METHODS OF REPRESENTING THE STRUCTURE OF COMPLEX INDUSTRIAL PRODUCTS ON COMPUTER FILES, TO FACILITATE PLANNING, COSTING AND RELATED MANAGEMENT TASKS.

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SARA BURNS

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ABSTRACT

When the original concepts for the computerisation of product structures were developed in the late 1960's the available computer power was very limited. A modularisation technique was developed to address the situation in which a number of similar products were being manufactured. This technique tried to rationalise these products into family groups.

Each member of the family differed from the others due to the possession of different features or options. However there was also a high degree of commonality to give the product membership of the family. Modularisation involved the identification of the options and features providing the variability. Those parts remaining tended to be common to all members of the family and became known as the common parts. Separate Bills of Material (BOMs) were set up for each of the identified options or features. Another BOM was set up for the common parts. The simple combination of the required options and/or features BOMs with the common parts BOM specified a product. Computer storage requirements and redundancy were reduced to a minimum. The Materials Requirements Planning (MRP) system could manipulate these option and feature BOMs to over plan product variability without over planning the parts common to all members. The modularisation philosophy had wide acceptance and is the foundation of MRP training.

Modularisation, developed for MRP, is generally parts orientated. An unfortunate side effect tends to be the loss of product structure information. Most commercial software would list 6 resistors, Part No. 123, in the common parts BOM without concern as to where the resistors are fitted. This loss of product structure information can hide the fact that two products using these 6 resistors 'in common' are in fact different as they do not use the resistors in the same 6 places. Additional information must be consulted to enable the correct assembly of the 'common' portion of these products.

The electronics industry is especially affected by this situation. This industry has changed considerably since the late 1960's. Product variability can be very high. Changes and enhancements are a constant factor in products having a relatively short life span. The modularisation technique does not have a good mechanism for the situation where an option itself has options or features. This situation can exist down a number of layers of the family tree structure of an electronics product. Maintenance of these BOMs is difficult.

Where there are options within options the designers and production staff need to know the inter-relationship of parts between options to ensure accuracy, compatibility and plan assembly functions. The advent of computerised spreadsheets has made the maintenance of this type of product structure information easier. This matrix is another separate document which must be maintained and cross checked. It will inevitably differ from the BOMs periodically.

This thesis develops a product structure Relational BOM based on the matrix for the family of products. The processing power of the 1990's computer is fully utilised to derive the common parts for any or all of the selected products of the family. All product structure information is retained and the inter-relationship of parts is highly visible. The physical maintenance of the BOMs is simple. The BOM serves all purposes without the need for supplementary information. It is fully integrated into the Sales Order Entry , MRP, Costing, Engineering Design and Computer Aided Manufacturing (CAM) systems.

This technique has been proven by being the only system used in one Electronics Design and Manufacturing organisation for over 1 year without any major problems.

As described in Section 1.6 user satisfaction has been high. The response of the users to the suggestion 'lets buy an "off the shelf" package' is very negative, as it would not incorporate this BOM system. Users have expressed the opinion that EXICOM could not continue, with present staffing levels, using the traditional BOM structure.

ACKNOWLEDGMENTS

I wish to thank the management and staff of EXICOM without whose co-operation this study would not have been possible. The faith they pinned on a totally untried concept demonstrates the desperate situation which had developed. The fact that management were unable to find consultants able to suggest a better course of action is indicative of the lack of understanding within this country, and possibly further afield, of this problem. Most consultants had not thought beyond the accepted methodology as developed in the late 1960s.

One group of consultants which may have been able to assist have been of extensive assistance to me with the writing of this thesis. I refer to the staff of the Production Technology Department of Massey University. I wish to thank Harvey Barraclough for his guidance especially in the wider thinking of how this concept could be applied to other computer systems and Roger Browne for his guidance in the writing of this thesis.

I wish to thank Ned Davies, the contract programmer for EXICOM, who made this concept a reality. During previous projects Ned had given me a good grounding on how the PICK system file structures worked and generally taught me how to use the programming language. At that stage, as I was not permitted to write software code for the corporate computer, I had to rely on Ned's ability to translate my concepts into a robust useable code. He acted as a good sounding board for some of my ideas which initially sounded impossible. His teaching, combined with my own reading, was sufficient to allow me to take over all the programming tasks and maintain the system when his contract was reduced due to changes in the company financial situation.

Lastly I wish to thank my family who have lived with this study for two years. Without their continuing support and understanding this thesis would not have been possible.

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1. INTRODUCTION

1.1. Background

This study has been investigated and implemented within EXICOM New Zealand Ltd., a medium sized electronics designer and manufacturer situated within the Wellington area of New Zealand. Although the problems encountered by this manufacturer may be unique to this type of business it is highly probable that some of the solutions developed will be of use in other areas.

1990 marked the start of a major rewrite of EXICOM's Sales Order Entry, Configuration 'Expert' System and Inventory software to support the changed operating requirements of the business. My role, as Systems Analyst, meant that, in consultation with the users, I designed the system, wrote the specifications and tested the software. These specifications were translated into robust software code by Ned Davies, contract programmer. Burns [7]. These changes emphasised that the Bills of Material software was no longer appropriate to the pace of change required to stay within the market place. Any new system had to mesh with these existing systems. This limited the implementation to the currently-used PICK Database Management System (DBMS) which is a DBMS and an Operating System combined. PICK is now becoming available on a wide range of hardware platforms and may be run 'on-top' of UNIX if desired. This relational database, widely used in commercial applications overseas, has some unusual features which have been utilised. However, as will be discussed in Chapter 5, the concept which has been developed can be implemented on other systems with some changes to the data structures.

EXICOM management sought consultants within New Zealand to assist with suggestions as to how to design a Bills of Material system which would suit their 'unique' situation. Whilst many consultants professed to have extensive knowledge of manufacturing requirements and techniques few claimed to have the necessary knowledge of computer file structures to design a different system from scratch.

This study, to design a new type of Bills of Material, which would satisfy the needs of EXICOM, was approved by management in early 1991. My role changed to that of Analyst/Programmer shortly after the new Bills of Material software was introduced in June 1991.

1.2. Information Needs

There are certain features of any manufactured item which must be recorded. Traditionally these have been recorded in a number of different ways depending on the feature, department and the type of business.

1.2.1. Parts Listings

In a manual system different Parts Listings would be held by each department involved with the product. Engineering would probably hold a master listing of those parts which had been designed into the product. This master listing may have been through a Design Release procedure. Normally there would also be a form of Engineering Change Authorisation which would record approved changes to the design. These changes would be promulgated to the other interested departments within the organisation.

Purchasing would have their own translation of the parts listing which would include information on probable lead times, suppliers, costs and possibly other products using the same parts. This listing may, or may not, agree with the picking list held in the store.

Production's listing would include other features such as product structure, sequence of operations, work instructions, tooling, jigs and fixtures, labour hours, machine set-up times, quality control test methods, test specifications, performance specifications etc.

Costing would require information on material costs, labour times, machine set-up times, overheads etc.

1.2.1.1. Historical

The importance of knowing which parts or ingredients were used in a product or batch varies according to the type of industry. It may be of very little importance which batch supplied the timber for a custom made piece of furniture but may be vitally important in the food or drug industry to be able to trace the exact source of a contaminated ingredient.

The parts used in a prototype which is destroyed as part of the testing process, as would be normal within the munitions industry, must be documented. The prototype cannot be disassembled after testing to ascertain the design.

The Spare Parts division must be able to ascertain which parts were used in any particular model to provide an adequate service to customers. This requirement, like that of batch traceability, varies with different types of industry.

1.2.1.2. Present

The parts and/or materials required for the next production run of any product must be defined to enable the correct materials to be purchased in time for production commencement.

1.2.1.3. Future

Changes to the design, requiring different parts or materials, must be recorded to allow the correct materials to be ordered. An introductory date for each change is required. These changes will usually be advised via the Engineering Change Authorisation.

1.2.2. Engineering Drawings

Components or total systems to be manufactured or assembled are often defined on an Engineering Drawing. The parts and/or materials required are also often listed on the drawing. If the parts are listed on the drawing and on a separate parts listing the situation known as 'double masters' exists. In cases of dispute it is difficult to decide which is the ultimate master correctly defining the parts - the parts listing or the drawing?

1.2.2.1. Circuit Diagrams

The electronics industry uses a specialised engineering drawing known as a Circuit Diagram. This uses pictorial representations for different electronic components. These components are given circuit references and linked by lines on the circuit diagram. Usually each component has a value listed alongside and possibly some other information, eg. voltage. One circuit diagram may be used for a number of products sharing the same basic circuit layout. A circuit reference having different values for different products is listed in a matrix table.

1.2.2.2. Printed Circuit Boards

Another specialised electronics engineering drawing is the printed circuit board (PCB). Traditionally the PCB was produced as a scale drawing, in Indian Ink, of the exact copper tracks and pads used to form the PCB. Later the Indian Ink was replaced by adhesive tapes and pads in various widths and sizes. Very accurate photo-reduction is required prior to photo etching the PCB.

The taped PCBs are gradually being replaced by those using Computer Aided Design (CAD) technology. This change in technology was necessary to address the extremely tight tolerances required by the robotic machinery used to insert parts into the PCBs.

A legend giving the circuit reference for each set of holes is normally printed on the non-tracked side of the PCB. When tracks are placed on both sides of the PCB legends are also often printed on both sides.

1.2.3. Materials Nomenclature

All the above listings of parts and materials were likely to have used different naming systems. The descriptive language is likely to be that recognised by the craft to which the original writer of the information belonged. This led to confusion and multiple stocking of the same item under different names.

Imprecise parts descriptions, as used on the circuit diagram, left the decision as to which exact part to buy to the purchasing officer. As the range of parts available increased this become a very specialised area of responsibility. The circuit diagram is not an appropriate document to record specific details concerning the part as there is insufficient space. This became the role of a separate parts listing. The accuracy of this information was the responsibility of the engineer, not of the draughts person. The information was now listed on two documents, in differing degrees of detail. The situation referred to as 'double masters' exists.

1.2.4. Product Structure

A system or product may be made up of a number of sub-assemblies which can be manufactured and put into stock separately. It is likely that each of these will have its own parts listing. This can allow larger batches to be produced of stock items prior to final assembly into the required product. Each of these sub-assemblies must be incorporated into a higher level assembly until finally the listing is for an end product or system.

A sequence may be recorded to enable the correct production and assembly of all components to enable the final product to be manufactured in the most efficient way possible. This may include production lead times to allow Production Planning to launch each component so that all components reach final assembly in the correct sequence.

1.2.5. Manufacturing Processes

The manufacturing processes required to produce an item must be recorded to enable production to make one or many items. This item may be the total system or a small component of a much larger system. The processes would normally be written on the Engineering Drawing and may also be listed on a parts listing.

A component which is manufactured by one or more sub-contractors may include multiple processes, each requiring inspection before the next process can take place. They may possibly be stocked in a semi-finished state. This information may be included on the engineering drawing or on an accompanying instruction.

1.2.6. Tooling

Where tooling is required to produce a component or product this must be recorded. This would normally be part of the Production documentation.

1.2.7. Jigs and Fixtures

As with tooling, any jigs or fixtures required to produce an item must be recorded. Without this information in a readily available form a product can be delayed in production due to a jig etc being used on another product.

1.2.8. Work Instructions

These instructions tend to be product/operation specific. They must be recorded with the other production information. These often take the form of a diagram with reference to parts and/or materials. The 'double master' situation once again can exist.

1.2.9. Serial Numbers

In many industries each finished product is given a Serial Number or the equivalent. This often corresponds with some type of test record. In these cases it is desirable to be able to access all the production information, used to manufacture the product, to allow spare parts to be distributed. In the unfortunate case of a problem being identified 'in the field' it is essential that the exact parts, materials, or ingredients can be identified, possibly to the extent of the actual batch number used. Instructions can then be issued to allow the problem to be rectified or in the worst case the affected product can be recalled.

1.2.10. Costing

Any product, whether in the development phase or during its life cycle, must be able to be accurately costed. This requires the input of material, labour, overheads, tooling etc. In EXICOM's case each system has an almost identical labour content. Materials constitute approximately 95% of total costs. Therefore the BOM, with its associated material costings is very important.

1.2.11. Inventory

Every organisation requires a control system to track materials either in stock, as requirements or on order. Many manual techniques have been devised to assist with the planning and procurement of materials. These techniques were usually inexact, tended to require quite large safety stocks and were very labour intensive. Each business normally had extensive capital invested in its inventory. There were better techniques but the labour input made them impractical until the introduction of computers.

1.3. Development of Computerised Systems

1.3.1. Requirements Planning

The manual methods for planning material requirements were divided into two major categories, independent and dependant demand. In some cases they were mixed.

1.3.1.1. Independent Demand

This entailed replenishment to maintain a reasonably constant maximum quantity of each part based on previous consumption patterns. Reorder Point and Economic Order Quantities were some of the techniques used. This required quite high safety stocks and was not affected directly (only historically) by the products forecast to be manufactured. As a part was consumed by manufacturing it was replaced once a predetermined minimum stock level had been reached. This did not require a detailed parts list as the replacement parts were assumed to not be product dependant.

1.3.1.2. Dependant Demand

This methodology tries to order the materials required to make a forecast range of end products. A detailed parts list is required for each end product. For each part the quantity per product is multiplied by the planned production quantity for the product. This quantity of the part, plus any extra for contingencies, is the gross requirement for the part. The quantity of uncommitted stock of the part, already held within the inventory, is deducted from the total requirements giving the net requirements to be purchased.

Required = (qty/product x qty of product) - free stock

For example, Part A is used in Product Z in 5 places. There are 100 units of Product Z planned to be made. If there are 52 uncommitted units of Part A the total requirement will be as follows:-

Part A Requirement = (5 x 100) - 52

Part A Requirement = 448

1.3.1.3. Explosion Chart or Planning Matrix

The dependent demand is not only for one product but for all products forecast to be made in a stated production window. It is quite possible that the same part may be used in multiple end-products. This led to the development of the explosion chart as described in the Production and Inventory Control Handbook 1970 [23] (Figure 1.1). Each end-product would be listed in the left column of the chart. Each required part would be listed across the top of the chart. The total quantity of each product forecast to be made would be listed. If more than one of a part is used in any product the quantity is listed in the upper part of the cell. This allows the total gross requirements for all parts to be calculated. The net requirements can then be calculated from the uncommitted stock within the existing inventory.

Part Product	Required Qty	Part A	Part B	Part C	Part D	Part E	Part F	Part G
Product 1	2500	2500		2500	2500			
Product 2								
Product 3	2000		2000	2000		2000		2000
Product 4	1500	1500				1500		2 3000
Product 5	1000		3 3000	2 2000	2 2000	1000		
Total Required	7000	4000	5000	6500	4500	4500		5000
Total Available		388	5028	4215	5250	650		421
To Obtain		3612	0	1988	0	3850		4579

Figure 1.1 Example of an explosion chart or planning matrix.

This method works very well but becomes difficult for more than one time period. The computer can assist with this when planning must be done over multiple time periods.

The parts lists or Bills of Material for two of these products are shown below.

Product 1		Product 5	
Part	Qty	Part	Qty
A	1	B	3
C	1	C	2
D	1	D	2
		E	1

Figure 1.2 Bills of Material for Products 1 and 5.

1.3.1.4. Common Parts

As can be seen in Figure 1.2 Parts C and D are common to both Products 1 and 5. If these products are part of the same product family this knowledge can be very useful during the forecasting and requirements planning stage.

A group of developers, Orlicky, Plossl, and Wight mainly working for IBM in the late 1960's and early 1970's, developed a Bills of Material modularisation philosophy for each product family to best use this knowledge of common parts.

1.3.2. Data Elements of Bills of Material

A Bill of Materials, commonly abbreviated to BOM, is a specialised parts list consisting of two major data elements.

1.3.2.1. Item Master Data

This is all the information pertaining to a part except the information on linkages to other items. Many attributes can be stored in the Item Master depending on the extent of integration of the database. Minimum elements would include the Part Number, Description, Unit of measure and Cost.

1.3.2.2. Product Structure Data

This defines the structural relationships of an item. According to Mather [19] "One product structure record is needed whenever two parts are linked together". The items are linked together in a parent/child relationship. An item which is used in a product is known as a child whereas the product which uses the item is called the parent. This is always a two-way relationship.

Parent <> Child

The parent of one item may itself be the child of another parent.

One aspect, used by the electronics industry, but missing from most literature and software is the requirement to specify the position within the product where a part is to be fitted. Most software lists a total number of a specified part per BOM. If this information cannot be maintained within the BOM system it must be held in supporting manual files. This is a further manifestation of the 'double master' scenario which a computerised BOM strives to eliminate.

Ideally, each Bill of Materials is required to incorporate all the various manual parts listings into the one shared database. Richard Bourke [4] listed a definition of a sound BOM system as:

"The BOM system should provide for the appropriate organisation and maintenance of all data defining the product in one (computer based) filing system with necessary supporting manual files stressing minimal redundancy, and for the retrieval and reporting of multiple, diverse user requirements".

1.3.3. Material Requirements Planning (MRP)

MRP is based on a forecast or firm production load known as the Master Production Schedule (MPS). This lists all the end-products which are expected to be manufactured in various time periods. Forecasting is only an educated guess at the best of times so this also is only a best guess.

Most manufacturing industries make a variety of end-products which are variations of the basic product. These can be categorised as family groups. Each family is likely to have a group of options and features which can be selected to tailor individual end-products. As these options and features increase in number so factorially do the quantity of end-products. If there are 3 options and 4 features then there are a possible 12 different end-products (3 x 4). If the options are increased by one to 4 then the number of possible end-products increases to 16 (4 x 4).

The general philosophy for Bills of Material as described by Orlicky [21] , Plossl and Wight [22], has been to modularise family Bills of Material to identify those parts required for each option and feature. These are listed in their own Bill of Materials for the option or feature. The parts which are always used are designated as common parts as with the Planning Matrix. They also have their own Bill of Materials.

Once these BOMs have been identified they can be used in the MPS. Instead of forecasting 16 end-products the forecast can list:-

1 x Common Parts BOM
4 x Option BOMs
4 x Feature BOMs

This is a total of 9 BOMs instead of the 16 BOMs required for all the end-products.

Another advantage of separating the options and features from the common parts is that these can be overplanned to allow for unknowns in the actual demand. If the MPS calls for 100 items then only 100 sets of parts are required. However it may be desirable to allow for 10% extra for all the options and features to accommodate unplanned skewing of the forecast. With a modularised BOM only 100 sets of common parts need be forecast. However parts for each of the options and features can be increased. This only overplans for a few parts and has less effect on the total inventory.

1.3.4. Modularisation of the BOMs

Kneppelt [16] stated that "The definition of company policy on product offerings is a key criterion for product structuring to support the MPS". He suggests that the best technique to assist with defining the extent of common parts is the matrix BOM. This is similar to the planning matrix as used for the manual calculation of requirements outlined in section 1.3.1.3.

The unique product part numbers of the product family are listed across the top of the table. Sub-assembly, component and raw material part numbers are listed down the left side of the table. Internal columns illustrate the number of times a sub-assembly, component or raw material part number is used in each unique product. This illustrates the part numbers common to products within the family. Kneppelt [16] refers to the resultant BOM as a SuperBill.

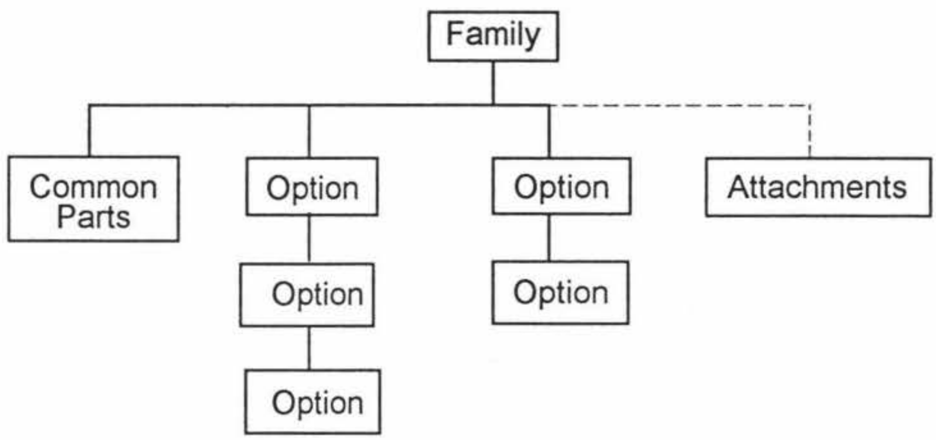

Figure 1.3 Super Bill for family of products.

This representation must be reflected within the company's product offering. Each vertical option chain represents one choice during the order entry process. One and only one option must be selected for each column. The attachments are optional extras which may or may not be selected.

The resultant BOM consists of :-

common parts
+ 1 of each vertical set
+ attachments if desired.

BOM maintenance is claimed to be simpler. If there is one common parts bill and 32 option bills then this is a total of 33 BOMs to maintain. The alternative is maintaining 4608 individual BOMs to cover every combination of unique end item part numbers. Add one option and this number magnifies.

1.3.5. Computer Memory Restrictions

One factor which must be acknowledged is the state of computer hardware development when these techniques were being developed. The memory on an average desktop computer today would probably exceed that available on large mainframes in the late '60s. Input was often in the form of punched cards and storage was in the form of sequential tapes. This imposed severe limitations and was probably a prime factor in the emphasis on reduction of redundancy and compression of information. The loss of product structure data, as demonstrated in the following examples, has been a criticism of the modularisation process.

1.4. Simple Example to Demonstrate EXICOM Situation

The product structures used in EXICOM are complex and therefore difficult to understand. The following very simplistic example is an attempt to illustrate the problem.

This example uses a number of strings of beads. Each strand of beads is deemed to belong to the same family as they have the same string length. This forms a constant factor which is an essential for any family group.

Each string of beads has 20 beads of varying colours. It is important for production to know the sequence of the colours on the string to ensure that they reproduce the exact string as specified in the marketing specification. Figure 1.4 displays the matrix for the first 5 members of the family.

Position	Strand 1	Strand 2	Strand 3	Strand 4	Strand 5
1	Blue	Blue	Blue	Blue	Blue
2	Green	Yellow	Red	Red	Green
3	Yellow	Red	Green	Blue	Blue
4	Black	Black	Black	Black	Black
5	Red	Black	Green	Red	Red
6	Red	Yellow	White	White	White
7	Green	Green	Green	Green	Green
8	Yellow	White	Black	Green	Blue
9	Blue	Blue	Blue	Blue	Green
10	White	Yellow	Green	Blue	Black
11	Yellow	Yellow	Yellow	Yellow	Yellow
12	Blue	Green	Red	Yellow	White
13	Green	White	Red	Blue	Black
14	Red	Red	Red	Red	Red
15	White	Green	Black	Blue	White
16	Red	Red	Red	Red	Red
17	Blue	Yellow	White	Yellow	Yellow
18	Black	Blue	Black	Blue	Black
19	Red	Red	Red	Red	Red
20	Green	White	Yellow	Red	White

Figure 1.4 Matrix BOM showing a simple family of beads.

Applying the techniques of modularisation gives a common parts BOM of the following:-

Position	Colour	Qty
1	Blue	1
4	Black	1
11	Yellow	1
14	Red	1
16	Red	1
19	Red	1

Figure 1.5 Common Parts for the bead family maintaining the product structure.

The more normal approach, available in most software packages, eliminates the position numbers and simply aggregates the total of each colour. This suits purchasing but does not suit production who must have supplementary work instructions to replace the position (product structure) information.

Part	Qty	Units
Blue	1	Ea
Black	1	Ea
Yellow	1	Ea
Red	3	Ea
String	60	mm

Figure 1.6 Common Parts for the bead family discarding the product structure.

Each of the strands of beads also has an option BOM, listing the parts unique to that strand. Only the version retaining the product structure will be shown.

Position	Strand 1	Strand 2	Strand 3	Strand 4	Strand 5
2	Green	Yellow	Red	Red	Green
3	Yellow	Red	Green	Blue	Blue
5	Red	Black	Green	Red	Red
6	Red	Yellow	White	White	White
7	Green	Green	Green	Green	Green
8	Yellow	White	Black	Green	Blue
9	Blue	Blue	Blue	Blue	Green
10	White	Yellow	Green	Blue	Black
12	Blue	Green	Red	Yellow	White
13	Green	White	Red	Blue	Black
15	White	Green	Black	Blue	White
17	Blue	Yellow	White	Yellow	Yellow
18	Black	Blue	Black	Blue	Black
20	Green	White	Yellow	Red	White

Figure 1.7 The option dependant parts retaining the product structure information.

1.4.1. Replacement of an Optional Part

If the colour of one of the optional beads on one of the strands is changed the manipulation to the BOM is very simple. The applicable option BOM is changed. There has been no affect on the common parts so the only BOM which is incorrect, prior to the change being effected, is that for the option. Only 1 BOM of a possible 6 BOMs require a change, and only 1 BOM needs to be checked.

1.4.2. Replacement of a Common Part

If the colour of one of the common beads is to be changed, for only one option, the effect is quite different. The BOMs for all the options are incorrect as the common parts are incorrect. The change must affect all members of the family. The now non-common bead must be removed from the common parts BOM and inserted into each of the optional BOMs. In one case only, a different coloured bead is inserted into the optional BOM. All 6 of a possible 6 BOMs require a change, and all 6 BOMs must be checked.

1.4.3. Effect on the Matrix BOM

The Matrix BOM used to derive the common parts originally is a very simple representation of a very complex situation. It would be quite common for the change to be documented on the 'Engineering Change Order' in the form of a matrix. In this representation only one 'cell' of the matrix needs to be changed and highlighted to convey the meaning clearly. The matrix representation has become very common with the extensive availability of spreadsheets on desktop computers.

In the electronics industry it is common to have multiple changes in the same Engineering Change Order. Often these changes will affect parts which were previously common.

1.4.4. Introduction of a New Option

The introduction of any new options often has the effect of reducing the proportion of parts which are common across the whole family. During the reconstruction process to implement the change order affecting all BOMs, the total family of products is inaccurate for the other aspects of MRP etc. The checking process is lengthy and tends to be error prone.

1.5. Definition of Family

A family is usually a collection of options and features which make up a product. Examples often cited in the literature vary from tractors (an optional range of engines and gear boxes) to televisions (optional teletext or remote control) to table lamps (optional stands and lampshades).

The first product family defined in the EXICOM situation is a Subscriber Terminal. As defined by Kneppelt [16] the options should reflect the company selling policy. These option categories, which must be selected are as follows:-

Transmitter	Duplexer	Receiver	Controller
Interface - A	Multiplexer	Interface - B	Frame

Attachments which may be selected are as follows:-

Power Supply	Mounting Hardware	Telex
Spares Kits	Antenna Kits	etc

Each of these options and most of the attachments have alternatives. Some of the option categories for the Receiver are listed below. As with any 'family' a selection must be made for each option.

Frequency band - presently a choice of 10
Mounting configuration - presently a choice of 3

Each frequency band has 3 channel spacing alternatives.

This Receiver option has 10 x 3 x 3 = 90 possible options. All these are offered for sale and must continue to be available in the future, for sale as replacement or spare modules, even once obsolete.

The materials required for the lowest alternatives, the channel spacing, are dependant on the next higher option, namely the frequency band.

There is a major component of the receiver which is frequency dependant. This is the printed circuit board. There are only two versions of PCB, one for VHF and the other for UHF. Each of these has a circuit diagram.

As stated by Wortmann [27], "the current standard software packages do not formally distinguish between a feature and an alternative within a feature".

To enable the alternatives within features to be accessed there is a temptation to move the family definition down one layer. In this case the 'family' could consist of the UHF Receivers. However this still does not address the alternatives within options.

1.6. Suitability of Accepted Philosophy

Unfortunately this accepted philosophy of the early '70s is not proving to be suitable for some industries in the early '90s. Recent work in Europe, Wortmann [27], Hegge and Wortmann [15], van Veen and Wortmann [25, 26] indicates that this philosophy does not address the increasing number of product variants within a product family.

These findings have similarities to those found at EXICOM leading to this study. However Wortmann [27] states "Maintenance of these bills-of-material continues to require organisational effort due to the large number of engineering changes (1000 per year) and the short life-cycle of the products. Because of the large number of decisions which require human attention in creating these bills, it must be doubted whether the process can be automated by certain algorithms. Instead, the effort indicates that a systematic policy to design the products in a modular way will be more effective."

EXICOM's products have been designed using a modular concept. However the complexity is still a factor within the modules. It is doubtful whether better design can remove the inter-relationship of options and alternatives.

The solution described within this thesis has the benefit of making obvious the inter-relationship of the parts required for each option and alternative. It follows the techniques used to identify the parts on the circuit diagram and preserves the product structure by retaining the circuit references. The benefits of the matrix BOM are utilised without then hiding the result in many artificial BOMs for the sole benefit of the MPS. However each option can be included in the MPS and processed normally.

Maintenance is simple and obvious. In effect the 'cell' is changed. The checking process only involves those parts changed, not the complete structure.

This solution may appear to incorporate a degree of redundancy of information. This is true but the present day power available in normal computers is utilised to provide the information which previously had to be ascertained through extensive modularisation of the BOMs. Finally the solution has been in use in a fully integrated MIS system for 15 months. Users would be very reluctant to return to a Bills of Material system using traditional methodology.

2. PROBLEM DEFINITION

2.1. Description of Problem

EXICOM designs and manufactures modular systems composed of a wide variety of separate options which are combined at final assembly and mounted within a frame. Many of the options are related to each other to the extent that they are based on the same printed circuit board (PCB). Each option having the same general function, based on the same PCB, is known as a variant of the generic module. This provides high flexibility for the customer but creates a housekeeping problem in the Bills of Material area.

Market forces require the continual introduction of significant variations of the original generic design. Each variation requires the values of a small number of the components, (5 - 30), scattered throughout the PCB, to be changed. Some components may be added or deleted in the new variant.

This number of changes, throughout the PCB, is possibly unique to the radio frequency (RF) section of the electronics industry. Each component and even the tracks printed on the PCB influence other components and tracks owing to their properties of capacitance and inductance. An unplanned change in the thickness of a track can require componentry changes. A planned change of a component value to provide a different performance characteristic may require balancing changes in other disassociated functional areas to return the total module to the required specifications.

Each PCB may have up to 500 discrete components. These new variants may potentially become part of the standard range for repeated manufacture. Figure 2.1 shows an unloaded PCB with a few of the component positions labelled.

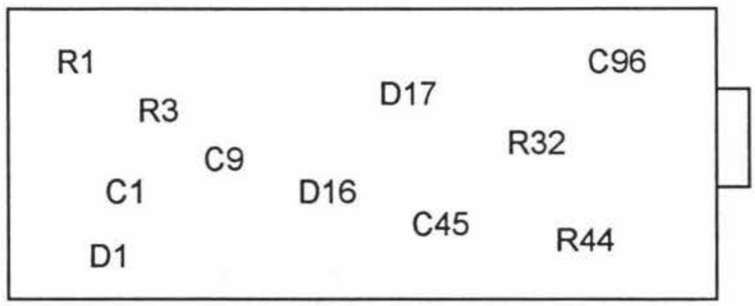

Figure 2.1 Printed Circuit Board showing some component positions.

D - Diode
C - Capacitor
R - Resistor

The existing Bills of Material system, which had been introduced in the mid 1980's, was a typical Family Tree built on the modular assembly concept, as described by Orlicky [21]; Plossl and Wight [22].

2.2. Structuring the BOMs

One large assembly, comprising the common parts used on all variants, constituted a significant proportion of the componentry and was essential information for efficient manufacture. This was often broken down into other sub-assemblies to demonstrate the structure of the product, Front Panel Assy, Rear Panel Assy, etc. A number of smaller assemblies, comprising the components used in functional blocks, were also developed. An example of a functional block assembly would be the componentry necessary to satisfy the frequency band (410-430MHz). These would be called the band dependant components. They were expected to be used on all variants providing that function. Figure 2.2 shows a functional block on the PCB.

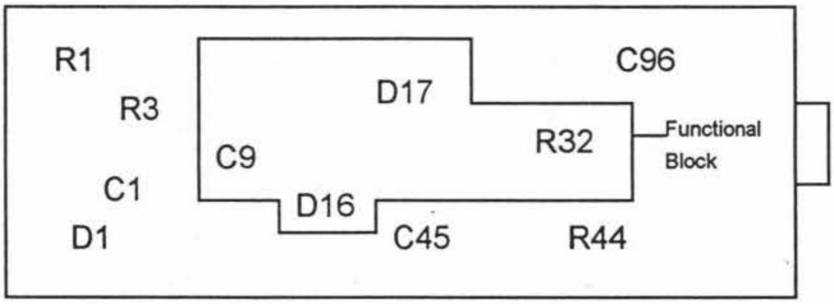

Figure 2.2 Printed Circuit Board showing a Functional Block.

Each variant, which was given its own unique product code, was made up from the common parts assembly plus a number of the functional block assemblies. Figure 2.3.

Each new variant took a few components away from the common parts assembly. These components had to find a new location within each of the old variants, as they had previously been common. A variant dependant assembly was developed to take these components. Figure 2.4.

A worse problem occurred when a few components were no longer common to a functional block.

Functional blocks were subdivided into common and variant dependant assemblies. Figure 2.5. Each old variant using the functional block was revamped.

As each change was made the number of levels in the BOM increased. One generic product had 200 assemblies.

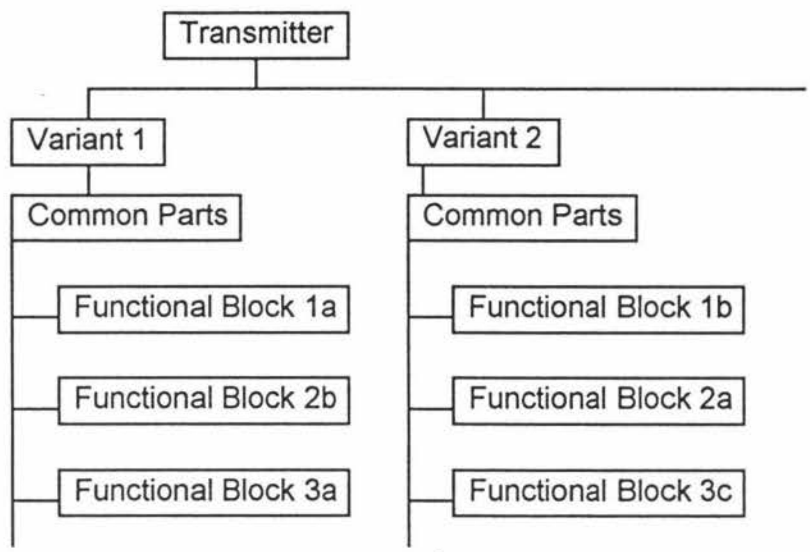

Figure 2.3 Variants made up of Common Parts plus functional block assemblies.

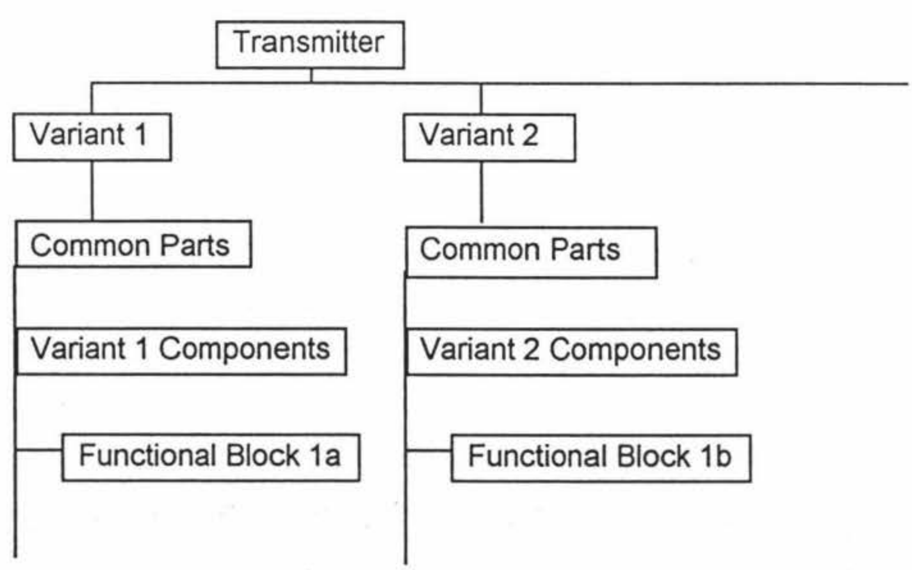

Figure 2.4 Redistribution of the Common Parts assembly amongst each variant.

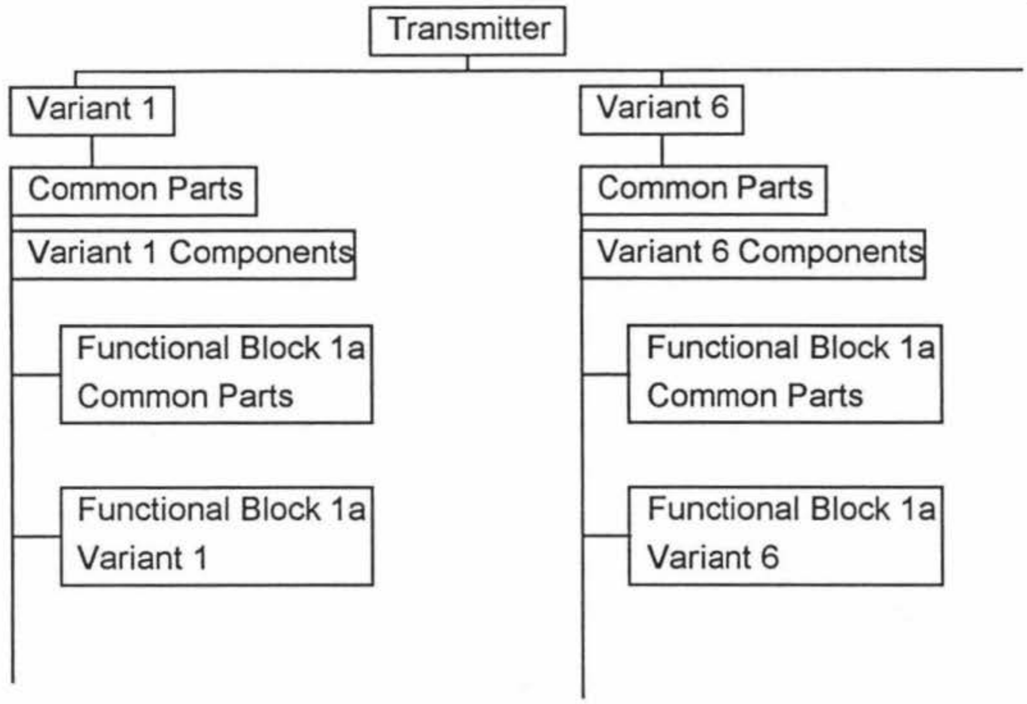

Figure 2.5 Redistribution of the common and variant dependant components of Functional Block1a between Variants 1 and 6.

In each of these cases the introduction of a new variant, with possibly only a few component changes, required the Bills of Material (BOM) to be torn apart and reformed, not only for the new variant but for every other existing variant. One moderately small change had required the generation of an Engineering Change Order (ECO) of 12 pages. Checking the accuracy of the change was very difficult.

Although there was a separate development area for provisional BOMs the existing system did not incorporate an isolated area which could be used for developing a revised version for comparison checking prior to acceptance of the change. Therefore the changes were made in the 'live environment' with other programs having access to the BOM in its confused state. Considering that the BOM is the foundation for many other production processes this made MRP calculations unpredictable, and stopped further production runs being set up until the BOM manipulations had been completed and checked. A Job BOM (JBOM) for each production run was copied from the master BOM and frozen.

This BOM system, which had become an essential component of the company's competitive edge, was cumbersome, error prone, difficult to understand and highly labour intensive. A better way had to be found if the company was to remain in this type of business environment.

A secondary problem had been in existence ever since the manual 'Parts Lists' had been computerised. The Design Engineers found it almost impossible to follow a modular BOM. Their requirement was to see the way component values altered between the different variants based on the same PCB. The important factor was the position within the circuitry. This translated to a pair of holes or pads on the PCB where the component was to be placed. Each variant had a component of a defined value in each position or the component was not fitted. The other major piece of documentation for electronic products is the Circuit Diagram. This gives each position a Circuit Reference and places the component value alongside. If the component is not common an asterisk is placed as the value. The non-common values are listed in a table: Circuit Reference vs variant.

These two foundation documents for any product had to be repeatedly cross checked to ensure accuracy. The Computer Aided Design (CAD) PCB could provide the foundation for the Automatic Insertion and Surface Mount machine programs but was not sufficiently detailed to generate the Bills of Material when multiple variants were involved.

However the machine programs could be compared with the BOM as individual part numbers were added to allow for correct component selection by the machines.

2.3. Description of Products

Rural Subscriber Links constitute the major part of EXICOM's manufactured product range. This equipment provides a telephone service to remote subscribers using parts of the radio frequency spectrum. Each link is composed of two terminals. One situated at an exchange site, possibly with many others, the other at the subscriber's home or business. Each terminal is made up of a number of modules supplying different features. This modularity provides a very versatile product range able to be adapted to the diverse requirements of the different telecommunications specifications throughout the world. Established telephone exchanges, from manual to the latest in digital technology, can be interfaced into this radio link.

Each module is connected to a motherboard which runs the length of the frame. Different motherboards are used for some functions.

A typical layout for the modules within a frame is illustrated in Figure 2.6.

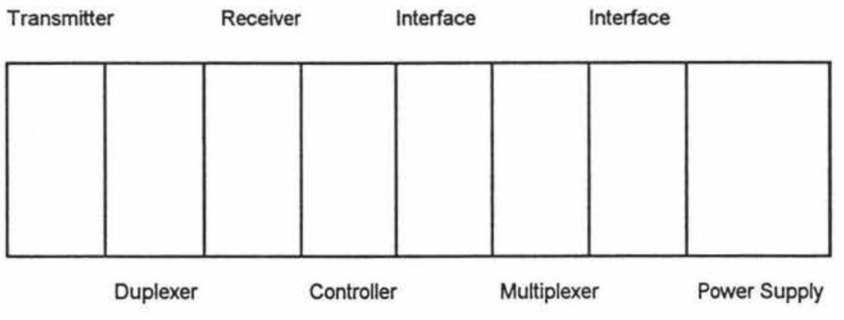

Figure 2.6 Layout of modules within a frame.

To satisfy the market requirements many variants for each module must be designed and documented. Some examples are as follows:-

```
Transmitter    - 35+ variants
Duplexer       - 12+ variants
Receiver       - 24+ variants
Controller     -  5+ variants
Interface      -  5+ variants
Multiplexer    -  3+ variants
Power Supply   -  4+ variants
```

Since this product range is continually expanding to address new markets the number of variants listed above is only a snapshot at one particular time. As new variants are generated so some older variants may become obsolete. The details for these must still be held for spares and product tracking. However it is desirable that these variants are not highly visible most of the time.

2.4. Product Code Derivation

Each variant built on a common PCB is given the same generic number which is built into the product code. By definition this also implies that they have a common Circuit Diagram and a common BOM. Therefore if there are 35 variants of the transmitter then there are 35 product codes sharing the same generic number. EXICOM developed a product code divided into 3 sections.

XX-YYYY-ZZZZZ

Where	XX	is the division selling the product
	YYYY	is the generic number
	ZZZZZ	is the variant - sometimes meaningful.

2.5. Sales Order Entry

The problems of processing BOMs is a manifestation of a deeper problem throughout the organisation. That is the definition of the exact mix of modules that the customer requires for a specific role. This system definition problem had increased progressively as a factor of the complexity of the product range. After multiple attempts the only effective solution found, as described in a previous paper, Burns [7] incorporated a type of Expert System as part of the Sales Order Entry process.

2.6. Summary

The problems with the BOM system are twofold.

a. The modular family tree concept is designed for options (generic modules) but does not adequately address the situation where the options themselves have variants incorporating extensive divergence.

b. The requirement to view the inter-relationship between the different variants of the generic module.

These problems manifest themselves mainly during the change procedure which is used for the introduction of a new product and the routine change to existing products. It must be checkable and auditable.

The following statements were made by staff using the existing system during a fact finding discussion.

Structuring implications are mind boggling.
Easy to make errors.
Need for training.
Changes are made manually as too complex for system software incorporating audit trail.
Risk of error.
Limited backup staff who understand system.
Takes lots of time.
Complexity means difficult.
Time lag.
The next Change Order may countermand the yet to be completed change.
No fail-safe method to ensure change has happened correctly.

The general feeling among the users was that a whole new approach was required to remove the 'mind boggling structuring' which was required to address the products. The alternative of 'redesign the products' was not an acceptable alternative.

3. TRADITIONAL METHODOLOGY

Computerised Bills of Material were generally developed as a prerequisite for the introduction of Material Requirements Planning (MRP). Each organisation wishing to implement MRP normally needed to massage their existing manual parts listings or computerised BOMs into a form that best utilised the facilities offered by MRP. The process involved was generally known as the Modularisation of the Bills of Material. Joseph Orlicky [21] described the two somewhat different objectives of modularisation as:

a. To disentangle combinations of optional features
b. To segregate common from unique, or peculiar, parts

The first of these is to facilitate forecasting while the second is to minimise inventory holdings.

If a manufacturer only makes one product the Bills of Material (BOM) can be very simple as each part of the product is listed in the order of assembly. However this is not the usual case. Most manufacturers will have the situation where a product range, often called a family, will consist of variable combinations of options. These options may be very simple, allowing the customer some freedom of choice, rather than the well known quote about Henry Ford who offered Model T's in any colour providing it was black. Alternatively they may be very complex entirely changing the functionality of the product.

A typical example found within EXICOM would be a Transmitter used in the Rural Subscriber Link. A small number of the possible optional features are listed in Figure 3.1.

Optional Feature	Qty
Frequency Band	4
Channel Spacing	3
Stability	2
Mounting	1

Figure 3.1 A selection of possible optional features.

For a manufacturer to have a BOM for each of these combinations would require

$$4 \times 3 \times 2 \times 1 = 24$$

separate BOMs, each with its own unique product code. If the marketplace shows a requirement for an alternate type of mounting then the number of BOMs and product codes is doubled.

$$4 \times 3 \times 2 \times 2 = 48$$

Even with the advent of computers it would be a vast task to maintain this many BOMs. Every time the marketplace demands an extension of one of the existing features or an entirely new feature the number of BOMs doubles, or worse.

This proliferation of BOMs makes the planning of material requirements very time consuming and forecasting becomes a nightmare unless the market requirements are very predictable. Generally when a product family offers a variety of features it is difficult to accurately predict the options mix. Each option would probably be slightly overplanned to allow for forecasting errors. This has a cumulative effect on those parts used in many or every option. These parts are progressively overplanned for each option and accumulate.

The technique of modularisation was developed to attack this problem.

3.1. Modularisation

Prior to this process taking place it must be assumed that each part, to be listed within any BOM, has a unique part number. Depending on the type of products being manufactured this part number may or may not include multiple suppliers of the same generic part. Some manufacturers will have parts that fall into both these categories.

Each option must be identified and given an identifying code. This code has the same requirement for uniqueness as any other part number. This option may or may not be potentially assembled and stored within the inventory during or prior to the final assembly of the variant.

Those parts included in all of the identified options are placed in another sub-assembly, also given a unique identifier, known as the common parts for the product family. This will often comprise common pieces of metalwork and the hardware used to assembly the selected options into the final product.

After modularisation the transmitter may be shown to have the structure as shown in Figure 3.2.

Having dissected the parts lists into common parts and options they can now be reassembled as required into products to be manufactured.

Each of the assemblies, whether common or optional, are set up as separate BOMs. Some type of designator is often used to identify that although they are stand-alone BOMs they are not a finished product. In some cases they may constitute a finished part or semi-finished part. They may be assembled in advance and booked into the inventory and in some cases may be sold as spares. Each type of manufacturer will differ in these respects.

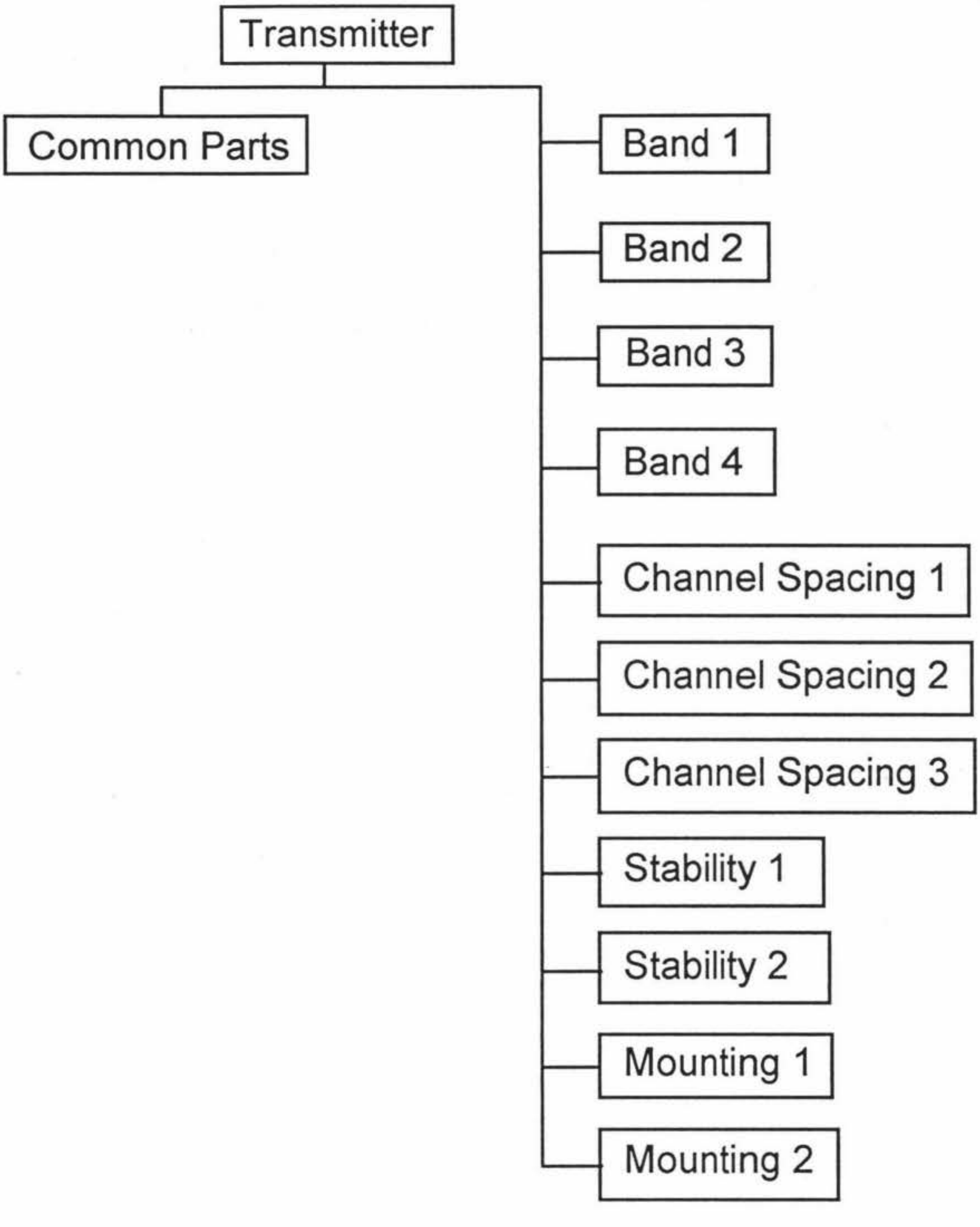

Figure 3.2 Common Parts plus Options for a generic product.

The MRP requirements can be addressed by combining common parts and proportions of options, with suitable overplanning of the options only, to give a basis for calculating the true requirements for each part. These BOMs are sometimes known as S-Bills or Super Bills.

3.2. Single Master Concept

To take this a stage further the same group of parts may be used in more than one option. Two of the Band options may have a large amount of similarity. These parts can be set up as a separate assembly which is called up in both options. This once again reduces the possibility of those parts being progressively overplanned. This also addresses another factor - how to ensure that the change to one option is carried across to the other option(s). This concept is shown in Figure 3.3

	Option 1		Option 2
R1	aaaab	R1	aaaab
R2	aacba		
R3	abaca	R3	abaca
R4	xyzaa	R4	abcde

Figure 3.3(a) Both options before modularisation.

		Option 1		Option 2
1	-	zzzzz	-	zzzzz
1	R2	aacba		
1	R4	xyzaa	R4	abcde

Figure 3.3(b) Single Level BOMs after modularisation.

		Option 1
1	-	zzzzz
2	R1	aaaab
2	R3	abaca
1	R2	aacba
1	R4	xyzaa

Figure 3.3(c) Indented BOM for Option 1 after modularisation.

Figure 3.3 Creating a sub-assembly from two similar options.

As shown in Figure 3.3(a) R1 and R3 are exactly the same parts with the same Circuit Reference. Therefore they could be extracted into a sub-assembly zzzzz as shown in Figure 3.3(b).

3.3. Multi-level BOMs

An additional feature has been added to Figure 3.3(b) in the left column. This is known as a level indicator. The listing in this figure is a Single Level BOM. It does not show the components making up assembly zzzzz. Figure 3.3(c) shows an Indented BOM for Option 1. This shows by the indentation of the level indicator the relationship of each assembly to the others within the BOM.

Part of the difficulty of disentangling the options from the original listings is deciding the degree to which modularisation should be taken. The example in Figure 3.3 would not normally be dissected to this degree with this small number of parts. However if it is important to show the inter-relationship of parts between similar options it may be warranted. This requirement will vary according to the type of manufacture and the complexity of the products.

3.4. Phantom Assemblies

The assemblies which are created through this process of modularisation fall into two distinct categories.

a. Assemblies which constitute actual semi-finished or finished products which may be stocked within the inventory, and possibly sold as spares.
b. Assemblies which are only created for the convenience of the modularisation process.

The convenience assemblies are usually referred to as Phantom Assemblies. They are distinguished in some manner, software dependent. The MRP system processes these two categories differently.

3.5. Mini-BOMs

Non-phantom assemblies designed in-house may be assembled by the manufacturer or may be a bought in part. If the part has been designed by the manufacturer it will usually have been set up as an assembly. This will once again be a BOM in its own right and is sometimes referred to as a Mini-BOM.
A flexible system will allow the part to be designated as being made in-house or sub-contracted. Some systems allow this designation to be adjusted as required.

3.6. Circuit References - Balloon Numbers

Within the electronics industry an additional feature is the circuit reference of the part. This denotes the position where that part is to be placed on the PCB. Each PCB will have a solderable joint, either surrounding holes for leaded parts, or simply as small pads for surface mount parts, at the end of each track printed on the surface of the board. Usually a legend will also be printed on the board listing the circuit references.

Most BOM software packages do not allow multiple entries of the same part within the same assembly. Instead they aggregate all occurrences of the part with an appropriate quantity. This reduces the number of entries in a BOM, reduces the storage space required, and makes the modularisation task easier as there is one less factor. However this is not a suitable situation for most efficient electronics manufacturers.

3.7. Multiple BOMs

Any BOM system is likely to have multiple users with different requirements. This usually means that historically each group of users will have generated their own version of BOM.

Some often quoted versions within the literature are:-

Planning Bills -	for the MRP system
Super Bills -	for the MRP system
Manufacturing Bills -	split into detailed structures
Engineering Bills -	for the engineers/designers
Picking Bills -	to allow picking to the correct work station
Others	

It is unfortunate that this proliferation of different BOMs are frequently advocated within the literature as they potentially lead to extensive rework and errors.

4. EXISTING BOM SYSTEM AS USED BY EXICOM

The software package being used by EXICOM was selected in the early 1980's to run on the existing hardware used for corporate data processing. This hardware used the PICK operating system. A number of software enhancements were implemented initially by the suppliers prior to installation and later by in-house programmers.

Although this was sold as a full Material Requirements Planning (MRP) package it was not fully implemented, as general reading on the subject of Just in Time (JIT) and the Theory of Constraints, Goldratt's "The Goal" [12] lead to changes in thinking. However later enhancements, in the areas of Forecasting, Sales Order Entry, Inventory Management, Materials Planning, Production and Distribution, produced an effective system suited to the requirements of EXICOM. The basic features provided by the original software are fully integrated into the total system. Therefore these features have been preserved within the new system. Only the major data structures within the BOM have been changed.

4.1. Material Numbers

The Parts Master is known as the MATERIAL File and the numbers as Material Numbers. Each Material Number consists of a three part alphanumeric code.

Annnn-nnnnn

The initial alpha designates the role of the 'part'.

R	Raw material as purchased
C	Component assembly made up of more than one part
S	Sub-contract process, may be in-house
T	Tooling

The 4 numerics before the hyphen designate the major and minor group. Each part was grouped according to its function.

The major group was a broad category eg. capacitor. The minor group was a subset of this major group eg. electrolytic. To maintain consistency each group has a precise input form. The correct form is displayed when a new number is requested by the input Annnn-NEW.

The last 5 digits are a unique non-meaningful number. This 5 digit number can be used in any place where a Material Number is required. The file is indexed to provide access via the following:-

Total Material Number, 11 digits alphanumeric
Unique last 5 digits of Material Number
First word of description
First + second words of description
First + second + third words of description
Up to the first 3 words of description with ? in place of
unknown previous word - ? ? PANEL

The input forms ensure that the first 3 words are always in the sequence expected. An alternate free form description format is available for misfits but this is not often used.

There are some special categories within the material groups.

R9060 - Finished Products
C0100 - Phantom Assemblies
E0101 - Systems - For sales only
E0102 - Options - For sales only

These groups have special handling by the Material Requirement Planning processing, Dispatch and Invoice processing and some of the BOM Explosion routines depending on the type of reports requested.

The MATERIAL File is the repository for all of the descriptive information concerning materials, semi-finished or finished products. Types of information stored against each number are as follows:-

Value	Voltage	Tolerance
Description	Manufacturer	
Manufacturer Code	Supplier No.	Average Cost
Stock Units	Purchase Unit	Conversion
Manufactured Y/N	Serial No. Required ?	
Sales Group	Selling Price	Currency
Obsolete/Status	New Selling Price	
New Currency		

An extended description is also provided for inclusion within the sales documentation. The information contained within this file would be used in a large proportion of routine processing.

4.2. Centre File

This holds a list of work centres. The structure of the code is Mnnn.

4.3. Operations File

This holds a list of operations. The structure of the code is nnn.

The Centre and Operations are concatenated to produce a code used to designate where an assembly process is to take place. Mnnn-nnn. These are known as M00#.

M003-010 Final Assembly - Operation 010

The picking lists are segmented based on these codes to produce a list for each designated work station. Picking of each M00# can be staggered to coincide with the lag time from production start. Labour can be calculated for each M00#.

The existing system placed a M00# within a BOM in the Material Number position. This caused all parts below this M00#, at the same level, to be sent to that destination until superseded by a following M00#, or raised to a higher level. See Figure 4.1

This was the method used by EXICOM to indicate routing. It effectively combined the BOM and routing into the same document. However if a part changed its assembly area the product structure within the BOM had to be changed. Using Figure 4.1, if R33 was to be changed to M002-010 either R33 must be physically moved adjacent to R16 or it must have a M002-010 inserted before and an M002-011 added after to keep the structure correct for R45.

C0100-00001 Transmitter Common Parts

1	M002-010		PCB Hand Assembly 1		
1	R0501-00002	R1	Resistor 4K7	1.00	Ea
1	R0501-00003	R16	Resistor 1K0	1.00	Ea
1	M002-011		PCB Hand Assembly 2		
1	C0790-00004	L6	Inductor A4/12345		
2	M002-001		PCB Pre-Assembly		
2	R0701-00005	a	Former	1.00	Ea
2	R1090-00004	b	Wire	10	mm
1	R0501-00003	R33	Resistor 1K0	1.00	Ea
1	R0501-00003	R45	Resistor 1K0	1.00	Ea

Figure 4.1 M00# placed within an indented BOM

4.4. Mini-BOMs

Any assembly which was to be made to an EXICOM specification was made into a stand-alone BOM. This consisted of the parts and processes required to produce a finished item. These were usually metalwork items to EXICOM drawings or inductors etc made in-house or by a sub-contractor. Often these would incorporate unusual parts which a sub-contractor would not normally stock. A mechanism was developed to structure the Mini-BOM to convey the processing required for these parts.

A Mini-BOM to be assembled in house listed all parts required but did not list any processes. This caused all parts listed to be included in the parts requirements. Figure 4.2(a)

A Mini-BOM to be supplied by a sub-contractor listed all parts required plus at least one process. These parts were not included in the parts requirements. Figure 4.2(b)

If a part was to be purchased by EXICOM and supplied to the sub-contractor it was listed with a 'P' in the purchase attribute of the Mini-BOM. A 'P' with a process caused that part only to be included in the parts requirements. Figure 4.2(c). The date required for this part was moved into the previous planning period - monthly. Nested Mini-BOMs with 'P' flagged parts were progressively moved through the planning periods.

1	C0790-00004	L6	Inductor A4/12345			
2	M002-001		PCB Pre-Assembly			
2	R0701-00005	a	Former		1.00	Ea
2	R1090-00004	b	Wire		10	mm

Figure 4.2(a) All parts to be included in parts requirements.

1	C0790-00004	L6	Inductor A4/12345			
2	M002-001		PCB Pre-Assembly			
2	R0701-00005	a	Former		1.00	Ea
2	R1090-00004	b	Wire		10	mm
2	S1111-00006		Fabricate to A4/12345			

Figure 4.2(b) No parts to be included in parts requirements.

1	C0790-00004	L6	Inductor A4/12345			
2	M002-001		PCB Pre-Assembly			
2	R0701-00005	a	Former	P	1.00	Ea
2	R1090-00004	b	Wire		10	mm
2	S1111-00006		Fabricate to A4/12345			

Figure 4.2(c) Only 'P' flagged parts to be included in parts requirements - R0701-00005.

This mechanism, whilst relatively simple, was not well understood. Changing the supplier of the part required a restructuring of the Mini-BOM, a process which required an Engineering Change Order.

4.5. Assembly Codes

A late addition to the BOM information was a 12 digit alphanumeric field which allowed a work instruction type code to be entered against any circuit reference containing assembly instructions for the part.

5. RBOM - A RELATIONAL BILLS OF MATERIAL

The existing BOM system as used by EXICOM appeared to have severe limitations. However this system was based on the accepted modular, family tree type concept. A scheme had to be devised which would overcome the problems identified with the existing traditional BOM philosophy and not introduce new problems.

The simple Matrix BOM for the string of beads family, as shown in Section 1.4, has been used as the model for RBOM. This demonstrates the relationship of parts (colours) between the variants for each position.

This chapter describes a model which can be used in any computer system as it employs flat files. As part of this investigation a very generalised program was developed using the Pascal language. Files were accessed using a B-Tree index. This non-database approach would be unlikely to be used in a commercial situation but was a suitable medium to prove the validity of the theory. It is anticipated that generally a relational database would be utilised.

The relational terminology, as used by C.J. Date [10], has been used.

Chapter 6 provides a general description of the PICK Database to enable the reader to appreciate how the 3 dimensional built-in structure can be applied to RBOM.

In this Chapter each file within the data model is expanded to show some attributes which may be desired. These attributes are generally additional to the essential relationships and therefore can be extended to suit any industry requiements. In many cases they allow reports or displays to be sequenced. This is often desirable but not essential. Other approaches are possible.

Chapter 7 describes in greater detail some of the attributes used in EXICOM's implementation of RBOM.

Finally a BOM explosion mechanism is described in pseudo code.

5.1. General Data Model

The data model must address the inter-relationship of the parts to be inserted into circuit reference positions for each variant of a generic module. The part must be valid at the stated time. This validity is explored under the heading Effectivities.

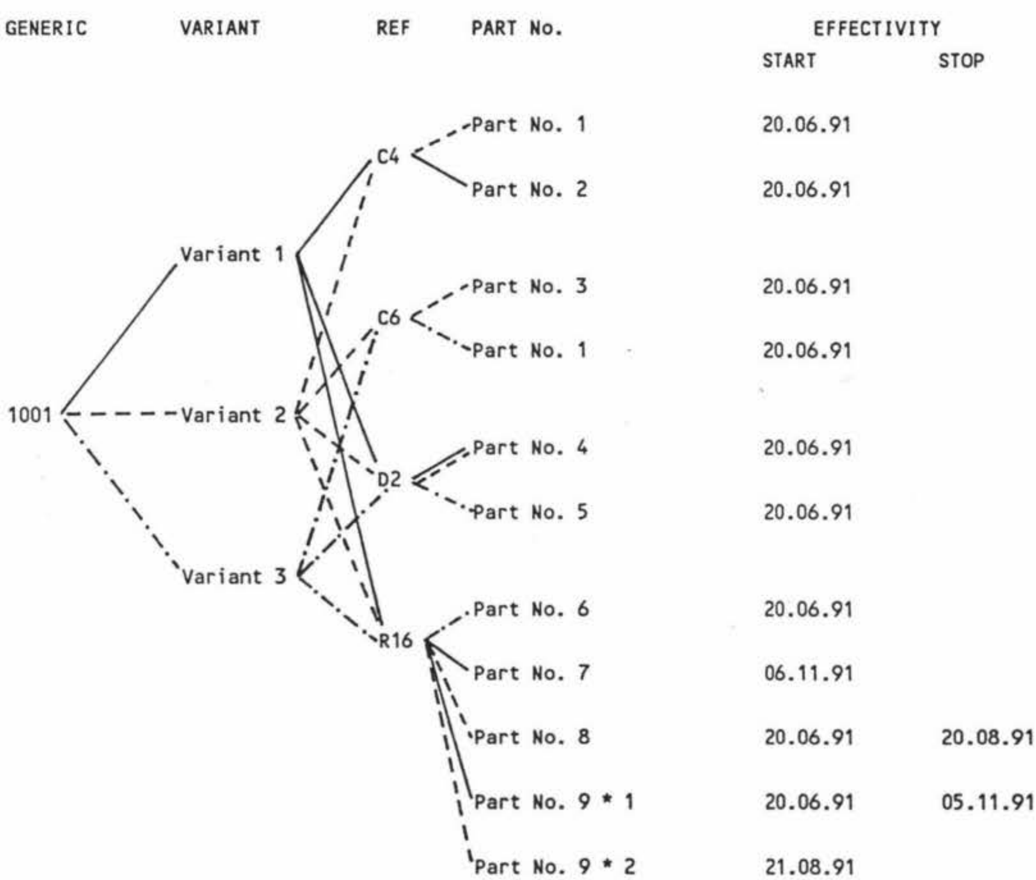

Figure 5.1 Model of a Relational Bills of Material.

Figure 5.1 demonstrates the complex inter-relationships of the main attributes of a small segment of a BOM. The Generic/ Variant/ Reference/ Part/ Seq/ Effectivity. One representation of these relationships, in normalised form, would be as listed in the following paragraphs. Discussions later will show that this may not be the ideal form in all situations.

Figure 5.2 shows these major inter-relationships in the form of an Entity-Relationship diagram. Relationships of Parts to Materials and Variants to Materials have been omitted to reduce complexity.

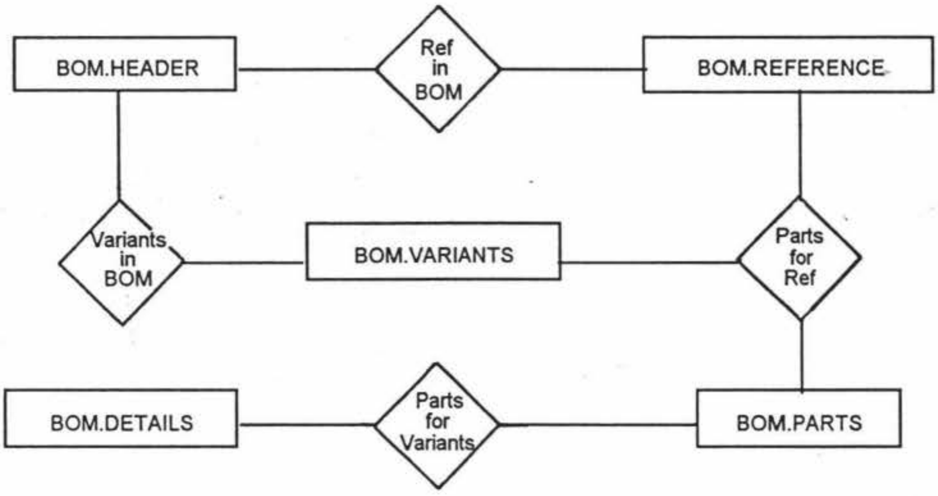

Figure 5.2 Entity-Relationship Data Model.

5.2. Generic Header

Each generic BOM has a header which lists the various attributes unique to that BOM. Some possibilities are listed in Figure 5.3.

BOM.HEADER	BOM#
	Description
	Accounting Group
	Manufacturing Option
	First Variant
	First Reference
	Last Reference Number
	Notes

BOM#	Desc	Group	Mfg	F.Variant	F.Ref	L.Ref.#	Notes
1001	Tx	0001		1001-01123	D1	162	Y
1002	Rx	0002		1002-21143	D2	43	
1003	Ct	0006	A	1003-00001	}1	10	Y

Figure 5.3 BOM.HEADER Table showing some possible attributes.

5.3. Generic - Variants

Each generic BOM has one or more variants. These are defined products which are manufactured and sold either separately or in combination with other products. The variant is given a meaningful Product Code, defined within the MATERIAL file, which is used in all commercial applications.

Each variant has a status indicating if the information for that variant is complete or still provisional. The effects of this status will be developed in a number of sections.

As it may be desirable to display variants in a certain sequence, to benefit from patterns formed by a pictorial representation, pointers can be used. The first variant is listed in the BOM.HEADER file.

BOM.VARIANTS	Generic * Variant#
	Variant Status
	Backward Variant
	Forward Variant

BOM# * Variant	V.Status	B.Variant	F.Variant
1001 * 1001-01123			1001-01124
1001 * 1001-01125	P	1001-01124	
1001 * 1001-01124	P	1001-01123	1001-01125

Figure 5.4 BOM.VARIANTS Table showing some attributes.

5.4. Generic - Reference

Each generic BOM has many references. In the electronics industry this is the key element. Most references are circuit references as defined on the circuit diagram and silk screened on to the surface of the printed circuit board. Other parts are given phantom references (}) to enable an acceptable key to be derived. The last phantom reference to be allocated to a particular generic BOM is recorded as the last reference number within the BOM.HEADER.

It is a normal requirement to specify the sequence in which references are to be listed within a BOM, especially the screen display. The BOM.REFERENCE file may hold backward and forward pointers.

BOM.REFERENCE	Generic * Reference#
	Backward reference
	Forward reference

BOM# * Ref	Backward.Ref	Forward.Ref
1001 * C4	}5	C6
1001 * C6	C4	D2
1001 * D2	C6	R16
1001 * R16	D2	R17
1001 * }6	R17	

Figure 5.5 BOM.REFERENCE Table showing possible attributes.

A new BOM#*Ref entry may be made in this table without entries being required within the other tables listed in paras 5.5 & 5.6. This would be the situation during the implementation of an Engineering Change Order prior to completion.

5.5. Generic - Reference - Part

Each reference for a generic BOM may have one or many parts which can be used in that position. Like the variants these parts must be records within the MATERIAL File. The sequence number is used to cater for multiple occurrences of the same part for the same reference. (These could be valid for different variants at different times - see Part No 9 for reference R16 in Figure 5.1 or may be for different quantities, M00#, Assembly# etc).

The sequence number is the total number of occurrences of this part for this BOM * Reference * Part.

BOM.PARTS Generic * Ref * Part

BOM#	*	Ref	*	Part	Seq
1001		C4		Part No. 1	1
1001		C4		Part No. 2	1
1001		C6		Part No. 3	1
1001		C6		Part No. 1	1
1001		D2		Part No. 4	1
1001		D2		Part No. 5	1
1001		R16		Part No. 6	1
1001		R16		Part No. 7	1
1001		R16		Part No. 8	1
1001		R16		Part No. 9	2

Figure 5.6 BOM.PARTS Table showing some attributes.

5.6. Parts or Materials

A parts or MATERIAL table is necessary to define both the parts used and the variants which are sold as finished products. This table together with possible related tables, dependant on the overall data model, holds information specific to parts.

MATERIAL
- Part#
- Description
- Unit of Issue
- Unit of Purchase
- Conversion Factor
- Cost
- Supplier#
- Selling Price
- etc

Part#	Desc	Unit	Cost	Supplier#	Sell Price
Part1	Diode	Each	0.05	1234	
Part2	Cable	M	5.32	2413	10.00
Vari1	Widget	Each	9.57	0001	30.50

Figure 5.7 MATERIAL Table showing some attributes.

5.7. Generic - Reference - Part - Sequence - Variant

These relations are now combined in the following table.

BOM.DETAILS	Generic * Ref * Part * Seq * Variant
	Qty
	M00#
	P Flag
	Assembly#
	Current Change#
	Effectivity Start
	Effectivity Stop
	Option
	Change Order#

BOM#*Ref*Part*Seq*Variant	Opt	Qty	M00#	Start	Stop
1001*C4*Part1*1*Variant2	Y	1	M001	20.6.91	
1001*C4*Part2*1*Variant1	Y	1	M002	20.6.91	
1001*C6*Part3*1*Variant2	Y	1	M002	20.6.91	
1001*C6*Part1*1*Variant3	P	1	M002	20.6.91	
1001*D2*Part4*1*Variant1	Y	1	M002	20.6.91	
1001*D2*Part4*1*Variant2	Y	1	M002	20.6.91	
1001*D2*Part5*1*Variant3	P	1	M001	20.6.91	
1001*R16*Part6*1*Variant3	P	1	M001	20.6.91	
1001*R16*Part7*1*Variant1	Y	1	M001	6.11.91	
1001*R16*Part8*1*Variant2	Y	1	M001	20.6.91	20.8.91
1001*R16*Part9*1*Variant1	Y	1	M001	20.6.91	5.11.91
1001*R16*Part9*2*Variant2	Y	1	M001	21.8.91	

Figure 5.8 BOM.DETAILS Table showing some of the possible attributes.

5.8. RBOM Explosion

The BOM explosion mechanism can be described in the following pseudo code. The initial input is a Product Code and effectivity (likely to be a run number).

```
    Get Effectivity from JOB.GROUP
    Extract Generic BOM from Product Code - XXXX
    Read BOM.HEADER - Generic
    Get first reference
┌── Read BOM.REFERENCE Generic*Ref ──────────────────┐
│     Select BOM.PARTS - Generic*Ref to REF.BOM.PARTS │
│  ┌── For each REF.BOM.PARTS                         │
│  │   Read BOM.DETAILS - Generic*Ref*Part*Seq*Variant│
│  │     Check Effectivity                            │
│  │  ┌── If valid                                    │
│  │  │    Check Options Flag                         │
│  │  │  ┌── If valid                                 │
│  │  │  │ ┌── If Part is a C0100 or Mini-BOM         │
│  │  │  │ │     Explode BOM.HEADER (recursive) ──────┘
│  │  │  │ ├─Else
│  │  │  │ │     Call Output processing subroutine
│  │  │  │ └─End If
│  │  │  └── End If
│  │  └── End If
│  └── Next Part
└── Next reference
Process list of parts and quantities as required.
```

For multiple variants an additional loop is required for each REF.BOM.PARTS manipulation.

5.9. Summary

This section has described a series of relations which would be required to operate the RBOM. As flat files, they should be a basis for use in any operating system.

As will be shown in Chapter 7 this data structure has been extensively modified for the implementation within the PICK operating system to fully utilise the unique built-in data structure.

6. PICK DATABASE DESCRIPTION

This chapter describes PICK in sufficient detail to allow the reader to understand how RBOM, described in chapter 5, can benefit from the built-in 3 dimensional structure of PICK. The question as to whether PICK is a relational database will be briefly discussed, prior to a description of some of the simple conveniences available in the built in query language.

6.1. PICK Structure

The PICK operating system was initially conceived in the mid 1960's. A system was developed on paper, without an actual machine in mind, to provide an end-user orientated operating system which would reduce the requirement for the users to concern themselves with the physical manipulation of the data. It was firstly a database management system and secondly an operating system.

The resultant system is portable across an increasing number of hardware platforms with little obvious differences. The only major difference between the implementation on an IBM PC AT and an IBM 4300 mainframe is that the application will probably run slower on the PC.

PICK is not a 'number-crunching' system but shines in the role of complicated data structure manipulation. This is due to its relational database and method of storage which usually requires only one or two disc accesses to retrieve any piece of data.

6.1.1. File Structure

PICK is organised as a series of hierarchical files. Two types of files are predominant. These are dictionary files and data files. One of the unusual features of PICK is that both have the same structure. The data file(s) hold the actual data while the dictionary file(s) maintain the relationships between the data. This could be related to a Table in common usage.

Files are automatically expanded or shrunk to accommodate the changing requirements. There is no maximum size limit, within the available disc space, although there is a minimum. The disc is divided into blocks of 512 bytes, usually, known as frames (or pages). These frames are numbered from 1 until the disc space is exhausted in intervals of 1. The address of each frame is known as its frame-ID or (FID).

The creation of a file requires two parameters - the modulo and separation. These reserve a contiguous set of frames for the file. The modulo defines the number of groups contained in the file while the separation defines the number of frames per group. This original estimate is known as the primary area and is the minimum size of the file. If this estimate proves to be inadequate the operating system will link in and release extra frames as required. The frames are linked together via both forward and backward links. Figure 6.1 gives a pictorial representation of the file structure.

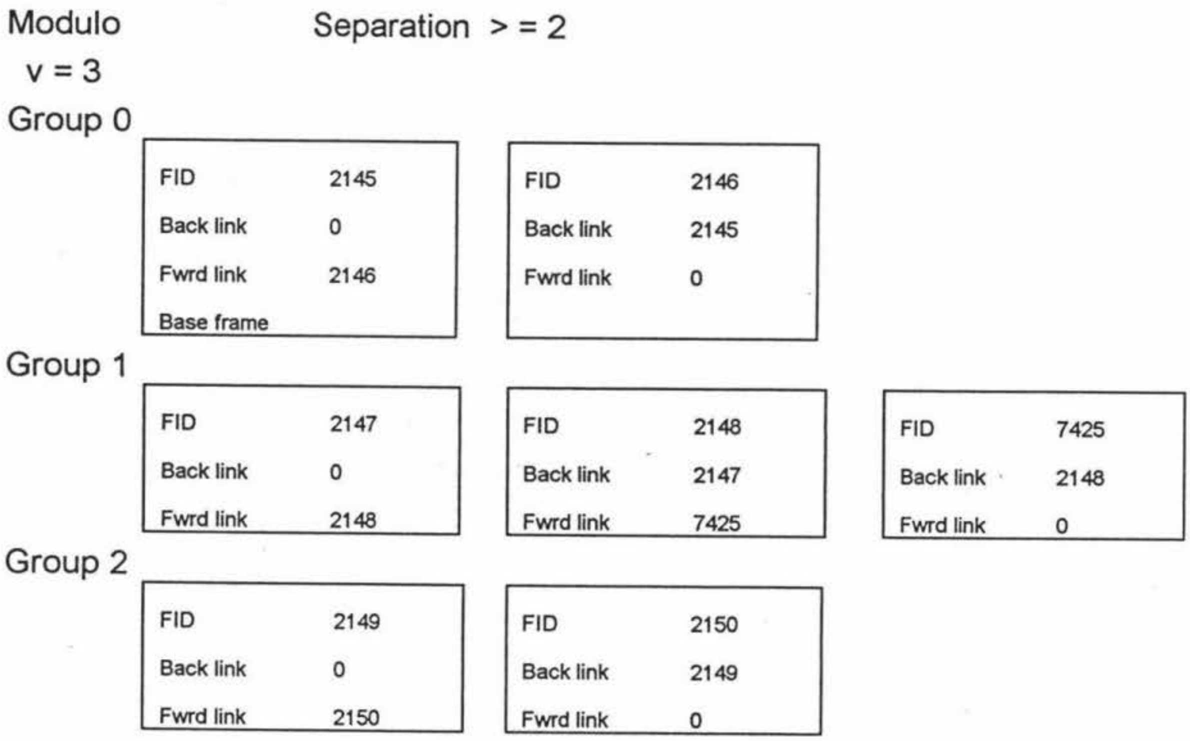

Figure 6.1 Pictorial representation of PICK file structure showing modulo and separation.

6.1.2. **Data Storage**

The PICK terminology for a record within a file is an item. Each item has a unique primary key known as the item-ID or simply ID. The most unusual feature of the PICK system is the manner in which data is stored within the item. All data are held as an ASCII string of characters which is totally variable in length to a maximum of 32 Kbytes.

Each item consists of a number of attributes, known as fields in more traditional systems. There is no size limitation on any attribute nor is there a maximum number. Each attribute is separated from others by means of a delimiter called an attribute mark (AM = decimal 254). This is usually printed as '^'.

Name^Address^Sales

Each attribute may in turn be subdivided into values. Each value is separated from others by means of a delimiter known as a value mark (VM = decimal 253). This is usually printed as ']'.

Name^Street]Suburb]Town^1stQtr]2ndQtr

Each value can be further subdivided into sub-values or secondary values. Each sub-value is separated from others by means of a delimiter known as a sub-value mark (SVM = decimal 252). This is usually printed as '\'.

Name^Street]Suburb]Town^Jul\Aug\Sep]Oct\Nov\Dec

Each item is separated from the next item by another delimiter known as the segment mark (SM = decimal 255). This should never be used within strings or data values.

The use of delimiters obviates the requirement for fixed length fields and removes the requirement for trailing spaces in descriptive fields or leading zeros in numeric fields. A null field is simply represented by a delimiter which is interpreted by the system as null or zero for arithmetic calculations. Therefore the storage space for each item is reduced to the exact minimum required for the data plus the space for the delimiters and the item-count portion of the item. A delimiter is not required at the end of a multi-value or sub-value as the delimiter of the next higher category is in place.

The first 12 bytes of the frame form the control section reserved for linking information etc leaving 500 bytes for data. The contents of a group can be dumped to the screen as represented in Figure 6.2.

```
FID:  1247   TO:  23654                  FROM:  0

    1:IDcount^This is the first attribute of this record:
   51:^It is followed by the second attribute^Which is i:
  101:n turn followed by the third attribute^This attrib:
  151:ute has a number of MULTI-VALUES   - first multi-:
  201:value]second multi-value]third multi-value]and a f:
  251:inal multi-value^This is the final attribute^_IDco:
  301:unt^This is the first attribute of the second item:
  351:which goes on until the item is complete at which :
  401:stage a segment marker is placed between items^The:
  451:same routine continues^Attributes^Multi-values]and:


FID: 23654   TO: 0                       FROM:  1247

    1:more multi-values followed by subvalues\first\and :
   51:second until more multivalues]and attributes^until:
  101: the last item in the group is complete^A segment :
  151:mark follows the last giving two segment marks to :
  201:end the group^_ _                                 :
  251:                                                  :
  301:                                                  :
  351:                                                  :
  401:                                                  :
  451:                                                  :
```

Figure 6.2 Typical layout of the contents of a group showing attributes, multi-values and sub-values.

6.1.3. **Item Storage**

Each item must have its own unique item-ID. This may consist of up to 50 characters and may be composite. It is used to calculate the address of the item within the file. This mechanism uses a hashing algorithm calculated as follows:

convert item-ID to decimal equivalents
weight according to position within ID
divide sum by modulo of file
remainder = group

The modulo should be a prime number to allow as even a distribution across the groups as possible. It is beneficial to have an item-ID which is sequential for a good distribution.

Unless each item within the file is expected to be in excess of one frame, 512 bytes, a separation in excess of 1 is not likely to improve access in a multi-user system as the disc read heads will normally have moved to another section of the disc before the next frame is read.

The modulo and separation of the dictionary file is likely to be different to the data file. The physical positioning of these files is in the hands of the operating system.

When an item is read from the group into memory the items later in the group move into the space vacated. When the item is written back to the group it is placed at the end of the group. Each item has an item-length count as part of the control section of the item. Once this count has been satisfied the next character must either be the start of another item or the end-of-data indicator.

6.2. **Data addressing**

This unique totally variable length item complete with its 3 dimensional matrix of possible attributes, multi-values and sub-values must be addressed in some manner which is exact. In general any item can be considered as a 3 dimensional dynamic array. Each element within the array is referenced by its location.

arrayvariable<X,Y,Z> or arrayvariable<AM,VM,SVM>

Therefore the 3rd sub-value of the 5th multi-value of the 2nd attribute of arrayvariable would be accessed via the reference

arrayvariable<2,5,3>

The logical representation of the data within an item is as a two-dimensional matrix. A previous example showed the printed symbols to indicate the structure of the item. Figure 6.3 shows the logical representation.

Name^Street]Suburb]Town^Jul\Aug\Sep]Oct\Nov\Dec

```
item-id     :  2435
attribute 1:   Name
attribute 2:   Street]Suburb]Town
attribute 3:   Jul\Aug\Sep]Oct\Nov\Dec

item-id     :  2435
attribute 1:   JONES TOM
attribute 2:   34 CHEWS LANE]NEWTOWN]WELLINGTON
attribute 3:   2316\24365\86532]45923\\234
```

Figure 6.3 Logical representation of an item.

If this item had been read from disc it would be possible to ascertain Tom Jones' sales for November by the expression

SALES.INFO<3,2,2>

In the case of Tom Jones, who had been on holiday in November the answer would be 0. A null value is simply represented as two adjacent delimiters.

SALES.INFO<3,1,3>

would give a value of 86532 as the sales for September.

SALES.INFO<2,1>

would return a 'value' of 34 CHEWS LANE. As all data is stored as characters there is no distinction between numeric and character types.

6.3. **Relational Database**

There is some question as to whether PICK is a relational database. In his book An Introduction to Database Systems, C.J. Date [10] defines the properties of relations as follows:-

. There are no duplicate tuples (items)
. Tuples are unordered (top to bottom) within a table (file)
. Attributes are unordered (left to right)
. All attributes are atomic

1. There are no duplicate tuples - this requires that there is a unique primary key. PICK also demands this to allow direct access via a hashing algorithm.

2. Items (tuples) are unordered (top to bottom) within a file - the random ordering of items within a frame within the group is only possible due to this property being observed.

3. Attributes are unordered (left to right) - the ordering of attributes, multi-values and sub-values form the foundation of the PICK data structure. In this respect PICK is totally position dependant.

Programming using the position references only can be extremely cryptic and should be avoided. A mechanism is available to equate attribute positions with meaningful names. This allows very extensive names which when used make programs easy to read and understand. Attributes, multi-values and sub-values can be added or amended at any time without disturbing the remaining data. The insertion of an attribute in the middle of a table would require an additional attribute mark to be inserted into every existing item in the new position. If no data was inserted then two ^^ would be adjacent indicating a null attribute. It is normal to add new attributes to the end of the table. This only requires attention if there is data to be inserted into a particular item. As no trailing delimiters are required the item is only as long as there is available data.

There is no such restriction on the addition of multi-values or sub-values. However care must be taken where values in one attribute are position dependant on another attribute. This is demonstrated in the following example where the children's ages are position dependant on the previous attribute, children's names.

Figure 6.4 shows two items on the Employees file with different quantities of data as only one has children listed.

```
item-id      : 1234                   1235
attribute 1: JONES TOM                WALKER FRED
attribute 2: TIMARU                   AUCKLAND
attribute 3: M                        M
Attribute 4: Married                  Single
attribute 5: 2
attribute 6: Martha]Thomas
attribute 7: 7]3
```

Figure 6.4 Items of the Employees file

1234^JONES TOM^TIMARU^M^Married^2^Martha]Thomas^7]3

1235^WALKER FRED^AUCKLAND^M^Single

If a date attribute, held in internal format, was added at attribute 8 the following would be the revised items.

1234^JONES TOM^TIMARU^M^Married^2^Martha]Thomas^7]3^8500

1235^WALKER FRED^AUCKLAND^M^Single^^^8500

Although there is extensive flexibility it is still important to plan the attribute layout from high to low usage for best utilisation of storage space. Delimiters can be a significant factor in large databases.

4. All attributes are atomic - or relations do not contain repeating groups. This is the equivalent of the relation being 'normalised'. PICK is able to satisfy this requirement by eliminating the multi-values and sub-values. Items containing attributes only do satisfy this requirement. Another way of putting this same property is that for every row-column position within the table there always exists precisely one value, never a set of values.

This precision of the row-column address could be extended within the PICK structure to incorporate the ability to precisely address an exact part of a relation on more than 2 axes. Both the normal programming language PICK/BASIC and the query language ACCESS can select a stated multi-value but at this stage it is only possible for the PICK/BASIC language (not ACCESS) to access sub-values.

During 1992 the term 'post-relational database' has been used to describe the next step in the evolution of databases. PICK has been described as a possible example of a post-relational database.

6.4. **Query Language**

6.4.1. **General**

The name of the query language differs according to the implementation. Whether it is ACCESS, INFO/ACCESS, ENGLISH, RECALL or INFORM the general structure is the same.

6.4.2. **Data Dictionary**

Each file can have one or more dictionary files. One dictionary can serve one or more files. It is not essential to have a dictionary as the formal structure of the item within the file makes access to any defined position possible. However any ACCESS report will have more meaning with sensible headings provided by a dictionary definition. The items within the dictionary file are of the same structure as any other item in any other file. They once again are divided into attributes, multi-values and sub-values. However in the case of dictionaries the attribute properties are predefined. Each attribute within the file can be given a name within the data dictionary. Synonyms can also be defined which may be identical but with a different name or may be displayed with different parameters. A common example of a synonym would be an attribute justified left or right. This has a major effect during sorting operations. Left justified will sort variable length numbers from the first number regardless of its place value. The following sequence will be the sorted result.

1 11 2 21 3

This is not usually acceptable as a sorting sequence by humans. Right justified will sort variable length numbers, including alphas, into a 'normal' sequence.

1 2 3 11 21

Within the commercial environment this is highly desirable. It is quite common for an ACCESS enquiry to sort using a right justified synonym but display or print the information using the left justified dictionary definition.

6.4.3. **Conversions**

Each dictionary definition can contain conversion factors which influence the appearance of output for a particular report regardless of the manner in which the information is stored within the item. Dates are usually stored in an internal format, the number of days since 31 December 1968. This simple numeric is easy to store and able to be involved within calculations. A conversion at the time of output will convert this into many different forms. Figure 6.5 shows some of the possible outputs with the simple use of a conversion code within the dictionary definition.

Internal Format	External Format
8803	06.02.92
	06 FEB 1992
	06/02/92
	6 (Day)
	FEBRUARY
	1992
	Thursday

Figure 6.5 Conversions of dates.

6.4.4. **Translations**

Information can be extracted from other files using a reference recognised by both files. This formula is lodged within the dictionary definition for a synonym. For example the description of a part will be an attribute of the dictionary for the MATERIAL File. This will be defined within a different dictionary by a synonym like DESC or DESCRIPTION. This translation can use the whole of the reference in the primary file or can be a portion of a combined key or attribute. This is the equivalent of a Foreign Key in relational terminology. The translation process can continue through multiple files using the latest reference as the key for the next translation. Continuing the theme of a single data structure these multiple translations are listed as a multi-valued attribute within the dictionary item.

The supplier's name for a part used in an item in the BOM file may be required. This entry 'Supplier' in the BOM dictionary would first translate to the MATERIAL file using the part number stored in the specified attribute of the BOM as the MATERIAL item-id. This would access the item with that item-id in the MATERIAL file and read the supplier number stored in the stated attribute. The next step would use this number as the item-id in the Supplier file and read the Supplier's name from the stated attribute. The Supplier's Name could then be converted from upper case to upper and lower case before being displayed to the user. Figure 6.6 shows the route for the Supplier's Name translation from Supplier file to BOM file.

```
BOM                        MATERIAL                  SUPPLIER
ID  1001*C3          ┌──>R0101-12345           ┌──>2536
1                    │                         │    ACME LTD
2                    │                         │
3                    │                         │
4   R0101-12345<─────┘                         │
5                                              │
6                          2536<───────────────┘
7
```

Figure 6.6 Translation between files to obtain information for ACCESS enquiries.

7. PICK IMPLEMENTATION

This chapter builds on the descriptions of the 'pure' RBOM in chapter 5 and the PICK structure in chapter 6 to describe how the features of PICK have been utilised to build an efficient BOM within the PICK environment for EXICOM. If the built-in 3 dimensional structure of PICK were not utilised an identical 'pure' version of RBOM, as described in chapter 5, could also be built in PICK.

The two files used in this implementation are described in detail with the extensions developed for the EXICOM situation. As is shown by these extensions the basic structure can be extended to customise the theory to different types of industry.

The concept of Effectivity dates and the relationship to Engineering Change Orders and temporary substitutions are developed. Some possible screen displays are printed to provide a feel for the system prior to a description of the installation phase.

7.1. PICK Record Structure for RBOM

The record structure developed as part of this project for use within the PICK environment has made use of the 3 dimensional built-in item structure. As described in section 2.1 the BOMs required by EXICOM are reasonably large. If a BOM has 500 discrete references, with varying quantities of parts per reference, disk access will be considerable. Using flat files as described in chapter 5 would mean that a BOM with 10 variants and an average of two parts per reference would require

$$500 \times 2 \times 10 = 10{,}000$$

records to be read to explode a BOM. This ignores the reads from the MATERIAL file for descriptions, units etc.

The PICK implementation making use of the multi-values and sub-values has reduced this same BOM to 500 items (records).

The major factor allowing this type of structure is the ability to have totally variable length items up to 32 Kbytes. The second factor is the complete reliance of the PICK structure on position dependency. If this was unreliable the whole system would break down.

The data model as described in section 5.1 is still valid for this implementation.

The Entity-Relationship data model as depicted in Figure 5.2 is still valid. However there are now only two files. A revised Entity-Relationship model is shown in Figure 7.1.

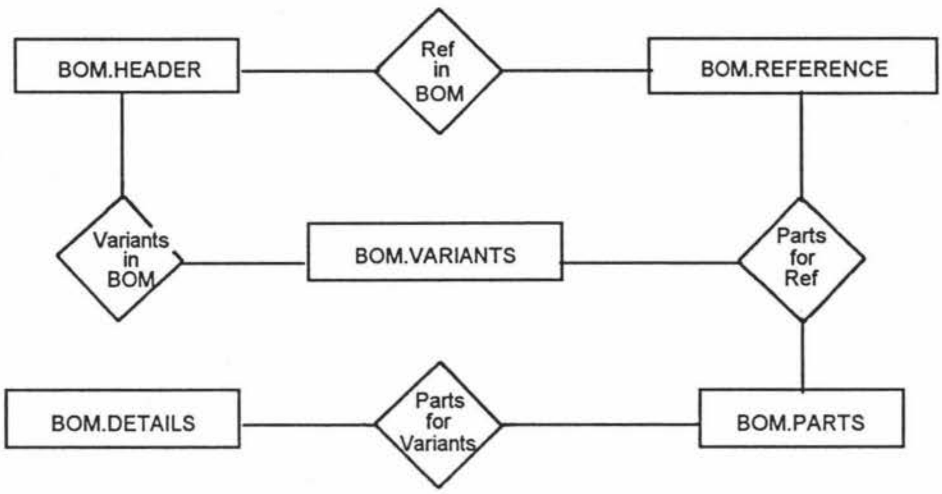

Figure 5.2 Entity-Relationship Data Model. (Reproduced).

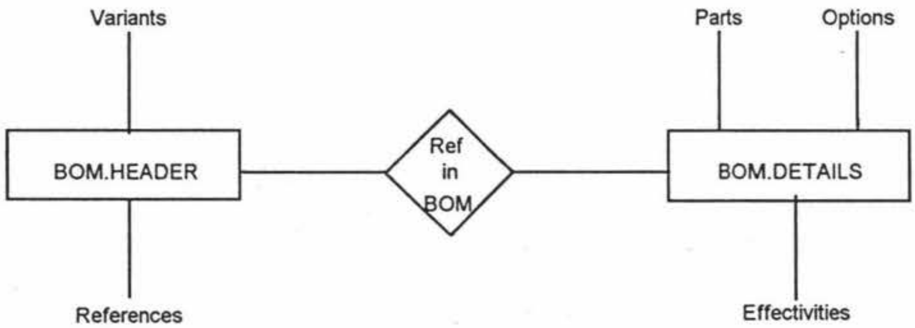

Figure 7.1 Entity-Relationship Data Model showing the two files used. The major attributes are listed against the applicable files.

7.2. Generic Header - (BOM.HEADER)

7.2.1. Generic BOM's

Each BOM has a generic header which lists the various attributes unique to that BOM. Some are listed in Figure 7.2.

```
BOM.HEADER       ID   BOM#
                 1    Variants         - multi-valued
                 2    Variant Status   - multi-valued
                 3    Last Ref Number
                 4    Index            - multi-valued
                 5    Description
                 6    Accounting Group
                 7    Manufacturing Option
```

ID	1001
1	Variant1]Variant2]Variant3
2	]P]P
3	63
4	C4]C6]D2]R16
5	WIDGET
6	0001
7	

Figure 7.2 BOM.HEADER file showing a typical logical view for a Generic BOM based on Figure 5.1.

The major difference between this and Figures 5.3, 5.4 and 5.5 is the placement of all variants as multi-values of attribute 1, all associated variant status as multi-values of attribute 2 and all references as multi-values of attribute 4.

The order of references in attribute 4 is a built-in sequence for displays and printouts. It is a standard feature of PICK to insert, delete or replace values at designated positions within an attribute.

7.2.2. Phantom C0100's

The facility to still use Phantom BOMs was incorporated into the structure. This was to be invoked when multiple printed circuit boards were to be part of the same generic product. This mechanism is not to be recommended but was necessary to accommodate an existing situation.

The variants within the C0100- phantom must exactly duplicate those within the parent in every way. It is not possible to use the same C0100 within two different generic BOM's as these would require a different set of variants. If this is required the C0100- should be made into an R9060- Finished Product. The R9060- product's generic BOM can have any number of variants. The correct variant is specified as the R9060- to be incorporated into the parent BOM.

The variant status is not listed against the C0100- but is carried across from the generic BOM. This prevents changes to the C0100- if not accessed through the generic BOM or through the Change Order procedure.

ID	C0100-12345
1	Variant1]Variant2]Variant3
2	
3	47
4	}1]}2]}24]R12]R13]R24]C2]C4]L45
5	
6	
7	

Figure 7.3 BOM.HEADER file showing a typical logical view for a Phantom C0100 BOM.

The description is read from the MATERIAL file.

7.3. Mini-BOMs

The requirement for Mini-BOMs was described in section 4.4. The Mini-BOM continues within RBOM as a BOM.HEADER. The complex method previously used to govern which parts were to be purchased by EXICOM and which by the sub-contractor has been alleviated. Within the BOM.HEADER an attribute exists for the Manufacturing Option. This is set as follows:-

S - Sub-contract
M - Manufacture in house

Parts for purchase and supply to a sub-contractor are still 'P' flagged. However it is the Manufacturing Option which guides the Materials Requirements Planning (MRP) software. Changing the venue for manufacture is simply via this option within the BOM.HEADER. It does not require a Change Order.

ID	C0201-23456
1	
2	
3	
4	
5	
6	
7	S

Figure 7.4 BOM.HEADER file showing a typical logical view for a Mini-BOM.

As for the C0100- the description is read from the MATERIAL file.

7.4. Generic - Reference - (BOM.DETAILS)

7.4.1. Generic BOMs and C0100's

Each reference listed in the index attribute of the BOM.HEADER becomes part of the item-ID of an item within the BOM.DETAILS file. This includes C0100's which also have an index of references. Some of the possible attributes are listed in Figure 7.5.

```
BOM.DETAILS     ID    BOM# * Reference
                1     Reference              - multi-valued
                2     Part Nos.              - multi-valued
                3     Quantity               - multi-valued
                4     MOO#                   - multi-valued
                5     P Flag                 - multi-valued
                6     Assembly Code          - multi-valued
                7     Change Orders          - multi-valued
                8     Options                - sub-values
                9     Effectivity            - sub-values
                10    Drawing Issue#         - multi-valued
                11    Current Change
```

```
ID      1001*R16
1
2       Part6]Part7]Part8]Part9]Part9
3       1]1]1]1]1
4       M001-010]M001-010]M001-010]M001-010]M001-010
5
6       B5]B5]B10]B5]B5
7       8526]]]8526
8       \\2]1]\1]1]\1
9       20.06.91]06.11.91]20.06.91\20.08.91]20.06.91\05.11.91]21.08.91
10
11      8526
```

Figure 7.5 BOM.DETAILS showing a typical logical view for a Generic BOM*Ref or a C0100-*Ref based on Figure 5.1. The date would normally be stored in internal format.

7.4.2. Mini-BOMs

Mini-BOMs also have a BOM.DETAILS item which is slightly different to the Generic*Reference. The Mini-BOM item-ID is identical to the BOM.HEADER item-ID. A typical example is depicted in Figure 7.6.

ID	C0201-23456
1	a]b]c]d
2	Part1]Part2]Part3]Part16
3	1]2]1]50
4	
5	]]P
6	
7	]]]3527
8	
9	20.06.91
10	
11	3527

Figure 7.6 BOM.DETAILS file showing typical logical view for a Mini-BOM.

The major difference between the Generic*Ref BOM.DETAILS and the Mini-BOM version is that the options attribute is empty for the Mini-BOM. A Mini-BOM is the equivalent of a raw material. It can be used or not used within an option. If the Mini-BOM needs variants then multiple Mini-BOMs are required each with a different Material Number. All Mini-BOMs are constructed to allow the part to be ordered from a sub-contractor. Therefore in theory each Mini-BOM can be ordered, received and placed in the Raw Material store in a unique location.

Part of the Engineering Change Order procedure for Mini-BOMs must include the question -

'Is this part interchangeable with previous stock?'

If the answer is NO a new Mini-BOM must be set up with a new Material Number as the item-ID.

7.5. Attribute Properties

7.5.1. BOM.HEADER

7.5.1.1. Variants

Each variant must be an R9060- item on the MATERIAL file before it can be added to a BOM.HEADER. Variants are added to the end of the array in attribute 1 as values. Section 2.4 described the product code as having the form

XX-YYYY-ZZZZZ

The YYYY is the generic BOM number. Each R9060- variant has an associated product code. This is only valid if it includes the same generic number as the BOM. Material numbers are basically non-meaningful sequential numbers which have little meaning to the human users. Therefore although the R9060- number is lodged in the BOM the user sees this translated into the associated product code read from the MATERIAL file.

In many cases the ZZZZZ portion of the product code is meaningful. This can act as a check for accuracy as a pattern should be seen for similar variants. The random effect of adding variants to the end of the array is counteracted during all displays or printouts by the use of indirection (a further array points to the variants in the desired order). Variants are sorted into order based on the ZZZZZ portion of the product code. This revised order is used for all further processing.

A further piece of information concerning variants is held in the MATERIAL file. This is the status of the variant. As new variants are added some variants may become obsolete. In normal situations the users are only interested in the non-obsolete variants. The system defaults to a non-obsolete display. This can be simply switched between all variants or only current as required. As will be discussed in later sections, the Change Order mode always shows all variants.

Figures 7.7 to 7.10 show possible screen displays for the various BOM.HEADERS described.

```
                         B111 - BOM MAINTENANCE
                         ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.             1001
1.  Description  Transmitter Type 1001
2.  MFG Group           0001
3.  MFG Option
4.  Notes               Entered
5.  Variants            Status              Description
R9060-10001                                 10-1001-01123 Variant 1
R9060-10028             P                   10-1001-01124 Variant 3
R9060-10012             P                   10-1001-01125 Variant 2
```

Figure 7.7 A possible screen display of the BOM listed in Figure 5.1 with all variants current. The variants have been sorted into ZZZZZ order.

```
                         B111 - BOM MAINTENANCE
                         ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.             1001
1.  Description  Transmitter Type 1001
2.  MFG Group           0001
3.  MFG Option
4.  Notes               Entered
5.  Variants            Status              Description
R9060-10028             P                   10-1001-01124 Variant 3
R9060-10012             P                   10-1001-01125 Variant 2
```

Figure 7.8 A possible screen display of the BOM listed in Figure 5.1. In this case Variant 1 has an Obsolete flag set in the MATERIAL File.

C0100- and Mini-BOMs also have BOM.HEADERS

```
                         B111 - BOM MAINTENANCE
                         ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.          C0100-12345
1.  Description Assy Transmitter Control PCB
2.  MFG Group
3.  MFG Option
4.  Notes
5.  Variants         Status            Description
R9060-10001                            10-1001-01123 Variant 1
R9060-10028                            10-1001-01124 Variant 3
R9060-10012                            10-1001-01125 Variant 2
```

Figure 7.9 A possible screen display of a C0100- assembly with all variants current. Description is read from the MATERIAL File.

```
                         B111 - BOM MAINTENANCE
                         ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.          C0201-23456
1.  Description A4/12345 PANEL FRONT TX 1001
2.  MFG Group
3.  MFG Option  S
4.  Notes
5.  Variants         Status       Description
```

Figure 7.10 A possible screen display of a Mini-BOM. Description is read from the MATERIAL File.

7.5.1.2. Variant Status

Each variant has a status of -

P	Provisional
'Null'	Current

A variant status of Null is represented by adjacent delimiters. As most variants will be current, Null, then storage space is only occupied by delimiters. In the case of Mini-BOMs where variants and therefore variant status are not valid the attribute is empty. In C0100- the variant status are not held in the BOM.HEADER.

7.5.1.2.1. Provisional Status

A new variant will normally be given Provisional Status when it is added to the BOM.HEADER. This allows the option flags against this variant to be manipulated without the requirement of an Engineering Change Order. The option flag against a part for a provisional variant may be set to 'Y' or 'P'.

If a flag is set to 'P' the MRP program will ignore the part so flagged. This allows the development of a BOM to indicate the likely part but does not set purchasing in motion until all testing has been completed. Previously a development BOM was set up in a development area and only parts available for purchase were transferred into the live area. This had the effect of double masters and was difficult to maintain accurately.

All parts flagged 'Y' in a provisional BOM are listed by MRP and are able to be allocated (pegged) for production. However once the variant has been manufactured and may be available for sale it is essential that a history is kept for all parts used in that product. A gate has been incorporated into the Issue program, as the final stage, which will not allow the BOM for a provisional variant to be exploded and parts issued to the factory floor.

7.5.1.3. Last Reference Number

As the reference is part of the combined item-ID for the BOM.DETAILS file it is essential that all parts have a reference. Where circuit references are not available a phantom reference is generated. The last number generated is recorded in the BOM.HEADER for future reference. These phantom numbers have been prefixed by a '}' symbol to remove any ambiguity.

7.5.1.4. Index

The index, within the Generic BOM or C0100-, lists all references as multi-values in the sequence in which they are required for the display or printout. This attribute (as usual) is of variable length and each reference can be considered as an element within a dynamic array.

Insertion or deletion of an element of the array is very simple. However deletion is always questioned, unless all valid variants for the reference are provisional, as otherwise history may be destroyed. The BOM.DETAILS item for the reference is not destroyed, it is merely detached and no longer called up by the BOM.HEADER.

This built-in dynamic array allows the user to move around the BOM very quickly without the need to generate linked lists or follow a sequence by reading multiple records. A screen of information can be written sequentially or a requested line number can be accessed directly.

When a new reference is added as part of an Engineering Change Order it is inserted into the index. Until the change has been completed this has the effect of showing a reference without any contents. This draws attention to the fact that a change is pending but not yet complete.

```
                              BOM INDEX MAINTENANCE
                              ---------------------
Gnn Add Change Insert Delete Search Matrix eXit End
PRODUCT NO.              1001

1. Reference             M00#           Part
1        )1              M002-010       C0201-27266 A3/28435 PANEL REAR
2        D1              M005-010       R0401-32438 DIODE 1N4148
3        D2              M005-010       R0401-32438 DIODE 1N4148
4        D3              M005-010       R0401-25964 DIODE 1N4002
5        R1              M005-010       R0501-16397 RESISTOR 1K0
                         M005-010       R0501-16798 RESISTOR 1K2
                         M005-010       R0501-16834 RESISTOR 4K7
6        R2              M002-010       R0501-16397 RESISTOR 1K0
7        R4              M005-010       R0501-16834 RESISTOR 4K7
                         M002-010       R0501-16834 RESISTOR 4K7
```

Figure 7.11 A possible screen display of the Index showing references read from BOM.DETAILS and descriptions read from MATERIAL.

```
                              BOM INDEX MAINTENANCE
                              ---------------------
Gnn Add Change Insert Delete Search Matrix eXit End
PRODUCT NO.              1001

1. Reference             M00#           Part
1        )1              M002-010       C0201-27266 A3/28435 PANEL REAR
2        D1              M005-010       R0401-32438 DIODE 1N4148
3        D2              M005-010       R0401-32438 DIODE 1N4148
4        D3              M005-010       R0401-25964 DIODE 1N4002
5        R1              M005-010       R0501-16397 RESISTOR 1K0
                         M005-010       R0501-16798 RESISTOR 1K2
                         M005-010       R0501-16834 RESISTOR 4K7
6        R2              M002-010       R0501-16397 RESISTOR 1K0
7        R3
8        R4              M005-010       R0501-16834 RESISTOR 4K7
                         M002-010       R0501-16834 RESISTOR 4K7
```

Figure 7.12 A possible screen display of the Index showing a new reference R3 added through the Change Order procedure.

7.5.1.5. Description

This is a brief description of the generic BOM. This attribute is not required for the BOM.HEADERS of C0100's or Mini-BOMs as these both must have their item-IDs recorded in the MATERIAL file. The description is read from the MATERIAL file.

7.5.1.6. Accounting Group

This may be used to categorise products within the Work in Progress ledger.

7.5.1.7. Manufacturing Option

This attribute can take three options plus null.

M	Manufacture in house
S	Sub-contract
A	Advance manufacture

The first two are applicable to the BOM.HEADERS of Mini-BOMs whilst the last is only applicable to generic BOM.HEADERS.

This flag is used by the MRP, allocation and issue programs. It is also used to formulate different printouts for production.

7.5.1.7.1. Manufacture in house

All parts listed within the Mini-BOM BOM.DETAILS are to be purchased and issued to the factory floor for in house assembly.

7.5.1.7.2. Sub-contract

Only parts which are 'P' flagged within the Mini-BOM BOM.DETAILS are to be purchased. These are to be supplied to the sub-contractor with the order. MRP is to back schedule these parts one month, per level, from the normal Goods into Store (GIS) date for other parts. A 'P' flagged part which is called up by a parent Mini-BOM, which is also 'P' flagged will be back scheduled by two months.

7.5.1.7.3. Advance Manufacture

Some generic products incorporate other Finished Products. These may be manufactured as part of the main product. However there are times when the Finished Product must be made in advance to allow adequate testing prior to incorporation into the main product.

Alternatively the Finished Product may be very small and may need to be made in multiple sets of say 20. In this case there may be 20 small, possibly postage stamp sized, PCB's laid out on the one 'flat'. The automated machinery has a minimum size PCB which can be manipulated. Often multiple copies of a small PCB are placed on one larger 'flat' which can be handled by the machinery. The small PCB's are then separated for final assembly.

In these situations the Manufacturing Option for the Finished Product generic BOM.HEADER is set to

A - Advance Manufacture.

The MRP software will check stock quantities of the finished Product and if required will explode the BOM for the Finished Product into the component parts. However allocation and issue programs will not explode these products. They allocate and issue the Finished Product.

```
                          B111 - BOM MAINTENANCE
                          ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.             1002
1. Description  Transmitter Switch Type 1002
2. MFG Group            0001
3. MFG Option   A
4. Notes
5. Variants             Status          Description
R9060-10134                                     10-1002-00001 Variant 1
R9060-10135                                     10-1001-00002 Variant 2
```

Figure 7.13 A possible screen display of the BOM for Advance Manufacture.

7.5.2. BOM.DETAILS

7.5.2.1. Reference

This is a multi-valued attribute used within Mini-BOMs to define balloon numbers. There is a direct relationship between the position within this attribute and the corresponding position of the associated part in attribute 2. These references are usually lower case alpha characters used on the drawing for the part. To follow through the theme of 'one master only' the component parts are not listed on the drawing. The drawing is only a pictorial representation of the finished part. It is incomplete without the Mini-BOM being attached. These references join the two documents together.

It is possible to have a printed circuit assembly as a Mini-BOM with circuit references. This would be the case where there is only one possible variant of the assembly which can be called up in any number of BOMs. As is the case with any Mini-BOM this will be required or not required. There would not be another Assembly * Ref item within the BOM.DETAILS file.

```
                         BOM.DETAILS MAINTENANCE
                         -----------------------   Effectivity 08.02.92
nn Options Effectivity Hide, eXit, FIle
PRODUCT NO.              C0201-23456
                                       2.  Notes
3. Part         Quantity  M00#   P flag  Assembly  Ref  Changes Issue#
R0201-23465       1.00  M001-020                    a    8852

R0901-21947       2.00  M001-020                    b

R0903-28163       2.00  M001-020                    c
```

Figure 7.14 A possible screen display of a Mini-BOM with references as listed on the drawing.

7.5.2.2. Part Numbers

This multi-valued attribute defines the possible parts for this reference. A new part number is added to the array whenever there is a change in any way. This could be a different combination of option flags, a different M00# for one of the options, quantity change etc. The part number must exist in the MATERIAL file prior to inclusion. All attributes except the Current Change are position dependant on this attribute.

As an item may expand to 32 Kbytes there is plenty of scope for extensive additions within each item. With some BOMs having in excess of 40 variants this area reflects the major changes as the product evolves.

7.5.2.3. Quantity

This multi-valued attribute has a direct position dependant association with the Part No. Each Part must have a quantity. This defaults to 1 as each circuit reference normally has one part. Hardware, wire etc have differing quantities.

Where there are varying quantities required for different variants multiple entries will be needed for the same part with different quantities.

7.5.2.4. M00# - Centre and Operation

This multi-valued attribute has a direct position dependant association with the Part No. The M00# is used by the Issue program to direct where the part is to be delivered. If the M00# changes for any variant then another Part must be added to attribute 2. This is often required for parts inserted by machinery. Due to the presence of some other part on a particular variant the machine may not be able to gain access. This part will need to be transferred to the Hand Assembly area. A decision will need to be made as to whether all parts should be transferred or only that with the interference problem. Usually it will be the latter as machine insertion gives less opportunities for errors.

7.5.2.5. 'P' Flags

These are only used on Mini-BOMs. There is a direct position dependant association with the Part No. If the part is 'P' flagged and the Manufacturing Option is 'S' then these 'P' flagged parts only are purchased and provided to the sub-contractor. Other parts not 'P' flagged are supplied by the sub-contractor.

If the Mini-BOM Manufacturing Options is M then all parts are purchased and issued to the factory floor.

7.5.2.6. Assembly Code

This multi-valued attribute has a direct position dependant association with the Part No. It is likely to be influenced by the M00# as well. These are both dependant on the Part. This code is a 12 digit alphanumeric which describes the preparatory work prior to attachment of a part. It may also refer to a written work instruction.

7.5.2.7. Drawing Issue Number

This multi-valued attribute has a direct position dependant association with the Part No. The main area for its use is for Circuit Diagrams. This allows the configuration control activity to associate a production run with an issue of the circuit diagram. With the emphasis on the introduction of ISO9001 this ability becomes essential.

The drawing issue number is of less use with other types of drawings. As described in section 7.4.2 each change order must ask if the new part is interchangeable with the old. If YES there is no need to change the material number with an increase in the issue number of the drawing. The change may have been to a note or a correction of a mistake. Use of the Drawing Issue number in BOM.DETAILS for these situations can lead to misinformation. Stock held in the store against a part number may quite legally be of differing issue numbers.

7.5.2.8. Change Orders

The change order and substitution procedures insert the correct change order number, for that change, into the correct place within this multi-valued attribute. The change order is position dependant on the associated Part No. Only the last change order per position is retained within this file. The change order procedure will be described in detail in section 8.6.

7.5.2.9. Options

This is the attribute which ties the whole system together. This is a multi-valued attribute which is position dependant on the Part No. These values are sub-divided into sub-values position dependant on the variants in attribute 1 of the BOM.HEADER.

There are 3 possible entries as options.

'Y' - stored as a 1
'P' - stored as a 2
'N' - stored as a null

The 'P' is only available if the variant is still provisional.

The display and printouts only print 'Y' and 'P' as this was found to be the easiest to understand. Therefore if the part is valid for that variant it is flagged accordingly.

The flag is positioned under the ZZZZZ portion of the product code which is displayed or printed vertically.

```
                         BOM.DETAILS MAINTENANCE    Hide Off    Obsolete
                         -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.              1001
                         R16              2.  Notes
3. Part         Quantity M00#   P flag Assembly Ref  Changes  Issue#
0                           0                        0
1                           1                        1
1                           1                        1
2                           2                        2
3                           4                        5

Part6            1.00    M001-010                    8526
                            P
Part7            1.00    M001-010
Y
Part8            1.00    M001-010
                                                     Y
Part9            1.00    M001-010                    8526
Y
Part9            1.00    M001-010
                                                     Y
```

Figure 7.15 Possible BOM.DETAILS display of Figures 5.1 and 7.5 showing all products and parts.

```
                      BOM.DETAILS MAINTENANCE                Obsolete
                      -----------------------   Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.           1001
                      R16          2.  Notes
3. Part      Quantity M00#  P flag Assembly Ref Changes Issue#
0                     0                         0
1                     1                         1
1                     1                         1
2                     2                         2
3                     4                         5

Part6         1.00   M001-010                   8526
                      P
Part7         1.00   M001-010
Y
Part9         1.00   M001-010
                                                Y
```

Figure 7.16 Possible BOM.DETAILS display of Figures 5.1 and 7.5 showing all products but only valid parts for the effectivity date shown.

7.5.2.10. Effectivity

This is a multi-valued attribute position dependant on the Part No. Within each value are stored at least one and possibly multiple sub-values of dates in internal format. The use of the effectivity date to decide if a part is valid is expanded in section 8.2.

```
                         BOM.DETAILS MAINTENANCE    Hide Off    Obsolete
                         -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.              1001
                         R16               2.  Notes
3. Part         Quantity M00#   P flag  Assembly  Ref  Changes Issue#
0                        0                             0
1                        1                             1
1                        1                             1
2                        2                             2
3                        4                             5

Part6             1.00  M001-010                       8526
20.06.91
                         P
Part7             1.00  M001-010
06.11.91
Y
Part8             1.00  M001-010
20.06.91 20.08.91
                                                       Y
Part9             1.00  M001-010                       8526
20.06.91 05.11.91
Y
Part9             1.00  M001-010
21.08.91
                                                       Y
```

Figure 7.17 Possible BOM.DETAILS display of Figures 5.1 and 7.5 showing all products and parts. An effectivity date has been included, in external format as in Figure 7.5.

7.5.2.11. Current Change

This attribute stores the last change order against this BOM.DETAILS item. The change order procedures check to ascertain if the current change has been completed before allowing another change. This is to avoid the possibility of two changes being in effect concurrently.

7.6. Installation

After extensive testing and acceptance by the users the PICK version of this model was installed into EXICOM on 17 June 1991.

Conversion programs were written to transfer the information from the old format to the new. A trial version, implemented to assess user acceptance of the concept but without update facilities, had been available since early 1991. Even with the requirement to reconvert a BOM prior to use this had proven so useful for production engineering that it could not be removed. A day's work transposing information into a spreadsheet was condensed into less than 1 hour, with a corresponding increase in accuracy, as the BOM printout gave exactly the information required. The presence of two similar versions made programming and testing a little more complex than originally anticipated.

Only current products and Mini-BOMs were converted.

User reactions and problems encountered will be discussed in chapters 10 and 11.

8. FEATURES OF NEW SYSTEM

This chapter describes how to use the EXICOM version of RBOM. Initially the mechanism to navigate through the layers of RBOM are described including the built-in ability to continuously enter lower level BOMs. The different modes of screen display are shown prior to a detailed description of the mechanism developed to store historical data through the use of Effectivities.

The BOM explosion mechanism is described in pseudo code for this 3 dimensional PICK implementation of RBOM.

Section 8.4 describes the mechanism to create a new variant of a generic module. The various flags which may be set are discussed.

The Change Order procedures and mechanisms to implement these are discussed in detail prior to a description of the Where-Used facilities and substitutions.

Finally some of the available BOM reports are detailed with examples. These use the Matrix BOM concept, as described in Section 1.4, to graphically show the relationship of parts used in different variants for each position.

8.1. Navigation through RBOM


```
                              BOM.HEADER

 Input BOM Number             Generic BOM
                              C0100-
                              Mini-BOM

 View Product Codes              nn       - edit field nn
 (Default to current)            S2       - Screen 2 index
                                 O        - Obsolete On/Off
                                 D        - Delete BOM
                                 X        - eXit (not save)
                                 FI       - FIle Item
```

```
                              BOM INDEX

 Input S2 for details            <cr>     - next reference
 (from BOM MAINTENANCE)          Gnn      - Go to line nn
                                 T        - go to line 1
                                 S        - Search for:
                                      R        Reference
                                      P        Part number
                                      D        Description
                                      E        Extended
                                 N        - Next search
                                 M        - Matrix display
                                 X        - eXit (not save)
                                 E        - End
```

```
                              BOM.DETAILS

 Input M for Matrix              nn       - edit field nn
                                 O        - display Options
                                      V      Variants
                                      E      Effectivities
                                      D      Descriptions
                                 H        - Hide On/Off
                                 E        - Effectivity
                                 X        - eXit (not save)
                                 FI       - File Item
```

Figure 8.1 Navigation through RBOM.

8.1.1. Recursion

A major deficiency of the previous BOM system was the method of navigation through a complex BOM. The screen display was of a Single Level BOM. To ascertain the contents of a lower level (either a C0100- or a Mini-BOM) required the present BOM to be exited and the next level to be entered from the beginning.

RBOM has adopted the philosophy that all levels should be accessible from the generic BOM as shown in Figures 8.2 to 8.4.

If the cursor is placed alongside the lower level BOM within the BOM.DETAILS screen and 'M' for Matrix is input the system will recursively explode the lower level BOM. A C0100- will present the BOM INDEX screen whereas a Mini-BOM will present the BOM.DETAILS screen.

As the variant status is not held against lower level BOMs this mechanism is essential if a provisional variant is to be manipulated without a change order.

```
                           BOM INDEX MAINTENANCE
                           ---------------------
Gnn Add Change Insert Delete Search Matrix eXit End
PRODUCT NO.                1001
```

1.	Reference	M00#	Part	
1	)1	M002-010	C0201-27266 A3/28435 PANEL REAR	M
2	D1	M005-010	R0401-32438 DIODE 1N4148	
3	D2	M005-010	R0401-32438 DIODE 1N4148	
4	D3	M005-010	R0401-25964 DIODE 1N4002	
5	R1	M005-010	R0501-16397 RESISTOR 1K0	
		M005-010	R0501-16798 RESISTOR 1K2	
		M005-010	R0501-16834 RESISTOR 4K7	
6	R2	M002-010	R0501-16397 RESISTOR 1K0	
7	R4	M005-010	R0501-16834 RESISTOR 4K7	
		M002-010	R0501-16834 RESISTOR 4K7	

Figure 8.2 Against C0201-27266 in the BOM INDEX screen input M for Matrix display to see details of which variants use the Mini-BOM.

```
                         BOM.DETAILS MAINTENANCE
                         -----------------------   Effectivity 08.02.92
nn Options Effectivity Hide, eXit, FIle
PRODUCT NO.              1001
                 )1                2.  Notes
3. Part          Quantity  M00#  P flg  Assembly  Ref  Changes Issue#
0                           0                           0
1                           1                           1
1                           1                           1
2                           2                           2
3                           4                           5

C0201-27266      1.00  M001-020                         8852          M
Y                           Y                           Y
```

Figure 8.3 Further explosion of the Mini-BOM is actioned by the input of an M for Matrix against the line entry.

```
                         BOM.DETAILS MAINTENANCE
                         -----------------------   Effectivity 08.02.92
nn Options Effectivity Hide, eXit, FIle
PRODUCT NO.              C0201-27266
                                   2.  Notes
3. Part          Quantity  M00#  P flg  Assembly  Ref  Changes  Issue#
R0201-23465      1.00  M001-020                    a    8852

R0901-21947      2.00  M001-020                    b

R0903-28163      2.00  M001-020                    c
```

Figure 8.4 Recursive explosion of a Mini-BOM from the generic BOM. The BOM.HEADER is suppressed.

8.1.2. Display Options

The BOM.DETAILS screen gives three display options.

- **V**ariants
- **E**ffectivities
- **D**escriptions

The system defaults to the Variants display as this shows the important inter-relationship between part and variant.

```
                        BOM.DETAILS MAINTENANCE              Obsolete
                        -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit File
PRODUCT NO.             1001
                        R16              2.  Notes
3. Part        Quantity M00#   P flg Assembly Ref  Changes  Issue#
0                         0                         0
1                         1                         1
1                         1                         1
2                         2                         2
3                         4                         5

Part6            1.00   M001-010                    8526
                          P
Part7            1.00   M001-010
Y
Part9            1.00   M001-010
                                                    Y
```

Figure 8.5 BOM.DETAILS with Variants Option. The option flag is positioned below the vertical <u>ZZZZZ</u> of the applicable variant.

```
                      BOM.DETAILS MAINTENANCE            Obsolete
                      -----------------------  Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.           1001
                      R16           2. Notes
3. Part      Quantity M00#  P flg Assembly Ref Changes Issue#

Part6          1.00   M001-010                   8526
20.06.91
Part7          1.00   M001-010
06.11.91
Part9          1.00   M001-010
21.08.91
```

Figure 8.6 BOM.DETAILS with Effectivities Option. The effectivity is shown in external format for ease of understanding. Normally this would be in internal format.

```
                      BOM.DETAILS MAINTENANCE            Obsolete
                      -----------------------  Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.           1001
                      R16           2. Notes
3. Part      Quantity M00#  P flg Assembly Ref Changes Issue#

Part6          1.00   M001-010                   8526
Description of Part 6
Part7          1.00   M001-010
Description of Part 7
Part9          1.00   M001-010
Description of Part 9
0                      0                          0
1                      1                          1
1                      1                          1
2                      2                          2
3                      4                          5

                                                  Y
```

Figure 8.7 BOM.DETAILS with Descriptions Option. The description within the MATERIAL file is displayed for each part. The option flag for the last displayed part (Part9) is written.

8.1.3. Obsolete switch

A BOM is in effect throughout the life of a product. During this time new variants are added as the product evolves. At the same time older variants may become obsolete. This status is recorded in the MATERIAL file against the variant R9060- number.

When a BOM is displayed initially the obsolete variants are suppressed from the display, both in the BOM.HEADER and in the BOM.DETAILS. The display of obsolete variants can be switched from the BOM.HEADER by actioning **O**bsolete.

The 'Obsolete' is displayed when the obsolete variants are visible.

```
                              B111 - BOM MAINTENANCE              Obsolete
                              ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.            1001
1.  Description  Transmitter Type 1001
2.  MFG Group          0001
3.  MFG Option
4.  Notes              Entered
5.  Variants           Status          Description
R9060-10001                                    10-1001-01123 Variant 1
R9060-10028            P                       10-1001-01124 Variant 3
R9060-10012            P                       10-1001-01125 Variant 2
```

Figure 8.8 Screen display of all variants including obsolete. The word Obsolete is displayed to advise the user.

```
                              B111 - BOM MAINTENANCE
                              ----------------------
nn, S2 - details, Obsolete, Delete, eXit, FIle
PRODUCT NO.            1001
1.  Description  Transmitter Type 1001
2.  MFG Group          0001
3.  MFG Option
4.  Notes              Entered
5.  Variants           Status          Description
R9060-10028            P                       10-1001-01124 Variant 3
R9060-10012            P                       10-1001-01125 Variant 2
```

Figure 8.9 Screen display of non-obsolete variants only.

8.2. Effectivities

There are at least 2 possible approaches to the historical aspect of BOMs.

a. Make a copy of the Master for each production run and freeze. This doesn't allow projections into the future. EXICOM used this approach in the old system.

b. Add information to the BOM to allow for evolution.

RBOM introduced the concept of effectivity keys. These keys are stored within RBOM as a date held in an internal format. This internal format constitutes the number of days since 31 December 1968.

A JOB GROUP table is created which links each job group with a specific date. No two job groups may share the same date. However multiple production jobs may be linked to a job group. This date is the closest possible estimate of the picking date for the group.

If more than one job group could share the same date it would be impossible to have a substitute for one group and not the other. It is assumed that all production runs to be started on the same day, ie. processed together by planning and production engineering, will belong to the same job group.

Each BOM.DETAILS record has Effectivities for every part listed. The effectivity start is requested when a new part is added. The default is the effectivity assigned to the BOM through the effectivity option or if not assigned the default is 'today'. The action to make a part inactive requires the effectivity stop date to be entered. The same part may become active again in the future. If so a new effectivity start date is added etc. The effectivity attribute array is arranged so that start dates are odd elements and stop dates are even elements.

All BOM explosion programs must have at least one effectivity key, either a production job or a specific date. In some cases the effectivity key will be different for different variants. The Effectivities within the effectivity array are compared with the required effectivity date for each part in the BOM.DETAILS item.

If the date is found to occupy an element within the array then the part is valid.

If the required effectivity key would occupy an even element, if it were inserted into the array in ascending order, then the item is valid.

Part aaaaa	8555\8689\8709
Part bbbbb	8690\8708

If the effectivity date is 8700 the following validation would take place.

Part aaaaa - not listed in array - if inserted into array would occupy element 3. Therefore not valid.

Part bbbbb - not listed in array - if inserted into array would occupy element 2. Therefore valid.

Not only can Effectivities be useful historically but they can also be a means to change a part in the future. This has always been a problem when a part is to be replaced in the future. What part does the MRP explosion use? Each forecast must also have an effectivity key. Therefore a part can be activated in the future and MRP will respond correctly.

This concept of Effectivities has proven to be the hardest concept for staff to grasp.

8.2.1. Hide or Unhide

The screen display defaults to an effectivity of today. Only those parts current for this effectivity are displayed. The effectivity may be changed at any time by selecting the Effectivity option from the BOM.DETAILS screen.

If it is wished to view non-current parts these can be switched on or off using the Hide switch.

```
                         BOM.DETAILS MAINTENANCE              Obsolete
                         -----------------------   Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.              1001
                         R16              2.  Notes
3. Part        Quantity  M00#   P flg  Assembly  Ref  Changes  Issue#

Part6            1.00   M001-010                       8526
20.06.91
Part7            1.00   M001-010
06.11.91
Part9            1.00   M001-010
21.08.91
```

Figure 8.10 BOM.DETAILS with Effectivities Option. The Hide switch is on and only current parts are shown.

```
                         BOM.DETAILS MAINTENANCE   Hide Off   Obsolete
                         -----------------------   Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.              1001
                         R16              2.  Notes
3. Part        Quantity  M00#   P flg  Assembly  Ref  Changes  Issue#

Part6            1.00   M001-010                       8526
20.06.91
Part7            1.00   M001-010
06.11.91
Part8            1.00   M001-010
20.06.91 20.08.91
Part9            1.00   M001-010
20.06.91 05.11.91
Part9            1.00   M001-010
21.08.91
```

Figure 8.11 BOM.DETAILS with Effectivities Option. The Hide switch is off and all parts are shown.

8.3. BOM Explosion Mechanism

The BOM explosion mechanism can be described in the following pseudo code. The initial input is a Product Code and effectivity (likely to be a run number).

```
Get Effectivity from JOB.GROUP
Extract Generic BOM from Product Code - XXXX
    Read BOM.HEADER item
    Locate Variant(s) position(s) in Variants array
    For each reference in index array
        Read BOM DETAIL item XXXX * reference
        For each value
            Check Effectivity
            If valid
                Check Options flag
                If valid
                    If line is a C0100 or Mini-BOM then
                        Explode BOM.HEADER (recursive)
                    Else
                        Call Output processing subroutine
                    End If
                End If
            End If
        Next value
    Next reference
```

Process list of parts and quantities as required.

8.4. Creation of new variant

In many cases the addition of a new variant to an existing range of variants requires the changing of a few parts. This mechanism caused the downfall of the modular approach to BOMs. The few parts to be changed occur throughout the BOM due to the effects of capacitance and inductance of electronic componentry when in close proximity. The parts which must be changed are often not in the same functional block. The changes are required within many modules of a modular type BOM.

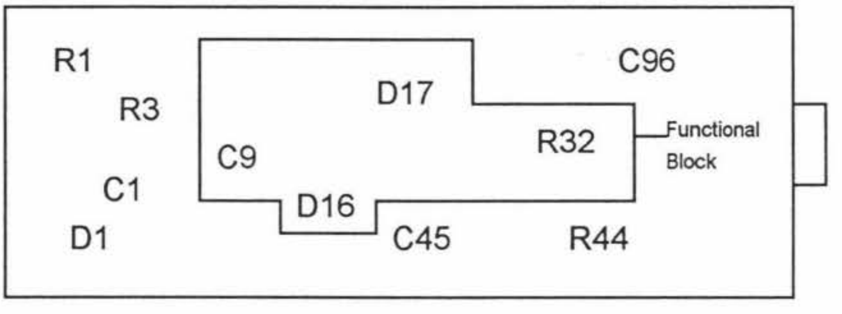

Figure 8.12 Printed Circuit Board showing a Functional Block. All these components may need to change although the true change is only within the functional block.

A new variant can be added to a Generic RBOM at any time providing the product code exists within the MATERIAL file. This is achieved by entering the BOM MAINTENANCE screen. Field 5, Variants, is selected then A to Add a new variant. The program requests either the product code or R9060- number of the new variant. The product code is read from the MATERIAL file and the generic portion -XXXX- is compared with the BOM.HEADER. A non-match prevents further processing.

The new variant is added to the end of the BOM.HEADER variant array. The system prompts for a close variant to use as a template.

8.4.1. Option Flag Status

If a variant is input to act as a template the system will ask if the option flags are to be provisional. Each reference is read from the index in the BOM.HEADER. The applicable BOM.DETAILS item is read and the status against the template is written to the new variant, which is positioned last in the array.

If the option flags are to be provisional each entry against the new variant will be 'P' or ''.

If the option flags are not provisional each entry against the new variant will duplicate the template.

The maturity of the existing BOM will be the main guide for the option flag status. BOMs under development may have the majority of option status as 'P'.

8.4.2. Provisional status

The next prompt is for the status of the variant's BOM. This is aimed at the total BOM for this variant not individual parts. The default is 'P' which allows alterations to be made to this variant without the use of the Change Order program mechanism. This will affect the few components to be changed to reflect the requirement for the new variant.

8.4.2.1. Preservation of history

The single BOM concept with the use of Effectivities as the mechanism to decide which parts are applicable to each production run means that no changes must be allowed without an audit trail once the product has been placed in the marketplace. The audit trail is invoked by means of the Change Order program.

A trap has been placed within the system to stop any provisional BOM being actioned by the Issue program. This allows provisional BOMs to be manipulated by MRP and the normal allocation programs.

However the final stage of issuing parts from the inventory to the factory floor cannot be achieved while the BOM is still provisional.

Once the provisional flag has been removed from the variant status any change to any part for that variant can only be made via the Change Order program. This records the change order number against the change and provides good checking and audit trail facilities.

In exceptional circumstances this provisional flag may be reinstated. However this is only if product made against the prototype run cannot possibly enter the marketplace.

8.5. Reference as Key

Whether building a BOM for the first time or adding parts to an existing BOM the key field is the reference. This is either the circuit reference as quoted on the Circuit Diagram and silk screened on the PCB or a phantom reference provided by the program as the next available number which is held in the BOM.HEADER. Each item within the BOM.REFERENCE, BOM.PARTS and BOM.DETAILS files has the reference as an integral part of the primary key (item-ID).

8.6. Change Order System

The Engineering Change Order is the mechanism by which changes to designs are approved, implemented and recorded for future reference. Every non provisional BOM must use the Change Order program for all changes.

Every Change Order must have an effectivity to ensure that the change is incorporated into the correct version of any BOM outputs. This effectivity may be a specific run number, especially for retrospective changes found to be required during production, or for future changes today's date is often used. Changes planned some time in the future, as existing parts are exhausted, can use the effectivity of the appropriate monthly forecast. This will interface with the MRP processing to change over the required part in the correct forecast.

By default, in Change Order mode, all variants are displayed. This ensures that retrospective changes are also applied to applicable obsolete variants.

8.6.1. Printout of stated references

Change Orders can be very difficult to write clearly. Instructions are often being given to widely different areas within the organisation. Directions for the drawing office are quite different to those required to manipulate the BOM correctly. To lessen the ambiguity within the BOM processing a printout has been developed to accompany any Change Order. This allows only the references affected by the Change Order to be included on the print. The option flags can then be 'marked-up' by hand to show the before and after requirement. This printout should mirror the screen display seen by the operator who is to change the BOM. This is an adaptation of 'One picture is worth a thousand words'.

8.6.2. Too complex to be software driven

Analysis of the required change mechanisms showed that this would require very complex software. Instead the approach used was to allow normal editing functions in a parallel file. The BOM.CHANGE file holds a copy of every affected BOM.DETAILS item. These are edited as per the instructions. Every change automatically has the Change Order number recorded against the applicable parts.

8.6.3. Change Order timing

Only one Change Order may be in existence against a BOM.HEADER. The program records the latest Change Order in the BOM.HEADER. If this Change Order has not been completed the process will not proceed.

8.6.4. Check print audit trail

Prior to acceptance of a Change Order a comparison is made between the live BOM.DETAILS file and the BOM.CHANGE file to report all differences. This report can be checked against the instructions within the Change Order to ascertain if the changes have been made correctly. This becomes a permanent record against the Change Order.

8.6.5. Printout incorporating Change Order

A further printout is available which shows the BOM with the Change Order incorporated, even though it has not yet been completed. This is an additional check feature which can be used for very complex changes.

Once the Change Order is checked and confirmed to be as required it is completed within the Change Order program. This overwrites the BOM.DETAILS item with the updated item from BOM.CHANGE file. The BOM.CHANGE item is deleted.

8.7. Editing Changes

If any parameters change against a Reference * Part details line there must be a new details line set up. History must be preserved for future access. The Change Order program requests an effectivity date (change effectivity) to be entered. This is likely to be a production run, if retrospective, or today. Care must be taken with these effectivity dates.

8.7.1. Close line

Where the variants using this details line change, history is preserved by closing the line. An effectivity close of (change effectivity - 1) is entered by the system.

8.7.2. Copy line

This allows for single or multiple copies of a details line to be made prior to editing. The effectivity start is (change effectivity). The details line being copied may be closed as part of the procedure. This would be the normal action. See Figures 8.13 and 8.14.

Each new copy of the details line has the variant option flags manipulated to produce the desired result. Any parameter of the new details line can be changed including the part number. Normal changes would provide one new details line for the existing part, with a lesser number of applicable variants and at least one other details line for a new part with at least one variant. Alternatively one part may be completely changed for another part with all the same variants.

8.7.3. Reopen line

It can happen that due to changes in design a closed details line is exactly right for the design change now required. This details line can be reopened with a new effectivity start of the (change effectivity).

8.7.4. Add or Insert a details line

This enables a new details line to be added to the bottom of the list for a reference or inserted above the cursor position. In both cases the option flags can be set against the applicable variants.

8.7.5. Change details line

It is possible to change the part number against a details line. This would not be a normal occurrence but may be required due to a previous error. The system will prompt 'Are you sure you wish to change this part possibly destroying history'.

```
                         BOM.DETAILS MAINTENANCE                 Obsolete
                         -----------------------  Effectivity 06.11.91
(- close) (+ copy) More Hide Change Add Insert eXit
PRODUCT NO.              1001
                         R16              2. Notes
3. Part        Quantity  M00#    P flg Assembly Ref  Changes  Issue#
0                          0                           0
1                          1                           1
1                          1                           1
2                          2                           2
3                          4                           5

Part6             1.00   M001-010                      8526
20.06.91
                           P
Part9             1.00   M001-010                     8526
20.06.91
Y
Part9             1.00   M001-010
21.08.91
```

Figure 8.13 Part9 is to be copied (+) and closed. The new part is Part7 which will have an effectivity start of today - 06.11.91.

```
                    BOM.DETAILS MAINTENANCE    Hide Off    Obsolete
                    -----------------------    Effectivity 06.11.91
nn Options Hide Effectivity eXit File
PRODUCT NO.             1001
                        R16             2.  Notes
3. Part       Quantity  M00#   P flg  Assembly  Ref  Changes  Issue#
0                        0                            0
1                        1                            1
1                        1                            1
2                        2                            2
3                        4                            5

Part6           1.00    M001-010                      8526
20.06.91
                         P
Part7           1.00    M001-010
06.11.91
Y
Part8           1.00    M001-010
20.06.91 20.08.91
                                                      Y
Part9           1.00    M001-010                      8526
20.06.91 05.11.91
Y
Part9           1.00    M001-010
21.08.91
                                                      Y
```

Figure 8.14 Part7 has replaced Part9 from 06.11.91. The effectivity close for Part9 is one day earlier.

8.7.6. Delete details line

Once again it is possible to delete a complete details line if an error has been made. It is possible for one change order to countermand an earlier change. If no production has used the incorrect change it is less confusing to eliminate it from the BOM. A prompt will question the wisdom of this action.

8.8. Where-Used

An essential of any BOM system is the inverted BOM or Where-Used. This enables any part to be tracked upwards to the assembly parent or Mini-BOM, if applicable, and eventually to the generic header.

8.8.1. Effectivities

The where-used also uses Effectivities to ascertain which parts are to be displayed. Each part is an item within the WHERE-USED file. The header and reference are attributes within the item. The concatenation of the header and the reference gives the BOM.DETAILS item. The effectivity array for each occurrence of the part within the BOM.DETAILS is interrogated to ascertain if it is valid for the requested effectivity. Those valid are displayed on the screen or printout.

8.9. Global Change

A not uncommon requirement is to change all occurrences of a part to a replacement part. This will usually be brought about by a supplier discontinuing a range of parts or a change in packaging.

The WHERE-USED file is used to ascertain all parts current at the stated effectivity. Each part has an effectivity close date added to the array within the applicable BOM.DETAILS item. If an existing effectivity close date is already listed this will be changed to that of the global change.

The details line being closed is copied to a new details line for the replacement part. If the new part already exists within the BOM.DETAILS and is a perfect match this will be made current for the stated effectivity.

Normally the other attributes of the details line will be copied unchanged from the closed line. However there are some situations where the quantity must be changed. A prompt is incorporated to use this route if required.

8.10. Substitutes

8.10.1. All or nothing

The predominance of machine placed parts has led to a philosophy of all or nothing substitutes. The machine program is set up so that a specified part is placed in a position for stated variants. It is not easy to handle the situation where 50% are one part and 50% a substitute part. Therefore if a supply problem means that a substitute must be arranged, the part in that position is totally substituted for that production run.

A program has been provided to automatically insert the substitute part. This program copies the normal detail line to a new line for the substitute part. The effectivity start and stop dates for the new line are the effectivity date of the production run.

The substitute effectivity is located within the array for the normal part. The effectivity close is the production run -1 day. The effectivity start (reopen) is the production run +1 day. This mechanism is shown in Figure 8.15.

8.10.2. Seek existing substitute to reuse

Substitutions can be frequent occurrences. Therefore it is desirable to seek an existing details line for the substitute part within the BOM.DETAILS item. The attributes of Quantity, M00#, Assy#, 'P' Flag, (Mini-BOM Ref) and option flags must match exactly for a details line to be reused.

Changes to the M00# and/or Assy# may be required. These attributes are able to be changed without change orders. It is a common situation for the substitute part to be placed at a different work station. Often the substitute part will be the same physical part packaged differently.

If a M00# or Assy# is changed after the substitute this details line will not be found to be a match next time the same substitute is required. Additional questions may be asked to overcome this if this situation is encountered often.

```
                              BOM.DETAILS MAINTENANCE    Hide Off    Obsolete
                              -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.                   1001
                              R16              2.  Notes
3. Part          Quantity     M00#    P flg  Assembly  Ref  Changes  Issue#
0                               0                             0
1                               1                             1
1                               1                             1
2                               2                             2
3                               4                             5

Part6              1.00     M001-010                          8526
20.06.91
                               P
Part7              1.00     M001-010
10.10.91 10.10.91 06.11.91
Y
Part8              1.00     M001-010
20.06.91 20.08.91
                                                              Y
Part9              1.00     M001-010                          8526
20.06.91 09.10.91 11.10.91 05.11.91
Y
Part9              1.00     M001-010
21.08.91
```

Figure 8.15 Part7 has been substituted for Part9 on the production run with an effectivity of 10.10.91. The Effectivities show Part7 to be the current part for variant 01123 on this date.

8.11. Search facilities

A BOM is made up of many references and parts. Each part has a description. These can be ordered in many different ways and may incorporate a number of levels of assemblies and Mini-BOMs.

A major shortcoming of the previous BOM system was the difficulty of locating a specific item whether it be by reference, part or description.

RBOM has introduced search facilities. These apply in whole or part to references, part numbers or descriptions. These may be at the existing level or an extended search will recursively explode C0100- assemblies and Mini-BOMs. Once found the search can continue for the next occurrence.

The ability to quickly locate a reference or part has proven to be a very popular feature of RBOM. This is used for Change Order research and for finding non-current parts. A difficulty has always been finding the correct part from a partially known description. Previously the BOM would need to be exited to allow interrogation of the MATERIAL file or a query language access would be used if only part of a free form description was known. With a large MATERIAL file these queries could take quite a long time. Now only the parts listed within the BOM form the source for the query.

8.12. BOM Reports

RBOM offers many different styles of report through a simple selection process. Instead of the normal list of different types of reports the user is able to customise each report at the time of calling. The heading of each printout gives details of the selection process for that particular print. Facilities presently available cover the following:-

Standard BOM Reports

- all or selected variants

- choice of
    - Explode lower levels - Indented BOM
    - not Explode lower levels - Single Level BOM

- choice of
    - Explode Finished Products
    - not Explode Finished Products

- choice of
    - All parts
    - Common parts - within the selected variants
    - Non-common parts " " " "

- all or a selected M00#

- all or selected references

- may include an incomplete change order to ascertain the effects.

Costed BOM

-This is for one variant only.

Technical Manuals BOM

As with the screen displays the printed report is structured like a spreadsheet. The last 5 digits of the variant product code are printed vertically under the header section.

Each reference is listed with all parts valid for the variants and Effectivities included on the report. A part not used by the variants listed, or not valid for the Effectivities listed is not listed on the report.

There are two possible listings under the variants column for each part.

Y denotes the part is used in that variant at that effectivity.

P denotes the part is provisionally used in that variant at that effectivity.

To improve readability there is no entry if the part is not valid in a particular variant.

Wherever possible these reports support the philosophy of exception reporting. Production staff need to know what has changed since the last time this product was manufactured. These are generally the only areas that need action.

8.12.1. Indented BOM - All parts

The Indented BOM shows the inter-relationship of parts to variants. This is essential to Engineering and Production staff.

BOM report for 1001 as at 12:48:40 08 AUG 1992 Page 1

Explode lower levels is ON
Explode Finished Products is ON
All parts are listed

Effectivity	Variant	Description
08.08.92	10-1001-00001	Variant No. 00001 of 1001
08.08.92	10-1001-00002	Variant No. 00002 of 1001
08.08.92	10-1001-00003	Variant No. 00003 of 1001
08.08.92	10-1001-00004	Variant No. 00004 of 1001
08.08.92	10-1001-00005	Variant No. 00005 of 1001
08.08.92	10-1001-00006	Variant No. 00006 of 1001

Ref		Part	Qty	Units	M00 #	Assy	C.O.	VARIANTS					
								0 0 0 0 1	0 0 0 0 2	0 0 0 0 3	0 0 0 0 4	0 0 0 0 5	0 0 0 0 6
1		Part1	1.00	EA	M003-010		1234	Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART1													
1	PCB	Part2	0.05	EA	M008-010		1235	Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART2													
1	R3	Part3	1.00	EA	M008-010			Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART3													
1	R3a	Part4	1.00	EA	M003-010	ON R3	1236			Y	Y		
DESCRIPTION OF PART4													
1	R3a	Part5	1.00	EA	M003-010	ON R3	1236					Y	Y
DESCRIPTION OF PART5													
1	L1	Part6	1.00	EA	M003-010		1176	Y	Y	Y	Y		
DESCRIPTION OF PART6													
2	a	Part7	40.00	mm	M003-050								
DESCRIPTION OF PART7													
1	L1	Part8	1.00	EA	M003-010		1176					Y	Y
DESCRIPTION OF PART8													
1	L2	Part9	1.00	EA	M003-010			Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART9													

Figure 8.16 Indented BOM showing parts for all levels.

8.12.2. Indented BOM - Common Only

Production staff usually want to know which parts are common across the variants being made in any production batch. This report only lists those parts common to all the selected variants.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                    Page 1

Explode lower levels is ON
Explode Finished Products is ON
Common parts are listed

Effectivity          Variant             Description
08.08.92             10-1001-00001         Variant No. 00001 of 1001
08.08.92             10-1001-00002         Variant No. 00002 of 1001
08.08.92             10-1001-00003         Variant No. 00003 of 1001
08.08.92             10-1001-00004         Variant No. 00004 of 1001
08.08.92             10-1001-00005         Variant No. 00005 of 1001
08.08.92             10-1001-00006         Variant No. 00006 of 1001

Ref          Part     Qty   Units              MOO #   Assy          C.O.
VARIANTS
                                                                     0 0 0 0 0 0
                                                                     0 0 0 0 0 0
                                                                     0 0 0 0 0 0
                                                                     0 0 0 0 0 0
                                                                     1 2 3 4 5 6
1            Part1    1.00         EA    M003-010             1234   Y Y Y Y Y Y
  DESCRIPTION OF PART1

1     PCB    Part2    0.05         EA    M008-010             1235   Y Y Y Y Y Y
  DESCRIPTION OF PART2

1     R3     Part3    1.00         EA    M008-010                    Y Y Y Y Y Y
  DESCRIPTION OF PART3

1     L2     Part9    1.00         EA    M003-010                    Y Y Y Y Y Y
  DESCRIPTION OF PART9
```

Figure 8.17 Indented BOM showing only the parts common for the selected variants for all levels.

8.12.3. Indented BOM - Non-Common Only

Both Engineering and Production staff need to easily view the parts differences between variants.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                   Page 1

Explode lower levels is ON
Explode Finished Products is ON
Non-common parts are listed

Effectivity          Variant              Description
08.08.92             10-1001-00001          Variant No. 00001 of 1001
08.08.92             10-1001-00002          Variant No. 00002 of 1001
08.08.92             10-1001-00003          Variant No. 00003 of 1001
08.08.92             10-1001-00004          Variant No. 00004 of 1001
08.08.92             10-1001-00005          Variant No. 00005 of 1001
08.08.92             10-1001-00006          Variant No. 00006 of 1001

Ref          Part     Qty          Units    M00 #    Assy          C.O.     VARIANTS

                                                                            0 0 0 0 0 0
                                                                            0 0 0 0 0 0
                                                                            0 0 0 0 0 0
                                                                            0 0 0 0 0 0
                                                                            1 2 3 4 5 6
1     R3a    Part4    1.00         EA       M003-010         ON R3   1236         Y Y
   DESCRIPTION OF PART4

1     R3a    Part5    1.00         EA       M003-010         ON R3   1236             Y Y
   DESCRIPTION OF PART5

1     L1     Part6    1.00         EA       M003-010                 1176     Y Y Y Y
   DESCRIPTION OF PART6

2     a      Part7   40.00         mm       M003-050
   DESCRIPTION OF PART7

1     L1     Part8    1.00         EA       M003-010                 1176             Y Y
   DESCRIPTION OF PART8
```

Figure 8.18 Indented BOM showing only the non-common parts for the selected variants for all levels.

8.12.4. Indented BOM - Parts for a specified M00#

Production staff need to know which parts are to be assembled at each work station. This report specifies only those parts with the M00# of M003-010.

BOM report for 1001 as at 12:48:40 08 AUG 1992 Page 1

Explode lower levels is ON
Explode Finished Products is ON
All parts are listed
Restricted to M003-010

Effectivity	Variant	Description
08.08.92	10-1001-00001	Variant No. 00001 of 1001
08.08.92	10-1001-00002	Variant No. 00002 of 1001
08.08.92	10-1001-00003	Variant No. 00003 of 1001
08.08.92	10-1001-00004	Variant No. 00004 of 1001
08.08.92	10-1001-00005	Variant No. 00005 of 1001
08.08.92	10-1001-00006	Variant No. 00006 of 1001

Ref		Part	Qty	Units	M00 #	Assy	C.O.	VARIANTS 00001	00002	00003	00004	00005	00006
1		Part1	1.00	EA	M003-010		1234	Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART1													
1	R3a	Part4	1.00	EA	M003-010	ON R3	1236			Y	Y		
DESCRIPTION OF PART4													
1	R3a	Part5	1.00	EA	M003-010	ON R3	1236					Y	Y
DESCRIPTION OF PART5													
1	L1	Part6	1.00	EA	M003-010		1176	Y	Y	Y	Y		
DESCRIPTION OF PART6													
1	L1	Part8	1.00	EA	M003-010		1176					Y	Y
DESCRIPTION OF PART8													
1	L2	Part9	1.00	EA	M003-010			Y	Y	Y	Y	Y	Y
DESCRIPTION OF PART9													

Figure 8.19 Indented BOM showing all parts for M00# M003-010 for all levels.

8.12.5. Indented BOM - Comparison between selected variants

Production and planning staff often wish to know the differences between two or more variants. In this case the variants are at the same stages of development and have the same effectivity date. Only non-common parts are listed as this shows the differences between the variants.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                Page 1

Explode lower levels is ON
Explode Finished Products is ON
Non-common parts are listed

Effectivity           Variant              Description
08.08.92              10-1001-00004          Variant No. 00004 of 1001
08.08.92              10-1001-00005          Variant No. 00005 of 1001

Ref            Part      Qty          Units   M00 #      Assy          C.O.    VARIANTS
                                                                              0 0
                                                                              0 0
                                                                              0 0
                                                                              0 0
                                                                              4 5
1     R3a      Part4     1.00         EA      M003-010          ON R3   1236    Y
   DESCRIPTION OF PART4

1     R3a      Part5     1.00         EA      M003-010          ON R3   1236      Y
   DESCRIPTION OF PART5

1     L1       Part6     1.00         EA      M003-010                  1176    Y
   DESCRIPTION OF PART6

2     a        Part7    40.00         mm      M003-050
   DESCRIPTION OF PART7

1     L1       Part8   1.00           EA      M003-010                  1176      Y
   DESCRIPTION OF PART8
```

Figure 8.20 Indented BOM showing comparison between two variants for the same effectivity. Only non-common parts are listed at all levels.

8.12.6. Indented BOM - Comparisons between a variant at different Effectivities.

As a product evolves the BOM changes, sometimes significantly. There are many situations where it is very useful to be able to view part changes within the same variant at different stages of the evolution.

One major user of this information is the costing clerk who must investigate why costs have changed.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                   Page 1

Explode lower levels is ON
Explode Finished Products is ON
Non-common parts are listed

Effectivity            Variant              Description
01.05.92               10-1001-00003          Variant No. 00003 of 1001
08.08.92               10-1001-00003          Variant No. 00003 of 1001

Ref            Part      Qty           Units    M00 #     Assy          C.O.     VARIANTS
                                                                                 0 0
                                                                                 0 0
                                                                                 0 0
                                                                                 0 0
                                                                                 3 3
1      PCB     Part11    0.05          EA       M008-010                         Y
   DESCRIPTION OF PART11

1      PCB     Part2     0.05          EA       M008-010                1235       Y
   DESCRIPTION OF PART2

1      R3a     Part4     1.00          EA       M003-010        ON R3   1212     Y
   DESCRIPTION OF PART4

1      R3a     Part5     1.00          EA       M003-010        ON R3   1236       Y
   DESCRIPTION OF PART5
```

Figure 8.21 Indented BOM showing comparison between the same variant at different stages of evolution. Only non-common parts are shown for all levels.

8.12.7. Indented BOM - Exploded lower levels

A BOM can be composed of multiple layers. These Mini-BOMs may be totally exploded showing all levels of parts making up the completed BOM. An example of a multiple layer BOM is shown below. The number in the left column indicates the level in the BOM.

BOM report for 1001 as at 12:48:40 08 AUG 1992 Page 1

Explode lower levels is ON
Explode Finished Products is ON
All parts are listed

Effectivity	Variant	Description
08.08.92	10-1001-00001	Variant No. 00001 of 1001
08.08.92	10-1001-00002	Variant No. 00002 of 1001
08.08.92	10-1001-00003	Variant No. 00003 of 1001
08.08.92	10-1001-00004	Variant No. 00004 of 1001
08.08.92	10-1001-00005	Variant No. 00005 of 1001
08.08.92	10-1001-00006	Variant No. 00006 of 1G01

Ref		Part	Qty	Units	M00 #	Assy	C.O.	VARIANTS 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 6
1	PCB	Part2	0.05	EA	M008-010		1235	Y Y Y Y Y Y
	DESCRIPTION OF PART2							
1	L1	Part6	1.00	EA	M003-010		1176	Y Y Y Y
	DESCRIPTION OF PART6							
2	a	Part7	40.00	mm	M003-050			
	DESCRIPTION OF PART7							
1		C0100	1.00	EA	M003-010			Y Y Y Y Y Y
	DESCRIPTION OF SUB-ASSEMBLY C0100							
2		Part21	2.00	EA	M003-010			Y Y Y
	DESCRIPTION OF PART21							
3	a	Part22	1.00	EA	M003-010			
	DESCRIPTION OF PART22							
3	b	Part23	6.00	EA	M003-010	JIG P2		
	DESCRIPTION OF PART23							
2	SW1	Part24	1.00	EA	M003-010	JIG P5		Y Y
	DESCRIPTION OF PART24							
1	D1	Part25	1.00	EA	M008-010			Y Y Y Y
	DESCRIPTION OF PART25							

Figure 8.22 Indented BOM showing explosion of lower levels.

8.12.8. Single Level BOM

The single level BOM does not explode any of the sub-assemblies or Mini-BOMs. The following reports show the single level BOMs for the parent and the C0100 sub-assembly.

8.12.8.1. Single Level - Parent BOM

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                              Page 1

Explode lower levels is OFF
Explode Finished Products is OFF
All parts are listed

Effectivity             Variant                Description
08.08.92                10-1001-00001            Variant No. 00001 of 1001
08.08.92                10-1001-00002            Variant No. 00002 of 1001
08.08.92                10-1001-00003            Variant No. 00003 of 1001
08.08.92                10-1001-00004            Variant No. 00004 of 1001
08.08.92                10-1001-00005            Variant No. 00005 of 1001
08.08.92                10-1001-00006            Variant No. 00006 of 1001

Ref             Part       Qty            Units     M00 #      Assy          C.O.      VARIANTS
                                                                                      0 0 0 0 0 0
                                                                                      0 0 0 0 0 0
                                                                                      0 0 0 0 0 0
                                                                                      0 0 0 0 0 0
                                                                                      1 2 3 4 5 6
1      PCB      Part2      0.05           EA        M008-010                 1235     Y Y Y Y Y Y
   DESCRIPTION OF PART2

1      L1       Part6      1.00           EA        M003-010                 1176     Y Y Y Y
   DESCRIPTION OF PART6

1               C0100      1.00           EA        M003-010                          Y Y Y Y Y Y
   DESCRIPTION OF SUB-ASSEMBLY C0100

1      D1       Part25     1.00           EA        M008-010                          Y Y  Y Y
   DESCRIPTION OF PART25
```

Figure 8.23 Single Level parent BOM.

8.12.8.2. Single Level - C0100 Sub-assembly or Mini-BOM

BOM report for C0100 as at 12:48:40 08 AUG 1992 Page 1

Explode lower levels is OFF
Explode Finished Products is OFF
All parts are listed

Effectivity	Variant	Description
08.08.92	10-1001-00001	Variant No. 00001 of 1001
08.08.92	10-1001-00002	Variant No. 00002 of 1001
08.08.92	10-1001-00003	Variant No. 00003 of 1001
08.08.92	10-1001-00004	Variant No. 00004 of 1001
08.08.92	10-1001-00005	Variant No. 00005 of 1001
08.08.92	10-1001-00006	Variant No. 00006 of 1001

Ref		Part	Qty	Units	M00 #	Assy	C.O.	VARIANTS 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 6
1		Part21	2.00	EA	M003-010			Y Y Y
DESCRIPTION OF PART21								
1	SW1	Part24	1.00	EA	M003-010	JIG P5		Y Y
DESCRIPTION OF PART24								

Figure 8.24 Single Level BOM for the C0100 sub-assembly.

9. INTERACTION WITH OTHER SYSTEMS

Within EXICOM the BOM is the linchpin to the total sales and production process. It is an integral part of most systems and therefore must exist as one only master.

This means that the BOM must cater for the requirements of all departments within the organisation. RBOM has been developed to provide all these aspects.

9.1. Sales Order Entry

The initial entry into the sales/production system is in the form of a Quotation Type Q or Sale Type S. These constitute two of a possible five different forms of the same Sales Order Entry (SOE) system. The other forms being Forecasts Type F, Production jobs Type P and Sales/Production jobs Type SP.

Although the factory produces a series of modules the customer buys a total system which will provide certain functions. According to the requirements for functions, frequency bands and other parameters, modules must be selected from a very wide range. The selection process is very complex as there are a number of mutual exclusivities.

To assist with selection an expert system known as the Configuration System had been developed in 1990, Burns [7] and incorporated into the SOE. This takes the form of a question and answer decision tree which produces a customer specification known as the System Details. This incorporates the selling policy. A second specification known as the Ops Details is also produced. This fully specifies all the modules to be manufactured. The System Details must integrate with the invoicing system while the Ops Details must integrate with the BOM, Material Requirements Planning (MRP) and production systems. Each module specified is a variant within the BOM system.

The total cost to manufacture all modules specified in the Ops Details is automatically extracted from the costing system. A comparison between costs and selling prices for the quotation/sale is presented prior to approval.

Any changes to the Ops Details of an approved sale, after release to Operations, must automatically be flagged and filter down through all other processes. Both System and Ops Details have Version numbers which change if any alterations are made. The version numbers change independently for each level. These version numbers are also held against all other processes within other departments. This allows end of day processing to check that all stages are synchronised. Any differences are reported to allow action to take place. This action cannot be automated as it differs according to the stage of the sale within the production cycle. Once again exception reporting is used for this purpose.

9.2. Forecasting

Production revolves around a monthly forecast rate. A total quantity of systems to be built each month is defined. This must encompass a lead time for componentry of up to 6 months and include a 10-12 week production cycle. Therefore generalised forecasts are defined for the next 8-9 months.

The agreed total number of systems per month are divided into likely major parameters. Factors such as past trends, known quotations and sales staff predictions are all taken into account during this process. The best selection of variants which reflect these parameters are incorporated into each monthly forecast (Figure 9.1).

A Type F forecast for each month is entered into the SOE system. This consists of a list of all the selected variants, at the Ops Details level only, of the SOE system. However being a Type F it is treated differently by the MRP system. Once again these modules are variants within the BOM system.

An attribute is available within the Ops Details of the SOE system known as the Explode Flag. All variants which are part of a forecast have this flag set to Y. When the allocation program is run the variant is automatically exploded through the BOM system into its component parts.

Both Type F and Type P SOE's are treated by the MRP system in the same way as a Purchase Order. They represent a quantity of that product due into the inventory on a defined date. This representation allows products in the Ops Detail level of a Type S sale to be hard allocated or pegged to a forecast or production job.

This process ensures that the forecast for a specific month is not exceeded. Often the variants listed in the forecast are not those actually required by customer orders. A forecast can easily be changed to the correct variants as soon as the Type S sale is received by operations. Whilst is it simple to change the variants the total number of variants of a generic type, using the same printed circuit board, must not be increased without research and consultation.

Forecast - for delivery November 1992

Product Code	Description	Qty	Alloc
10-1001-00001	Variant 00001 of 1001	25	
10-1001-00003	Variant 00003 of 1001	5	
10-1025-03102	Variant 03102 of 1025	100	
15-1329-00011	Variant 00011 of 1329	10	
15-1329-00031	Variant 00031 of 1329	3	

Forecast - for delivery December 1992

Product Code	Description	Qty	Alloc
10-1001-00001	Variant 00001 of 1001	25	
10-1001-00003	Variant 00003 of 1001	2	
10-1001-00004	Variant 00004 of 1001	3	
10-1025-03102	Variant 03102 of 1025	50	
10-1025-03205	Variant 03205 of 1025	50	
15-1329-00031	Variant 00031 of 1329	55	

Figure 9.1 Forecasts for November and December deliveries.

9.3. Production Groups

Each approved SOE is given a production (job) group. This slots it into the correct forecast month for planning purposes. Each production group has a number of attributes.

- Effectivity date.
  This selects only those parts in the BOMs with that effectivity date. This date is selected to be as close as possible to the predicted picking date of the job.

- Manufacturing Goods Into Store date (Mfg GIS).
  This is the date by which all parts are required to be received by the store. Used by MRP as date required for Types F, P and SP.

- Production completion date.
  This is the date when this production should be available for incorporation into Customer Sales.

- Sales GIS date.
  This is the date used to select the correct forecast for a sale. Used by MRP as date required for Type S.

The production group is used by MRP during the allocation process.

9.4. Material Requirements Planning

Each monthly Type F forecast is processed through the allocation program to establish a requirement for all parts listed in each variants' BOM. The program reads each variant in turn. As the Explode Flag is set the BOM is exploded using the effectivity date in the production group to select the correct parts. All requirements for each part are aggregated and finally posted to the inventory as a requirement for the forecast against the Mfg GIS date.

This requirement is displayed on the Purchasing Officer's screen against the forecast number (Figure 9.2). This type of allocation where the requirement is set up but not pegged to any specific purchase orders is known as a soft allocation.

The forecasts are reallocated each week to reflect changes to either a forecast or any of the BOM's, capturing the latest information. Each forecast allocation takes approximately 20 minutes to run.

Finally the Requirements Report is run (Figure 9.3). This once again works by exception only. If there are insufficient parts ordered to satisfy any forecasted requirement by the required date the shortfall is listed on the report. The report is styled as a spreadsheet with the parts as rows and the monthly buckets as columns. The first and last dates of the monthly bucket are printed as column headings. Parts are listed by group (type) and by supplier within that group. This means for instance that all the Philips resistors will be listed together. This simplifies the purchasing task.

As demands are variable and lead times are unpredictable there is no built-in intelligence within this process. It is up to the individual purchasing officer to make decisions on quantities and deliveries based on current information.

Back/Forward Orders

Part No. Part 2 Description of Part 2

Job No.	Customer	Date Reqd	Qty Reqd	Stock Alloc	Total	PO Alloc
Available today					1052	
F11/92	NOV Forecast	15.09.92	725		327	
F12/92	DEC Forecast	15.10.92	753		-426	
F01/93	JAN Forecast	15.11.92	706		-1132	
F02/93	FEB Forecast	15.12.92	721		-1853	
F03/93	MAR Forecast	15.01.93	703		-2556	

Figure 9.2 Screen display for Part 2 showing forecast requirements. The Date Reqd (Mfg GIS) gives 6 weeks from the first picking date until the first delivery for the month.

Requirements Report

Parts for which there is a shortage as at:

Month Starting		16.07.92	16.08.92	16.09.92	16.10.92	16.11.92	16.12.92
Month Ending		15.08.92	15.09.92	15.10.92	15.11.92	15.12.92	15.01.93
Part No.	Description						
Part 1	Description of Part 1					4832	6259
Part 2	Description of Part 2			426	706	721	703
Part 3	Description of Part 3					26	12
Part 4	Description of Part 4			5	5	5	5
Part 5	Description of Part 5						
1							
Part 6	Description of Part 6					9643	12052

Figure 9.3 Requirements Report showing only those parts where an insufficient quantity is in stock or on order. These quantities are for the specified month only and are not aggregated.

9.5. Allocation of Customer Sales to Forecast

As each Customer Sale is approved and released to Operations it is allocated to the correct forecast. The Back/Forward Order display shows all forecasted finished products and all approved sales also as finished products. Each product on a sale is hard allocated (pegged) to a forecast.

Back/Forward Orders

Part No. Part 42 10-1001-00001

Job No.	Customer	Date Reqd	Qty Reqd	Stock Alloc	Total	PO Alloc
Available today					2	
F11/92	NOV Forecast	01.11.92	25	<25>	27	
123/92	Joe Bloggs	06.11.92	<5>	2	22	3
124/92	Fred smith	15.11.92	<20>		2	20
F12/92	DEC Forecast	01.12.92	25	<25>	27	
132/92	Fred Smith	15.12.92	<20>		7	20
145/92	ACME Coy	17.12.92	<10>		-3	7

Figure 9.4 Back/Forward Orders showing all proposed movements for Part 42.

Quantities in < > signify the quantity due out of the inventory or the total allocated quantity against a forecast or purchase order.

Order 145/92 is taking the last 2 from F11/92 and the remaining 5 from F12/92. This still leaves a deficit of 3 modules. Where possible the forecasts are adjusted to satisfy the actual customer orders.

Forecast - for delivery November 1992

Product Code	Description	Qty	Alloc
10-1001-00001	Variant 00001 of 1001	25	25
10-1001-00003	Variant 00003 of 1001	0 *	
10-1025-03102	Variant 03102 of 1025	100	95
15-1329-00011	Variant 00011 of 1329	10	7
15-1329-00031	Variant 00031 of 1329	3	2

Forecast - for delivery December 1992

Product Code	Description	Qty	Alloc
10-1001-00001	Variant 00001 of 1001	30 *	28
10-1001-00003	Variant 00003 of 1001	2	2
10-1001-00004	Variant 00004 of 1001	3	1
10-1025-03102	Variant 03102 of 1025	50	6
10-1025-03205	Variant 03205 of 1025	50	24
15-1329-00031	Variant 00031 of 1329	55	35

Figure 9.5 Forecasts after adjustment to suit actual Customer Sales received.

Back/Forward Orders

Part No. Part 42 10-1001-00001

Job No.	Customer	Date Reqd	Qty Reqd	Stock Alloc	Total	PO Alloc
Available today					2	
F11/92	NOV Forecast	01.11.92	25	<25>	27	
123/92	Joe Bloggs	06.11.92	<5>	2	22	3
124/92	Fred smith	15.11.92	<20>		2	20
F12/92	DEC Forecast	01.12.92	30	<28>	32	
132/92	Fred Smith	15.12.92	<20>		12	20
145/92	ACME Coy	17.12.92	<10>		2	10

Figure 9.6 Back/Forward Orders now show sufficient product forecast to satisfy all known Customer Sales.

This adjustment of the forecasts between variants is a continual requirement as forecasting is never accurate. The ability of the BOM to quickly provide a list of parts which differ between two variants allows the Production Planner to make a judgement as to the feasibility of manipulating the forecast.

The Back/Forward Order status of those parts which are different can be interrogated to ascertain the effects of the change.

9.6. Operations Approval

Prior to approval of any Customer Sale an Operations approval must be given. This is a check to ensure that the delivery date is possible taking into account the content of the sale. There are two aspects to be checked.

- In-house manufactured products.
  Uncommitted product from applicable forecast.
  Design status of all products included in the sale.
  Factory loading.

- OEM (Original Equipment Manufacturer) products.
  This is equipment which is purchased from another manufacturer for inclusion in our sale. The delivery on these products may be longer than our usual delivery.

Once an acceptable delivery has been agreed between Sales and Operations this is recorded in the sale. A Production Group which equates to a monthly forecast bucket is entered into the sale.

The size of the sale is estimated as the number of 'dual channel terminal' equivalents. The factory works on a daily rate of these 'dual channel terminals'. The rather erroneous term 'kanbans' is used to describe the movement of each of these terminals. Therefore they will refer to a daily rate of 10 kanbans.

It is expected that the Customer Sale will be approved shortly after this process. However this does not always follow as approval must wait for payment facilities to be established.

9.7. Production Planning

Each morning and as required at other times, a report is called by the Production Planner to check for any approved Customer Sales which have not been processed. This method of pulling the information is totally reliable whereas waiting for the Sales department to send a copy of the approved sale is reliant on too many other factors.

The same report also reports on any altered approved sales where the Ops Version No. does not agree with the version number held against subsequent processes. The Production Planner may need to reprocess these sales.

The approved sales are hard allocated to the applicable forecast to ensure that they can be delivered by the agreed date. The previously entered Production Group is used to allocate the sale to the correct forecast. It is possible that other sales have been approved since the delivery date was agreed. In this case the forecast may be totally committed. Negotiation for a change of delivery date must take place with Sales. This situation cannot be overcome and is totally dependant on the customer establishing payment facilities.

If necessary the Production Group is changed and the allocation process repeated.

The approved sale automatically appears on the Production Schedule. The previously entered number of 'kanbans' is used to calculate the actual delivery date using the daily rate in the production calendar. The newly approved sale is listed at the bottom of the schedule. A further planning attribute is a sequence number. This is entered by the Production Planner to place the sale into the correct production sequence.

At this stage an incorrect Production Group is obvious amongst others in the surrounding sequence (Figure 9.7).

Production Schedule Report

Job No.	Customer Name	Kanbans	Delivery Schedule	Approval Date	Delivery Required	Prodn Group	Final Assy	Seq
123/92	Joe Bloggs	5	09.11.92	12 08 92	30.11.92	11/92	02.11.92	32
124/92	Fred Smith	20	11.11.92	12.08.92	30.11.92	11/92	03.11.92	33
130/92	Large Customer	120	25.11.92	14.08.92	30.11.92	11/92	05.11.92	34
.								
.								
.								
.								
132/92	Fred Smith	20	17.12.92	01.09.92	20.12.92	12/92	09.12.92	56
145/92	ACME Coy	10	18.12.92	09.09.92	20.12.92	12/92	11.12.92	57
150/92	New Sale	5	19.12.92	20.09.92	20.11.92	*11/92	12.12.92	

Figure 9.7 A section of a Production Schedule Report. Daily Kanban rate of 10 per day.

Final Assembly indicates the calculated date the sale will enter the final assembly stage. All OEM equipment is required by this date.

150/92 approval has been delayed as shown by the Prodn Group which is out of sequence. The * indicates that the sale has not yet been reviewed by an Operations team.

9.8. Production Release

Although the desirable production focus is the Customer Sale there are some processes which benefit from larger quantities. These are as follows :-

- the picking process in the store

- processing by the automatic insertion machine

- processing by the surface mount machine

As the machines each have a maximum number of component cartridges, generally some of these must be changed for each generic product. Every different lead spacing for the same component requires a separate cartridge. The automatic insertion machine only has 64 cartridges. One product exceeds 64 different components and therefore requires two setups.

To address this situation the following method has been developed. A number of Customer Sales are aggregated together into one production batch for the first three processes, picking, surface mount and automatic insertion. This takes economies of scale into account. All subsequent processing is on a pure Customer Sale basis.

The size of a production batch is completely variable and is based on the total number of 'kanbans'. A production batch of one customer is the ultimate aim but this will not eventuate until the picking process is eliminated. However the mechanism is the same regardless of the size of the production batch.

A production group is set up for the production batch. This is linked into the Work In Progress (WIP) accounting system for labour and materials.

Each Customer Sale included in the batch has its production group changed to this new group. This sets up a mechanism to allow all further processing to be called via the production group rather than each individual Customer Sale. Each member of the group will be processed in turn. However it is still possible to process one member of the group in isolation if circumstances dictate.

The type of each Customer Sale about to be released to production is changed from Type S to Type SP. The Production Planner is prompted at this stage to select automatic setting of the Explode Flags for all Finished Products to Y. This can be manually over-ridden for any Finished Product held as stock.

Works orders are circulated to initiate the production of this batch of Customer Sales. Production Engineering check that all applicable Engineering Change Orders have been processed prior to requesting the Purchasing Officer to hard allocate parts to the Production Batch.

The allocation program once again processes each variant within each Customer Sale. If the Explode Flag is set the BOM is exploded and individual parts are allocated (pegged) to the Customer Sale. This allocation includes a quantity for shrinkage if applicable. Although the batch is being processed all allocations and issues are to the individual Customer Sale. This allows comparisons between actual costs for parts and labour with the selling prices for the Customer Sale.

A shortage report for the batch is printed showing any parts which are not in stock for immediate picking. This report can be run for an individual Customer Sale if required.

Shortages may require a Customer Sale to be removed from the batch. If so the production group for that Sale is changed back to a forecast. The remaining batch is reallocated and the shortage report rerun.

Often a shortage can be alleviated by using a substitute part. Although stock of a part mounted on tape for one of the machines is not available it is often also held as a loose part. In this case the BOM will be changed, for this production group only, to use the substitute part. This will often also require the M00# to be changed as the part will be inserted at a different work station.

The BOM will have a new line item against one or a number of circuit references. The normal part will have a closing date of the effectivity of the production group minus one day. The substitute part will have an opening and closing date of the production group effectivity. The normal part will then have an opening date of one day after the production group. If this substitute has been used before the detail line will be found and reopened (Figure 9.8).

```
                       BOM.DETAILS MAINTENANCE    Hide Off    Obsolete
                       ----------------------     Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.            1001
                       R16             2.  Notes
3. Part       Quantity M00#   P flag Assembly Ref  Changes Issue#
0                      0                           0
1                      1                           1
1                      1                           1
2                      2                           2
3                      4                           5

Part9            1.00  M001-010                    8526
20.06.91 05.11.91
Y
Part9            1.00  M001-010
21.08.91 07.02.92 09.02.92
                                                   Y
Part10           1.00  M002-010
08.02.92 08.02.92
                                                   Y
```

Figure 9.8 BOM showing Part 10 is substituted for an effectivity of 08.02.92 in place of Part 9.

9.9. Issue

Once all shortages have been addressed the Purchasing Officer runs the Issue Reports. These are processed as a group but produce individual reports which are frozen until actual picking has taken place. Allocations must not be changed after the Issue Report has been run.

This is the final stage to catch Provisional BOMs. A provisional BOM can be changed without the use of an Engineering Change Order. However once a product is produced for possible sale the history of parts included in that product must be preserved. Therefore the restrictions provided by the Change Order Mode must be invoked. The Issue Report is the final stage prior to picking and manufacturing the product. Therefore this cannot proceed with provisional BOMs.

The Issue Report explodes the BOM for each variant in turn and reports the number of parts required for each M00# work station. This includes rounded-up shrinkage where applicable. Also listed are the number of parts allocated for that M00#. Allocations are not divided into M00#s they are an aggregate. If a part is used in multiple work stations the quantity + shrinkage reported for each M00# is deducted from the total allocated. If insufficient parts are allocated the final M00# will show less parts allocated than required. (Rounded-up shrinkage has deducted too many for previous M00#s.)

A combined picking list is called in the store to aggregate all the frozen Issue Reports into one list. This is sorted by M00# and by part number within M00#.

Labels are produced for each part listing M00# and quantity.

Any actual shortages are recorded on the picking list. These are where less parts than the quantity allocated are found on the shelves.

Once all picking has taken place the Mass Issue program is run in the store. This moves the parts from the computer inventory into WIP. The first stage of this process requests exceptions where less parts were found than were allocated. This changes the quantity to be issued and is recorded on the Issue Report which is archived.

9.10. Machine Programs

Once the BOMs are correct for the production batch the comparison programs can be run to check the machine programs for the Automatic Insertion and Surface Mount machines. This is an automated process working directly from the Indented BOM report for each variant in turn.

Once again the vital information for the machine programs is which part is placed in each position on the printed circuit board for the variant being produced. The position is known as the circuit reference.

This cross reference program also acts as a bridge between the Computer Aided Design (CAD) system and the BOM system. Although it would be possible to develop a BOM directly from the CAD programs the designers do not wish to include that level of detail within the CAD system. They limit the description of the individual part to its shape and value rather than a specific Part Number. After discussions it was decided not to attempt to integrate the two systems.

9.11. Serial Numbers

Serial numbers are produced for all electronic products. Test result cards are indexed by serial number for every product.

Serial Numbers are allocated to every applicable product within a Customer Sale if the Explode Flag is set. This identifies a specific product within a system on the Customer Sale. Reports generated for production list the products and serial numbers for all components of a terminal or 'kanban'.

Interrogation of the Serial Numbers file will list the specific Customer Sale and system within that sale for which the serial number was allocated. The production group is also recorded. It is a simple matter with this information to interrogate the BOM to ascertain which parts would have been fitted for the product. This information is important for spares enquiries and servicing.

It is possible that the allocated serial number is not sent to the original customer. A problem found during the testing process may stop the module being sent to that customer. As each Customer Sale is booked from Work in Progress back to the store the Serial Numbers of all modules, regardless of Explode Flag, are recorded. This Serial Number can be written on the Export Documentation for customs purposes.

Therefore a record is kept of both the original customer for which the module was made and the customer which actually received the module. These will normally be the same.

9.12. Boardline

Not all parts can be inserted by the robotic machines. For varying reasons a quantity of parts are hand inserted on the boardline. This is the last stage prior to the printed circuit boards being processed through the wave solder machine.

Boardline staff were originally employed to make large numbers of the same type of product in a production line environment. This has now changed completely. Separate work stations have been set up for each generic product. It is quite possible that each work station would make ten different variants of their generic product in one day.

This has placed a quite different demand on the staff who were employed for highly repetitious work.

All parts used in the generic product for that work station are placed in bins labelled with the part number and circuit reference. Each bin has a light emitting diode (LED) fitted.

A BOM report is called for each variant in the production run listing all parts for that M00# only. Using the exception principle often a BOM report will be requested which only lists differences since the last production run for that variant.

A PC drives the LEDs on the boardline bins so that only those applicable to the variant being made are illuminated. The worker removes the part from the bin and places it in the printed circuit board using the circuit reference listed on the bin label.

This has allowed extensive flexibility and has reduced placement faults significantly.

9.13. Costing

All costing is based on the BOM. Every part has a cost held within the Material File as a weighted average. On a regular basis the Costing Clerk runs a program which explodes the BOM for every non-obsolete variant and writes the new material costs to a file.

When material costs change significantly they are updated for factory output.

As a product is developed the BOM evolves. Engineers and marketing are always interested in the estimated final ex-factory cost of a product being developed. The costing clerk can query different stages of an evolving BOM to ascertain where and why cost changes are taking place.

A full Costed BOM report is available but its use is usually limited to evolving products or specific queries. Presently only the current weighted average cost for each part is used for reporting. A possible development would be to record more cost history against dates and to allow the costed BOM reports to use the actual cost relevant to the effectivity.

This would aid trying to account for changes in product costing but does have other problems. Often early buys are for very small quantities with significantly higher costs which distorts the true picture.

10. USER REACTION

10.1. Environment

RBOM was introduced into EXICOM on 17th June 1991. At the time EXICOM was in severe financial difficulties as their major export customer had defaulted on a number of very large orders. About 24 staff and management from throughout the organisation were made redundant and within a week of the introduction of RBOM the factory was working a 4 day week for 4 days pay. Sales staff were working a 5 day week with a 5% pay cut. The factory corridor was lined with boxes, three tiers high, of non-standard product, which had been tailored for the defaulting customer and was now not able to be shipped. Morale was fragile.

The contract for the programmer who had written the code for RBOM was reduced to such an extent that he had to leave to find other employment.

The challenge facing EXICOM was extreme. With reduced staff, copious quantities of non-standard product and unfortunately some design difficulties, the company had to be turned around or would be closed by the Australian owners.

Prior to the introduction of RBOM the average time to set up a production batch was 2 weeks. This was a very labour intensive process requiring extensive manual cross checking to address changes to any of the products in the batch. The sudden loss of the export order created a large hole in production. The luxury of a 2 week window to set up a production batch no longer existed. The staff who traditionally processed the batch, performing the manual cross checking were no longer available for that task. Therefore EXICOM was totally reliant on the abilities claimed to be inherent in RBOM.

Using the facilities provided by RBOM the next production batches were set up in 1 day. This is a little shorter than is desirable but was necessary just to keep the factory functioning. Some production batches were very small as each Customer Sale received was put into production almost immediately. However this was only possible for those Customer Sales requiring frequency bands which coincided closely with the defaulted orders for which all components were available.

Design difficulties experienced at the time also meant that major changes were being made to the BOMs for a number of generic products. These changes had to be accommodated within new production batches. Existing product part way through production had to be reworked to the latest design. No product was delivered without the rework being accomplished.

An immediate requirement of RBOM was an ability to cross between the old and new systems to ascertain all differences between the original production job in the old system and the latest design in RBOM. This had not been possible in the old system.

This mechanism was used extensively over the next few months as staff tried to incorporate the non-standard defaulted product, lining the corridor, into new customer orders. This product had to be turned into standard product incorporating the latest design changes.

Rework on any product is undesirable as a certain amount of damage is always possible. In order to sell the last of this product some major changes had to be made. Without RBOM it would have been very difficult to evaluate the feasibility of differing modifications. RBOM made it a simple matter to ascertain how parts required for different variants changed in relationship to each other.

By the end of the 91/92 financial year EXICOM had not only survived but had made a profit for the first time in its history. The part RBOM had played in this turn-around was significant although probably not well recognised by management.

10.2. Breadth of Knowledge

Prior to the introduction of RBOM the ability to maintain BOMs was restricted to 1 - 2 staff. This was a very undesirable situation making the company vulnerable to staff leaving, being sick or taking holidays. The testing and evaluation of RBOM by almost all Production and Process Engineering staff meant that they all became proficient users of the system. Today Production Engineers set up their own BOMs for their developing products. This gives them complete control over their project with the resultant responsibility. Once the variant stops being provisional it is maintained through the Engineering Change Order system and becomes the responsibility of Engineering Support. Although this is still one person many others are capable of standing in when necessary. No longer is the BOM a complex mystical mechanism understood by few. It is an obvious display of the inter-action of different parts at a given circuit reference for all the variants of a generic product. It looks like a spreadsheet.

10.3. Increasing Variants

One of the major problems with the old system was the maintenance of an ever increasing number of variants for a generic product. This is no longer a problem. A new family of products being designed has, prior to the final pre-production run, no less than 56 variants for one generic product. All 56 variants are within the one BOM.

This BOM is being developed by one of the Production Engineers. His only complaint is that there are only 80 columns available on his VDU screen which doesn't enable him to have a vacant column between variants. The addressing of this problem is quite different to the previous problem when they couldn't possibly maintain the number of variants required. At that stage variants only numbered slightly over 30.

10.4. In-house Software

It was a very common occurrence for any BOM or production problems to be blamed on the computer system. The normal solution was to strongly suggest that an 'off the shelf' package should be purchased. After-all why should EXICOM's needs be any different from any other manufacturer? These suggestions are no longer heard from production staff using RBOM. If it is suggested that EXICOM should revert back to a traditional BOM methodology the reaction tends to be very negative.

11. PROBLEMS ENCOUNTERED

Problems with any new computer system tend to fall into two major categories.

- Problems with the design or concept.

- Problems with Version 1 of the software.

This section will describe these problems under these two headings. EXICOM's financial problems, leading to the departure of the contract programmer, has caused the problems in the second category to be addressed at a slower rate than may have been desirable. Prior to the situation described in section 10.1 my role was as the Systems Analyst. My official input into EXICOM's software code had been restricted to the occasional report and emergency editing of programs, under instruction by telephone from the contract programmer. More access than this to the software code was not acceptable to EXICOM management. These changes in circumstances made it completely acceptable for me to have unlimited access to any software. In fact I became totally responsible for the development and maintenance of all EXICOM corporate software without any reduction in my normal duties. This situation continued until early in 1992 when I was able to gradually hand over a number of my previous duties to a newly recruited Manufacturing Co-ordinator.

Even with this rather poor level of support the concept has been working reasonably well with only a few critical problems which had to be addressed immediately. Often problems were of a nature where training and discussions provided a solution.

The following comments are based on the experience gained from the constant use of RBOM for one year.

11.1. Problems with the design or concept

11.1.1. Concept of Effectivity Dates

This has proven to be the most difficult concept for staff to grasp. Previously the BOM system consisted of two categories. A Master BOM which incorporated all the latest changes and a series of Job BOMs (JBOM) which were snapshots of the Master BOM for each production run. It was difficult to keep the Master BOM correctly synchronised for design evolutions and impossible to incorporate design changes for future dates, a facility which is essential for the forward purchase of components.. Prior to any production the JBOM would be amended to ensure that it was consistent for that stage in the evolution of the product.

RBOM is a combination of the Master BOM and all the JBOM's in the one BOM which covers all stages of the evolution. The effectivity date input for any display or report selects only those parts which are valid for that date (unless specifically over-ridden for a screen display only).

11.1.1.1. Changes made after the Effectivity

Initially changes were made to RBOM after the applicable effectivity date had passed. The effectivity date for a production batch was set as the estimated picking date. If delays occurred changes could be made after this date had passed. One rule was that an effectivity date could never be changed as it provides the only link to the valid parts.

Following their previous practice, when the Master BOM was always the latest, the effectivity being used was that of 'today' rather than the correct mechanism of entering the production batch and therefore accessing the correct effectivity date. This caused considerable confusion when the parts were not picked for the production run.

This problem was particularly prevalent with parts added inside Mini-BOMs. As with many of the initial problems a short discussion with those involved solved the problem.

11.1.2. Provisional BOMs getting to the Issue stage

This is an inconvenience rather than a problem. The Purchasing Officer invokes the Issue Report program which takes up to 2 hours to run, depending on the number of products within all the Customer Sales. The program stops if it finds a BOM which is still provisional. The BOM must have the provisional flag removed and the process repeated.

The solution to this problem has been to include the status of the BOM on one of the reports used by Production Engineering during the production setup procedure.

Even with this report being available some BOMs are left in a provisional state by oversight. However the mechanism must remain.

The insistence of this mechanism causes some problems for products at the prototype stage. The number of parts required for a prototype run makes it highly desirable to use the built-in mechanisms for allocation, picking and issue of parts. This requires the BOM to stop being provisional. The Change Order Mode must now be used for all updates to the BOM.

If experience with the prototype shows a requirement for extensive changes to the BOM it is possible to revert to a provisional status. Access to this reversal is restricted and must only be allowed if it is absolutely definite that none of the prototypes could possibly have been released to customers as evaluation product. If any were released, even on the understanding that they were prototypes, records must be kept. Therefore a reversal is not possible as all changes must be made via the Engineering Change Order process.

11.1.3. Variant not in BOM - obsolete product

The conversion process from the old system to RBOM did not include products or variants which were marked obsolete. It was assumed that these products would not be required in the future.

However some obsolete products had been included in some long standing quotations. These are usually first trapped during the forecast allocation process. The programs stops when it cannot find a variant within the BOM system. Each situation is appraised and treated as appropriate. A whole BOM can be converted if it was not part of the original conversion or an individual variant can be set up as though it were a new variant.

The solution is often to change to a current variant. This situation has been exacerbated by changes in staff. New staff do not know the history of products and are therefore reliant on others giving them correct answers. Sometimes the non-availability of a variant within a BOM is an indicator that the product which has been specified is incorrect.

11.1.4. Changing the Manufacturing Option

A number of areas which had previously been seen as major problems were addressed by RBOM. These problems were then forgotten. However the actual effects of some of these solutions were gradually overlooked as were the repercussions of changing options.

It took much investigation to ascertain why parts for a Mini-BOM were not being issued by the store. There had been no obvious change to the content of the Mini-BOM but although the parts were listed and the Effectivities all appeared correct they were not allocated or issued. Finally it was noticed that the Manufacturing Option had been changed from

M - Manufacture in house to
S - Sub-contract.

The effect of this small change was to suppress any action in house as the system assumed that all parts, not P Flagged, were to be provided by the sub-contractor. Those items P flagged are listed on the Mini-BOM which is attached to the drawing. These parts would have been issued to the sub-contractor when the part was ordered.

11.1.5. Maintenance of obsolete variants

One philosophical area is still being debated by the users. This is whether parts for an obsolete variant should be updated. Under the old system where variants shared modular assemblies there was no choice. As an assembly was updated for current product the associated obsolete products were also updated. This may or may not have been correct.

RBOM presently automatically displays all variants, current or obsolete, in the Change Order Mode. This enables a choice to be made as to whether the obsolete variant should be ignored or included in the change.

There is no concern about history not being conserved as the Effectivity date preserves the BOM for any previous production group. However obsolete variants will not be physically tested to ascertain if the change is correct.

At present it is not easy to ascertain whether a variant is current or obsolete. After further discussion it is possible that obsolete variants will be marked in some way on the screen display in Change Order Mode.

There is probably not a definitive answer to this question. The type and reason for the change will probably dictate the handling of each situation.

The normal screen display, not in Change Order Mode, defaults to current variants only. This can be over-ridden if desired.

11.2. Problems with Version 1 of the software

Unfortunately even after extensive software testing bugs and omissions are found during use. RBOM was no exception. Some problems were obvious whilst others were quite subtle and didn't show until a previously used method was found to be missing or behaving differently.

11.2.1. Access Restrictions - once approved

Once a variant of a BOM has been approved and the provisional flag removed no changes may be made to any parts used by that variant, except via the Change Order program. It was found that this restriction was not being rigidly enforced under certain conditions.

If a part is to be changed the status of every variant using this part must be checked. If any are not provisional the part may not be manipulated except via the Change Order program. The validation checking was enhanced to check all variants and the problem was solved.

This restriction was not being passed down to the Mini-BOMs. In fact Mini-BOMs were able to be changed at any stage.

Each Mini-BOM also needed to have a provisional or approved status. This defaults to provisional when a new Mini-BOM is created. The operator is now prompted on exiting a provisional Mini-BOM to indicate if the Mini-BOM is to remain provisional. If it remains provisional further changes are allowed. Otherwise the Mini-BOM has the same restricted access as any other variant. Changes can only be effected through the Change Order program which produces an audit trail.

11.2.2. Adding unconverted Mini-BOMs into products

The conversion process from the old system to RBOM only converted current BOMs and variants. This was a good method to cleanse the database of old products especially those not now belonging to EXICOM. The complete history of these products was kept in a separate location within the computer for interrogation but was not to be part of the current system.

After conversion of the BOMs the applicable Mini-BOMs were converted. Prior to conversion of each Mini-BOM the converted BOMs were interrogated to ascertain if the Mini-BOM was in use within the current BOMs. Only those in use were converted.

Each Mini-BOM has a part number within the Material File. It is this part number that is listed against the BOM. Therefore it was possible to incorporate a Mini-BOM into a product without realising that the contents had not been converted. This usually referred to a new Mini-BOM which had not yet been included within any product or the reuse of a older Mini-BOM.

RBOM must query the BOM.DETAILS file to ascertain if the Mini-BOM is in existence. This has not yet been put in place as the problem is of low priority.

11.2.3. Addition of a C0100- Assembly to an existing BOM

A C0100- assembly is very similar to a Parent BOM. It must have the same variants as the Parent BOM. Therefore the mechanism to add a C0100- assembly to an existing BOM requires the Parent BOM's variants to be copied to the BOM.HEADER of the C0100. The original conversion to RBOM copied the variant list from the Parent to the C0100 as part of the process.

This mechanism had been overlooked in Version 1 of the software. Use of C0100- assemblies is generally to be avoided but is extensively used in one product family where each printed circuit board was set up as a C0100- assembly. The preferred method is to set up separate generic BOMs where product consists of multiple printed circuit boards.

If necessary these generic BOMs can become part of another BOM by including the R9060- Finished Product code.

At the time the BOMs for this family were set up there was considerable discussion as to the best way to handle the product. The engineer's wishes prevailed but experience has shown that the use of multiple C0100's was not a wise decision as is shown in the next section.

The mechanism to copy the Parent BOM variants has since been included in the initial setup of the BOM.HEADER for the C0100. The operator is prompted for the number of the Parent BOM. The variants listed against the Parent are copied to the C0100.

11.2.4. Spares utilising only one C0100 assembly

The designs for the family of products using the C0100- assemblies for multiple printed circuit boards have since been sold to another electronics company. However EXICOM will continue to manufacture the product for some months.

The new owners do not want to receive the total product at once. They wish to order each printed circuit board separately possibly in different quantities.

The BOMs had not been structured for this type of production as C0100's are only Phantom Assemblies, not necessarily any form of finished or even semi-finished product. Therefore separate product codes were set up for each required C0100- assembly. This product code could include multiple C0100 - assemblies.

The inclusion of a new variant within RBOM provides for the copying of the most similar variant or none. In this case only some of the many C0100s were to be copied to the new variant. This requirement had not been foreseen.

A new program was written for this specific situation.

11.2.5. Need to know when a variant has been added

When the BOMs were converted from the old system all variants were current and existing. After RBOM had been in existence for a while an insidious situation began to be noticed. A report would show parts for variants within the BOM. These parts may have been those converted in June 1991. A closer look at a report for an earlier effectivity, with knowledge of the products, showed that some of the listed variants had not been designed at the effectivity date of the report.

A single BOM covering the roles of Master and Production BOMs must include an initialisation date for each variant. Part of the validation checking for reports etc must first validate that the requested variant was valid at the effectivity date specified. Reports must exclude those variants which were not in existence at the specified effectivity.

A common requirement is for a report listing all current variants. In this case instead of listing the variants required an * is input by the operator. A variant which has been added to the BOM after the effectivity date specified is not in fact 'current'.

This situation has been acknowledged but not as yet addressed. It is not of high priority but will become more important as time progresses.

11.2.6. Too many variants for screen display

The BOM DETAILS screen display distributes the variants evenly across screen (Figure 11.1). This makes the screen easy to read. However there are only 80 columns available on the standard monitor. Once the ability to handle a large number of variants was introduced the limitations of an 80 column screen became obvious. Up to 40 variants give one spare column between each variant. More than 40 variants eliminates the spare column (Figure 11.2).

```
                                 BOM.DETAILS MAINTENANCE               Obsolete
                                 -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.              1001
                         R16                2.  Notes
3. Part        Quantity  M00#   P flag  Assembly  Ref  Changes Issue#
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 4 4 4 4 4 4 5 5 5 5
2 2 2 3 3 3 3 4 4 1 1 1 1 2 2 3 1 1 1 1 1 2 2 2 2 1 1 2 2 3 4 1 2 3 4
3 4 5 1 2 3 4 2 4 1 2 3 4 1 2 1 1 2 3 4 5 1 2 3 4 1 2 1 2 1 1 1 1 1 1

Part6            1.00   M001-010                        8526
                  Y Y Y Y Y Y Y             Y
Part7            1.00   M001-010
Y Y Y Y Y Y Y Y Y                                             Y Y Y Y
Part9            1.00   M001-010
                                                  Y Y Y Y Y Y
Part24           1.00   M002-010                        9003
                                Y Y Y Y Y Y   Y Y
```

Figure 11.1 BOM.DETAILS screen display showing up to 40 variants with one spare column between each variant.

Another feature is shown very well by this screen. Part6 for variant 01322 appears to be in the wrong place. Many errors have been found by the patterns formed by the flags. As all variants are arranged in numerical order patterns are very meaningful. This presumes that the variant code is itself meaningful. The advantages of this are obvious.

```
                                        BOM.DETAILS MAINTENANCE                Obsolete
                                        -----------------------    Effectivity 08.02.92
nn Options Hide Effectivity eXit FIle
PRODUCT NO.            1001
                       R16                   2. Notes
3. Part      Quantity  M00#   P flag  Assembly  Ref  Changes Issue#
0000000000000000000000000000000000000000000
1111111111111111111111111111111111111111111
1111111112222222233333333444444555566666666
2223333441111223111112222112234123411122345
3451234241234121123451234121211111112312111

Part6           1.00   M001-010                       8526
         YYYYYY      Y
Part7           1.00   M001-010
YYYYYYYYY                   YYYY
Part9           1.00   M001-010
                        YYYYYY    YYYYYYYY
Part24          1.00   M002-010                       9003
                YYYYYY YY
```

Figure 11.2 BOM.DETAILS screen display showing over 40 variants without a spare column between each variant.

This situation was initially only a problem when the obsolete variants were displayed. This tended only to be in Change Order mode therefore only affecting one operator. Although it is difficult to line up the correct variant it is not impossible as the depth of the screen is not great.

Development of a new range of products with high variability produced no less than 56 variants prior to any production. None of these were obsolete. This started affecting more operators, particularly the Production Engineers who were setting up the provisional BOMs.

There are many possible mechanisms to overcome this situation. The screen could be scrolled left to right or divided into two or more separate pages. However the operators wish to see all variants at once to make full use of the pattern recognition. Therefore the use of a 132 column screen is being investigated.

11.2.7. Too many variants for printout

The BOM reports layout listed the variants and flags on the right hand side of the printout as a continuation of the details against a part number. This very much reflects the rows and columns of a spreadsheet. Each variant 'column' was set at a spacing of 2 characters. The increasing number of variants in the new products exceeded the available number of characters causing the printout to wrap to the next line.

The mechanism acceptable on the screen, deleting the separating column, was not practical on a printed report due to the length of each page.

This same situation is common with spreadsheets. Often separating columns of vertical lines are used to aid the reading process. This mechanism was adopted with the BOM report. Initially groups of 3 variants were printed together. Each group is separated by vertical lines. The eye can easily judge whether a single 'Y' in a group is positioned left centre or right within the column. The correct variant can be assessed from the position. This mechanism could be extended to groups of 5 without loss of clarity (See figures 11.3 to 11.5).

Number of columns with groups of 1 variant = 40
Number of columns with groups of 3 variants = 60
Number of columns with groups of 5 variants = 66

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                    Page 1

Effectivity                 Variant                     Description
08.08.92                  10-1001-01123            Variant No. 01123 of 1001
.
08.08.92                  10-1001-01651            Variant No. 01651 of 1001
                                                                .
Ref            Part      Qty          Units                              VARIANTS
                                                          0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
                                                          1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
                                                          1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 3
                                                          2 2 2 3 3 3 3 4 4 1 1 1 1 2 2 3 1
                                                          3 4 5 1 2 3 4 2 4 1 2 3 4 1 2 1 1

1      R16       Part6     1.00         EA                                    Y Y Y Y Y Y
   DESCRIPTION OF PART6
1      R16       Part7     1.00         EA                Y Y Y Y Y Y Y Y Y
   DESCRIPTION OF PART7
1      R16       Part9     1.00         EA
   DESCRIPTION OF PART9
1      R16       Part24    1.00         EA                                                Y
```

Figure 11.3 Indented BOM showing groups of 1 allowing 40 columns.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                    Page 1

Effectivity                 Variant                     Description
08.08.92                  10-1001-01123            Variant No. 01123 of 1001
.
08.08.92                  10-1001-01651            Variant No. 01651 of 1001
                                                                .
Ref            Part      Qty          Units                              VARIANTS
                                                          000 000 000 000 000 000 000 000 0
                                                          111 111 111 111 111 111 111 111 1
                                                          111 111 111 222 222 233 333 333 3
                                                          222 333 344 111 122 311 111 222 2
                                                          345 123 424 123 412 112 345 123 4

1      R16       Part6     1.00         EA                   |   |   | YY|YYY|Y  |   | Y |
   DESCRIPTION OF PART6
1      R16       Part7     1.00         EA                YYY|YYY|YYY|   |   |   |   |   |
   DESCRIPTION OF PART7
1      R16       Part9     1.00         EA                   |   |   |   |   |   |   |   |
   DESCRIPTION OF PART9
1      R16       Part24    1.00         EA                   |   |   |   |   | YY|YYY|Y Y|Y
```

Figure 11.4 Indented BOM showing groups of 3 allowing 60 columns.

```
BOM report for 1001 as at 12:48:40   08 AUG 1992                                      Page 1

Effectivity                 Variant               Description
08.08.92               10-1001-01123           Variant No. 01123 of 1001
.
08.08.92               10-1001-01651           Variant No. 01651 of 1001
                                                                .
Ref           Part     Qty          Units                         VARIANTS
                                                    00000 00000 00000 00000 00000 000
                                                    11111 11111 11111 11111 11111 111
                                                    11111 11112 22222 23333 33333 444
                                                    22233 33441 11122 31111 12222 112
                                                    34512 34241 23412 11234 51234 122

1      R16    Part6    1.00         EA                   |     |YYYYY|Y    |  Y  |
  DESCRIPTION OF PART6
1      R16    Part7    1.00         EA              YYYYY|YYYY |     |     |     |
  DESCRIPTION OF PART7
1      R16    Part9    1.00         EA                   |     |     |     |     |YYY
  DESCRIPTION OF PART9
1      R16    Part24   1.00         EA                   |     |     | YYYY|YY YY|
```

Figure 11.5 Indented BOM showing groups of 5 allowing 66 columns.

This mechanism is also used for screen displays of the BOM reports and may be utilised within the BOM.DETAILS screen display.

The group of 5 using a 132 column display would allow 110 variants to be displayed.

11.2.8. Receipt of parts specified in Mini-BOMs

A Mini-BOM with a Manufacturing Option of 'S' is to be made by one or multiple sub-contractors. Each process is given a number within the Material file. The alpha preceding the group number is S. The Purchasing Officer will order one or more processes on a Purchase Order from the sub-contractor.

When the parts are booked into the store against the Purchase Order there must be a method to ascertain if this is the last process or if the parts must go to another sub-contractor for further processing. If it is the last process the parts are booked into the main part of the inventory, after suitable inspection, against the number of the Mini-BOM. If there is to be further processing the parts are booked into a processing location within the inventory. The Purchasing Officer is advised to raise a Purchase Order for the next process.

The method used is simple. If the process is the last item within the Mini-BOM it is assumed that the part is complete.

The previous BOM system only held the latest master against a Mini-BOM number. Therefore there was only ever one entry of any process within the Mini-BOM. RBOM holds the whole history of the Mini-BOM using effectivity dates to ascertain the valid parts or processes. Therefore there may be multiple entries of a process depending on how the Mini-BOM structure has been modified over time.

The procedure to ascertain the correct process entry must include a check for validity. The effectivity date for the validity check must be the date the Purchase Order was raised. This date may not always be correct but it is the only date that can be derived.

Once the correct valid process is found then a check must be made to see if it is the last valid process for the effectivity. If so the part is complete.

The fact that Mini-BOMs may change their structure was initially overlooked when Version 1 of the software was written. It is not a usual situation. However a number of processes were combined to remove costing anomalies.

The method used to change the structure of the Mini-BOM was basically to close off every process within the old structure and set up a new line for each required process. The new process numbers were repeats of some of the numbers used in the old structure, but there were fewer of them. This method may not have been the best solution but it made sense to the users, therefore the software must be able to handle the effect.

The effect was product being booked into store against the last process was finding the first entry for the number within the old structure of the Mini-BOM. As there were further entries within the Mini-BOM, namely the new structure, the part was still booked into the processing location instead of being booked into the store against the Mini-BOM number.

Validation of the process number against the Purchase Order date ensured that the correct entry was found before ascertaining if it was the last valid entry for the Mini-BOM.

11.2.9. Where-Used Effectivities and Obsolete

The Where-Used reports provide the following information for any part.

Parent Reference M00# Quantity Product

The parent is usually the product. In this case there is no entry under product. If the parent is a C0100- or a Mini-BOM then the generic parent of this assembly is listed under Product. It is quite possible that a Mini-BOM has multiple generic parents. In this case the entry is as follows:-

in n products

where n is the number of generic BOMs using the Mini-BOM.

Initially all products using the part were listed. This caused confusion when a part was only used in an obsolete variant within a BOM. When the BOM was interrogated an active variant using the part could not be found.

The Where-Used has been modified to default to a display of only those parts which are in current variants. This can be switched to include Obsolete variants on request.

12. FURTHER WORK

12.1. Purge BOM of obsolete or unwanted variants

As a generic product is developed certain expectations are held. These are usually governed by the Design Specification. This specification describes the functional parameters of the generic product and therefore should be a guide as to the variants which should be set up in the BOM.

The initial decisions may be changed based on experience of the design. Many factors may influence the range of variants being offered. It is possible that some of the variants initially set up in the BOM may not be required.

A mechanism is required to totally remove these variants from the BOM rather than simply making them obsolete.

This situation has been highlighted as a result of the ease of using RBOM. A completely new design has been developed for a number of generic modules. The old restrictions governing the practical maintainable number of variants was no longer a factor. Without this restraint the BOM for one generic product was found to contain 56 variants. This was before the prototype runs had been completed.

The major reason for the extended range was that the same functional variants were being used in different types of cabinets (frames) which required different metallic sleeves (shrouds). This would cause a problem for a customer who would not wish to stock spares for each different type of frame. It was therefore decided to have yet another series of variants which did not include the shrouds. A replacement module could use the existing shroud attached to the frame.

Reason finally prevailed and the decision was made to list the shrouds as part of the frame BOM rather than the individual modules.

The ease of using RBOM with a large number of variants had hidden another problem. Now the invalid variants must be removed from the BOMs.

In the future it may be desirable to remove very old variants from an active BOM. This may be influenced by the decision as to whether obsolete variants should be maintained. In this case an archived copy of the BOM will be necessary. The mechanism to be used is still under discussion.

13. PORTABILITY OF RBOM

This thesis has described a BOM suitable for an electronics design and manufacturing organisation. As described in Section 1.6 recent European literature [14,15,25,26,27] also describes the complex product structures required for electronic products. This would indicate that EXICOM is not alone and that there is a definite requirement for an alternative within the electronics industry. The basic flat file structure of RBOM, as described in Chapter 5, is simple and could be transported to almost any existing computer system. The major factor would be the speed of data access. The type of system would govern the indexing requirements. It is this aspect of data access that makes PICK probably one of the most efficient systems available due to the built-in 3 dimensional data structure.

The attributes listed in the files can be extended to suit any other industry. For example in BOM.DETAILS a drawing version number or batch number could be added. If these change often it could lead to very long BOMs but the ability to trace these to the exact production run may be essential. A system of archiving BOMs at regular intervals may be adopted to avoid major size problems.

To allow this concept to be transported to any other system, PICK or otherwise, does require the same basics as for the modularisation of any BOMs. Unique part numbers must be available and the existing 'Parts Listings' must be correct. However once the matrix has been derived, showing which parts are common and which are option or feature dependant, the last normal step of destroying the matrix is not invoked. Instead the matrix is entered into the database.

A decision will need to be made as to which products, options, features etc belong within the same generic BOM. A guide can be taken from EXICOM's experience. The governing factor has been the printed circuit board and associated circuit diagram. A bead manufacturer may use the string length as the common factor. A lamp manufacturer may group together all desk lamps.

Generally items within a BOM will expect to have a relatively constant set of options. A lamp manufacturer may have options of:-

Stands, Shades, Bulbs, Supports, Colours, Hardware, etc

If one of the options is not required it can be omitted without difficulty. However it is very obvious that the option is not fitted.

As each 'part' called up in a variant can be another Parent, at a lower level, RBOM can act as a check list. A manufacturer assembling Motor Mowers may have a BOM for different assembled products listed in his catalogue. He may mix and match many options using the reference in RBOM to ensure that he has all requirements listed.

	a	b	c	d	e
Motor					
2 stroke	Y		Y	Y	
4 stroke		Y			Y
Chassis					
Steel	Y	Y	Y		Y
Aluminium				Y	
Wheels					
15 cm			Y	Y	
20 cm	Y	Y			Y

etc

Each of the options probably has its own RBOM listing every nut and bolt or alternatively they may be bought-in parts. This type of display is often reflected as a Matrix in the catalogue of many suppliers and will be familiar to many readers.

Wherever it is desirable to reference a physical 'position' or attribute and record which part or option is to be fitted, RBOM offers an easily understood mechanism. A chemical manufacturer may vary the quantity of ingredients according to the potency of the individual product.

	a	b	c	d	e
Expensive ingredient No 1					
1%	Y	Y	Y		
2%				Y	
5%					Y
Water					
50%	Y				
40%		Y			
30%			Y		
20%				Y	Y

A baker may use a similar structure for variety breads.

The similarity of RBOM to the familiar spreadsheet must not be overlooked. However it is a database and forms the foundation to all other logistics, costing, production and possibly sales order manipulation.

The portability of RBOM is restricted only by the imagination. Each situation will be different but the principles as proven by EXICOM's experience, work in the real situation.

14. CONCLUSIONS

The aim of this study was to develop a method which adequately represented the structure of complex industrial products in a form useable by all the various departments within a design and manufacturing organisation. The main users of the system were to be the multiple Engineering departments who design the product and maintain the Bills of Material, Logistics who obtain and store the parts required to make the product, Production who assemble the products, Costing who need accurate, timely information for costing and Sales who must be able to correctly specify the product for the customer and predict likely income.

The users within the Engineering departments had found the traditional methodology almost unworkable due to the high variability of the products constituting each family group. The aspect of alternatives within options is not well addressed by the normal modularisation techniques, and often the important product structure information is completely lost. Continual changes and extensions to the product range, as is required in the 1990s to address market forces, must be simply implemented without requiring major restructuring of the Bills of Material.

The inter-relationship of different variants within a product family must be obvious to Engineering, Production and Logistics. The commonality of parts between the variants being made in a particular production run may be more important than the commonality across the complete family.

Redundancy and economy of computer storage, prime factors in the 1960s, are no longer important with the cost and power of computers in the 1990s.

The Relational Bills of Material as developed in this thesis, based on the matrix principle, listing the part used in each position for every variant within a product family, involves an extensive amount of redundant information. However this is a small price to pay for the visibility of the inter-relationship of parts between variants and the ease of maintenance of the information.

Common parts are derived 'on the fly' whenever that information is required. With careful programming this mechanism could be transported into other systems such as the MRP system to derive this information through some pre-processing prior to the net requirements being calculated. In this way overplanning of non-common parts only could be achieved.

The mechanism for maintenance of the information is obvious and simple employing the principle of a matrix or spreadsheet. Experience has shown that staff can be easily trained to maintain very complex family groups using this system. The printouts provide an obvious communication mechanism to convey changed requirements especially when only those affected positions (circuit references) are printed.

Chapters 9 and 10 describe the interaction with other systems within the organisation. These are all fully integrated with the BOM and utilise the information, mainly using exception reporting. The effects have been enormous. EXICOM has survived a major crisis due to the ability to respond rapidly and recycle non-standard product. Production set-up time has been slashed using fewer people. Boardline staff have met the challenge of adapting to high product variability and are recording a continually decreasing fault rate. All the foregoing have allowed an effective planning system to be introduced which is based on a daily rate. Due date performance has improved significantly due to many factors. BOM accuracy with all the down stream effects have reduced part shortages and lead to an improvement in the turn-on yield as faults and rework have reduced.

However the major effect of the new BOM has been the ability to add a new variant to any generic BOM, in minutes instead of weeks, without jeopardising any existing variants or taking the BOM out of service. The effect of this simple change on an organisation is immeasurable but the effect of not being able to do so can be very expensive.

The validity of a concept can only really be assessed through a test situation. This Relational Bills of Material system has been in use within EXICOM since June 1991. 15 months experience has proven the concept to be sound in this situation. Staff would be very reluctant to return to a traditional modular BOM.

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16. GLOSSARY

Bills of Material (BOM) A listing of parts required to make a generic product. There may be one or many variants of the same generic product within a BOM.

Chips Usually small SMDs which are glued then soldered to the PCB.

Explosion of BOM The breakdown of a BOM for a variant into the individual component parts.

Finished Product The product or module which is usually produced for sale. Usually this is a variant of a generic product.

Generic A generic product is defined as all those variants using the same printed circuit board and therefore part of the same BOM.

Module A finished product which is produced by the factory. Usually combined with other modules to make a system for a Customer Sale. Each module is normally a variant within a generic BOM.

PCB See Printed Circuit Board.

Printed Circuit Board (PCB) A board consisting of a fibreglass substrate covered in copper on one or both sides. The copper layer is etched leaving tracks which form connections between pads. Pads for all leaded components have a hole drilled in the centre. The component leads are inserted through the holes, trimmed to length and crimped prior to being wave soldered. A 'double sided' board has copper laid through the holes providing a connection between tracks on both sides of the PCB. Pads for surface mount devices (SMD) are not drilled. The SMD is glued to the PCB prior to the soldering process. Areas of the copper which are not to accept solder, all except the pads, are covered by a solder resist coating.

SMD Surface Mount Devices - usually small devices, 1-2mm, often called Chips, which are glued then soldered to the PCB. A special Surface Mount machine is usually used as the SMD's are very small and often unmarked. They are usually packaged on a tape mounted on a reel.

Wave Solder A process where the PCB with components attached is passed over a standing wave of solder in a bath. All exposed tinned copper, without a solder resist coating, accepts a thin layer of solder. Any component leads or SMD's are soldered to the PCB.

Where-Used A chain which links the part (child) with the parent to which it belongs. If the parent is in turn a child of another parent the chain will continue upwards until the final parent is found. The linkages are reported.