact categories and weighting factors are shown in Table 3 below.

Table 7-3, Impact categories and weighting factors used in Ecoindicator 99 (SimaPro).

DALY= Disability Adjusted Life Years,
PDF=potentially disappeared fraction of species.

Impact category	Weighting factor	Unit
Human health Cancirogen	300	DALY
Human health Resp. org.	300	DALY
Human health Resp. inorg.	300	DALY
Human health Clim.change	300	DALY
Human health Radiation	300	DALY
Human health Ozone Layer	300	DALY
Ecosystem Quality Ecotox	400	PDF*m2yr
Ecosystem Quality Acid/Eutrophication	400	PDF*m2yr
Ecosystem Quality Land use	400	PDF*m2yr
Resources Minerals	300	MJ surplus energy
Resources Fossil fuels	300	MJ surplus energy

For more information, see Goedkoop and Spriensma (2000), information in the SimaPro program and www.pre.nl.

EPS (Environmental Priority Strategies)
The EPS method is developed within Centre for the environmental assessment of Products and Material systems (CPM) in Sweden. The methodology is described in Steen (1999). Weighting is made through valuation on the five damage categories human health, ecosystem production capacity, abiotic stock resource, biodiversity and also cultural and recreational values. Each damage category consists of impact categories. Weighting factors should represent the willingness to pay to avoid changes, and is calculated as environmental load units (ELU). More information can be found in Steen (1999).

7.10 Results from the LCA

7.10.1 The war scenario:

In the war scenario, the most environmental hazardous process is the actual war impacts according to Ecotax 02 max, Ecotax 02 min (RT) and Eco-indicator 99. In the war process, the grenade is transported by truck and train and detonated outdoors.

According to EPS 2000 it is the mining of copper ore (copper conc 30%) in the grenade that has the largest environmental impact. These data are from IVAM 4,0. Copper is used in the Brass in the Cartridge case, in the PFHE Shell and the Primer. Copper is classified as type 2 with the MECO method.

7.10.2 The total grenade scenario:

The most important processes in the total grenade scenario from an environmental point of view are according to the different impact assessment methods:

- **Ecotax 02 max:**

  Primary aluminium production in Western Europe, this is used in the fuze body. Data are from IVAM 4,0. Aluminium is classified as type 3 according to the MECO assessment.

- **Ecotax 02 min (RT):**

Incineration of electronics. Electronics are used in the Fuze. We do not know what the actual electronics in the grenade contain, so we have used average data on electronics that are included in the database IVAM 4,0 in SimaPro. Since electronics have a large impact in the total grenade scenario, it is a good idea to evaluate these further.

- **Eco-indicator 99:**

The four processes that have the largest environmental impact are ECCS Steel, consisting of 20% steel scrap (26% of the total contribution), Electricity from oil (25%), Electricity from the Netherlands (13%) and Electricity from coal (11%). The ECCS Steel is used in the Shell body Skeleton, the Cap and the Blank Shell Case. Electricity from oil is used in the processing of Ammonium nitrate that is used in Hexogen and Octogen.

- **EPS 2000:**

Production of HNO3. HNO3 is used in mining of copper and production of Octol in the PFHE Shell. It is also used for production of Lead azide in the Fuze, Aluminium in the Fuze body, Hexogen in the Fuze, Brass in the Cartridge case and Nitrocellulose in the Cartridge. HNO3 is classified as type 2 according to the MECO assessment.

7.11 Results from the MECO analysis

This MECO assessment is used in this study as a complement to the quantitative LCA, and therefore only includes the dimensions Chemicals and Other. Electricity used and emissions that occur when producing or using the Grenade have not been included.

Table 7-4 show all substances included in the studied grenade, that is classified as type 1(very problematic). For more information and complete data se Hägvall et al. (2004). As can be seen in the table about 25 substances that should not be used are used in the shell greanade or during the manufacturing of the shell grenade.

Table 7-4, Chemicals in the grenade that are classified as type 1.

[1]Mining gas is assumed to be natural gas.
[2] R-phrases from Kemiska ämnen 8.0 Prevent
25 substances are classified as type 1.

Resource	CAS-number	R-phrase	The OBS-list	Type
Ammonia	7664-41-7	R10 T; R23 C; R34 N; R50	Yes	1
Benzene	71-43-2	F; R11 Carc.1; R45 T; R48/23/24/25	Yes	1
Chlorine	7782-50-5	T; R23 Xi; R36/37/38 N; R50	Yes	1
Cobalt	7440-48-4	R42/43 R53	Yes	1
Crude oil	8002-05-09	Carc.2; R45	Yes	1
Diphenyl amine	122-39-4	T; R23/24/25 R33 N; R50-53	Yes	1
Heavy fuel oil	92045-14-2	Carc.2; R45	No	1
Lead	7439-92-1	Repr. 1; R61 Repr. 3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Lead acetate trihydrate	6080-56-4	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Lead azide	13424-46-9	*E*; *R3* Repr1; R61 Repr3; R62 Xn; R20/22 R33 N; R50-53	Yes	1

Lead oxide	1317-36-8	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	Yes	1
Mercury	7439-97-6	T; R23 R33 N; R50-53	Yes	1
Methane	74-82-8	F+; R12	No	1
Mining gas[1]	64741-48-6	Carc.2; R45 Xn;R65	no	1
Naphtha	8030-30-6	Canc2; R45 Xn; R65	No	1
Natural gas	64741-48-6	Carc.2; R45 Xn;R65	No	1
Octogen[2]	2691-41-0	R3, R21, R50	No	1
Pentane	109-66-0	*F+*; *R12* Xn; R65 R66 R67 N; R51-53	No	1
Petroleum gas	92045-80-2	F+; R12 Carc.2; R45	No	1
Pitch	61789-60-4	Canc2; R45	No	1
Silver	7440-22-4	Repr.1; R61 Repr.3; R62 Xn; R20/22 R33 N; R50-53	No	1
Silver nitrate	7761-88-8	C; R34 N; R50-53	Yes	1
Sodium azide	26628-22-8	T+; R28 R32 N; R50-53	No	1
Trotyl (TNT)	118-96-7	E;R2 T; R23/24/25 R33 N;R51-53	No	1
Uranium	7440-61-1	T+; R26/28 R33 R53	No	1

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8 Munitions database

At present it is difficult to evaluate the environmental performance of munitions in the process of procurement of, for example, a weapon system. The Swedish Defence Materiel Administration (FMV) is trying to reduce the environmental impact by restrictions on certain substances (FMV 2003)but also by requirements on the producer. Life Cycle Assessments are tools that can be used when analysing the environmental impacts from products. A case study on a PFHE Shell Grenade has been made using both traditional quantitative and qualitative methodology. For descriptions on LCA and the case study see chapter 7 and also Hägvall et al. (2004).

This case study evolved into a project for making a database for the use in evaluating the environmental impact from munitions. We used the SimaPro software to make the database, partly because a lot of information already existed in the software but also because it was the simplest thing to do.

8.1 The use of a database

The goal with the database is to help different stakeholders, such as the Swedish Defence, FMV and industry, to make comparisons between different options of munitions and analyse potential environmental impacts that munitions have in a lifecycle perspective. The database includes different components of munitions.

8.2 Building a Database

When building a database for munitions there is a need for systematic categorisation of the substances. This categorisation has to be so transparent that it is easy to obtain the data for the user. To categorise substances that are included in munitions the idea was to categorise them according to their function. This is rather easily done when talking about the functional components like pyrotechnics and explosives. It creates a bit more work when there are substances that can be used in several areas in the grenade like metals and plastic. To solve this problem we have categorised them into what they are, like metals, plastic, paint and so on. This works well with the functional substances also. This categorisation was described in a previous progress report (Hochschorner, Hägvall et al. 2004).

8.2.1 Information gathering: Munitions examples view

During this stage information were gathered and placed into these categories. The goal was to obtain information of the materials and chemicals through different kinds of munitions. Therefore, several different munitions types were chosen and for each of these types one munitions were chosen to be "representative" munitions for that type. Information from these representatives was then gathered. The list of representative munitions that were chosen is presented in Table 8-1. The idea was that the database should contain examples of common munitions that could be used if information from suppliers and manufactures was not good enough. Then at least a simplified evaluation could be done.

The source of information was focused to FMV as buyer of these munitions effects. The effort was to find persons with knowledge of each munitions effect so that information from that effect could be entered the database.

The contacts with these persons were often very beneficial. Many times we could get the information about the munitions effect or the person could suggest alternative munitions effects. For example the information about air to surface missile 15 was available but due to classification issues we chose to use data from air to surface missile 24 instead.

The quality of the gathered data could be very different, for example the torpedo 613 was the first data we obtained from FMV. We received about 6000 drawings of the construction and several pages of information. Even though the information was plentiful it was difficult and very time consuming to render this information into LCI data that could be entered into the database.

Table 8-1, Munitions effects chosen for the study

Armed forces material number	Swedish name	Choice based on (when applicable)
M4084-405044	8,4 cm grenade launcher, smoke shell m/68/73/81	Titan tetrachloride
M4741-105501	Chock hand grenade	
M4742-110301	Hand grenade smoke m/56	White phosphorous
M4742-410101	Smoke thrower shell 90	Hexachloro ethane
M4745-100511	Illumination round	Illumination
M4057-702705	57 mm HE shell	Medium calibre
M4120-157200	12cm armour-piercing tracer projectile m95	Tank based munitions
M4120-054804	Strix, mortar shell	Advanced mortar shell
M4120-802604	12 cm Mortar shell	Mortar shell
M4155-002500	15,5 HE shell 54-77	Large calibre
M4400-015011	Air to surface missile 15	Missile
M4400-090011	Surface to air missile 90	Missíle
M4342-613001	Torpedo 613	Torpedo

Another example is smoke thrower shell 90, the information from FMV consisted of two pages that were not classified and after information from the project manager (Jansson 2005) we found the information about these materials meagre.

At this stage it was decided that gathering meagre information from FMV was not a good enough source. It was decided to focus on the materials and not from where they originated. The munitions examples were put aside.

8.2.2 Information gathering: materials view

There was now a change instead of collecting data from representative munitions, we collected data on materials we knew were usual in munitions. We contacted the weapons researchers at FOI divisions for weapons and protection (Eldsäter, FOI personal communication 2004 08-55503000, Wingborg, FOI personal communication 2004 08-55503000). We asked to receive the ten most used explosives and propellant in a first stage. That resulted in Table 8-2 that ten explosives materials and nine propellants materials were listed.

Table 8-2, List of top ten most used explosives and propellants materials (Eldsäter, Wingborg)

Explosives	Propellants
TNT	Nitro cellulose
HMX	Nitro glycerine
RDX	Ammonium perchlorate
Pentyl	HTPB
Ammonium Nitrate	CTPB
Nitro glycerine	PBAN
Nitro cellulose	Hydrogen peroxide
Tetryl	Aluminium
DNEG	kerosene
NTO	

The objective was to find LCI data, for these materials, in available databases in our case Ecoinvent, Ivam 4.0 and the databases that are included in the SimaPro program. We chose a database hierarchy so that we would chose data form different databases in the correct order. The hierarchy is shown below.

1. Ecoinvent Unit process
2. IVAM 4.0
3. Buwal 250
4. Pre database
5. Other

This hierarchy was used for choosing materials already in any of the databases available. When there was an information gap data was sought after from other sources. For simplicity data from internet sources were used when concerning explosives material. The sources where controlled by explosives chemist before use. These data is based on lab scale manufacturing of the explosive or propellant, these data were considered "better than nothing".

8.2.3 Constructing LCI data

In the work to collect LCI data for explosives and energetic materials to the database, many common substances in the area of energetic materials we had difficulties finding data. In order to find a first good estimation we follow the method in Geisler, Hofstetter et al. (2004). They built up a structure of the Estimation Procedure based on Life Cycle Investment (LCI). The LCI of any chemical product comprises a sequence of reactions used to synthesise the final product. In the estimation procedure lined out by Geisler, Hofstetter et al. (2004), each reaction is assumed to be carried out in its own process step as long as no other information is available from the literature.

Geisler, Hofstetter et al. (2004) has estimated two levels of impact, a best-case and a worst-case scenario. To these two cases they have estimated values for natural resources, need of solvents, energy demand and emission. Because some of the components are made in small quantities, by few manufacturers and in small specialised chemical factories, we choose to use the worst-case scenario, also to simplify the calculation. We choose the yield 0.87 with no major side products.

To take an example, ammonium perchlorate (AP) is produced be the chemical reaction (Hägg, Gunnar, 1964):

$HClO_4 + NH_3 \rightarrow NH_4ClO_4$

The yield is 0.87, so it is needed 0.98 kg $HCLO_4$ and 0.17 kg NH_3 to make 1 kg AP.

So the resources from nature to make 1 kg AP is 730 kg cooling water and 0.5 kg Nitrogen. From the technosphere is needed 0.7 MJ electricity and 7.7 kg steam. The emission to air is 1.7 g ammonia. The emission to water we assume what is left from the reaction. That is 18.3 g ammonia and 0.13 kg Perchloric acid, $HClO_4$. Ammonia, is found in the database with good data, but perchloric acid is not found, so then we have to repeat this procedure for perchloric acid.

In the database there are 26 substances calculated with this method.

8.3 The database

At this time we have 96 substances identified and entered into our database. For this report we have categorised the data into different categories these are:

I. Materials with good data
   These are materials that existed in already compiled database such as EcoInvent or materials that were calculated during the PFHE project (Hägvall, Hochschorner et al. 2004)
II. Materials with insufficient data
   These are materials were we have data from for example open data sources such as internet where the quality of the data is unknown.
III. Materials with calculated data
   Materials with LCI data calculated according to Geisler, Hofstetter et al. (2004)
IV. Materials with no data

The materials in each category can be seen in tables 4-8

Table 8-3, Categorised materials with good data

Acetic anhydride, at plant munitions	Octogen (HMX)
Aluminium, production mix, at plant	Octol
Ammonium nitrate	Potassium sulphate, as K2O, at regional storehouse
Boric acid, anhydrous, powder, at plant 2	Silver azide
Brass, at plant/CH U	Steel,converter, chromium steel 18/8, at plant 2
Carbon black, at plant	Trotyl (binder)
Crude Montana wax	Trotyl (TNT)
Graphite, at plant	Tungsten
Hydrogen peroxide, 50% in H2O, at plant	Demineralised water 3.0
Isopropanol, at plant	Zink for coating, at regional storage
Kerosene, at regional storage	
Lead, at regional storage	

Table 8-4, Categorised materials with insufficient data

Black powder	Nitro guanidine
Diamylphatalate	PETN
Hexogen	Primer body production
Hexotonal	Silver nitrate
Leadazide	Sodium azide
Nitrocellullose	Tetrazene
Nitro glycerine	Tetryl

Table 8-5, Categorised Materials with calculated data

Ammonium dinitramide, ADN	Hexamine
Ammonium perchlorate	Lead nitrate
Antimony trisulphide	Lead oxide
Barium chromate	Perchloric acid
Barium nitrate	Potassium Nitrate
Boron	Potassium perchlorate
Boron oxide	Phosphor pentoxide
Boron trifluoride, BF3	Sodium carbonate
2,2,5,5-Tetranitro-dihydro-pyrimidine-4,6-dione, $C_5H_2N_6O_{10}$	Sodium bisulphite
Chloronaphtalene	Sodium sulphite
Dinitramic acid, DNA, $HN(NO_2)_2$	Sulphur dioxide
Ethanol	White phosphorous
FOX-7	Zinc oxide
Hexachloro ethane	

Table 8-6, Categorised materials with no data

Acetonitrile	Guanidine nitrate
Aminoguanidine dibicarbonate	Hydrofluoric acid
Ammonium bisulfite	Lead acetate trihydrate
Ammonium chloride	PBAN
Antimony	PBAN (prop-bind)
Barium chloride	Phosphorous bronze
Boron tribromide	Polyester resin
Calcium silicid	Potassium chromate
Centralite I	Red Phosphorous
Chloric acid	Single base gun powder
Copolymer VDH/HPF	Sodium carbonate
CTBP	Sodium Nitrite
Dichloro ethane	Triple based gun powder
Dimethylanilline	Water acidulated
Diphenyle amine	Zinc hexa chloro ethane
Double base gun powder	HTPB
Fluoro acid	2-methyl-4,6-pyrimidinedione
Glycerol	Zirconium type A
Hexa chloro ethane	

8.4 Discussion about the database

In the current form the database has some gaps and to be able to really use it in many situations the data collection work has to continue. However it is possible to get environmental information about munitions which contains these substances. For the Swedish perspective this could be a fair amount of all the articles that at least exist in the inventory.

From our work several conclusions can be made:

1) Bad data is better than no data
2) Due to varied information level, gather data out of a material perspective
3) A lot of data will be calculated
4) There will always be materials with no data

8.5 Reference

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