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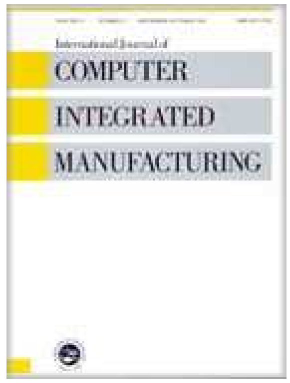

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A tool to improve training and operational effectiveness in remanufacturing

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Abstract

Remanufacturing, a process of returning used products to at least original performance specification from the customers' perspective and giving them warranties at least equal to that of new equivalents, is being regarded as a vital strategy in waste management and environmentally conscious manufacturing. The practice is hindered by a lack of remanufacturing knowledge and a paucity of readily available remanufacturing tools and techniques. This paper outlines the elements of remanufacturing and presents a tool in the form of a process model developed via the systems perspective using a practitioner-based research approach. Remanufacturers and academics examined the tool for replication logic and found it valid. The validation techniques used include the "review method" and practical use in organisations. The assessment criteria were the tool's sufficiency, clarity and usability in addressing the needs of academics and remanufacturers. Its key advantage is in reducing risk in remanufacturing by improving education, training and management in its operational processes.

Keywords: remanufacturing tool; model; environmentally conscious manufacturing; operational effectiveness.

1. Introduction: Research context

Increasingly severe legislation demands a reduction in the environmental impacts of products and manufacturing processes. For example, producers must recover used products to reduce landfill. However, research has shown that there is insufficient capacity to process used products collected from users. It is therefore critical to develop recovery-based end-of-life management techniques because millions of products have already been developed regardless of their undesired environmental impacts (Thierry et al, 1995). As the Basel agreement (http://www.basel.int/index.html) prohibits the export of waste outside the EU, European producers must manage their waste inside the EU. These circumstances combined with rising penalties of fiscal instruments such as the landfill tax (HM Treasury, 2004), makes remanufacturing expertise paramount for industry.

Remanufacturing, is a process of returning a used product to at least original equipment manufacturer (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). Its significance is that it can simultaneously offer a range of sustainable development benefits including profitability, reductions in landfill, the level of virgin material and energy used in production (Lund, 1984; Lund, 1996; Guide, 1999; Hormozi, 1996; McCaskey, 1994). Research indicates that 85% of the weight of a remanufactured product may come from used components, and that such products have comparable quality to equivalent new products, but require 50% to 80% less energy to produce. Its economic benefits include providing 20% to 80% production cost savings in comparison to conventional manufacturing (Lund, 1984). Remanufacturing can reduce the production of green house gases such as CO_2 that the Kyoto agreement has highlighted for reduction, because it limits raw materials production and the subsequent shaping and machining processes that for most products produce the highest CO_2 emissions. Because remanufacturing helps to divert a significant proportion of production waste from landfill, it helps to limit pollution such as methane leakage from waste sites as well as the pressure on landfill space. Research by Biffa (2002), indicated that the UK had only 6.5 years of space remaining in existing landfills, and that by DEFRA (2003) determined that house prices decrease near landfill sites making such sites undesirable in the urban areas where they are most needed. This is a great problem for highly populated countries such as the UK because of the demand for new houses and government initiatives to increase housing stocks.

The key problems hindering remanufacturing include a differential in the quality of remanufactured products and the lack of Public and OEM confidence in them that results. This is caused by a lack of remanufacturing knowledge (Melissen and Ron, 1999; Whybark and Ferrer, 2000), and expertise added to the paucity of readily available remanufacturing tools and techniques. This paper addresses these issues by detailing the principles of remanufacturing and presenting a tool to improve education, training and management in remanufacturing. The tool is in the form of a generic model of the remanufacturing business process, developed via a systems perspective and built using the IDEF0 modelling technique. The major rationale for developing tools and techniques specifically for remanufacturing include the following:

(i) Remanufacturing practitioners perceive the scarcity of effective remanufacturing tools and techniques, and the need to reduce production lead-time as a key threat to their industry (Guide, 1999).

(ii) 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).

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

(iv) 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 process, the activities involved and their interactions could lead to reductions in cost and lead-time and to quality improvements.

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

(vi) 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 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.

2. The remanufacturing concept

Remanufacturing differs from related product recovery processes of repair and reconditioning in four major ways. The most important of these is that remanufactured products have warranties equivalent to that of new alternatives whilst repaired and reconditioned products have inferior guarantees (Ijomah, 2002). Also, remanufacturing typically involves greater work content than the other two processes and as a result its products tend to have superior quality and performance (Ijomah, 2002). Additionally, remanufactured products lose their identity but repaired and reconditioned products retain theirs. The reason here is that in remanufacture all product components are assessed, and those that cannot be brought back at least to original performance specification are replaced with new. Thus a remanufactured product would comprise both new manufacture and remanufactured components. Finally, remanufacturing may involve upgrade of a used product beyond the original specification and this does not occur in repair and reconditioning. Remanufacturing also differs from recycling which describes the series of activities by which discarded materials are collected, sorted, processed and used to produce new products. Remanufacturing is preferable to recycling because it adds value to waste products by returning them to working order, whereas recycling simply reduces the used product to the value of its raw material.

Remanufacturing typically begins with the arrival of a used product (the core) at the remanufacturer, where it passes through a series of industrial stages including disassembly, cleaning, part remanufacture and replacing of unremanufacturable parts, reassembly and testing to produce the remanufactured product. Sundin (2002) states that the order in which these activities, shown in Figure 1, and described in Ijomah et al (1999) are undertaken may differ between different product types.

Figure 1 round about here

Andrue (1995) lists the characteristics of remanufacturable products as:

1. The product has a core that can be the basis of the restored product.
2. The product is one that fails functionally rather than by dissolution or dissipation.
3. The core is capable of being disassembled and of being restored to current specification.
4. The recoverable value added in the core is high relative to both its market value and its original cost.
5. The product is one that is factory built rather than field assembled.
6. A continuous supply of such cores is available.
7. The product technology is stable.
8. The process technology is stable.

From the definition of remanufacturing, provided in a previous section, it follows that a product that does not satisfy condition one cannot be remanufactured because it would be impossible for it to be restored to "like new" condition. For example, gaseous products are not appropriate candidates for remanufacturing because they evaporate and there would therefore not be a core to form the basis of remanufacturing. All the other characteristics result from purely economic reasons. If conditions seven and eight cannot be met, then the resources necessary for knowledge acquisition reduce remanufacturing's economic viability. Likewise with regard to condition six, in the absence of cores, used parts cannot be reclaimed and remanufacturing must proceed with expensive newly manufactured components. This would bring the cost of remanufactured products closer to that of conventionally produced alternatives. Because the primary advantage of remanufactured products is lower costs in comparison to manufactured products, the viability of the remanufacturing process would be significantly reduced.

The remanufacturing industry embraces an extremely diverse range of product types that fall into four main groups; industrial, commercial, automotive and residential equipment (Petrakis, 1993). Residential is the smallest sub-group because consumer prejudice towards "used goods" hampers the expansion of the sector. Remanufacturers are classifiable by size, organisational type or product type as explained in Lund (1984). The key remanufacturing operational problems of uncertainty, predicting the quantity and quality of incoming cores, intellectual property rights restrictions, core assessment criteria and quality control were explained in Ijomah et al (2005) along with the key remanufacturing success factors for the ability to produce high quality, low-priced products (Ijomah, 2002). The tool presented here helps remanufacturers' to achieve the key success factors by improving remanufacturing expertise. This is because it improves effectiveness in training, communication and operational management in remanufacturing, and is also a best practice model that can be emulated in setting up effective new remanufacturing operations.

3. Research methodology

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) was used as a foundation for developing the tool. The research was restricted to the mechanical and electromechanical sector of the UK remanufacturing industry to ensure its manageability by one researcher. It was undertaken via a three-phase research approach that followed Eisenhardt's case study methodology (Eisenhardt, 1989). Research validity was strengthened by the quality of research design, which included proper data collection quality control, and assessing results for replication logic. The former involved the use of techniques such as between-method and within-method triangulation, establishing a chain of evidence and key informant review of case study reports. The latter involved results assessment by members of the mechanical and electromechanical sector of the UK remanufacturing industry that were until then unconnected with the research. Care was also taken to ensure adequate representation of the research population. Thus the research covered a wide geographical area with practitioners being drawn from Scotland, the Midlands and South West of England, all types of remanufacturers, (OEM, contract and independent) as identified by Lund (1984) as well as large and small companies. Furthermore, a wide variety of product types, including, train and rolling stock, quarrying equipment, automotive transmissions, bottling plants and industrial compressors, were represented. Validation of the tool included peer group review via publications, assessment with a panel of experts according to the necessary properties of relevant research (Thomas and Tymon, 1982) as well as its use in organisations. This is described in section 5, Tool validation. The tool is in the form of a *comprehensive model of the generic remanufacturing process.* Space restriction prevents elaboration on modelling and modelling techniques but the interested reader is referred to Aguilar-Savén (2004). For this paper's purposes the rational for presenting the tool in the form of a model is that:

(i) 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), 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.

(ii) There are a few analytic models of remanufacturing (Guide and Srivastava, 1997a).

The rationale for developing the model via a systems approach was that although many small improvements can be made to a business process at the detailed level, when considering the design of whole business processes, for example manufacture or remanufacture processes; the process must be understood as an entity. This is because 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 whilst permitting concentration on the performance of the whole. Thus a key advantage of the process perspective in developing the model 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. This is recognised by researchers, for example; Guide and Srivastava (1997a) state that recoverable manufacturing systems require system-oriented solutions rather than optimisation of systems' sub-processes. Space constraint prevents a discussion of systems theory and business processes for which the author refers the interested reader to literature such as Checkland (1981) and Davenport and Short (1990).

In addition to the Ijomah, (2002) remanufacturing definition, the model had three additional bases; the 'Operate' process of the manufacturing reference model (Smart *et al*, 1999), the CIM-OSA Manage-Operate-Support business process architecture (CIM-OSA, 1989) and the IDEF0 modelling technique (IEEE, 1998). 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 remanufacturing 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. IDEF0 is a process modelling technique that illustrates the component activities and flows of a system, thereby helping the modeller to identify the activities involved and how they are performed, as well as opportunities for improvement in the existing system. Its main advantage is that it enhances involvement and decision-making using simplified graphical methods. A clear advantage of the IDEF0 method is its capability for decomposition (the breaking of an activity into its basic elements so that it can be examined in detail and fully understood). Space restriction deters detailed description of the IDEF0 method and its benefits. This can be found in a range of literature including FIPS PUB (1993), Le Clair (1982) or Colquhoun *et al* (1991). The final part of the research was the tool's validation. This was achieved by using the 'review' method (Landry *et al,* 1983) to test whether the model satisfied the 'needs of practitioners' (Thomas and Tymon, 1982) and by practical use in industry and is described in section 5, Tool validation. In this instance practitioners were remanufacturers and academics because they sought remanufacturing knowledge and expertise. The validating panel was drawn from the mechanical and electromechanical sector of the UK remanufacturing industry and academics in remanufacturing-related disciplines in order to satisfy the requirement for external validity (Yin, 1994) and replication logic (Creswell, 1994). The validating criteria were the model's suitability, sufficiency and clarity in addressing practitioners' needs.

3.1 Tool development

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 was required. This fits within the definition of the ‘operate’ process described in the CIM-OSA standard (CIM-OSA, 1989). The research was not concerned with the activities involved in setting the strategy and direction of the company nor its business planning. It did not seek to assess 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 research information to be controlled in manageable chunks. This first company remanufactured complex electromechanical products. Data was collected via key personnel interviews, direct examination of the process, augmenting documented information with staff and customers and verifying documented information. Once a model satisfying that company was achieved, case studies were undertaken to assess it against the practices of six other remanufacturing operations and thereby implement any alterations to make it valid for a wider range of remanufacturers. This was followed by further inspection (the initial validation) where an additional three organisations were asked to “walk” through the model and identify any dissimilarity with their own practices. Once the model satisfied all seven model development companies and the three initial test companies it was ready for final validation by review to assess its generalisability to the mechanical and electromechanical sector of the UK remanufacturing industry. Thus case studies were undertaken in seven different remanufacturing operations to develop the model. The reason here was to satisfy the recommendation of using between four and ten cases in multiple case study research, in order to obtain adequate data to support theory-building’s generalisation requirement whilst avoiding information overload (Chetty, 1996; Romano, 1989).

4. The remanufacturing-specific tool

4.1 Tool description

The tool is in the form a generic best-practice remanufacturing model. It is a comprehensive document that unambiguously displays the resource required in all areas of the remanufacturing process, including the activities of all its sub processes, as well as the interrelationships between those sub processes. It consists of twenty embedded diagrams. The top-level diagrams give a basic overview of the system and lower level ones give increasingly more detailed information. This allows the same model to be used by the range of personnel within an individual organisation to ensure a uniform understanding within the organisation about what the organisation does and how. For example, 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. Because of this "Russian doll" characteristic, the model may be used as a tool for planning and controlling remanufacturing operations, to help design and implement effective and efficient remanufacturing businesses as well as to improve the efficiency and effectiveness of existing remanufacturing operations. As the tool is generic, mechanisms (the means by which the activity is performed, for example person or machine) are omitted because this would vary between products and between companies. However, the model may be configured to individual company's requirements by adding the mechanism most suited to them. For example, if company A uses manual labour to transport components, company B, conveyor belts and company C, robots. The mechanisms shown by the model for transporting components in companies A, B and C respectively would be manual labour, conveyor belts and robots.

The key difference between the model presented here and existing alternative remanufacturing descriptions is that typically, the alternatives are part of other models relating to material re-use and sustainability, such as the model by Guide and Srivastava (1997b). Also, although the alternative descriptions, for example Tang et al (2004); Okumura et al (20030; Krikke et al (2003) and Seitz and Peitie (2004) are useful for explaining remanufacturing, they provide little assistance for organisations wishing to improve their management of remanufacturing activities or to start remanufacturing. Figure 2 shows the A-0, "Run remanufacturing business". The A-0 is a basic diagram of the environment of the remanufacturing business and shows the interaction of the business with its environment. 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.

Figure 2 round about here

This A-0 diagram can be decomposed to give the A0 diagram, Run Remanufacturing Business, shown in Figure 3. The A0 diagram displays the four major activities that make up the remanufacturing business process which are:

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 Original Equipment Manufacturer, (OEM), current 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).

Figure 3 round about here

Each of these major sub-activities is given with their various flows (inputs, outputs, control and mechanisms). They can also be decomposed themselves to reveal more detailed remanufacturing information. For example, Figure 4 below shows the A2 sub process, which is obtained by decomposing the A02 sub process in the A0 diagram. The A2 diagram is the remanufacturing operation and the major part of the remanufacturing business process because it is concerned with the actual process of remanufacturing. It comprises the following 9 major activities:

1. *Get core from store*: Select the required core from the remanufacturer's store.
2. *Strip core*: Reduce the core to its components.
3. *Remanufacture parts:* Bring 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 finishing e.g. by 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.

Figure 4 round about here

Only activities 2 and 3, pre-process & strip core, and remanufacture parts (the remanufacturing of component parts), differ significantly from conventional manufacturing. Although the rules of IDEF0 recommend a maximum of 6 activities in a diagram, the A2 diagram has 9 activities. This structure was the one that users in remanufacturing companies felt happiest with. Activities such as “store product” which could have been hidden at this level were felt to be important enough to justify the extra boxes. 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 5 below is the A22 Pre-process & 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 using experience, company policy (e.g. use of documentation such as OEM manual).
- Dismantling the used product (core) to its component level
- 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).

Figure 5 round about here

Figure 6 below shows the A23 sub process; remanufacture part, which is concerned with bringing component parts at least to current *OEM specification.* This is the most crucial part of the remanufacturing operation. It determines the success or otherwise of remanufacturing and makes or breaks the remanufacturer because it controls the issues of cost and quality that 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 into reclaimable and non-reclaimable groups then further sorting by type or size for example to facilitate effective cleaning.
- *A232: Clean parts*: This is the removal 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 remanufacture and finally undertaking their remanufacturing.

Figure 6 round about here

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 or that the cost of their remanufacture is unacceptable. This activity is the most crucial element of the remanufacturing operation because it is here that the essential decisions about the suitability of components for reuse are made. Because of this, inadequacy in this area can lead to losses in terms of high remanufacturing costs, long remanufacturing cycle time and poor reputation. Ijomah et al (1999) and Ijomah (2002), elaborate on these issues.

4.2 The complete set of model diagrams

This section displays the complete set of model diagrams following assessment and introduction of alterations recommended by the validating practitioners. These alterations are explained in section 5.1. For readers' convenience, the A-0, A0, A2, A22, and A23 diagrams, shown in the previous section as Figures 2 to 6 are reproduced here as Figures 8, 9, 14,16 and 17 respectively. The node tree, Figure 7 below, illustrates the model diagrams' hierarchy.

Figure 7 round about here

Figure 8 round about here

Figure 9 round about here

Figure 10 round about here

Figure 11 round about here

Figure 12 round about here

Figure 13 round about here

Figure 14: round about here

Figure 15: round about here

Figure 16: round about here

Figure 17: round about here

Figure 18: round about here

Figure 19: round about here

Figure 20: round about here

Figure 21: round about here

Figure 22: round about here

Figure 23: round about here

Figure 24: round about here

Figure 25: round about here

4.5 Interpreting the model diagrams

A simplified description of the A2, A22 and the A23 diagrams were given previously. To further explain the diagram interpretation, the A23: Remanufacture parts diagram, which is concerned with the bringing of parts to OEM specification, is interpreted below. The A23 is chosen because of its significance as explained previously. To improve clarity of description, activities are in bold (e.g. **activity**), controls in light italics (e.g. *controls*) whilst outputs are underlined (e.g. output).

4.5.1: Interpretation of A23; the remanufacture parts diagram

When component history document and remanufacturable parts arrive we prepare to **sort parts.** We sort the parts according to the rules of our stored knowledge and *company policy.* This produces sorted parts, scrap and an updated component history document.

The sorted parts travel with the updated component history document to the **clean parts** activity where the sorted parts are cleaned according to the rules of *company policy*, *industry standards* and *stored knowledge.*

The **clean parts** activity produces clean parts and an updated component history document which go on to the **bring parts to current spec** activity. There they are remanufactured according to the rules of *industry standards, remanufacturing order, company policy and stored knowledge.* This produces an updated component history document, remanufactured parts, and parts for rework.

The parts for rework go back into the system where they are dealt with in some way that at least redeems some value from them, for example they may be sold to a recycler if they cannot be successfully remanufactured within acceptable costs. At any rate the sentiment is to as far as possible, limit disposal to landfill.

5. Tool validation

Validation of the tool's clarity, sufficiency and suitability in meeting the needs of practitioners' (Thomas and Tymon, 1982) occurred in two ways; assessment by panels of experts using the 'review' technique (Landry *et al.* 1983) and, its actual use in organisations. Three sessions of the tool's validation by 'review' (Landry *et al.* 1983), were undertaken. The number of panel members in each case was restricted to nine to ensure proper management of the exercise and adequate input from participants.

5.1 Tool validation by the 'review' (Landry *et al.* 1983) *technique*

The validation by *'review'* (Landry *et al.* 1983) was undertaken at the author's university to prevent participants from being distracted by their normal work duties. The proximity also permitted the author to monitor their understanding of the IDEF0 modelling method and to guide the discussion to ensure systematic and rigorous validation. The validating panel was independent of the research and the author's university and consisted of roughly equal numbers of academics, case-study companies and non-case study companies. 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 by either group of remanufacturer. The panel was from the mechanical and electromechanical sector of the UK remanufacturing industry or academics in remanufacturing-related disciplines because the research was geared towards them. Also, they were drawn from middle management and above to ensure that they had adequate remanufacturing knowledge to properly assess the tool. The panel members were each given two booklets, one for use during the session and the other to be retained and returned with comments following use and discussion of the tool in their respective organisations. Both booklets contained the following documents:

- IDEF0 modelling technique description.
- Tool manual containing the complete generic model diagrams.
- Tool description with written interpretation of the generic model. This supported the tool manual. Its purpose was to help the participants to become accustomed to interpreting the model.
- An initial feedback sheet with twenty-two questions to record participants' assessment of the generic model as a whole, in terms of its clarity, sufficiency and suitability. This involved asking the participants the same question about each of the criteria in seven different ways to test their understanding of the model and to ascertain that they

understood the question. The last question was a comment box to record any additional comments that participants wished to make.

- Secondary feedback sheets pack. This contained feedback sheets to separately record the clarity, suitability and sufficiency of each individual model diagram.

To help ensure that the participants had adequate expertise in the IDEF0 technique to properly assess the tool, the validation began with a description and demonstration of the IDEF0 modelling technique, followed by a detailed demonstration and interpretation of the model. Following this each model diagram was displayed and described independently. Each time the panel discussed the diagram as a group before giving their individual and group assessments. The author recorded the group verdict on each diagram whilst the participants recorded their individual opinions on the appropriate secondary feedback sheet. Once all model diagrams were assessed the model was analysed as a whole and the participants recorded their opinions of the complete model on their initial feedback sheets. Following the assessment, the panel was asked to suggest potential uses for the tool. Before leaving, the panel handed in their initial feedback sheets but retained the secondary feedback sheets. These would be returned to the author with details of any further amendment proposals that may emerge during the discussions and use of the tool at their organisations. Once all secondary feedback sheets had been returned, the information from the validation exercises was combined and used to enhance the model to produce the version in this paper.

5.2. Tool validation by use in organisations.

The tool was used at the panels' respective organisations to examine its potential to enhance communication, assist operational improvement and deliver remanufacturing training and understanding in actual organisations. In the case of enhancing communication the panel was asked to use the tool to describe, to colleagues, their organisation's practices. With regards to assisting operational improvement the panel was asked to discuss and "walk through" the model with their colleagues to assess whether the tool could help them improve their operations. In the case of delivering remanufacturing training and understanding, the panel was asked to use the tool to explain remanufacturing to colleagues that had little remanufacturing knowledge.

6 Validation results

6.1 Validation by review results

The validating panel believed that the model was very accurate in its representation of remanufacturing. This is shown by the information given in their validation sheets. For example in the initial feedback sheets all panel members 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'. Also, 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'. Additionally, they 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 follow' and they also disagreed or strongly disagreed that they 'would not use this model to give a basic description of the remanufacturing business process'. The amendments that they suggested, from the secondary feedback sheets, relate to alteration of language to better reflect the understanding of participants but they indicated that most of these changes would not enhance the model's accuracy or sufficiency. Some practitioners requested further decomposition to give more detail of the reverse logistic chain. This request was not implemented because although the ability to source cores is critical to remanufacturing, reverse logistics is beyond the scope of the model. The tool is purely concerned with the actual process of remanufacturing. Also, it is difficult to maintain the 'generic' model at very low levels. Others asked for more detail about contracts because having contracts with original equipment manufacturers can greatly benefit remanufactures, for example through improved access to product technical information. This was not implemented because contracts are also outside the scope of the research. Tables 1a and 1b show the initial feedback sheet from a validation session. The numbers of the comments explicitly mentioned in the text are in bold and have a star. The letters SF (sufficiency), C (clarity) and ST (suitability) were not visible to participants but are included here for readers' convenience.

Table 1a round about here

Table 1b round about here

6.2 Tool use results

The organisations believed that the tool improved communication because it helped them to gain a better and more uniform view of their own practices. Some indicated that when the tool was used, individuals' views' of their organisations' current, and potential future practices were more accurately understood by their colleagues. The tool was also said to assist in uncovering differences in perceptions, within individual organisations, about their remanufacturing practices. The tool was believed to be highly useful for delivering remanufacturing knowledge and expertise, for example through its use for both on- and off-site training. For example the organisations reported that new recruits and colleagues that previously knew little about remanufacturing obtained increased understanding when the model was used to assist information delivery. The organisations also suggested that the tool could be used in place of written training manuals.

With regards to operational improvement, the organisations believed that using the tool, as a guide in designing and implementing remanufacturing operations would result in highly efficient and effective remanufacturing. Some indicated that by walking through the model and comparing it with their own operations, they and their colleagues had identified issues with their practices that they had gone on to address. Others believed that adopting some ideas in the model would help to improve quality and the image of their industry as a whole. For example, the organisations believed that the inclusion of the 'industry standards' control in the model diagrams was a significant reminder of the need to unify standards in the remanufacturing industry. They felt that implementing industry-wide standards would be a key measure in driving out 'cowboys' and improving consistency in remanufactured products' quality and thereby enhance the perception of remanufactured goods among the general public.

The practitioners cited error reduction as the tool's key advantage. They stated that this is because when used as a guiding manual during remanufacturing it can help to reduce the level of guesswork and complexity involved as the remanufacturing activities 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.

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. The evaluating panel believed that the IDEF0 modelling technique would be an ideal method for disseminating remanufacturing information because it presents information in a consistent and concise manner. This can be seen from the initial validation sheets. For example, they all strongly agreed or agreed that "generally the model is logical in the way that it describes the remanufacturing business process" and they "would consider using the model to describe the remanufacturing business process". They believed that these characteristics make it an effective method for explaining complex information clearly and therefore for promoting understanding. For example, from their initial feedback sheets they either strongly agreed or agreed that they "could analyse the information flows and activities of the remanufacturing business with the model" and that they "found the model easy to comprehend" also the majority either strongly disagreed or disagreed that they "found many details in the model ambiguous". Furthermore, the panel was able to discuss and use the tool in their respective organisations.

6.4 Ability to satisfy the needs of practitioners

6.4.1 Descriptive relevance

The validating panel believed the tool to be a sufficient remanufacturing representation. 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 but felt that these did not indicate any great errors in the model, but may help to enhance its clarity and therefore, its ease of use. A company offered to use the model as a marketing tool that illustrates the validity of their remanufacturing operation

6.4.2 Goal relevance

All members of the panel believed that the tool would be effective in 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.

6.4.3 Operational validity

Operational validity describes practitioners' ability to use the new knowledge easily. This requires that the new knowledge must be understandable to practitioners and presented in a format that enables them to manipulate it easily. The completed initial feedback sheets indicated that practitioners understood the tool because they either strongly agreed or agreed that they "find the model easy to follow". The feedback sheets also indicate that the tool 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". Additionally, they all took away copies of the model and were able to explain and discuss these with work colleagues who did not attend the session and went on to use the tool in their respective organisations as explained in section 5.2.

6.4.4 Non-obviousness

Prior to the validation session, none of the practitioners was familiar with the IDEF0 technique. This can be taken as a clear indication that they would not have considered using the generic model for documentation purposes or for identifying efficiency and effectiveness enhancement measures. They also 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, how it is undertaken as well as the complexities of the process.

6.4.5 Timeliness

No questions were asked about the tool's timeliness during the validation. However, it is extremely timely because the validating panel believed that it addresses the urgent remanufacturing problems described in earlier sections. For example, it provides a robust description of remanufacturing that could be used to enhance remanufacturing knowledge and understanding. In fact it was proven as an effective training tool through use in the validating panel's respective organisations. Also, it could help to improve the efficiency and effectiveness of remanufacturing operations when used as an integral part of their design and implementation. The timeliness of this tool is shown by the need for UK businesses to increase competitiveness whilst meeting national and international environmental requirements and by government commitment to global sustainable development, exemplified through DTI Technology Programme initiatives research and development programs in remanufacturing and related areas (DTI, 2005). The huge international need for remanufacturing knowledge, expertise and research results from global requirement for sustainable development, the inadequate research and publications in this area, international legislation to reduce waste and manufacturing process and products environmental impacts, and remanufacturing's great potential to address these issues. The tool described here helps to address these issues through its ability to improve remanufacturing expertise and knowledge.

6.4 Validation conclusion

Practitioners assessed the tool via review technique (Landry *et al.* 1983) and by its use in their organisations and found it legitimate. The validation criterion was its ability to satisfy the needs of the practitioner (Thomas and Tymon, 1982). All members of the evaluation panel reported that from their experience and knowledge of remanufacturing, the tool was a valid remanufacturing description and would be useful to them. They were also able to use it in their respective organisations for example, to improve communication and to deliver remanufacturing knowledge and training.

The tool's usefulness is highlighted by the great need for remanufacturing-specific tools and in particular analytic remanufacturing models to help remanufacturers enhance the effectiveness of their operations (Guide, 1999; Guide and Gupta, 1999). Additionally, academics require a robust remanufacturing definition as well as analytic models that will help them to understand remanufacturing so that they can undertake effectively remanufacturing research and also accurately disseminate their findings (Melissen and Ron, 1999; Ijomah, 2002). The tool is useful because the validating panel believed that it addresses these problems. The tool's usefulness to practitioners can be further illustrated by the uses that practitioners have proposed for it, some of which are shown in Table 2.

Table 2 round about here

7. Tool validity

The tool can be considered highly valid because of the quality of the research design and because it passed the test for replication logic. Criteria such as validity, reliability and generalisability are important in establishing research authority (Gummesson, 1993; Holloway, 1997; Yin, 1981; Eisenhardt, 1998; Lang and Heis, 1994; Easterby-Smith *et al.,* 1993)**.** Reliability and construct validity (Yin, 1994) were strengthened using techniques such as triangulation to enhance data collection quality control. External validity (Yin, 1994) was enhanced using techniques such as testing the extent to which the findings would hold in other instances of the phenomenon. This involved having the tool assessed by remanufacturing academics and by members of the mechanical and electromechanical sector of UK remanufacturing industry that were not involved in the research. Replication logic (Creswell, 1994) was used to test the research results through the validation by review technique (Landry *et al*, 1983). The information provided in the validation panel's feedback sheets and the results of the tool's use in their organisations indicate that its results held true. By the laws of replication logic those results can be accepted as valid for a much larger number of similar neighbourhoods, the neighbourhoods in this case being the mechanical and electromechanical sector of the UK remanufacturing industry.

8. Conclusion

Remanufacturing is vital for sustainable development because it extends the life of used products thus reducing waste, landfill and processing. Because it integrates waste back into the manufacturing cycle, and can do so profitably, remanufacturing can help producers to avoid penalties from environmental legislation whilst maximising their profits. Remanufacturing is hindered by inadequacy in remanufacturing knowledge and expertise and by a lack of effective tools and techniques that address its unique requirements (Ijomah, 2002; Melissen and Ron, 1999; Guide, 1999). Specifically, there is a paucity of analytic models of remanufacturing (Guide and Gupta, 1999).

This paper has detailed the concept of remanufacturing and presented a tool to improve education, training and operational management in remanufacturing. The tool is in the form of a robust, generic remanufacturing process model and was developed via the systems perspective using a practitioner-based research approach. Weaver (1995) proposes that specific business process 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) describes 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 tool presented here is remanufacturing reference model.

The model's novelty in comparison to existing alternatives is in the approach of analysing remanufacturing from a business process perspective. It also enhances the usefulness of remanufacturing models by providing a level of detail suitable for analysing industrial practice. The key beneficiaries are manufacturers, remanufacturers, potential industry entrants and academics because they require tools to address their needs for remanufacturing knowledge and expertise.

In the case of academics, the tool could help them to explicitly understand remanufacturing so that they could undertake valid remanufacturing research and accurately disseminate their findings. With regards to practitioners and potential industry entrants the key problems hindering the remanufacturing industry are quality and cost. The tool can help to address these issues when used to question the validity of existing remanufacturing operations, improve their management and facilitate the design of effective new ones. It would also help to reduce problems related to over-reliance on experience as well as training inconsistency and ineffectiveness (Ijomah, 2002) so that employees could more easily work to pre-agreed company-wide procedures. For example, training is often undertaken hands-on, with the more experienced employees teaching newer recruits (Ijomah, 1999). When used for off-site training the tool limits the time that time-served operators lose in training and supervising new recruits.

Since the tool was geared towards the mechanical and electromechanical sector of the UK remanufacturing industry, it was tested for replication logic within that sector and was found valid. Similar to the tool development process the tool validation was practitioner-based. It included remanufacturers and academics assessing it by the “review” method and its use in organisations. The assessment criteria were the tool’s sufficiency, clarity and usability in addressing the needs of academics and remanufacturers. A highly effective research design was used to enhance the research authenticity. For example, key concepts such as validity, reliability and generalisability that are vital in establishing research authority were applied. The measures taken to strengthen the research validity include ensuring proper data collection quality control and assessing for replication logic. The former involved the use of techniques such as between-method and within-method triangulation, establishing a chain of evidence and key informant review of case study reports. The latter involved testing results with members of the mechanical and electromechanical sector of the UK remanufacturing industry that were until then unconnected with the research. Care was taken to ensure adequate representation of the research population by covering a wide geographical area, and including all types of remanufacturers as identified by Lund (1984), a wide variety of product types, as well as large and small companies. Additionally, the number of case studies undertaken to develop the model satisfied that recommended for multiple case study research (Chetty, 1996; Romano, 1989). Further research could entail investigating whether the tool could be developed for other sectors of industry, given the large number of industry sectors and different product types.

Acknowledgements

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A tool to improve training and operational effectiveness in remanufacturing

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FIGURES & TABLES

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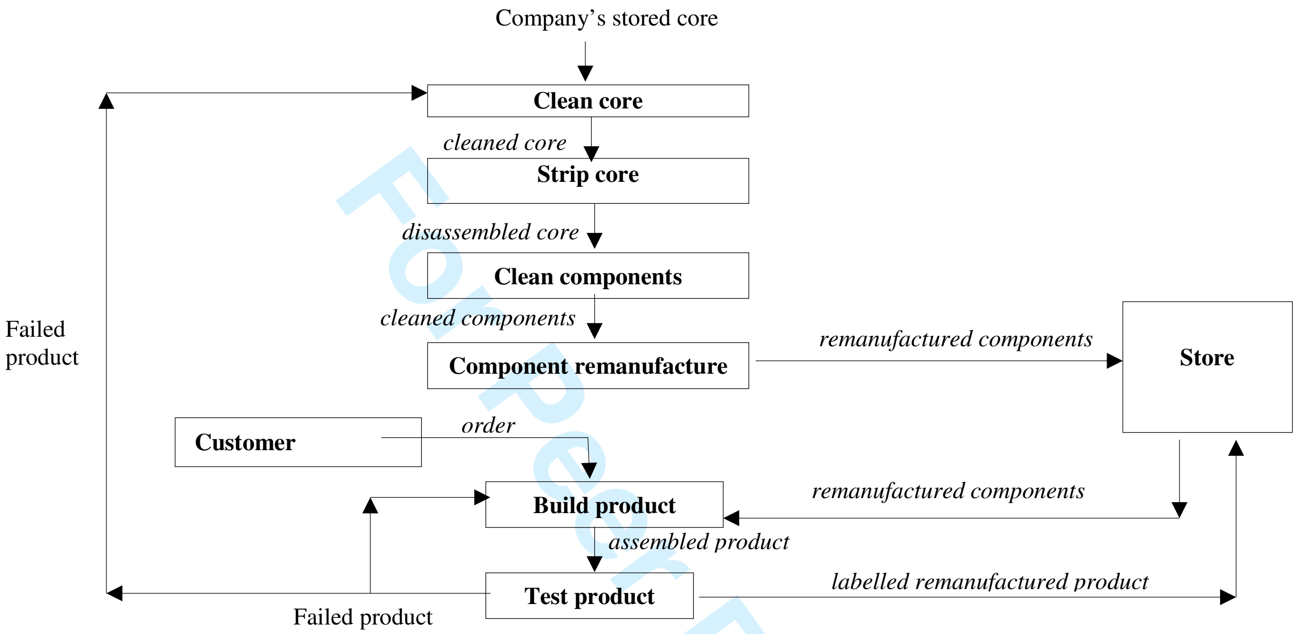


Figure 1. A generic remanufacturing process chart (Ijomah, 2002)

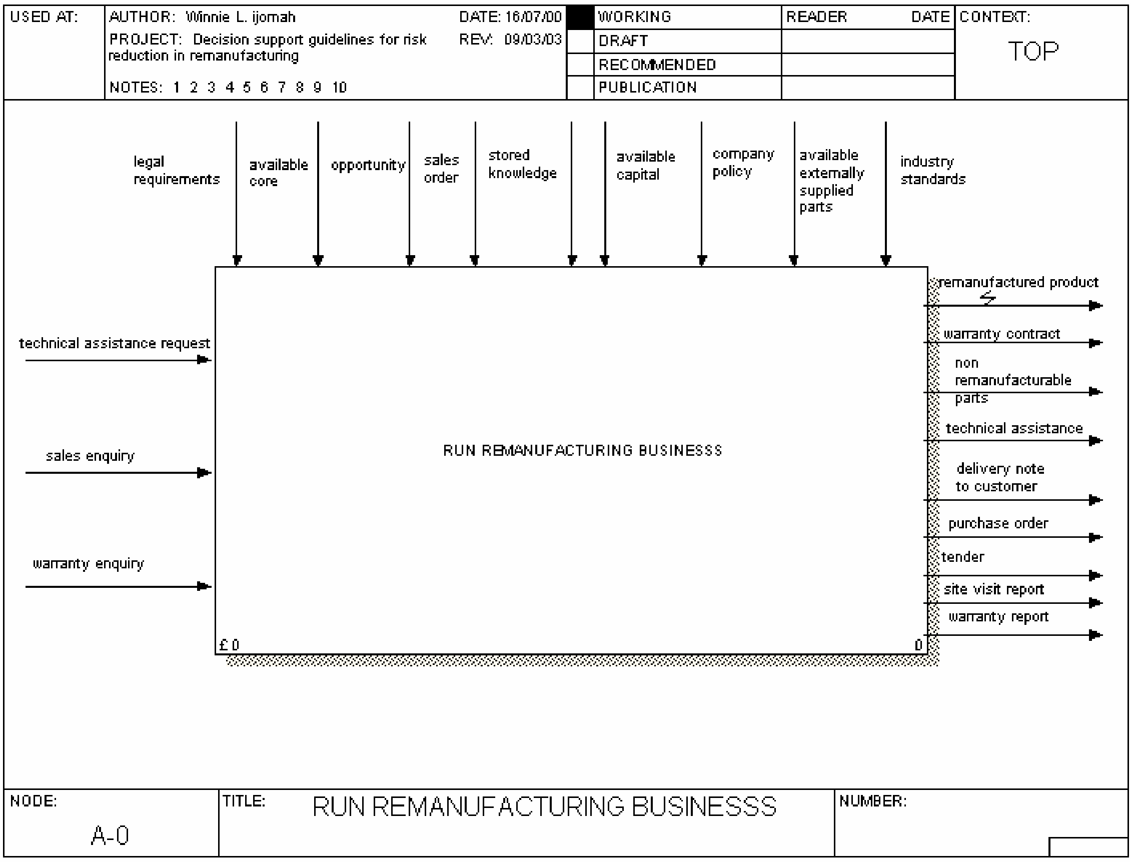


Figure 2. A-0 diagram

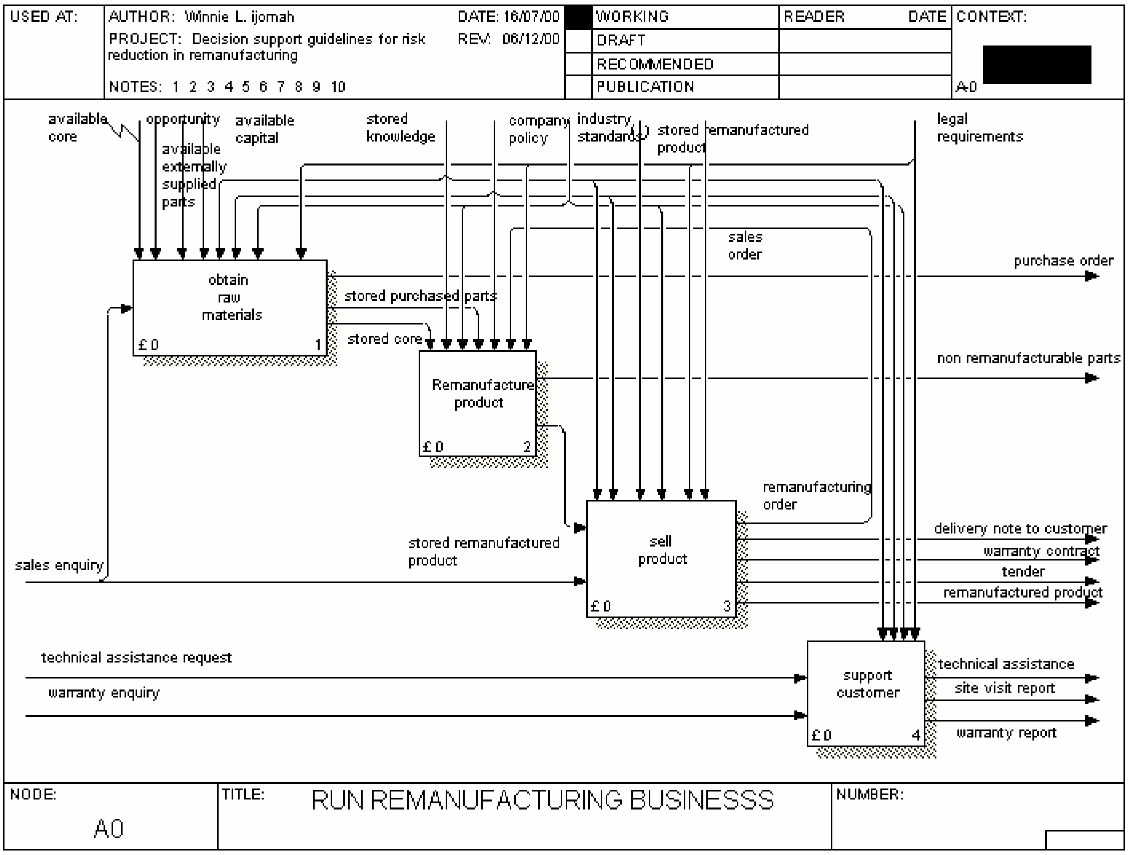


Figure 3. A0 diagram

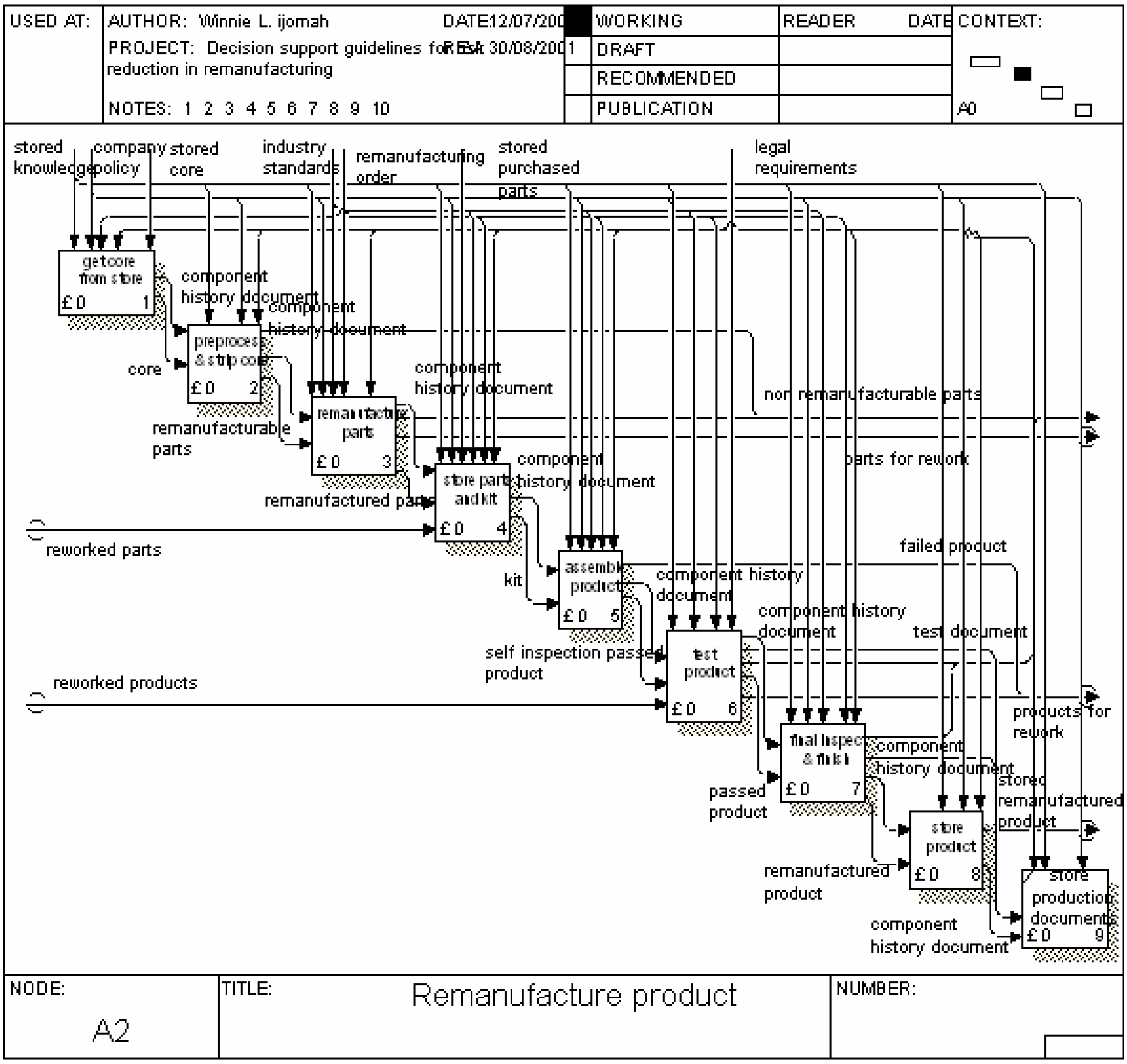


Figure 4. A2 diagram

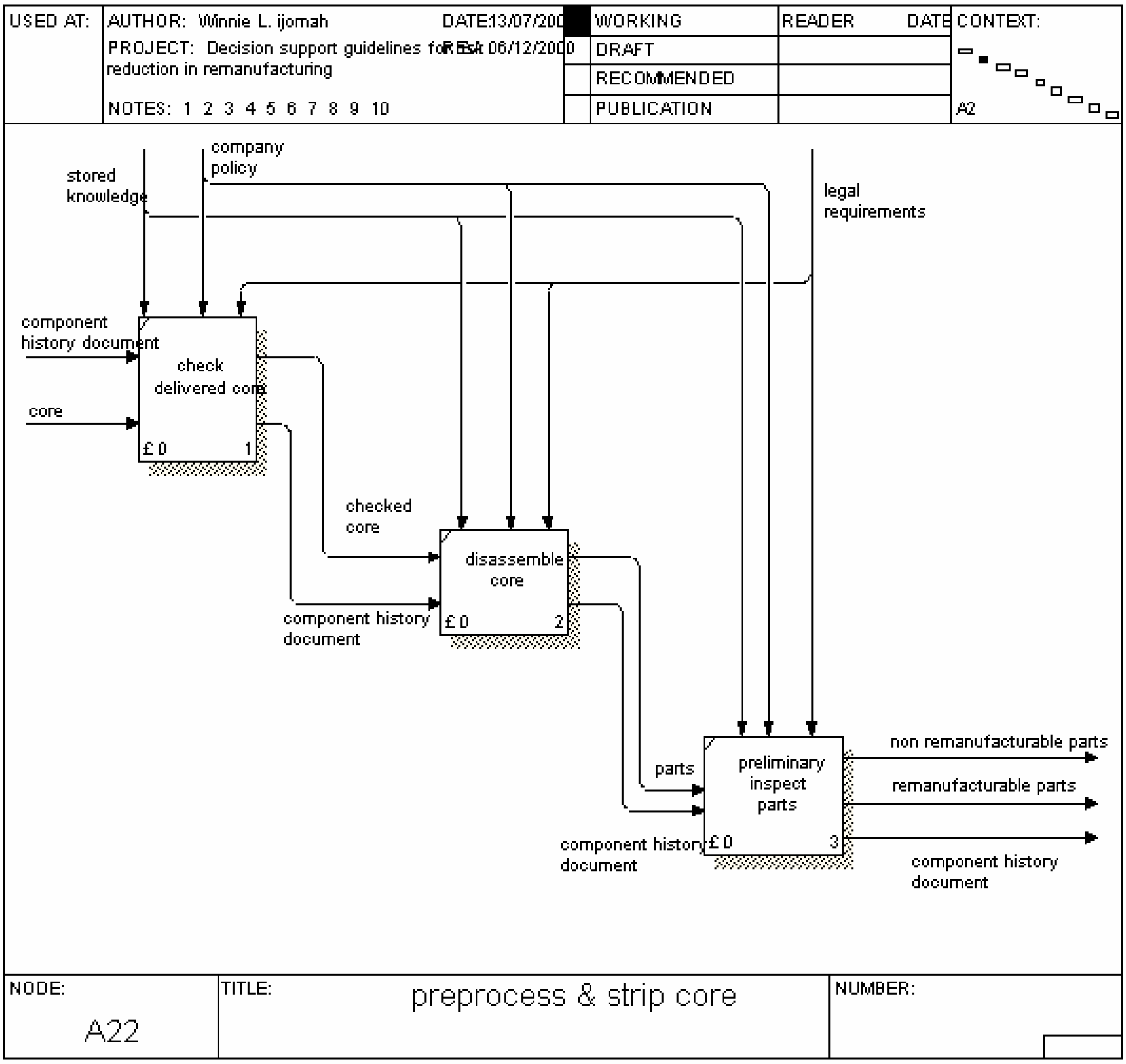


Figure 5. A22 diagram

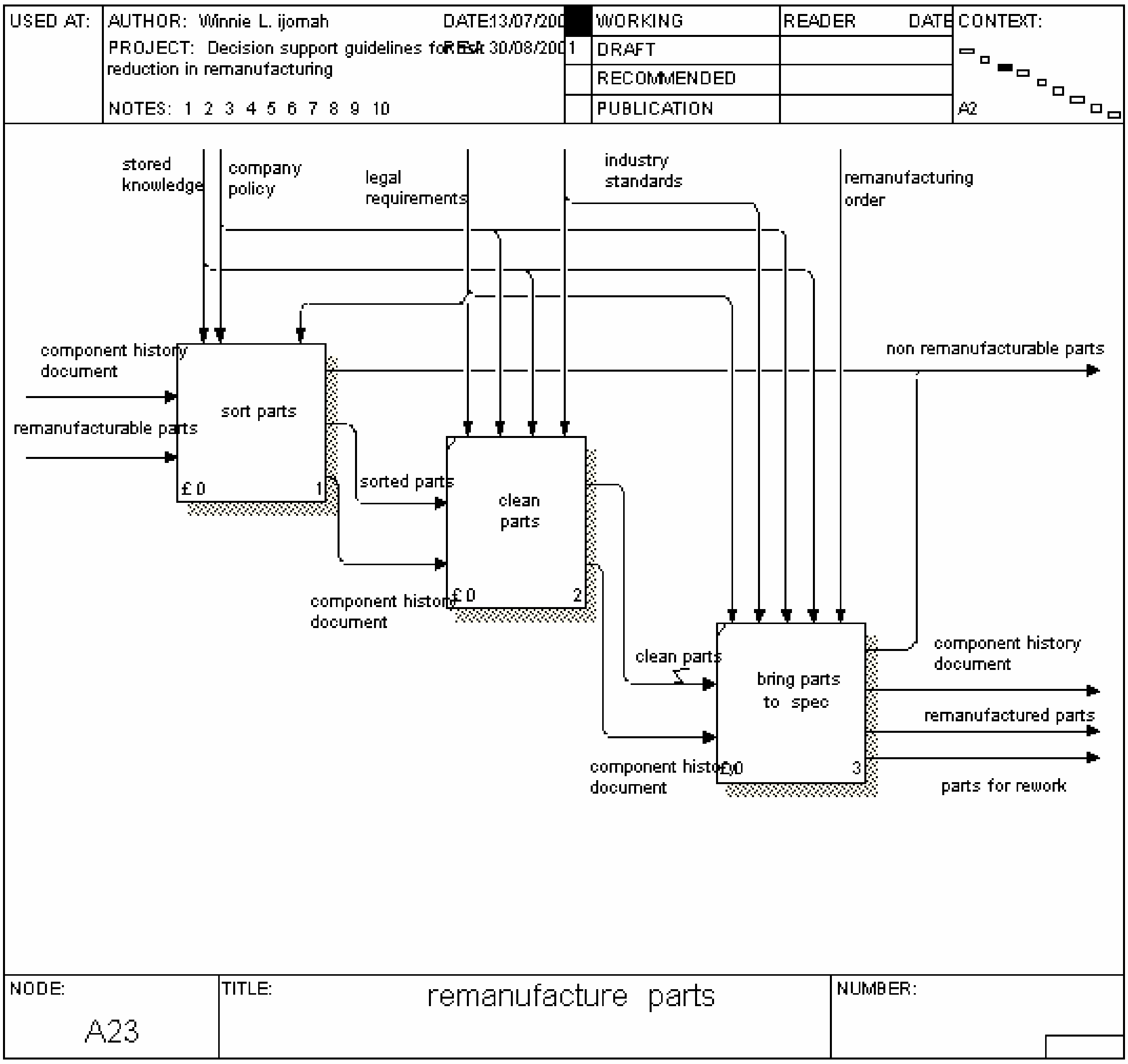


Figure 6. A23 diagram

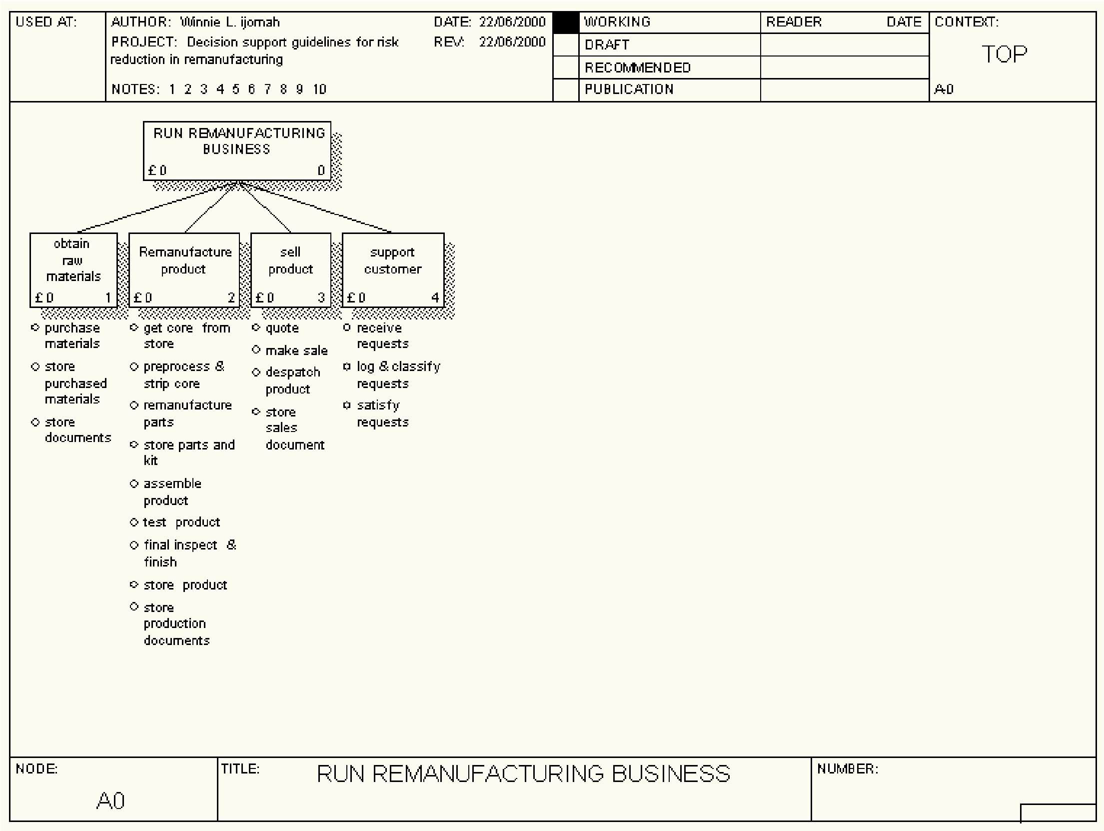


Figure 7: The Node tree diagram

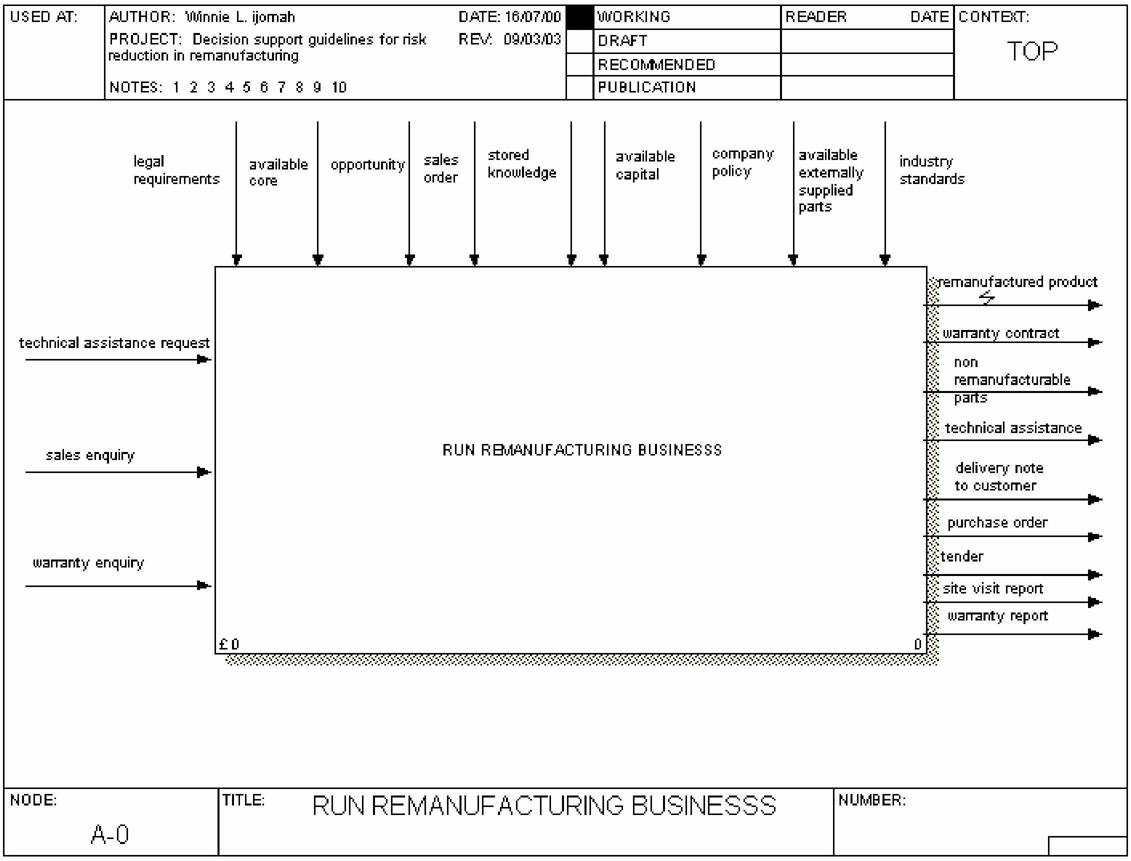


Figure 8: The A-0 diagram

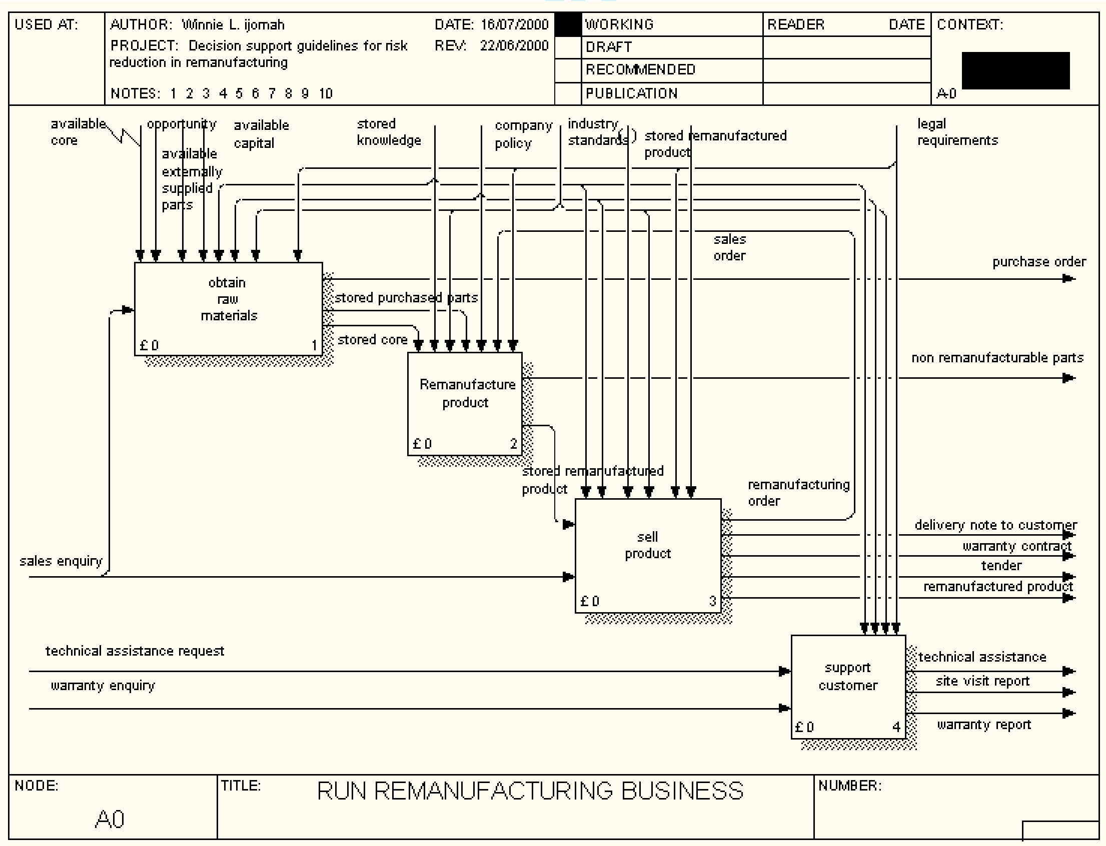


Figure 9: The A0 diagram

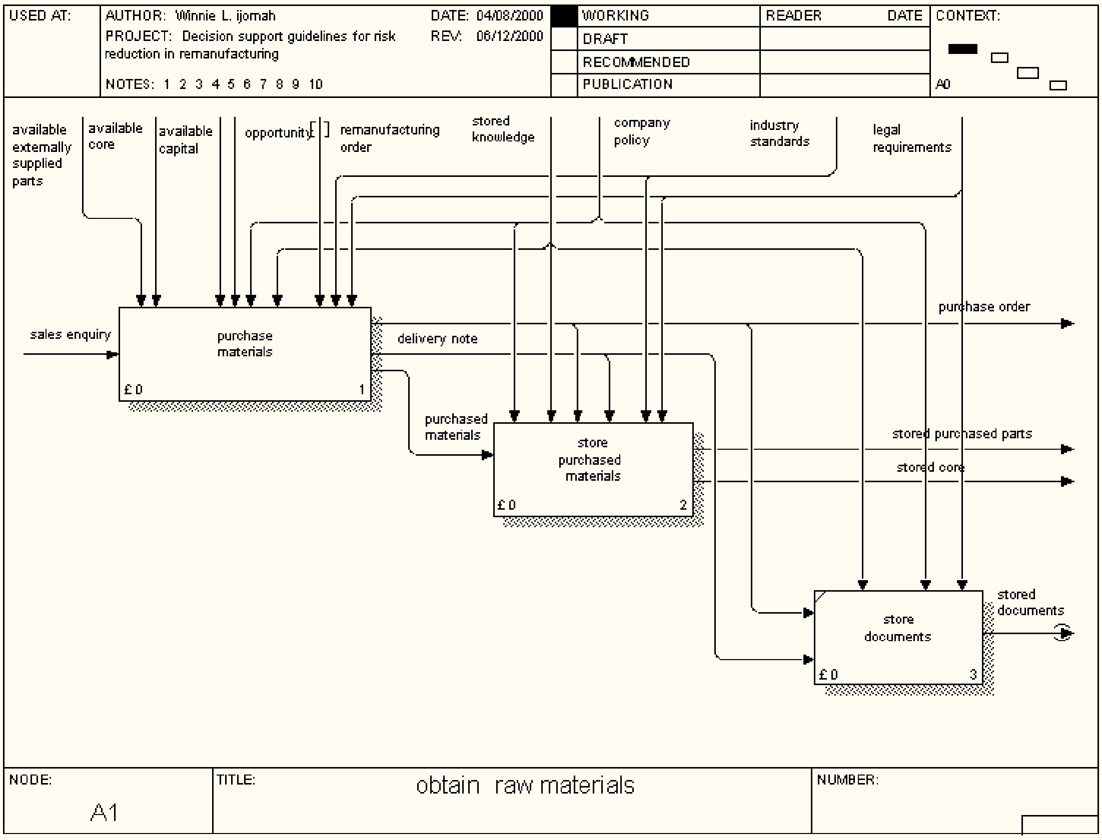


Figure 10: The A1 diagram

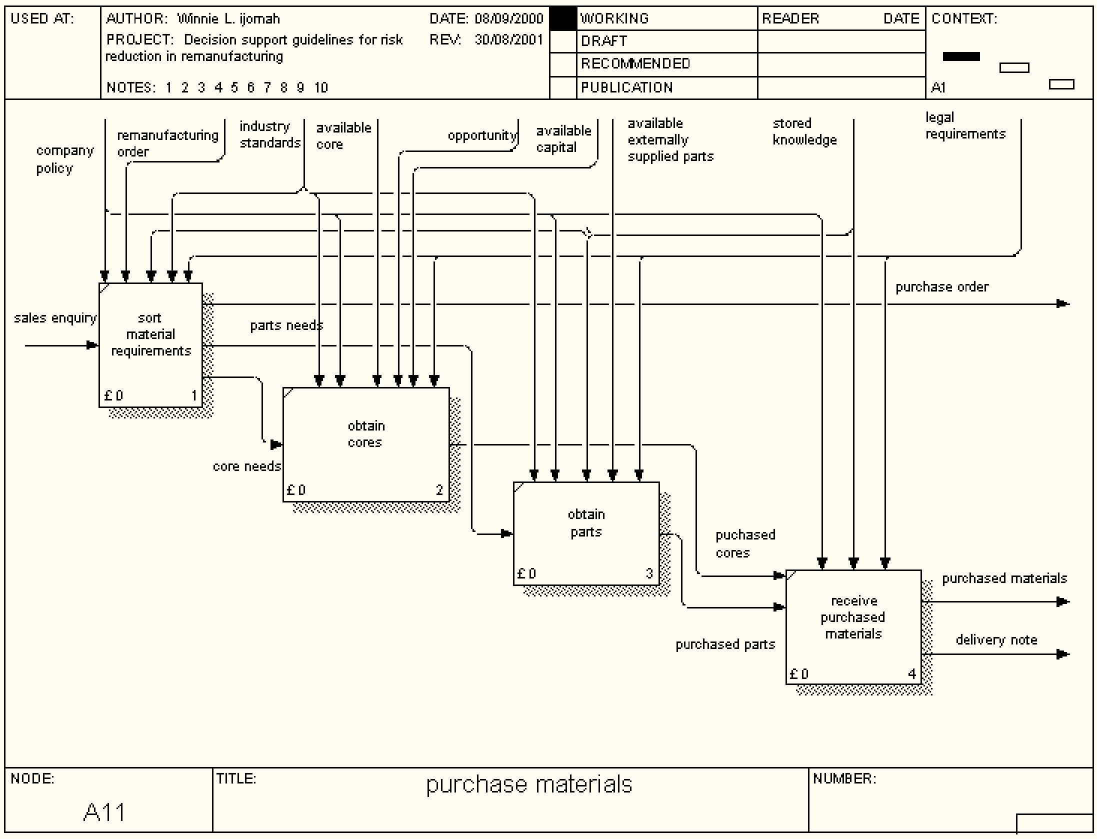
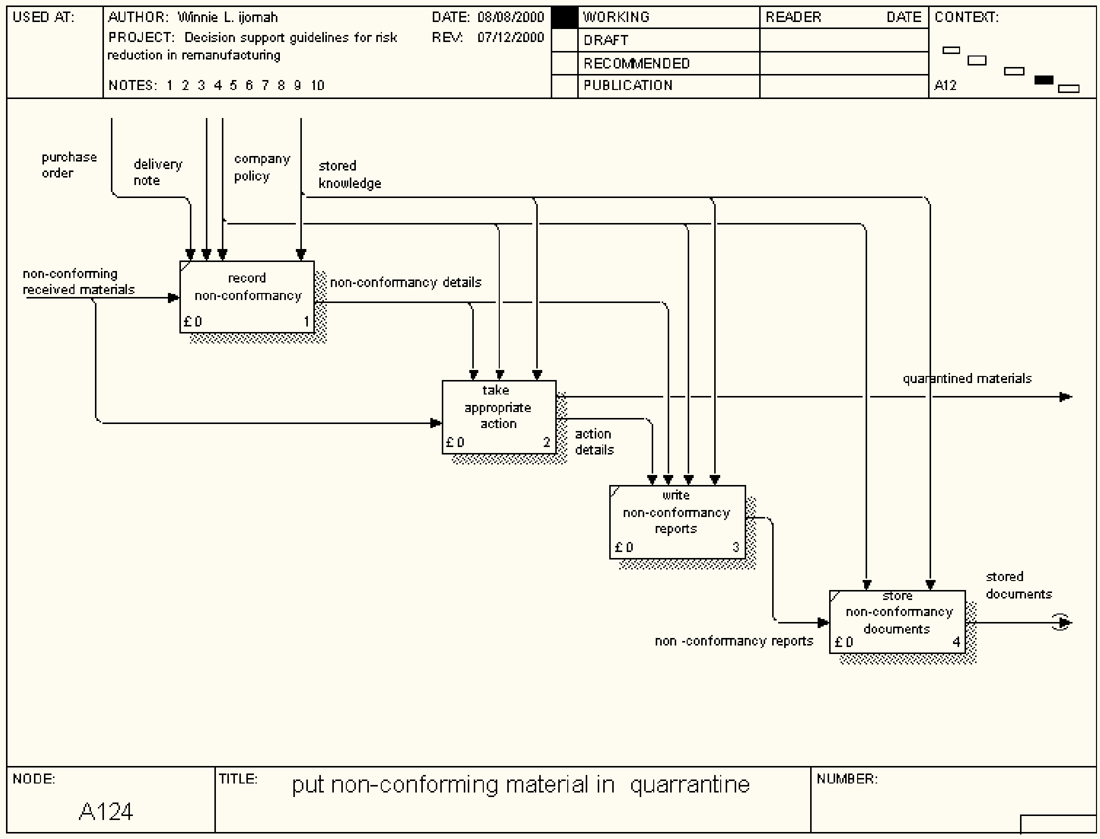


Figure 11: The A11 diagram



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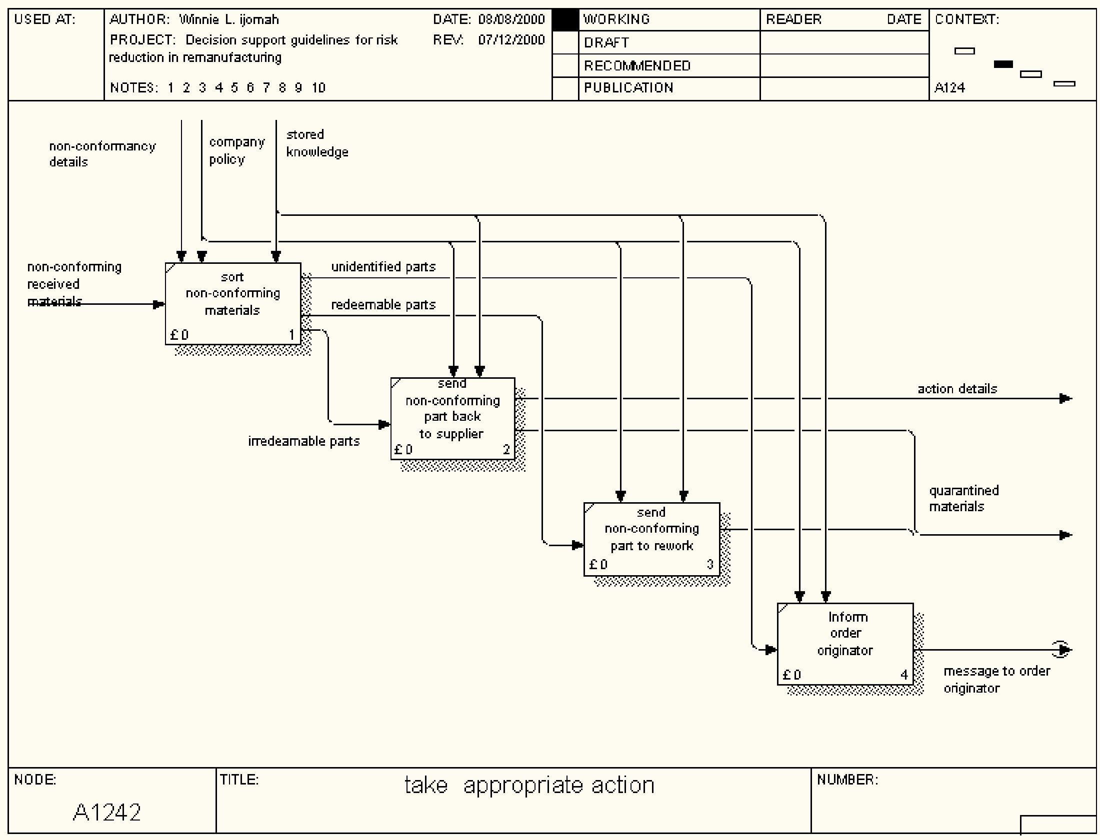


Figure 13: The A1242 diagram

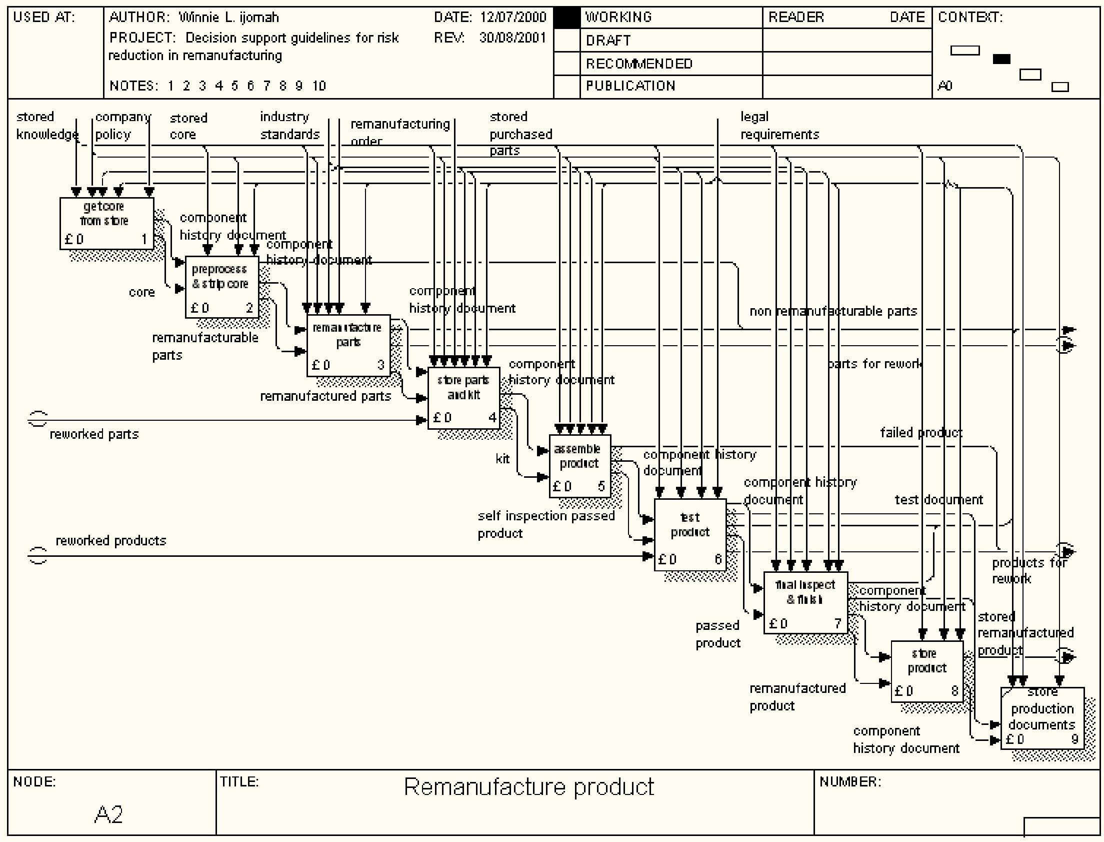
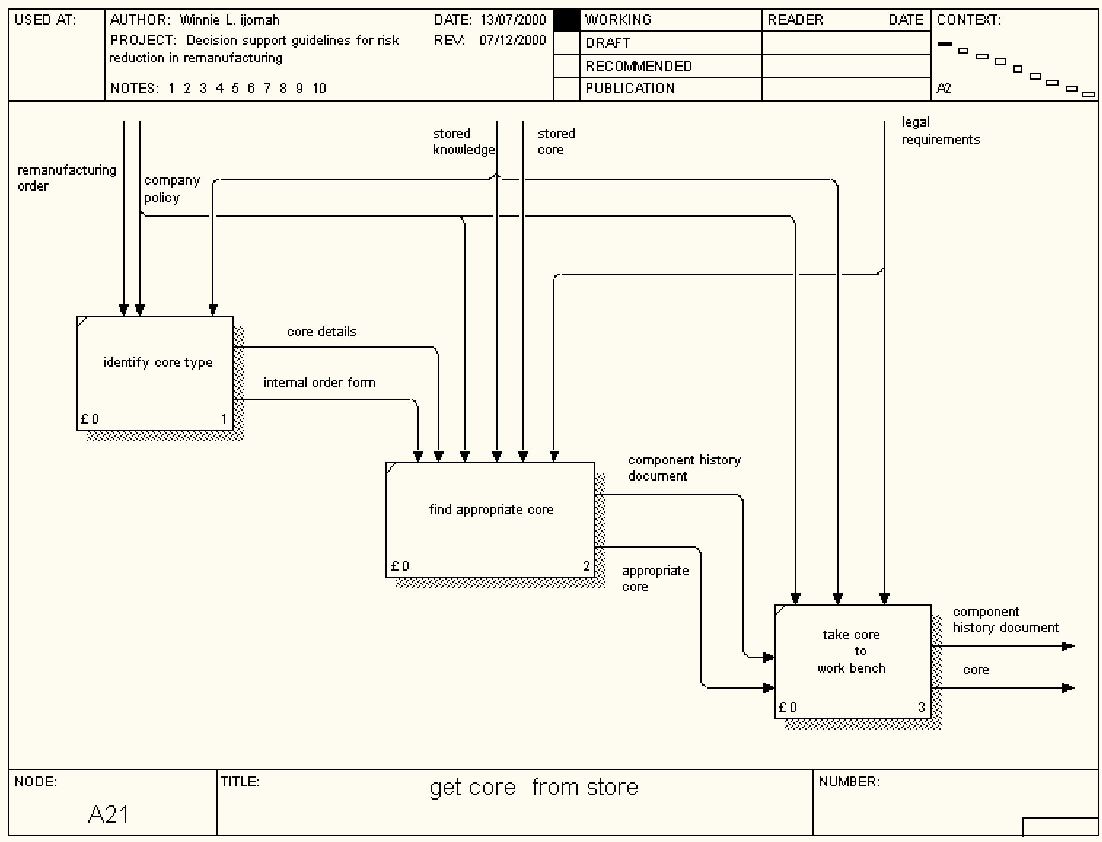


Figure 14: The A2 diagram



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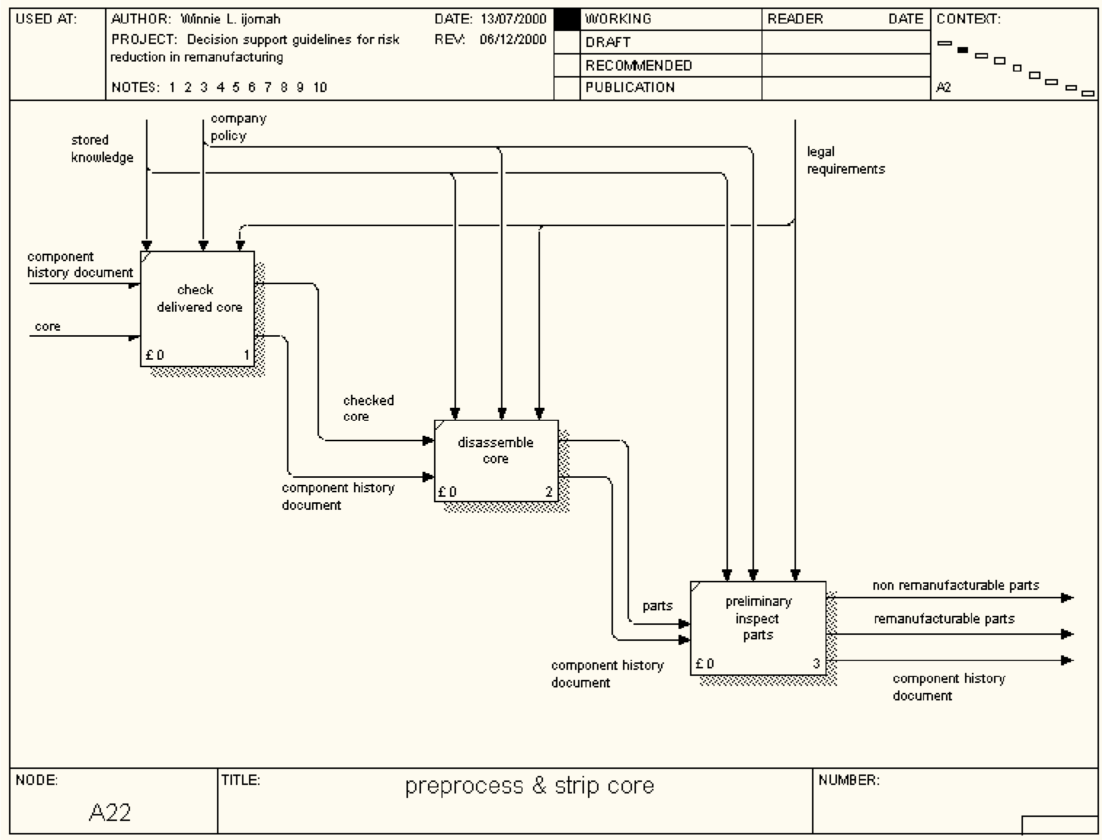


Figure 16: The A22 diagram

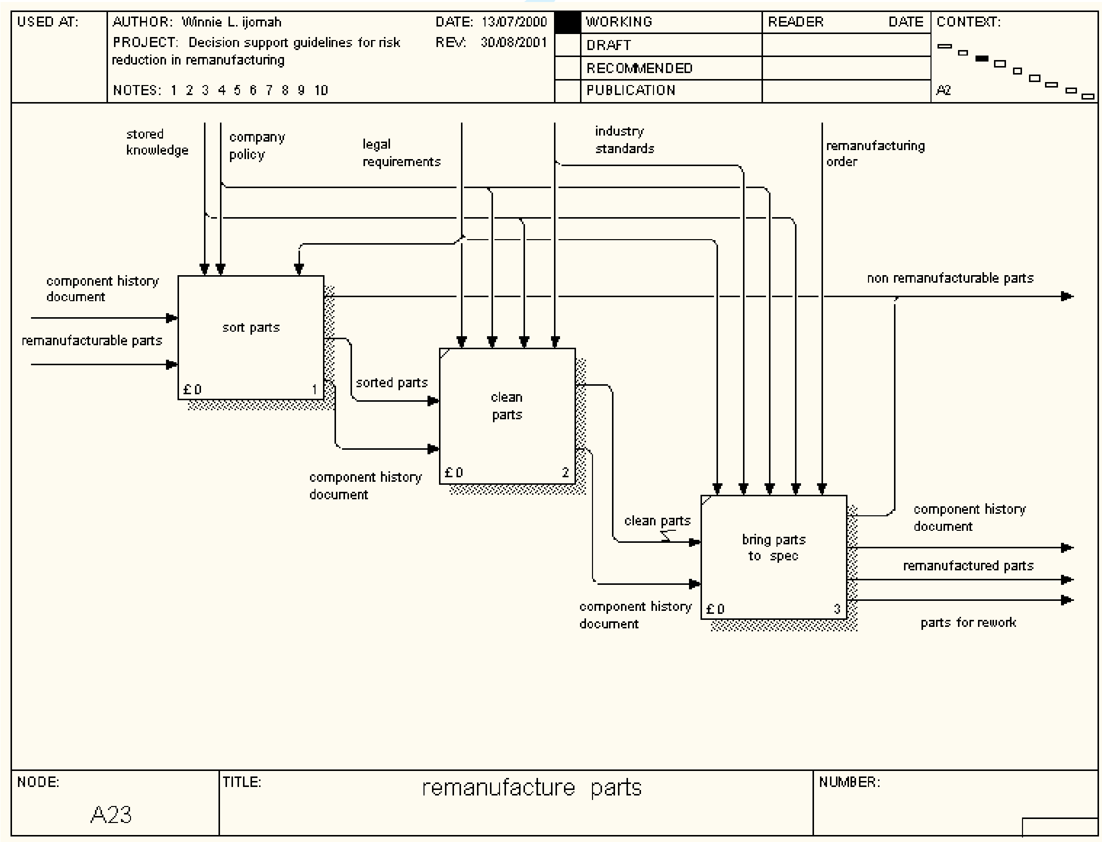
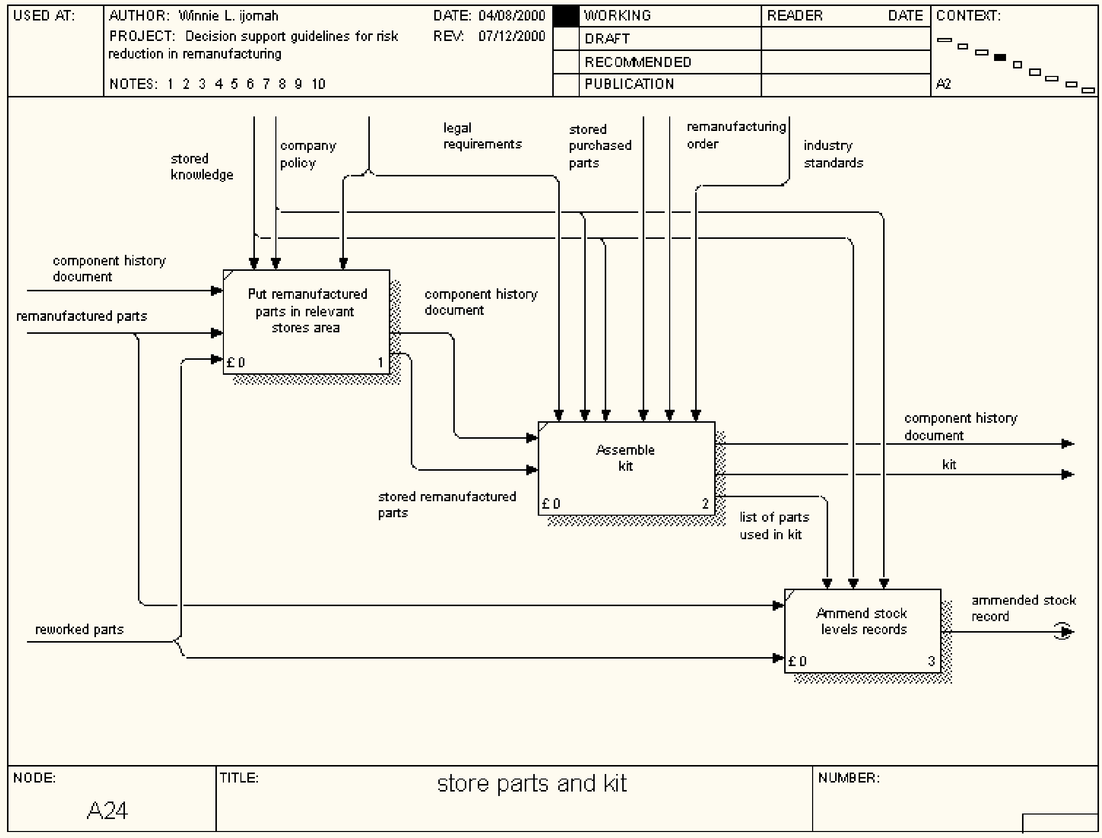


Figure 17: The A23 diagram



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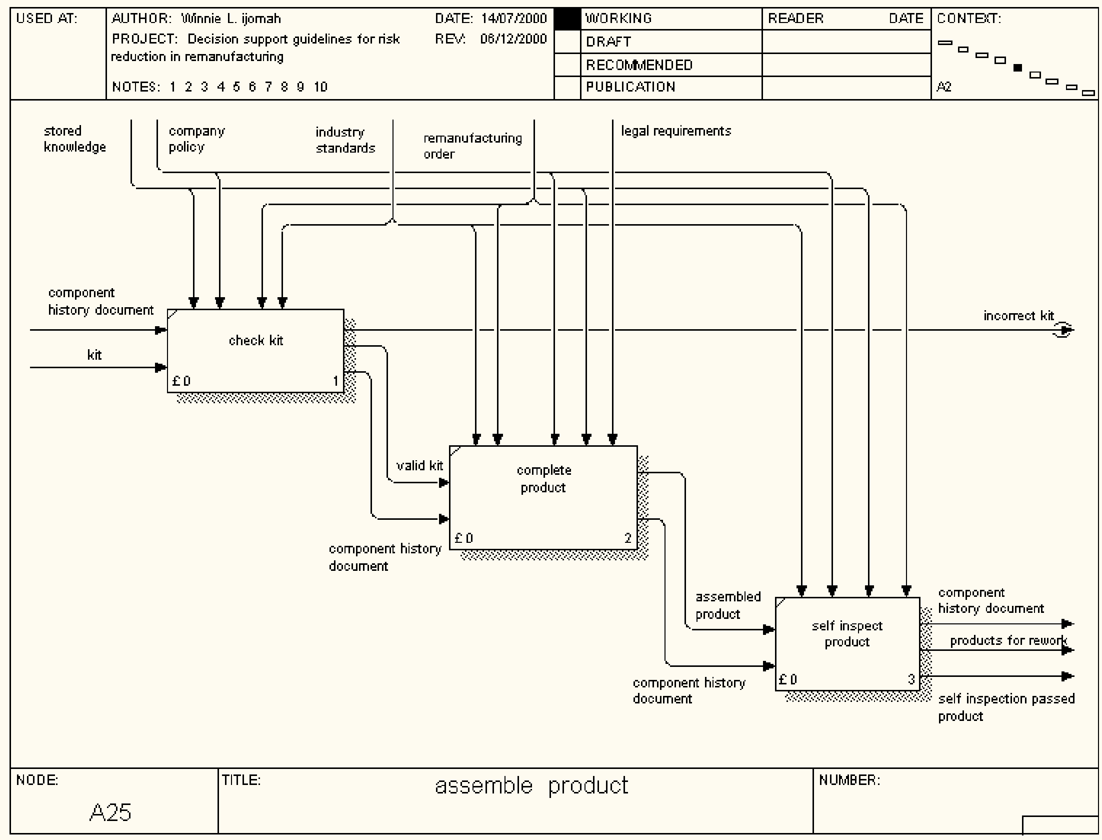
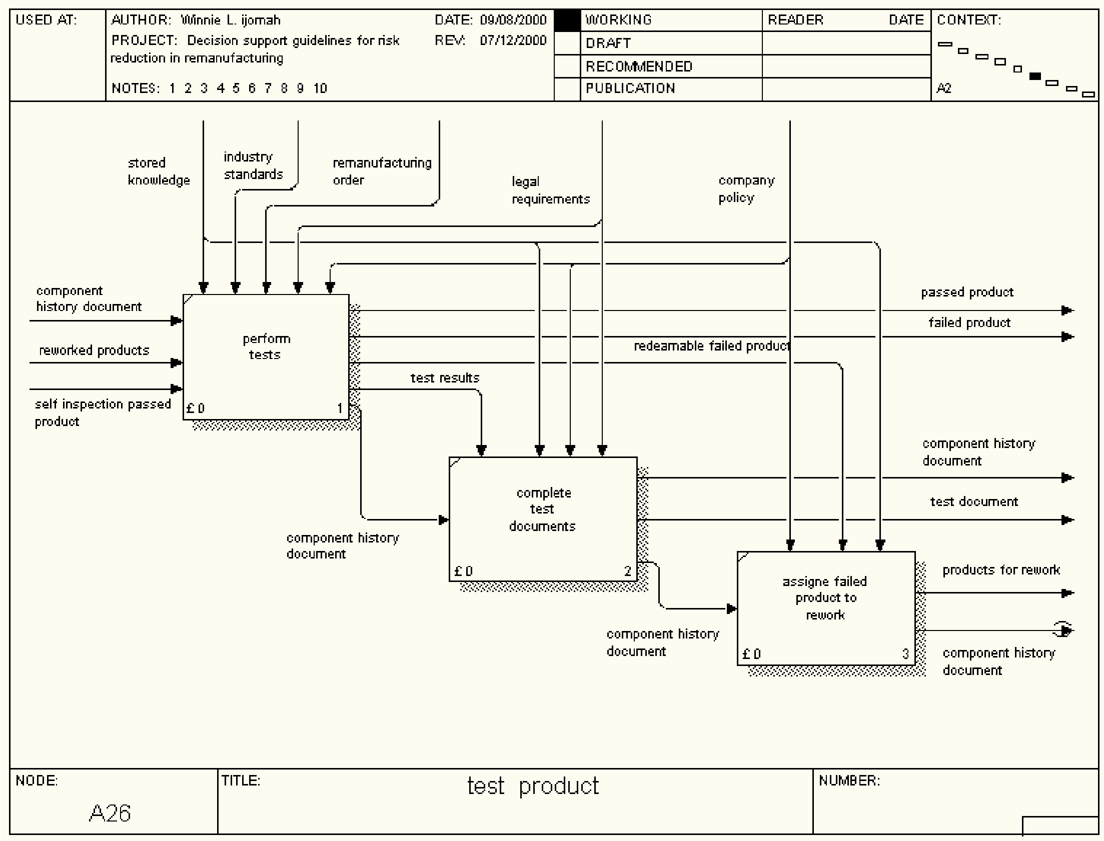


Figure 19: The A25 diagram



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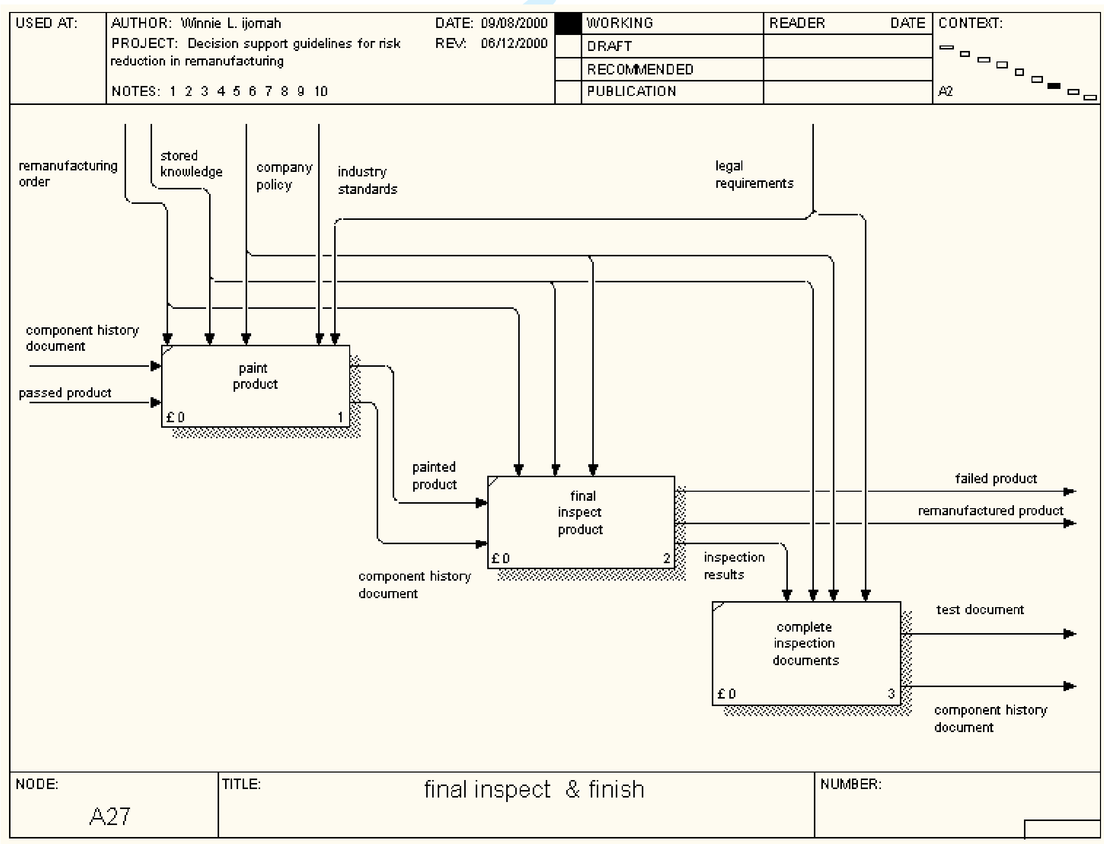

Figure 21: The A27 diagram

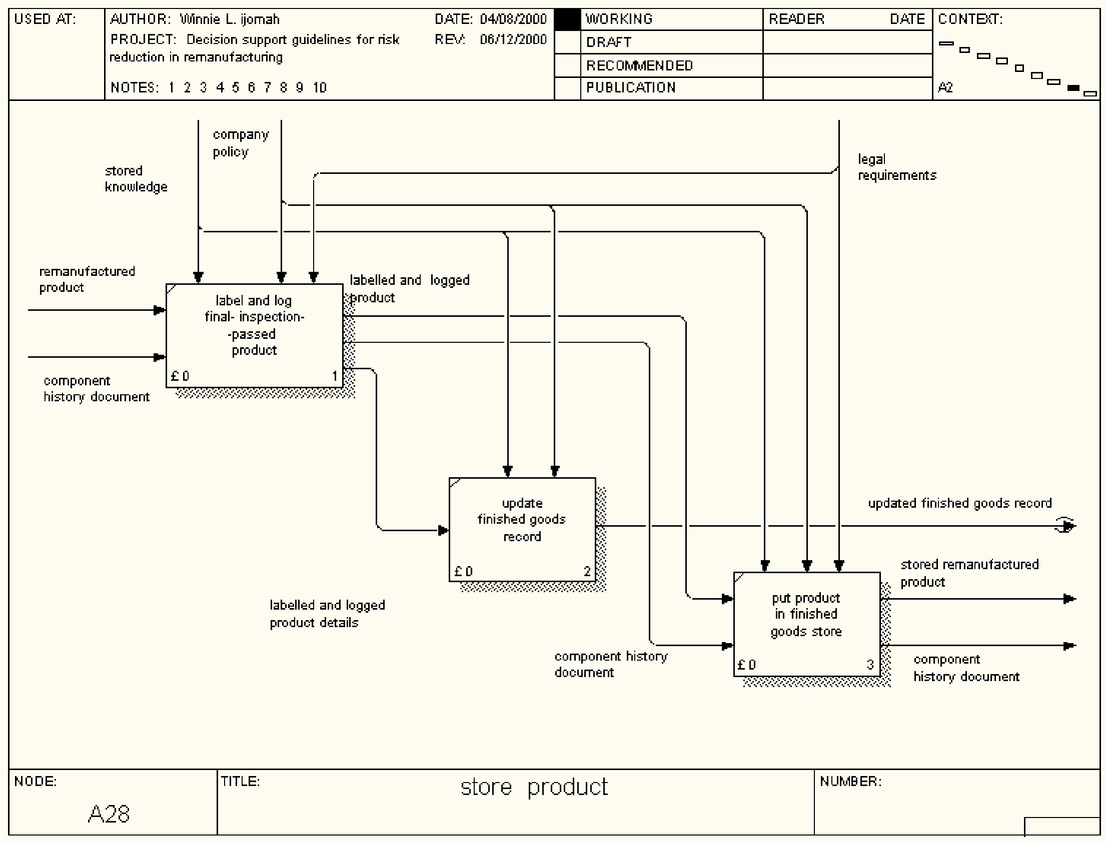

Figure 22: The A28 diagram

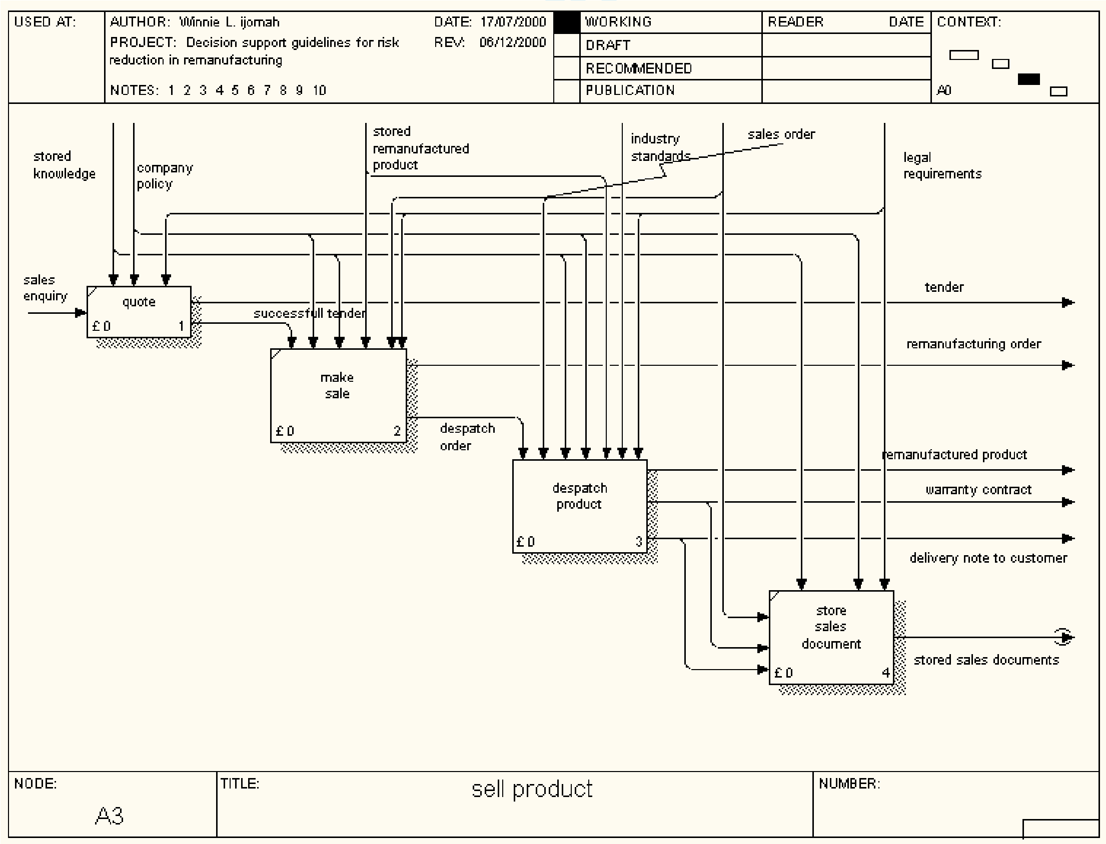

Figure 23: The A3 diagram

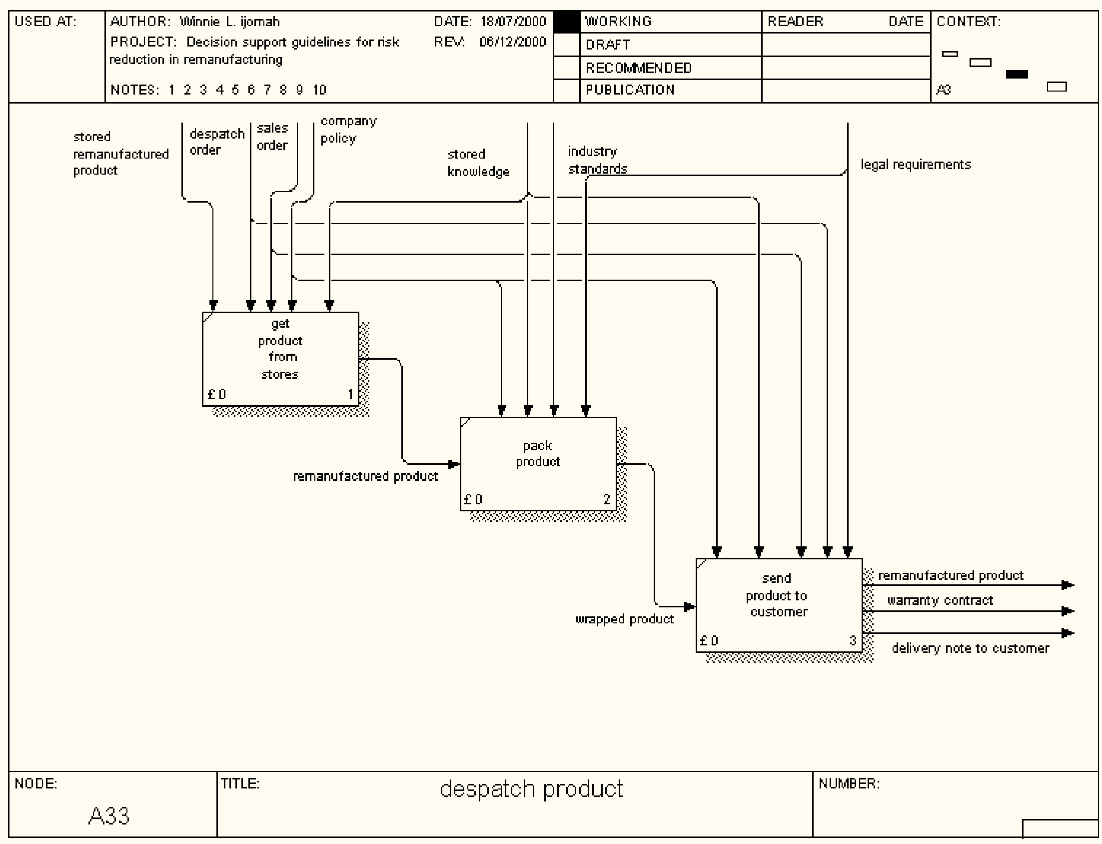

Figure 24: The A33 diagram

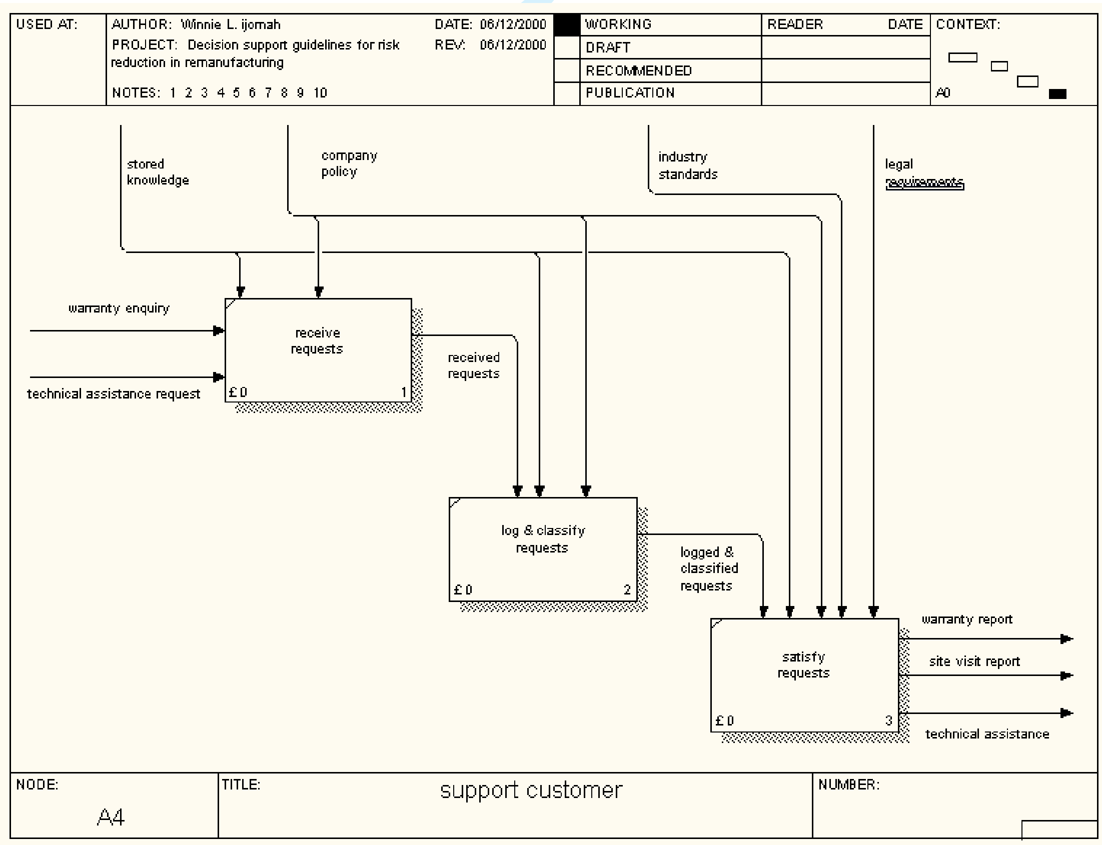

Figure 25: The A4 diagram

Table 1a: The initial feedback sheet

Name: **Organisation:** **Position:**

Please tick one box on each line to show how far you agree with each statement.

		Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
1 SF	Many major information flows and activities have been omitted in this model.			8	4	3
2 C	This model displays the required information clearly.	1	7			
***3 ST**	This model is an adequate representation of the remanufacturing business process	2	6			
4 C	I find many details in this model ambiguous			2	6	1
5 ST	This model does not reflect the remanufacturing business process to any great extent				6	2
6 SF	Only a few major activities and information flows have been omitted in this model	2	4	2		
7 ST	This model is correct in the way that it shows the basic elements of the remanufacturing business process	3	4	1		
***8 C**	I find this model easy to comprehend	1	7			
9 SF	I feel that this model captures the major information flows and activities of a remanufacturing business process	1	6			
***10 C**	I can analyse the information flows and activities of the remanufacturing business with this model	2	5	1		
11 SF	Only a few major information flows and activities are missing in this model	2	2	3	2	

Table 1b: The initial feedback sheet

Name: **Organisation:** **Position:**

Please tick one box on each line to show how far you agree with each statement.

		Strongly Agree	Agree	Neither	Disagree	Strongly Disagree
12 ST	This model is an acceptable description of the basic remanufacturing business process	1	7	1		
13 SF	This model requires many alterations before it can describe the remanufacturing business process			2	6	1
14 C	This model is extremely difficult to understand			1	7	1
***15 ST**	I would not use this model to give a basic description of the remanufacturing business process				5	4
***16 C**	Generally, this model is logical in the way that it describes the remanufacturing business process	1	7			1
***17 SF**	This model is a poor representation of the remanufacturing business process				6	3
***18 ST**	I do not recognise this model as being that of the remanufacturing business process				4	5
19 C	I find this model easy to follow	2	7			
***20 ST**	I would consider using this model to describe the remanufacturing business process	3	6			
21 SF	Many major details are missing in this model			2	4	3

22 Any additional comments:

Good way to break down process for quality assurance, costing, information capture.
Some titles need to be put in basic GCSE English!
Time to discuss with staff in my company for their opinions and comments.
Different eyes see different things.

THANK YOU FOR YOUR TIME

Table 2. Practitioners' proposed uses for the tool

Proposed tool use
Use to supplement and thereby enhance the clarity of quality control system and procedures
Use to replace lengthy procedure documentation
Use for sales promotion/marketing
Use as a map of remanufacturing
Use to improve communication
Simulation
Use for designing effective remanufacturing operations
Add a bit more text and use in place of present generation of quality control systems and procedures because these tend to be unwieldy and often confusing
Use to educate about remanufacturing
Use as a training document
Customise for the specific needs of individual companies (reference model)