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Abstract

Remanufacturing is a process of bringing used products (known as 'cores') to 'like-new' functional state by rebuilding and replacing their component parts. Remanufacture has long been used in many industries for high capital cost equipment, but it represents a new kind of business process for companies in other industries that, for a mixture of cost, regulatory and environmental reasons, wish to adapt to this mode of operation. The primary objective of this research was to develop a model of the business processes used in remanufacture. The methodology used included a review of candidate modelling techniques, case study work with companies, and evaluation work with a panel of experts based on the necessary properties of relevant research of Thomas and Tymon (1982). The outcome of the research was a model that has been validated in the electromechanical industry. The paper presents several diagrams to illustrate the structure of the model and concludes with some proposals for further work to build upon this understanding of this key business process for sustainability.

Keywords: remanufacture, business process, IDEF0, electromechanical industry

1. Introduction: The case for modelling remanufacturing

The practice of remanufacturing is particularly applicable to complex electro-mechanical and mechanical products which can, when recovered, have value added to them which is high relative both to their market value and to their original cost. Studies indicate cost savings in the region of between 20% and 80%, when compared to the cost of new manufacture, while providing quality comparable to that of an equivalent, current, all-new product (Lund 1984). Although remanufacturing has had a low profile, it has been a viable economic activity for many decades. Research records in excess of 73,000 firms engaged in some sort of remanufacturing in the late 1990s, in the United States alone (Lund 1998).

Remanufacturing has not been well defined or codified. Major remanufacturing problems include the insufficiency of remanufacturing knowledge (Nasr and Varel 1997) and the lack of models for analysing remanufacturing operations so that it can be better understood and improvements made to its operational processes if required. The motivations for developing tools and techniques specifically for remanufacturing are:

1) There are few analytic models of remanufacturing (Guide and Srivastava 1997) and remanufacturing practitioners perceive the scarcity of effective remanufacturing tools and techniques as a key threat to their industry (Guide 1999).

2) Remanufacturers incur great financial losses because of difficulties in undertaking some critical remanufacturing activities, for example, the ‘investigate core’ activity, a key but complex element of the remanufacturing operation for which no guidelines are currently available (Ijomah *et al.* 1999).

3) Practitioners require tools that would help them to improve the consistency and effectiveness of training (Ijomah 2002).

4) Remanufactured products must be of high quality and reliability, as well as low priced, to compete successfully against alternatives such as reconditioned and new products. However, with current remanufacturing practices, high levels of inspection and testing are required to obtain high quality products and this normally leads to higher production costs and longer production lead-time (Ijomah 2002). A better understanding of the business processes involved could lead to cost reductions and quality improvements.

5) Tools of conventional manufacturing are not ideally suited to remanufacturing because planning, controlling and managing operations are significantly different from traditional manufacturing production control (Guide 1999).

6) Most current remanufacturing-specific tools have been designed in-house by large remanufacturers, (typically, contract remanufacturers), that obtain the necessary expertise and even more importantly, immense financial investments that such projects demand from their original equipment manufacturer (OEM) partners. Because remanufacturing is a secretive industry and because such remanufacturers wish to obtain a competitive edge they are unwilling to share knowledge of their tools with potential competitors, in fact, very often their contracts with their OEM supporters would not allow them to do so (Ijomah 2002). Most remanufacturers, being small practitioners (Lund 1984), cannot afford the expense of such an undertaking (Ijomah 2002), thus these tools are unavailable to the bulk of the industry.

The objective of the research upon which this paper is based was to address these issues by developing a comprehensive model of remanufacturing. Models are proven methods of conveying information (Kubeck 1995; Wang *et al.* 1993) and also are recommended for analysing business processes and enhancing understanding (Smart *et al.* 1995; Bennett *et al.* 1995) because they can overcome communication problems such as ambiguity that are associated with other ways of understanding operational situations (Ould 1995). Thus an acceptable model of remanufacturing operations would allow the exchange of information between companies, such as to discuss problems or exchange good practice and simplify the analysis of processes within a company.

2 Existing models of remanufacturing

Many existing descriptions of the remanufacturing process are part of other models relating to material re-use and sustainability, such as the model by Guide *et al.*

(1997) shown in Fig 1. While useful in defining context, such a model has little significance for a company wishing to improve its actual activities.

[Take in Fig 1 near here]

Krikke et al. (2004) show how the remanufactured products can fit into alternative supply chains. This work is valuable in pointing out the closed loop in which material can circulate many times before disposal. However, the activities involved in remanufacture are all contained in one box.

A generalised description of the processes involved in remanufacturing can be found in Guide (1997) (Fig. 2) who distinguishes between disassembly and re-assembly operations, a similar view to that taken by Tang *et al*. (2004) (Fig. 3) who also describe the closed loop. Interestingly, these writers see the remanufacturing activities as not including disassembly and re-assembly, thus broadly equating it with repair of components.

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A more detailed model produced by Goggin and Browne (2000) shows the distinct stages of remanufacturing that form part of the reverse supply chain (Fig 4).

[Take in Fig 4 near here]

Okumura et al. (2003) show the flow of cores for remanufacturing from functional failure or physical failure from a production economics standpoint.

Specific work has been done for particular cases, producing more detailed but not generally applicable models. For example the flow chart of refrigerator supply loops by Krikke et al. (2003) includes the activities of disassembly, inspection and rebuilding that form part of remanufacturing (Fig. 5).

[Take in Fig 5 near here.]

Other specific diagrams include the reverse supply chain for Hewlett Packard's desktop PCs by Guide *et al*. (2005) and engine remanufacturing by Seitz and Peattie (2004). .

These models are valuable in identifying the context of remanufacture and the major stages involved, and in fact their purpose has been largely concerned with the definition of remanufacturing itself. Much more detail is required to provide a basis for analysis and development of operations within remanufacturing companies. This would be difficult without adopting a more formal modelling scheme. The aim of this research was to produce a detailed yet generic model of remanufacturing activities that would be of relevance and utility to managers in industry.

3. Methodology

To ensure manageability of the research, its scope was limited to the mechanical and electromechanical sector of the UK remanufacturing industry. The key research techniques were literature search and observational case studies. The model has four key foundations:

1. The definition of remanufacturing as 'The process of returning a used product to at least OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent' (Ijomah 2002, Ijomah *et al.* 2004) was used as a foundation for developing the comprehensive model of the remanufacturing business process.

2. The 'Operate' process of the manufacturing reference model (Smart *et al*. 1999) and

3. The CIM-OSA Manage-Operate-Support business process architecture (CIM-OSA 1989). These two pieces of work serve to delineate the concept of the "operate" process and to distinguish it from the "manage" and "support" activities.

4. The IDEF0 modelling technique (IEEE 1998). IDEF0 is a well accepted modelling technique based upon the activities carried out in a business system under examination. Its appropriateness for this application is examined by setting out the requirements that would be fulfilled by a suitable technique and comparing IDEF0 to two other widely accepted conventions, data flow diagrams and flowcharts (section 3.2).

The model development process was adapted from the author-reader cycle proposed in the original IDEF0 Architect's Manual (Ross *et al.*1980). It involved three activities: the development of a company-specific model of remanufacturing through an in-depth case study; assessment of the model for correctness and accuracy by the host company and by manufacturing and IDEF0 experts independent of the research; and refinement of the model by assessment against other remanufacturers in order to implement alterations that would make it valid for a wider range of remanufacturers. This was followed by validation of the model. This was achieved by exploring whether the research had obtained correct results that would be useful to practitioners. In this instance practitioners were remanufacturers and academics because they sought remanufacturing knowledge and expertise. This involved having a panel of practitioners, consisting of case study companies, non-case study companies and academics use the 'validation by review' method (Landry *et al.* 1983) to assess whether the model satisfied the 'needs of practitioners' (Thomas and Tymon 1982). The validating criteria were the suitability (or usefulness), sufficiency and clarity of the model. Steps taken to strengthen validity of the research include ensuring quality of research design by:

1. Ensuring proper data collection quality control. Techniques used here include between-method and within-method triangulation, establishing a chain of evidence and key informant review of case study report.

2. Testing for replication logic by testing results with members of the electromechanical sector of the UK remanufacturing industry who were hitherto unconnected with the research.

3.1 *A systems approach to modelling remanufacturing*

Many small improvements can be made to a business process at the detailed level, but when considering the design of whole business processes (such as the processes of manufacture or remanufacture) it is necessary to understand the process as a whole. A systems view sees the process as a whole system, containing a set of sub-systems that are controlled and which communicate (Checkland 1981). The whole-system understanding sets a context for evaluating or even removing lower level activities while allowing the analyst or user to concentrate on the performance of the whole. This is pointed out by Guide and Srivastava (1997) in relation to recoverable manufacturing systems, which require system-oriented solutions rather than optimisation of systems' sub-processes. The detail can be decided upon for the circumstances of each specific company.

Checkland (1981) defines a system as a set of elements connected together to form a whole entity, that exhibits the combined properties of the whole, rather than the properties of its individual component parts. Because a remanufacturing system falls within Checkland's definition of a human activity system (HAS), the research objectives must be achieved through qualitative research. A company can be seen as consisting of HASs of a type known as business processes. A business process is 'a set of logically related tasks performed to achieve a desired business outcome' (Davenport and Short 1990). Childe *et al.* (1994) propose that the business process 'starts and finishes with the external or internal customers who are served by the process' and that 'the process perspective encourages a holistic view of the activities that are needed to satisfy a customer requirement'. A key advantage of the process perspective is that it recognises that improving one part of the process in isolation may not significantly improve the overall process because the processes are interdependent.

3.2 *Process modelling*

A generic business process model displays only characteristics that are common to members of the business type that it represents. For example, a generic model of a manufacturing company will exhibit only those traits that are common to a series of manufacturing companies and will not show features that are unique to a particular manufacturing organization. Generic models can help to improve understanding because they provide accurate descriptions of the characteristics of typical members of the business type that they represent (Bennett *et al.* 1995). However, to make a model, a suitable modelling technique must first be identified.

The required modelling technique must be able to provide a complete, concise and consistent description of the activities and flows that form a system or process (Smart *et al.* 1995). Weaver (1995) proposes that it is possible only where the modelling technique is:

- Easy to use
- Usable for generic models as well as specific company models
- Capable of supporting decomposition (i.e. different levels of detail)
- Able to be integrated into a set of modelling techniques supporting all phases of a design and implementation project.
- Re-usable in a wide range of applications.

Modelling techniques that were considered to be candidates for this work were IDEF0, data flow diagrams and flowcharts.

IDEF0 has proven advantages in business process modelling, because it provides a picture of the activities and flows of a process or system (Smart *et al.* 1995). The suitability of the IDEF0 modelling technique can be assessed in terms of, firstly, its ability to satisfy the characteristics of appropriate modelling techniques and, secondly, by comparing its capabilities against those of some better-known alternatives.

According to the Architect's Manual (Ross *et al.* 1980), IDEF0 satisfies all the criteria above. In addition, its ease of use is described by Smith and Wang (1988). Maull *et al.* (1995) and Childe *et al.* (1996) point out that IDEF0 can be used for both generic and company-specific models. IDEF0's properties of decomposition are identified by LeClair (1982) and by Bennett *et al.* (1995). LeClair (1982) and Smart *et al.* (1995) show that IDEF0 is part of a set of modelling techniques that support all phases of a project.

The most obvious alternatives to IDEF0 were data flow diagrams and flowcharts.

Data flow diagrams (DFDs) model a system at any level of detail with a graphic network of symbols showing data flows, data stores, data processes, and data sources and destinations. They were introduced and popularized for the structured analysis and design of data processing systems in the late 1970s (Gane and Sarson 1979). They are effective for illustrating how information flows through a system and are used in the preliminary stages of systems analysis to help understand the current system and to model the required system. For large systems, DFDs can become cumbersome, difficult to translate and read, and time consuming to construct. DFDs can become confusing because different modellers use different symbols, for example, circles and rectangles to represent entities.

DFDs are weak at describing the activities performed, focussing principally upon the flow of data between activities and stores. They do not easily adapt to the modelling of the flow of material or of the control of activities.

Flow charts represent graphically the sequence of operations and storage activities in a process, for example, movement, delay, decision and inspection. Flowcharts use standardized symbols to represent the operation types and processes being undertaken. They are effective for documenting processes and interrelationships between process activities and can help to identify problems and improvement opportunities.

Initially in this study, flowcharts were used to document research information but the level of detail to be managed was a problem with a technique that could not support decomposition. The ability to decompose is a basic characteristic of an effective modelling technique because it permits the building of models that can represent the complexity of a system at whatever level of detail is appropriate for the required purpose (Doumeingts *et al.* 1992; Aguiar *et al.* 1993). Flowcharts may be used at the lower, more detailed levels of diagrams together with other techniques such as IDEF0 to manage the hierarchy.

For further discussion of alternative modelling techniques the reader is referred to the useful review by Aguilar-Savén (2004).

3.3 *The IDEF0 background and concept*

IDEF0 is a process modelling technique that illustrates the component activities and flows of a system thereby helping the modeller to identify what activities are performed, the circumstances regulating and controlling the activities, and the material and information flows between activities. It can also show the 'mechanism' (such as a person or a machine) that performs each activity in any particular case, although this is not relevant in a generalised model where different companies may use different means to perform the same activity. Limitations of space prevent a full explanation of the rules of IDEF0, for which we refer the reader to FIPS PUB (1993) or Colquhoun *et al.* (1991). For the present paper we provide a reminder of the familiar IDEF0 activity box showing the four arrow types identified by the side of the box to which each connects.

[Take in Fig 6 near here]

4. Development of the model

This research requires a model of the logistics chain, from the customer ordering a remanufactured product, through the company producing that remanufactured product, to the delivery of the product to the customer. This fits within the definition of the 'operate' process described in the CIM-OSA standard (CIM-OSA 1989). We are not concerned here with the activities involved in setting the strategy and direction of the company nor its business planning. We do not consider the analysis of the support activities facilitating the 'operate' or 'manage' processes. The boundaries of the model therefore encompass the activities involved in the customer ordering a remanufactured product, those involved in the company producing that remanufactured product, and the activities of delivering the product to the customer.

The model development process began with an in-depth, four-week duration case study to develop a company-specific model of the remanufacturing business process. Basing the model initially on information from only one company permitted the authors to control the research information in manageable sections. The first company was involved in remanufacture of complex electromechanical products. Data collection was through four activities: key personnel interviews, direct examination of the process, augmenting documented information with staff and customers and verifying documented information. Once a model that satisfied that company was achieved, it was assessed against the practices of three other case study companies to implement any alterations that would make it valid for a wider range of remanufacturers. This covered the three types of remanufacturer identified by Lund (1984); OEM, Contract and Independent. It also included both large and small companies. The validation of the model will be described in Section 6.

5. The generic remanufacturing model

The model consists of a series of nineteen nested diagrams where top-level diagrams give a basic overview of the system and lower level diagrams give increasingly more detailed information. Top-level diagrams give the macro-view of the remanufacturing process that top-level managers need to facilitate their strategic decision taking. The lower level diagrams provide detailed operational information to support shop floor workers in their everyday tasks.

Figure 7 shows the A-0 diagram, 'Run remanufacturing business'. The A-0 is a diagram of the context of the remanufacturing business and shows the interaction of the business with its environment. It shows, for example: inputs such as technical assistance request, sales and warranty requests from customers; outputs such as remanufactured products and warranty; and controls such as industry standards.

[Take in Fig 7 near here]

This A-0 diagram can be decomposed to give the A0 diagram, Run Remanufacturing Business, shown in Figure 8. This shows the four major activities that make up the remanufacturing business process:

- **Obtain raw material**: purchase externally supplied parts that are needed to remanufacture products. These include ‘cores’, conventionally manufactured components and externally remanufactured components.
- **Remanufacture product:** Return the core to at least Original Equipment Manufacturer (OEM) latest specification.
- **Sell product:** Give the remanufactured product to a customer in return for money.
- **Support customer:** Help the customer through services such as warranty obligations, technical assistance (e.g. installation and help in choosing an appropriate product).
-

[Take in Fig 8 near here]

Each of these major sub-activities is shown with its various flows (inputs, outputs, controls). Each is also decomposed to reveal more detailed remanufacturing information. For example, Figure 9 shows the A2 sub process, which is the detail of the

A2 subprocess in the A0 diagram. The A2 diagram represents the remanufacturing operation itself. It is concerned with returning the used product (core) to current OEM specification and is composed of the following major activities:

1. **Get core from store:** selecting the required core from the remanufacturer's store.
2. **Strip core:** reduce the core to its components.
3. **Remanufacture parts:** bringing the components to current OEM specification.
4. **Store parts and kit:** put the remanufactured parts into inventory store and assemble all the component types required to produce the finished product.
5. **Assemble product:** put the parts contained in the kit together to build the remanufactured product.
6. **Test product:** Carry out the assessments required to ascertain that the product is of current OEM specification.
7. **Final inspection & paint:** visual inspection for cosmetic reasons and painting to original colour.
8. **Store Product:** Put product in finished goods store to await sale or dispatch to customer.
9. **Store production documents:** File the papers that relate to the job.

[Take in Fig 9 near here]

Although the rules of IDEF0 recommend a maximum of 6 activities in a diagram, this nine-box structure was the one with which users in remanufacturing companies felt happiest. Activities such as 'store product' which could have been hidden at this level were felt by users to be important enough to justify the extra boxes. (For example the question of what and how much to store is important in remanufacture where core supply is often uncertain.) The structure of the model is therefore more intuitive to the industrial users, at a cost of some increase in the complexity of the diagram.

Figure 10 shows the A22 Preprocess & strip core sub process which is concerned with dismantling the core to its component level and involves:

• Ascertaining that the correct core has been picked (e.g. use of documentation such as OEM manual).

• Dismantling the used product (core) to its components

• Visual inspection to eliminate obviously non-reusable parts (e.g. parts that are obviously damaged beyond remanufacturing, obsolete parts and parts where the cost of remanufacturing exceeds the cost of purchasing new).

[Take in Fig 10 near here]

Figure 11 shows the A23 subprocess; remanufacture part, which is concerned with bringing component parts at least to current OEM specification. This is the most crucial part of remanufacturing operation. It makes or breaks the remanufacturer because it determines the issues of cost and quality and these are the essential measures of competent remanufacturing. This activity has four main elements:

• A231: Sort parts**.** This requires detailed inspection of the components to sort them according reclaimable and non-reclaimable groups then further sorting by type or size for example to facilitate effective cleaning.

• A232: Clean parts: This is the removing of dirt and contamination such as rust from the components.

- A233: Bring parts to current specification: This involves gauging the parts, deciding how best to bring them to current specification and finally remanufacturing them. Parts that have not been successfully remanufactured are put back into the system as rework and will keep on going through the rework and test cycle until they are adequate or else a decision is taken that they are beyond remanufacturing.

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[Take in Fig 11 near here]

6. Validation of the generic model

6.1 *Procedure and participants*

The model was validated by the review method (Landry *et al.* 1983) to assess its ability to satisfy the needs of practitioners described by Thomas and Tymon (1982). If they found the model insufficient (a poor representation), unclear (incomprehensible) or inappropriate (unusable) then the research would have failed because the model would have been unable to fulfil the purpose for which it was developed. The validating panel was drawn from the electromechanical sector of the UK remanufacturing industry and academics in remanufacturing-related disciplines. This was necessary in order to satisfy the requirement for external validity (Yin. 1994) and replication logic (Creswell 1994).

Participants were drawn from middle management and above to ensure that they had adequate knowledge of the remanufacturing business process required for proper assessment of the model. The four companies used for the detailed case studies were represented by manufacturing and/or general managers and directors, thus 4-8 people at each meeting. To ensure objectivity as far as possible the panel also included director-level representatives and others from four companies engaged with remanufacturing, one of which was the UK trade body for remanufacturers in the automotive transmission industry, thus a further 4-8 people. Most of these representatives, especially the latter, had wide experience in many companies. Care was taken to include only people who understood the remanufacturing process and environment in depth because they dealt with it on a regular basis. Directors were only allowed if they were still actively involved. In addition to the practitioners, the panel included two academics specialising in remanufacturing from universities not linked with the research. Each meeting included between 12 and 18 attendees, with all participants, and their colleagues, eventually seeing the model. The geographical spread of the validating panel was wide, including Scotland, the Midlands and the South West of England. .This format permitted case study and non-case-study practitioners to debate remanufacturing practices, and reach a consensus opinion in the event of anomalies being identified in the model. The model was presented in stages, and after each stage feedback was collected from participants. Initial feedback sheets were completed immediately (on general issues such as ease of understanding) and secondary sheets were returned later to provide detailed corrections following use, discussion and further reflection. Use of the secondary feedback sheets allowed participants to share and discuss the model with colleagues, which besides allowing time for careful reflection ensured that further individuals could contribute as required.

6.2 *The results of the validating panel's assessment of the model*

The model satisfied the validating criteria of usefulness, clarity and sufficiency. The validating panel believed that the model was very accurate in the way that it represents the remanufacturing business process. This is shown by the information given in their validation sheets. For example in the initial feedback sheets, it can be seen that all the members of the validation panel either strongly agreed or agreed that the 'model captures the major information flows and activities of a remanufacturing business process' and that the 'model is an adequate representation of the remanufacturing business process'. At the same time they all disagreed or strongly disagreed that 'the model does not reflect the remanufacturing business process to any great extent' and that they 'do not recognise this model as being that of a remanufacturing business process'.

The respondents also found the model easy to understand and felt that it could help satisfy their requirements. For example, from the initial feedback sheets they all strongly agreed or agreed that they 'find the model easy to follow' and at the same time they also disagreed or strongly disagreed that they 'would not use this model to give a basic description of the remanufacturing business process'.

6.3 *IDEF0 as a modelling technique*

Prior to the validation all the participants were unfamiliar with the IDEF0 modelling technique. However, none found the concept too difficult to understand and all very quickly became competent with the technique. All members of the evaluating panel were of the opinion that the IDEF0 modelling technique would be an ideal method for disseminating remanufacturing information because it presents information in a consistent and concise manner. For example, they all strongly agreed or agreed that firstly 'generally the model is logical in the way that it describes the remanufacturing business process' and secondly they 'would consider using the model to describe the remanufacturing business process'.

6.4 *Ability to satisfy the needs of the practitioner*

Thomas and Tymon (1982) propose that, for any new knowledge to satisfy the needs of the practitioner, it must satisfy five needs: descriptive relevance, operational relevance, goal relevance, non-obviousness and timeliness.

Descriptive relevance The validating panel believed that the model was a sufficient representation of the remanufacturing business process and could be used to describe it. For example, from their initial feedback sheets they either strongly disagreed or disagreed that 'the model is a poor representation of the remanufacturing business process' and they either strongly agreed or agreed that they 'would consider using the model to describe the remanufacturing business process'. They recommended some alterations using secondary feedback sheets but felt that these did not indicate any great errors in the model.

Goal relevance All members of the panel believed that the model would be an effective tool for enhancing the efficiency and effectiveness of new and existing remanufacturing facilities. For example, its use as a reference model could help practitioners to analyse their operations so that they could enhance their understanding and implement improvements if required. It could also be used as a framework for discussion of best practice, training and improvement activities.

Operational validity Operational validity describes practitioners' ability to use the new knowledge easily. This requires that the new knowledge must firstly be understandable to practitioners and secondly, must be presented in a format that enables them to manipulate it easily. The completed initial feedback sheets indicate that they understood the model because the majority of them either strongly agreed or agreed that they 'find the model easy to follow'. The feedback sheets also indicate that the model was presented in an easy to use format because they either strongly agreed or agreed that they 'can analyse the information flows and activities of the remanufacturing business with this model' and also they all either strongly disagreed or disagreed that they 'would not consider using this model to describe the remanufacturing business process'.

Non-obviousness The practitioners believed that 'walking through' and discussing the model highlighted problem issues that they had been unaware of or that they had incorrectly assumed to be 'the normal play of things'. The academics for their part felt that the model helped them to gain a much clearer idea about the concept of remanufacturing and how it is undertaken as well as the complexities of the process.

Timeliness Recent research (Ijomah 2002; Guide and Srivastava 1997) illustrates that practitioners and academics require analytic models of remanufacturing to help enhance its understanding and effective management. The generic model is seen as timely because the validating panel agreed that it addresses these pressing remanufacturing problems.

6.5 *Discussion: validity of the model*

All members of the evaluation panel reported that from their experience and knowledge of remanufacturing, the model was a valid representation of the remanufacturing business process. They also indicated that the model would be useful to them.

Criteria such as validity, reliability and generalisability are important in establishing the validity of a piece of research (Gummesson 1993; Holloway 1997; Yin 1994; Eisenhardt 1989; Lang and Heis 1994 and Easterby-Smith *et al*. 1993). Construct validity and reliability (Yin 1994) were strengthened by using techniques such as triangulation to enhance data collection quality control. External validity was ensured by testing 'the extent to which the research findings can be applied to other instances of the phenomenon' (Yin 1994). The measures taken to ensure the external validity of the research findings include having the model assessed by non-case-study companies from the electromechanical sector of the UK remanufacturing industry and academics studying remanufacturing.

Replication logic (Creswell 1994) was used to test the model through the validation by review technique. By the laws of replication logic the model can be accepted as valid for a much larger number of similar neighbourhoods, the neighbourhoods in this case being the electromechanical sector of the UK remanufacturing industry.

7 Uses for the model

We propose three main uses for the model. After the initial feedback from the workshops, companies validated the model in use, reporting their findings using the secondary feedback sheets. They all reported that they were able to use the model to explain remanufacturing and its activities to new recruits and to their suppliers and clients. This led to their proposal for the model to be used for both on- and off-site training and it was suggested that it could be used in place of written training manuals and perhaps presented in a multimedia system. They also felt that it helped them to understand their own activities better. One company adopted the model as a marketing tool.

7. 1 Error reduction

If the model is used as a guiding manual during the remanufacturing operation it can help to reduce the level of guesswork and complexity involved in remanufacturing because the activities of the remanufacturing operation are clearly detailed in a logical and easily accessible manner. Those activities requiring assessment and evaluation can be identified and suitable controls and procedures can be applied. This is of particular importance in the activities related to investigating cores and components.

7.2 Enhancing training

The model is a comprehensive document that could facilitate effective training. This is because it unambiguously displays the activities of the remanufacturing business process, including the activities of all its sub processes such as the remanufacturing operation, as well as the interrelationships between those activities.

When used in this manner the model could help to promote a consensus view of the remanufacturing business process. This development would help to reduce the problems related to over reliance on experience as well as inconsistency and ineffectiveness of training that were identified by the case studies in Ijomah *et al.* (1999) and Ijomah (2002) so that that employees could more easily work to a pre-agreed company-wide procedure.

The model may also help to reduce training costs. According to the evidence presented in Ijomah *et al.* (1999), in remanufacturing companies, training is often undertaken hands-on with the more experienced employees teaching newer recruits. The model could be used as an off-site training facility.

7.3 A reference model

Literature and case studies have shown that remanufacturers and academics face many difficulties because of the inconsistency in the definitions of secondary market operations. In the case of academics, the model could be used to help them to unambiguously and accurately describe remanufacturing. This development would help them to undertake effective remanufacturing research and also to disseminate their findings. With regards to practitioners this comprehensive model can be used to help question the validity of existing remanufacturing operations and to improve the management of existing ones, as well as to facilitate the design of more effective remanufacturing business processes.

Weaver (1995) proposes that specific business processes models can be built from existing generic models. This involves comparing the existing generic model to the business process for which a model is required and adapting the generic model so that it displays the characteristics of the business that requires a model. Vernadat (1996) and Smart *et al*. (1999) describe a reference model as a model which is not fully instantiated, and which can be reused and customized by business users for building their own particular models. The output of this research is a reference model for remanufacturing businesses that can be used to disseminate remanufacturing knowledge.

8 Areas for further research

Two main areas for further research have been identified.

8.1 A basis for establishing contracts between OEMs and remanufacturers

The model makes clear the extent to which the business process depends upon the continuing reliable supply of cores for remanufacture. In contrast with manufacturers who can source supplies with guaranteed delivery and quality, remanufacturers often have to depend upon disparate and unreliable sources, such as service engineers, users, manufacturers, etc. Other research, for example Ijomah (2002), shows that the most successful remanufacturers are those that have contracts for the supply of cores. In fact, contracts bring additional benefits that help to enhance remanufacturers' profitability. These include access to product design information from the OEM, as well as a ready market because core suppliers are also often customers.

The role of the model in the establishment of contractual arrangements is in the identification of the activities to be carried out by various parties. For example, third parties may perform initial disassembly and manage the supply of parts, or alternatively arrangements may be made for complete units to be passed to the remanufacturer. More research is needed, for which the model provides a base. In the context of take-back laws, the subcontracting (or not) of responsibilities may become a very important strategic question. OEM companies who do not become remanufacturers may nevertheless benefit from this research as it provides them with some control over products bearing their brand name. It also permits them to obtain product failure information that can assist product design improvements.

8.2 Research to extend the model into an ISO-type standard for remanufacturing

Remanufacturing industry is poorly regulated with no universal benchmark for assessing remanufacturing operations. There is perceived to be a lack of trust in remanufacturers and remanufactured products among the general public and also among OEM companies. Two key problems result from this. One of the biggest obstacles to the growth of remanufacturing in some product sectors is consumer prejudice against used products coupled with their inability to differentiate between remanufacturing and related secondary market processes (Lund 1984). Also, Original Equipment Manufacturers are often unwilling to form contracts with remanufacturers and allow them to remanufacture their used products because they are unsure of the quality of their work and do not wish to risk tarnishing their brand names (Ijomah 2002). The remanufacturers that validated the model indicated that they would welcome its extension into an ISO-type standard for remanufacturing.

This development would help to improve quality and consumer confidence in remanufactured products. Also, because it gives a clear description of the companies' processes, it would provide OEMs with a cost-effective method of assessing the work practices of particular remanufacturers and this would help to enhance their willingness to form contracts.

9 Conclusions

The originality of this paper lies in the approach of analysing remanufacturing from a business process perspective. This paper demonstrates that the generic model of the remanufacturing business process that has been developed could be used to describe a remanufacturing operation so that others would understand remanufacturing and also improve that operation if required. It provides a step forward from the existing models mentioned in Section 2 by providing a level of detail suitable for the analysis of practices in industry. The model was tested via a review technique (Landry *et al.* 1983) and assessed according to its ability to satisfy the needs of the practitioner (Thomas and Tymon 1982). The evaluating panel from industry and academia were confident that the model was a true and comprehensive representation of the remanufacturing business process and believed it would help them to addressing key remanufacturing issues.

Two main directions for further remanufacturing research have been identified. These are: using the research results as a basis for contracts between OEM and remanufacturing practitioners; and using the generic model as a reference model in real life remanufacturing operations. The output of the research is a reference model for remanufacturing businesses that can help to disseminate remanufacturing knowledge and encourage the effective and economic use of this important technique for sustainability.

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Figures for
A model of the operations concerned in remanufacture

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by Ijomah and Childe

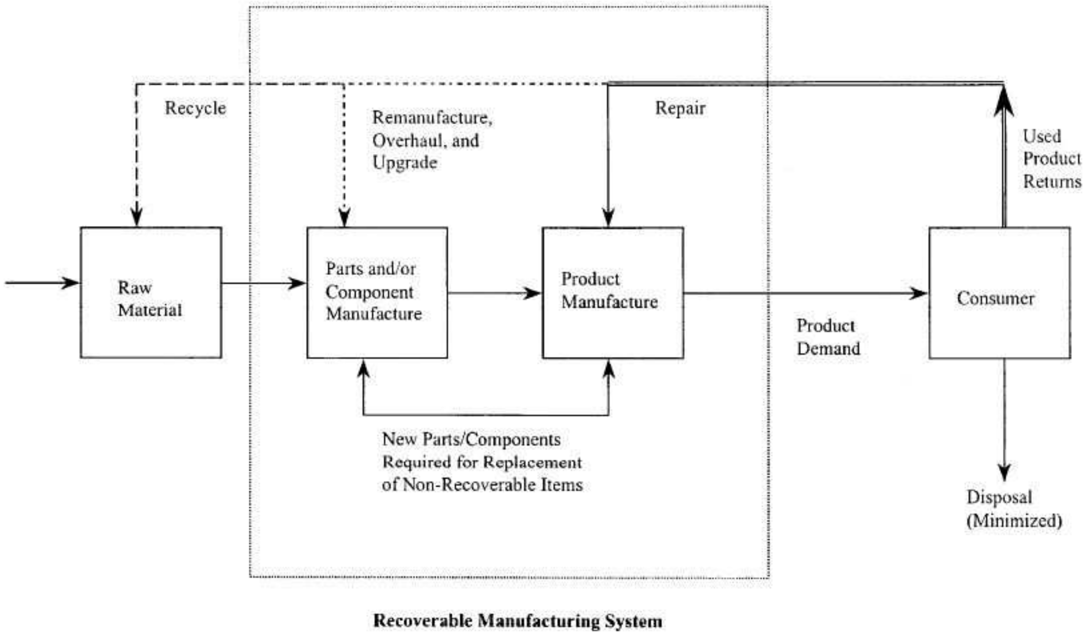

Figure 1 - The Recoverable Manufacturing System (Guide *et al*. 1997)

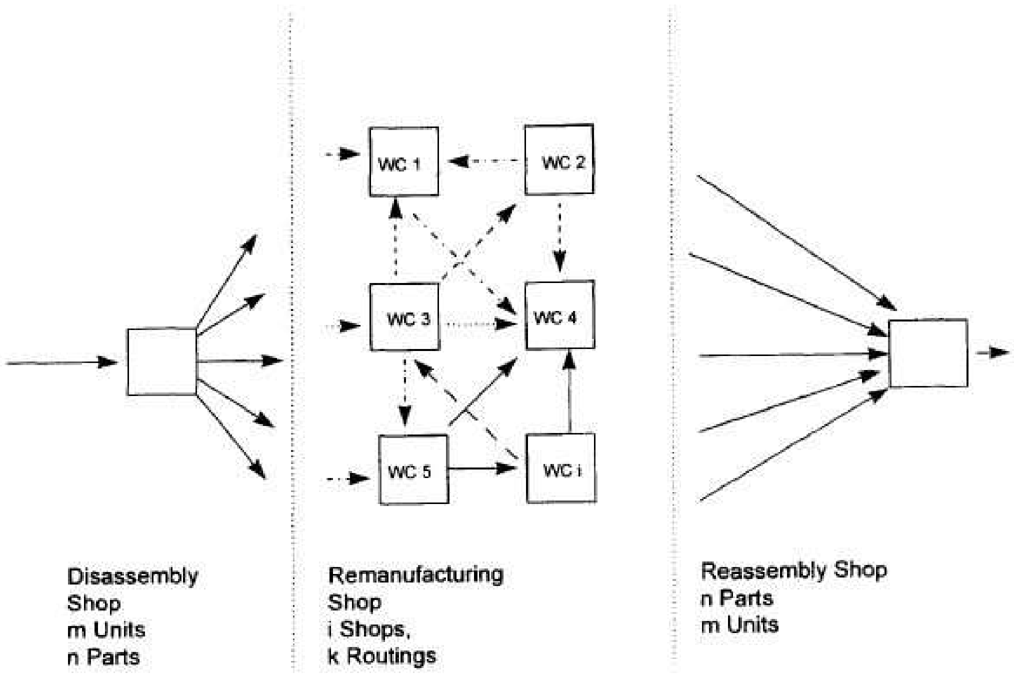

Figure 2 - Elements of a Remanufacturing Shop (Guide 1997)
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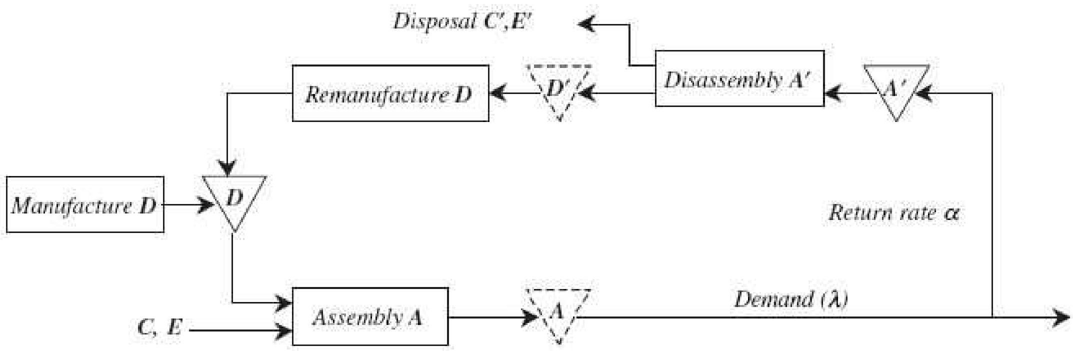

Figure 3 - Material Flow of a Disassembly / Remanufacturing System (Tang et al. 2004)

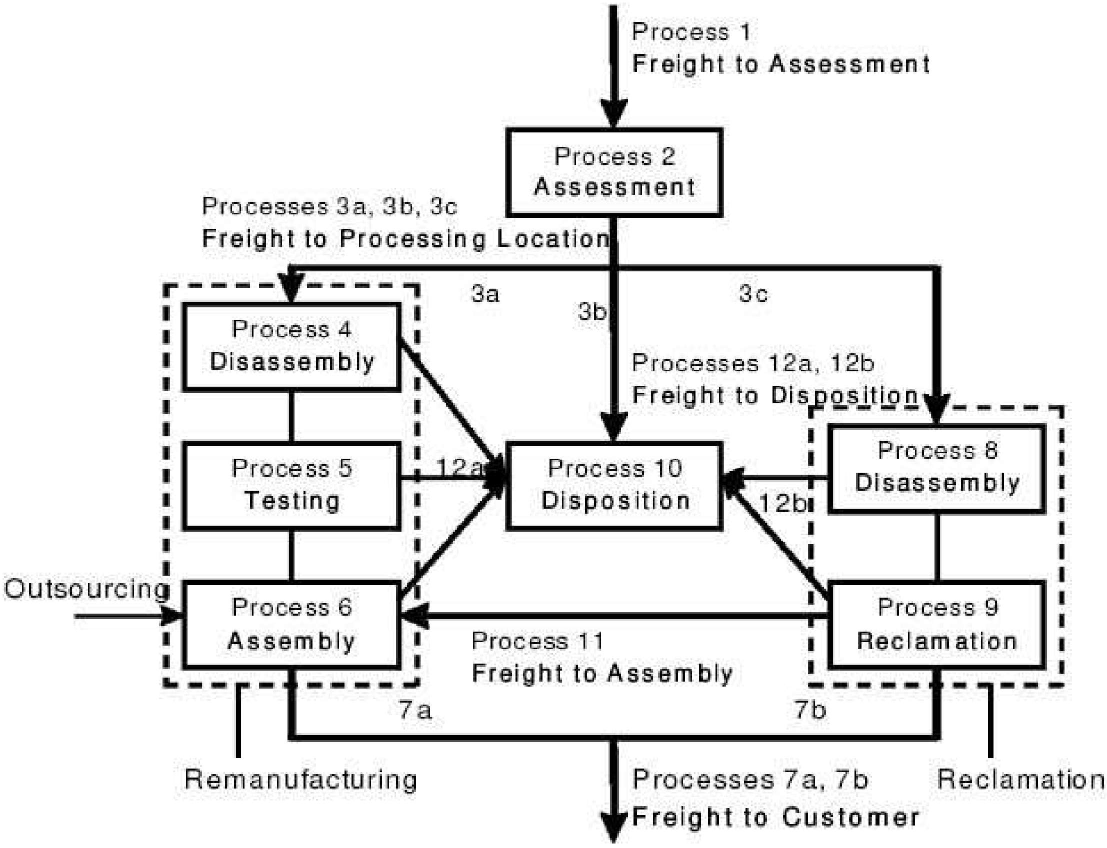

Figure 4 - Routes and Processes in the Value Cost Model for a reverse supply chain (Goggin and Browne 2000)

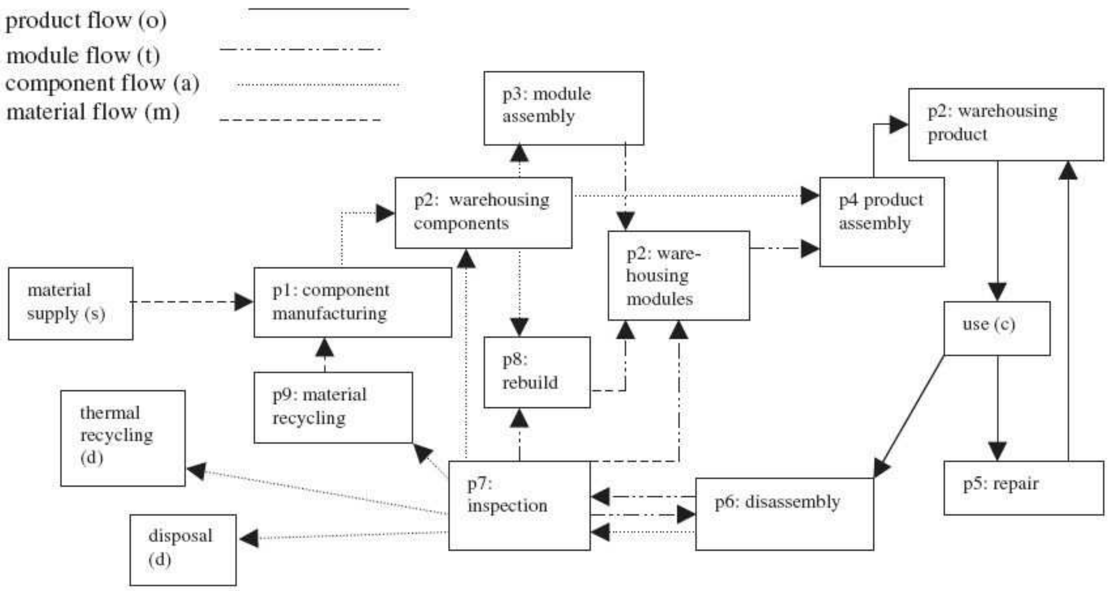

Figure 5 - Closed Loop Supply Chain for the Refrigerator Case (Krikke *et al.* 2003)

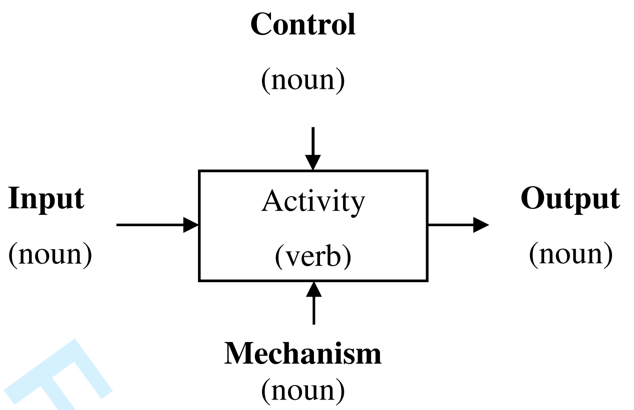

Figure 6. IDEF0 box and arrow conventions

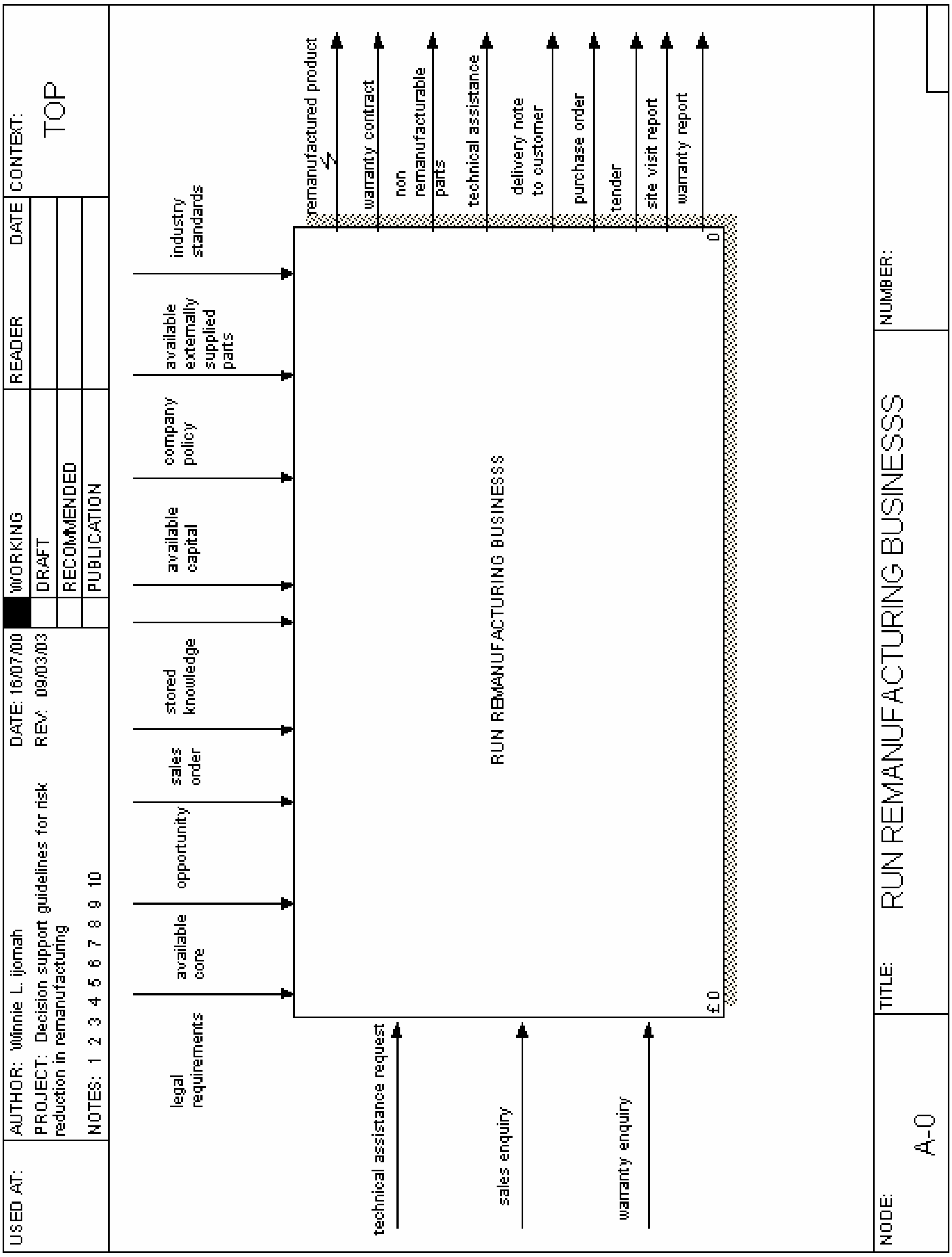

Figure 7. A-0 diagram – Context of 'Run manufacturing business'

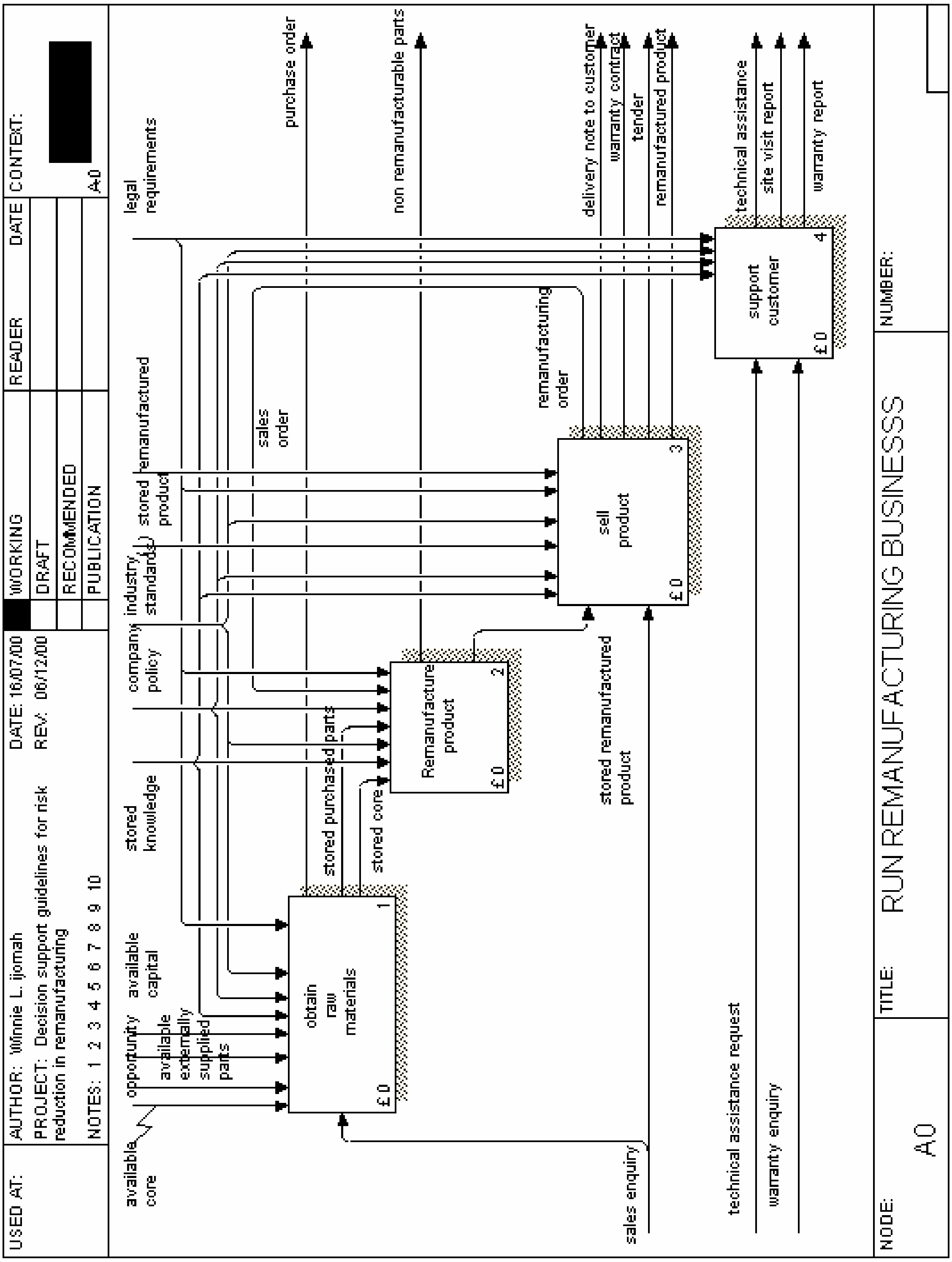

Figure 8. A0 diagram ‘Run remanufacturing business’

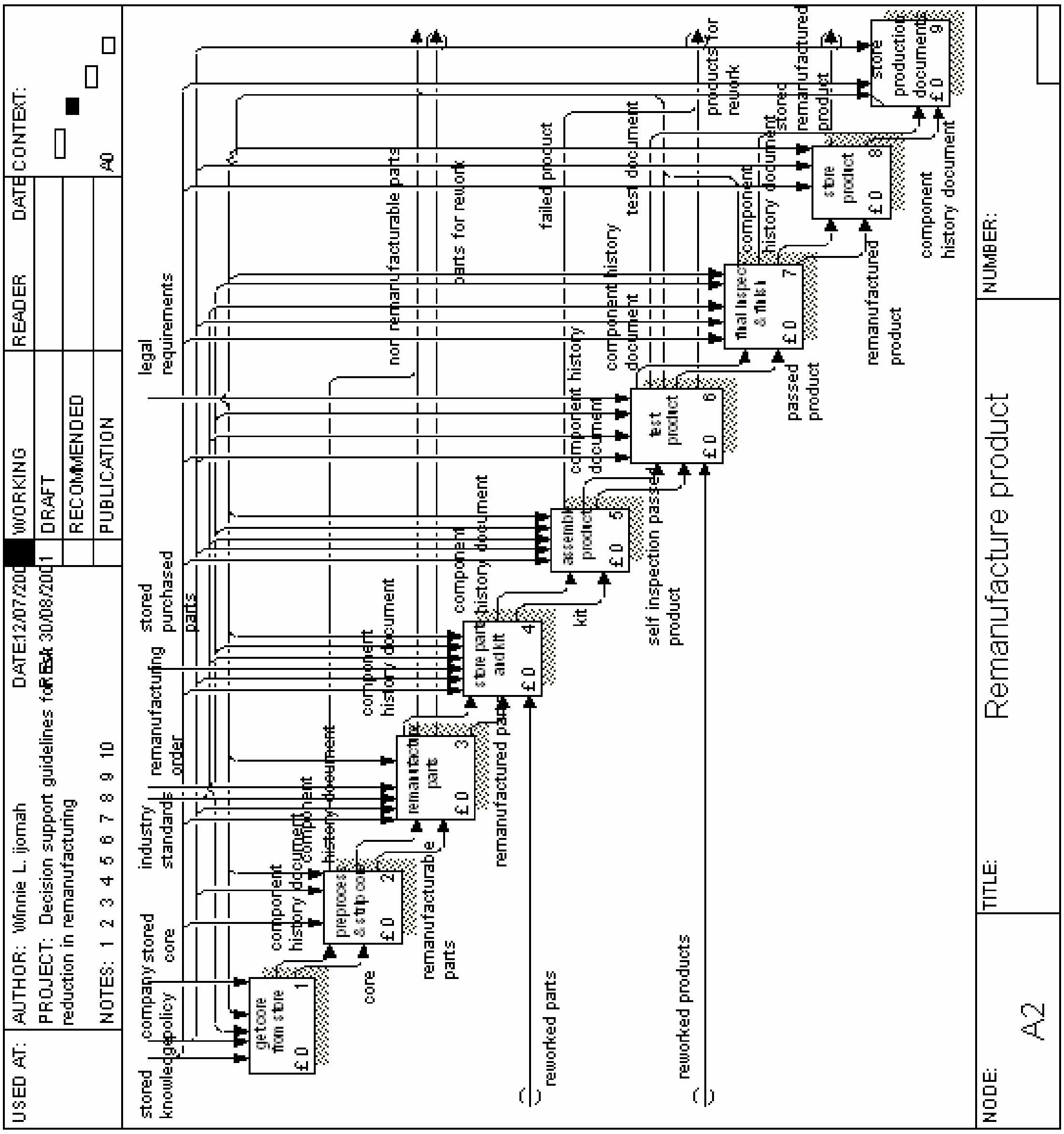

Figure 9. A2 diagram ‘Remanufacture product’

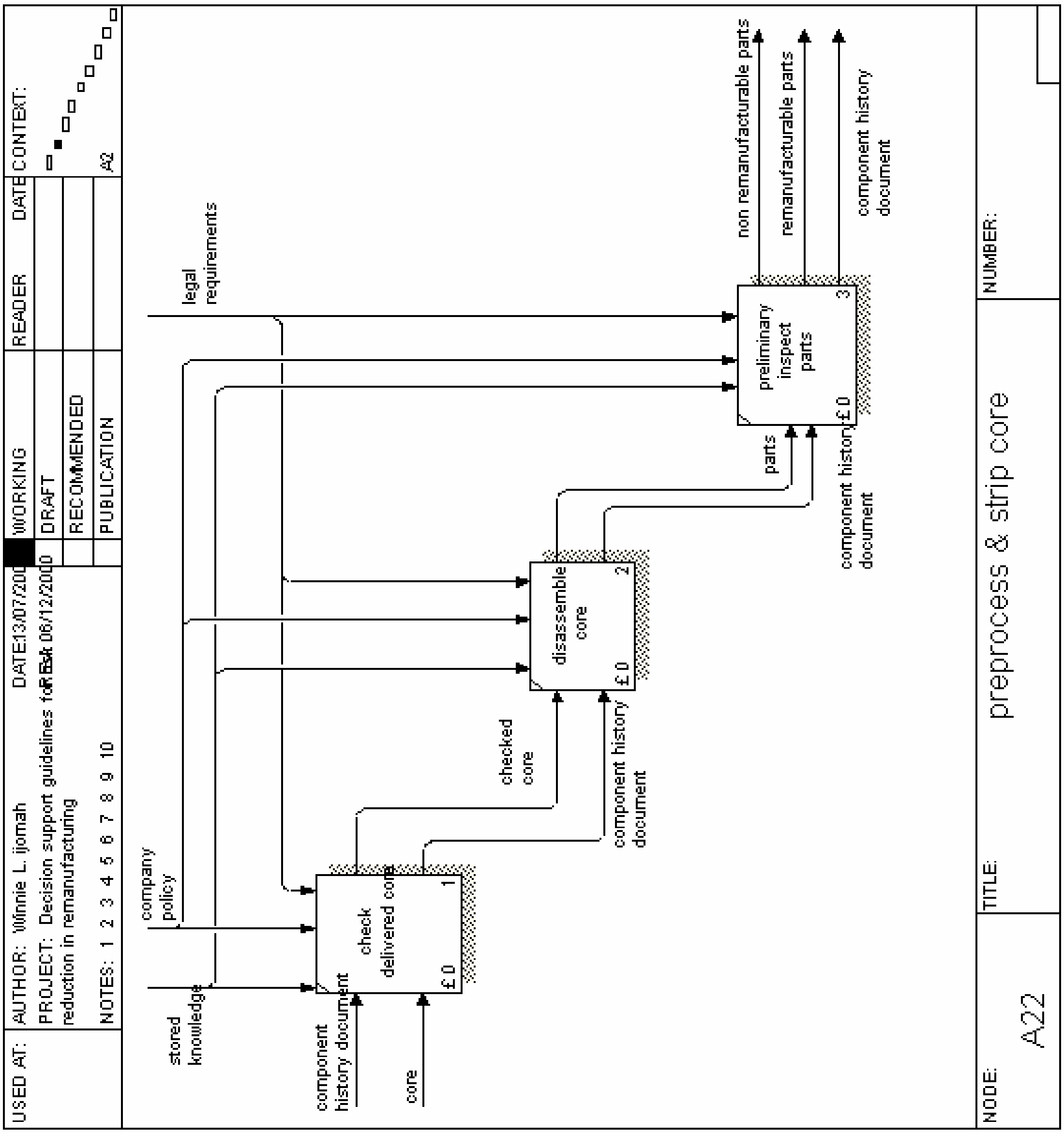

Figure 10. A22 diagram 'Preprocess and strip core'

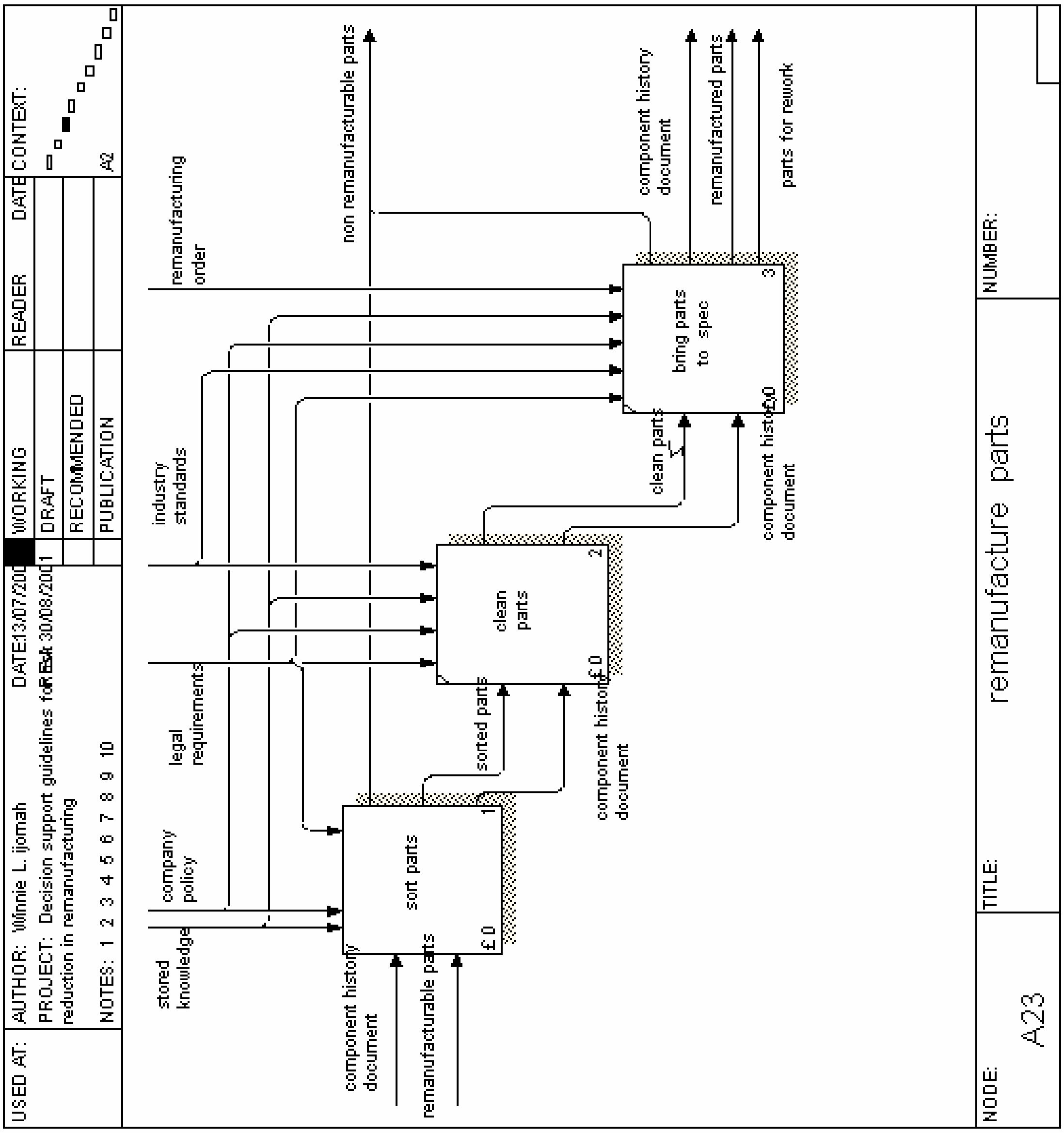

Figure 11. A23 diagram 'Remanufacture parts'