version 1.2 12/09/97

Loughborough University

Holonic Product

holon (**hohl**-õn) *n.* the autonomous and co-operative nodes in a hierarchy that behave partly as wholes or wholly as parts, according to the way they are looked upon.

Design (HPD)

holonic (**hohl**-õn-ik) *adj.* of or like a holon. □**holonic product design,** a method employed to make use of systems concepts and modular design.

A Workbook

This package provides a framework for companies who feel that modularity in their product architecture and manufacturing process would assist in providing:

1. flexible or agile manufacturing
2. a rationalised introduction of new technology
3. an efficient means of deploying customer requirements
4. a structured approach to dealing with complexity

Holonic product design (HPD) is a technique or process in which products are designed in a modular form, as oppose to an amorphous whole, the manufacturing system is also designed in accordance to these principles.

This is presented through a generic Product Introduction Process (PIP) in concordance with ISO 9000 and BS 7000 that embodies a process for modular design. Building upon this is a self assessment technique to tailor the process to individual situations. Finally leading to a series of checklists and guidelines to maintain control over the process and ensure that the process becomes an integral part of the company's PIP.

Full benefit will be gained by using this template on top of an existing PIP and integrating the techniques slowly and systematically. To provide a natural and successful process for providing the desired solution using the appropriate level of modularity.

product introduction.

hpd - methodology.

modular design.

manufacturing strategy.

self analysis.

checklists.

guidelines.

HOLONIC PRODUCT DESIGN WORKBOOK - VERSION 1.2.

Russell Marshall
Department of Manufacturing Engineering
Loughborough University
Telephone: +44 (0) 1509 222 929 Fax: +44 (0) 1509 267 725
E-mail: R.Marshall@lboro.ac.uk

CONTENTS

INTRODUCTION

This workbook provides a framework based upon systems engineering and systems thinking, for companies who feel that modularity can address a number of business issues. Through a modular product architecture and an associated modular manufacturing practice, attaining a flexible or agile manufacturing system will be facilitated. In addition this alternative perspective on product design and manufacture will provide an opportunity to strengthen market position through a rational introduction of new technology and customer requirements to the product family.

Section 1. The workbook begins by introducing a product introduction process (PIP) based on two British standards: BS EN ISO 9000 (formerly BS 5750) and BS 7000. This provides a basis of a popular standard to which many companies are accredited that provides a quality management system directly aimed to meeting customer requirements (ISO 9000), and a standard which provides direct guidance on the topic of manufactured goods (BS 7000, Part 2.). A generic systems engineering process is also outlined to highlight the links between the systems framework, the holonic product design (HPD) methodology and the modular design process.

Section 2. Additions to the generic PIP are highlighted and explained in greater depth.

Section 3. Having introduced the PIP the workbook goes on to provide detail on the process of designing for modular products, and how this process fits into the generic PIP. The detail of designing for modular products provides guidance on the process and some of the new issues that must be dealt with for a successful modular design.

Section 4. Complements the previous section by providing detail on the manufacturing strategy for modular products.

Section 5. The next section presents a self assessment to allow the HPD methodology to be integrated into current practice within the company. The self assessment aims to:

- ☑ clarify the reasons for the change to modular product architectures
- ☑ clarify the business strategy and corporate objectives
- ☑ define the required company organisation and working practices
- ☑ provide a platform on which to base the framework of the new HPD methodology
- ☑ examine existing and future products and their features for suitability to modularity
- ☑ provide guidance on the level of modularity suited to the product and the company.

The result from this section should be a clear understanding of what is required in terms of company goals and a modular product. In addition, there should also be a list of benchmarks, priorities and relevant guidelines to the specific needs of the user.

Sections 6 & 7. Provide a series of checklists and related guidelines. The aim of these is to ensure that the HPD methodology is followed and to provide guidance to the employees embarking on a new process and dealing with product architecture in an un-familiar manner. The guidance ensures that the best practice of HPD is instilled within the employees yet avoids imposing inflexible ‘rules’ which are not always practical.

Sections 8 & 9. The final sections provide guidance on maintaining the processes learnt and references to other material that may help address certain needs or clarify specific issues.

It is not the intention of this workbook to provide the solution to a whole product introduction process and the requirements for modularity. There are many good PIP’s in existence and to try to mould companies to any single one over an existing and equally good PIP would be self defeating. The aim to bear in mind is that the PIP and systems process introduced are generic and are used to provide structure to the modularity detail. This then provides a framework into which the company is free to place its existing preferred systems and practices and also allow the method to grow.

THE PRODUCT INTRODUCTION PROCESS (PIP) *Section 1*

AIM >> The aim of this section is: To present the generic PIP and systems engineering process, and to show how the HPD methodology and detail of modular design relate. To allow the users to relate their own PIP to the generic model. And to provide a basis from which to integrate the HPD methodology into the generic model and thus the individual custom PIP's.

The key to HPD is that it is a fresh approach to the development of products. In order to provide the necessary degree of relevancy, material and ideas are presented that can be related to individual situations. It begins by presenting a generic PIP from which the process can be built. The building will then serve to tailor the process to individual user requirements and to provide a greater understanding by actually performing the tailoring process.

A Generic PIP Based Upon ISO 9000 And BS 7000.

This section presents a product introduction process based on the standards below. The documents provide familiarity through the popularity of BS EN ISO 9000 accreditation, combined with the embodiment of current best practice in the form of the new BS 7000 Part 2.

- ISO 9001 (1994) Model for QA in design, development, production, installation & service.
- BS 5750 Part 4 (1990) Guide to the use of BS 5750 Parts 1, 2, & 3.
- BS 7000 (1989) Guide to managing product design.
- BS 7000 Part 2 (1997) Design management systems: Guide to managing the design of manufactured products.

The process of product introduction has to reflect on two aspects; the customer's needs and expectations, and the supplier's needs and interests. An organisation providing a product has to meet the customer needs and expectations fully but in the most economical way (meeting the suppliers needs) (BS 5750 Part 4 - 4.2.1, 1990). BS 5750 Part 4 presents the design function as the ability to take the customer requirements and translate these in a systematic and controlled way into a specification which defines a product or service. This specification should be such that the product is producable, verifiable and controllable under the proposed production, installation, commissioning or operational conditions. A number of points are highlighted:

- There must be an organised structure, with responsibilities clearly defined.
- Project plans should include:
    1. Identification of responsibilities for each design and development activity
    2. Qualified personnel with adequate resources
    3. Effective communication
    4. Monitoring and control of activities
    5. Timing and review
    6. Verification of design to requirements
- The design specification should comply with the customer requirements and contain all the necessary information from which the design can be created.
- During the process of design of the product, the acceptance criteria with respect to its required performance should be continually evaluated and means for verification should be provided.
- It is likely that changes will occur before the design is complete. These changes must be recorded, and a number of questions should be answered:
    1. Does the product still meet the specification?
    2. Is the fitness for purpose affected?
    3. Are changes to the spec possible in order to accommodate the change?
    4. Are associated parts of the product or system affected by the change?
    5. Is there need for further interface design?
    6. Does the change create problems in manufacture, installation or use?
    7. Does the product still remain verifiable?
- Design verification should be an ongoing process with regular and formal design reviews.

The Product Life Cycle.

Figure .1.
Idealised Product Evolution.

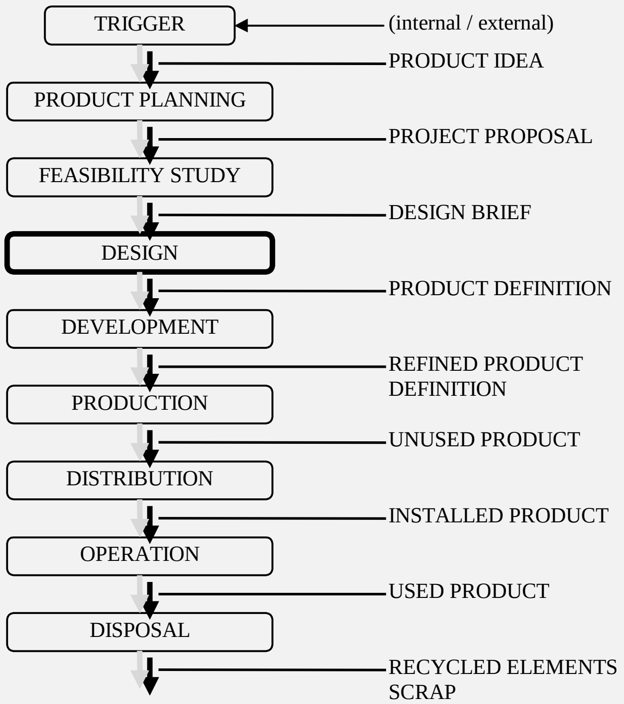


Figure 1. presents a generic product life cycle (BS 7000 1989) and embodies within it a product introduction process. This process covers from the trigger to the product launch (unused product point) and is presented in the following table in more detail (BS 7000 Part 2. 1997):

Phase of project	Process	Output
Concept phase	Trigger for the design project	Perceived opportunities
	Analysis of opportunities	Alternative business concepts
	Analysis of business concepts and product identification	Identification and selection of preferred business concept and product characteristics
	Formulation of the project, objectives and strategies	Preliminary definition and project proposal
	Preliminary evaluation and approval of the project by the corporate body	Permission to proceed
Feasibility phase	Planning, research and feasibility studies leading to the formulation of a project proposal	Criteria of acceptability to organisation
	Refine characteristics. Development of a functional specification	Product design brief
	Development of project configuration and work programme	Project plan. Resource plan
	Evaluation and sanctioning of project by corporate body and commitment of resources	Project approval
Implementation phase	Bringing together of a multi-disciplinary team of specialists to realise the project	Roles and responsibility matrix
	Design concept development. Rehearsing the customer-product experience	Preferred option
	Outline design (embodiment design or general arrangement design)	Product resolution
	Detail design	Specifications for product
	Construction and testing of pre-production prototypes	Confirmation of performance and reliability
	Finalisation of the completed design ready for manufacture. Design support for manufacture.	Product package
	Provisions for manufacture and delivery	
	Product launch	Product availability

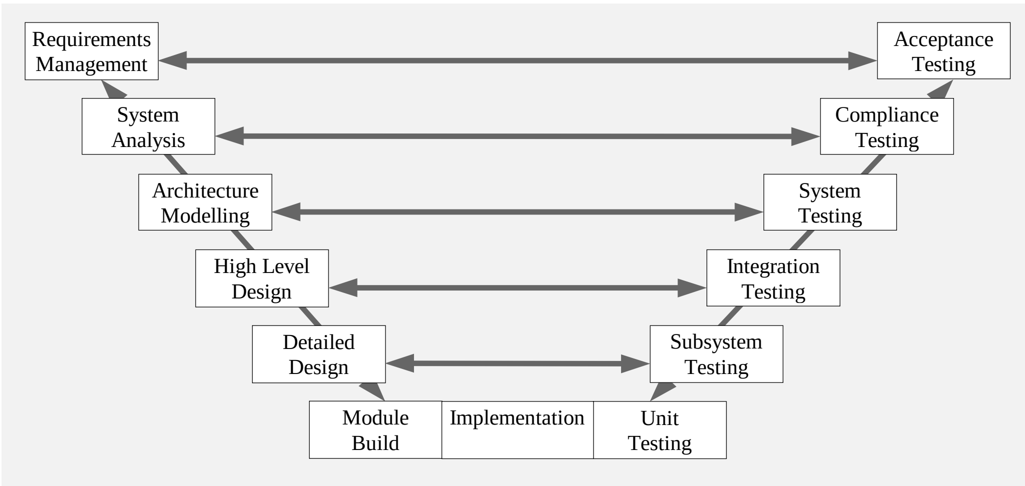
A detailed description of each process will be omitted as further information can be found in the relevant standards but a number of important features are present in this PIP.

- Stages should be undertaken in parallel as often as is possible.
- Concurrency of the work will emphasise good communication throughout the organisation.
- Project teams must be multi-disciplinary - this is extremely important to project success.
- Feedback plays an important part at all stages of the process.
- The process should be front weighted with effort. Effort must be expended in ensuring that things are right first time and that project decisions are sound.
- The awareness of manufacturing requirements must begin at the concept design phase and continue through to the actual manufacturing of the product.
- Customer requirements must be clearly, concisely, completely & correctly captured up front.
- Make use of techniques such as: Pugh concept selection matrices, QFD, dimensional management, DFA, value analysis, etc. where beneficial.
- Potential lies in the previous techniques through accepting and practising the principles and integrating them into an existing PIP.
- The process must take a total view and consider the whole life cycle, as areas outside of the PIP such as support and disposal are factors that are heavily influenced by design decisions.

In order to consider a total view, a systems engineering model is presented in Figure 2. This systems engineering V addresses key stages of modularity such as requirements management and system element interaction and integration in greater depth than the generic PIP. The presentation of this model also allows cross references between modularity, the generic PIP, and the systems engineering V. This highlights the integration of these processes and perspectives. Furthering the aim to integrate into company processes rather than replace them.

Figure .2.
The Systems Engineering V.

(adapted from Walker 1997).



THE HOLONIC PRODUCT DESIGN (HPD) METHODOLOGY *Section 2*

AIM >> This section is aimed to clearly highlight the relationship between the generic PIP, the systems engineering model, the HPD methodology and the modular design process. The relevant changes to the generic PIP that form the HPD process are also presented.

The Concept Phase.

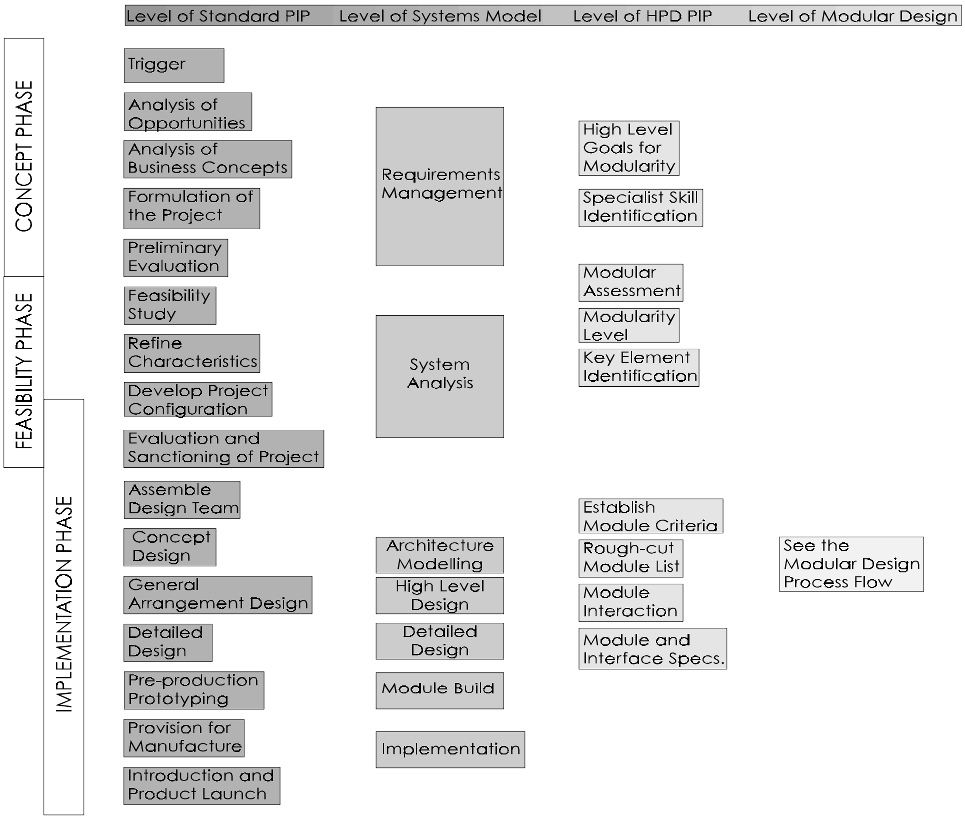
The first stage of the HPD is the concept phase and relates to the generic PIP and systems engineering model through the following processes. During the **analysis of opportunities** and **analysis of business concepts** additional consideration must be given to compatibility with corporate objectives and strategies. It is important that the corporate objectives should provide the foundation and main thrust of all activities, including design. Corporate strategies should be drawn up as prescriptions of approaches to be taken and how resources will be harnessed to achieve the corporate objectives set. These are fundamental company ideals and as such it is recommended that the appropriate corporate objectives and strategies be modified to include the company's wishes for modularity. Projects at this stage must then conform to these criteria.

The use of the corporate objectives and strategy in this way provides a universal platform for the integration of disciplines and the utilisation of resource in achieving business goals in an effective and efficient manner.

Modularity provides an excellent mechanism for enhanced product design, manufacture, testing and service. Used purely as a development methodology it can provide numerous benefits. One aspect of the modularity process is it's inherent capability of dealing with variety. The project should be considered in relation to existing and future products with the view to the development of a family of products to maximise the potential for the modules. Though future products may not yet be defined the capability to add models that use common modules must be considered, if only to be ruled out.

During the **formulation of the project** a project team should be assembled. A project team will involve a multi-disciplinary approach including, for example; design, manufacturing, test, and service personnel, but also have senior management buy-in and be prepared to include specialist personnel whenever required to lend a particular perspective. This team will then oversee the development of the project and make the key decisions along the project life-cycle, whilst maintaining a clear focus on product requirements. Depending on the size and available resource of the company, this team may also be the module team detailed later, but could also be high level body co-ordinating a number of module teams. During this phase specialist skills should be identified that can take a systems view of the design. Any bottlenecks to the change should also be identified, such as poor communication channels and employees unused to the team environment.

Figure .3.
The HPD Methodology and Relations.



The Feasibility Phase.

The second stage is the feasibility phase. During the **feasibility study** a product must be assessed as to whether it is suited to a modular architecture. If the project requires a highly integrated and refined design, where criteria such as weight, size, and functional interfaces are an issue, a modular design may not be suitable aim.

At this stage an idea of the level of modularity must also be agreed by the project team. (*Section 3*, LOM and Section 5, A3 provide further detail on agreeing a level.) Levels of modularity alter the properties of the product and it's flexibility. Levels are defined by three factors: *Complexity*, *Resolution*, and *Composition*, which relate to the degree of functionality, the number, and the standardisation of modules. It is important that a benchmark be set for the project in order for all modules to aim for this agreed level. Key elements of existing and planned products must also be identified to allow targeting of modules during the concept design phase. Key elements may include; specific electronics packages, power supplies, user interfaces, consumable items, and ease of access.

Though there are many benefits of defining certain characteristics toward modularity as early as possible, some companies may not be committed to having modular products that share modules to any large degree, it is therefore recommended that the previous stages be left to the concept design stage, where a modular architecture may form one of a number of options.

The **refine characteristics** stage is where the product design brief is developed. Included in the brief should be the information already gathered such as the level of modularity. It may also be useful, if possible, to assign key elements that that are important, to a module. This is especially true as regards legislated requirements or items related to product reliability.

During the **development of the project configuration** project reviews should be assigned for each step of the design phase. This is especially important due to the added complexity that a modular product and modular way or working may introduce.

The Implementation Phase.

The final stage of the HPD is the implementation phase. This phase represents the main area of activity in developing modular products. In accordance with the PIP introduced we shall present a modular design process that will superimpose itself upon the PIP, specifically those sections labelled as: **assembly of design team, concept design**, **general arrangement design** and **detail design.**

DESIGNING FOR MODULAR PRODUCTS *Section 3*

AIM >> This section aims to clearly define the process of designing a modular product and highlight the necessary steps to be taken to ensure a successful design.

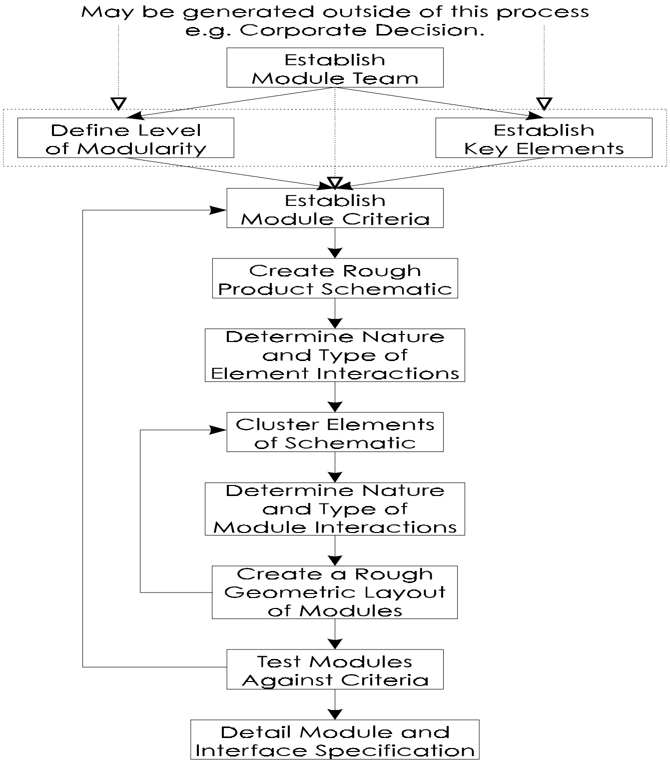
The Modular Design Process.

The process (Figure 4) was developed to be a logical flow based around the formation of a module team and occurs during concept and general arrangement design, early on in the PIP (Figure 3). As an initial activity the team would accept or determine a number of key requirements for the module for which they are responsible. The process of designing a modular product would then exhibit the following key points:

1. Establish team.
2. Define the level of modularity. *
3. Document key elements. *
4. Establish the module criteria. *
5. Create a rough product schematic.
6. Determine nature and type of element interactions.
7. Cluster elements of the schematic.
8. Determine nature and type of module interactions.
9. Create a rough geometric layout of modules.
10. Test modules against criteria.
11. Module and interface specification.

* These are requirements upon the system for modular design. It is important that each requirement is determined very carefully as they will have significant impact upon the outcome of the modular design process. It is possible that the source of the requirements will come from many areas, such as; customers, the company's corporate strategy, company departments, and the team itself, all requirements must be collected and considered for the module criteria. The result is a list of module criteria that function as a design specification.

Figure .4.
The Modular Design Process Flow.



Establish Team.

The initial priority is to establish a multi-disciplinary module team to develop the product. Team members must be familiar with product function as seen by the customer and should be aware that modularity is not just decomposition of a product but that the key is to maintain a total view whilst dealing with specific modules. The team must be co-located, properly resourced, allowed to communicate freely and have responsibility for their strategic direction.

The module team may be based around a core project team, but for a complex product likely to contain many modules, individual teams may be assigned to individual or small groups of related modules. This facilitates concentration of team members and also allows for parallel working. Each team has a representative that forms part of the main project team. Time must be set aside for regular full project group meetings.

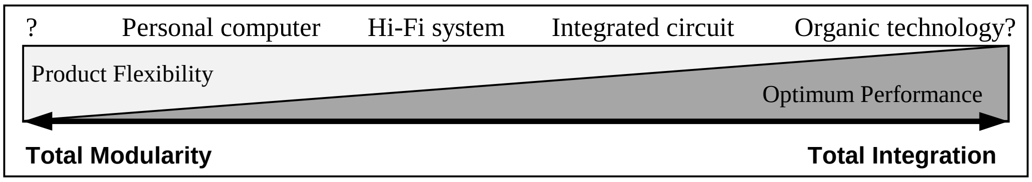
Define the Level of Modularity (LOM).

The level of modularity (LOM) must be defined in order to provide a fundamental direction to the process of defining modules. The level of modularity is defined by three factors:

1. *Complexity* - this is the functional level of modularity for each module. A module can contain anything from a single function to a combination of functions.
2. *Resolution* - this is the number of modules in the product. The number of modules relate to the complexity, where high numbers of modules will likely have low individual functionality
3. *Composition* - this is the degree to which complexity varies within a single product, and whether the product is a hybrid of an integrated common modules and variant modules.

Figure .5.
The Modularity Scale.

See *Section 5*, A3 for a detailed analysis of LOM.



Where products with a high LOM exhibit benefits in terms of flexibility, those with a low LOM act as an integrated whole and tend to be products where optimum performance is critical. There are many critical factors in the decision of the level of modularity.

1. The LOM gives a basis for development of modular products, to maximise the ability to utilise common modules. Products of greatly differing LOM are unlikely to be compatible.
2. The LOM will affect the flexibility and the performance of the product. Though highly flexible modular solutions can perform extremely well, they are unlikely to exhibit the optimal architecture and performance. However this only relates to examples of exacting performance, as non-integrated systems can also be designed to function to very high levels.
3. The LOM will affect the manufacturablity of the modules, and subsequently the product. The more common modules that can be used the more efficient the manufacture. The more complex the individual modules the more complex the manufacture.
4. The LOM will also affect, complexity, robustness (both in quality and flexibility), and cost.

Document Key Elements.

The documenting of key elements is a process whereby any feature that is important to the product is noted. Key elements may include a particular power supply that is required or desired for some reason, a specific software operating system, a particular product branding to be exhibited, a specific standard or legislated requirement to be met. Though these key elements may appear later in the design brief, the product specification or in the concept designs, this early stage in the actual modularisation phase allows these elements to be considered in the modular scheme. A considerable number of key elements may arise from analysis of existing products (see, *Section 5*, A6), such as common elements, implementations or modules to become generic throughout the range.

Establish the Module Criteria.

Module criteria takes the LOM, the key elements, and adds to them specific module requirements. Module criteria are features and functions that are deemed necessary, or essential by the modularity team. Module criteria act as a focus, a reminder and as a benchmark for the design of the modules. Module criteria will be analogous to system and design requirements e.g. Can be tested, Self-contained, Clear access, Totally interchangeable. Traceability and weighting (e.g. mandatory, important, and desirable) should be indicated against requirements. This allows actions to be traced to requirements and also trade-offs to be made if required.

Create a Rough Product Schematic.

Having determined the requirements these are then translated into an initial form for the product. This is done through a diagrammatic representation which represents the agreed understanding of the constituent elements of the product. A schematic is developed using a familiar technique such as FAST diagrams (functional analysis). The elements in the schematic may refer to physical concepts such as a ‘gearbox’, to critical components such as a ‘charge coupled device’ (ccd), or to a functional element that may not yet be described such as ‘deliver power’, or ‘rotate wheel’ (note the verb+noun format, this allows a high degree of freedom for the design process). The schematic should reflect the teams best understanding of the state of the product but does not have to include every imaginable detail. Schematics should avoid over complexity and may be related to the LOM if helpful. If the product is extremely complex the elements should be spit into differing hierarchical levels, each with their own schematic.

The schematic generated is already beginning the process of defining the product architecture, it is therefore recommended that a number of schematics are drawn up to facilitate the consideration of several product feature and architecture types. The best suited to the teams needs should be chosen for further examination.

Determine Nature and Type of Element Interactions.

Interactions between elements are determined to understand the implications of manipulating the elements. The interactions are defined using the product element interaction chart.

Figure .6.
The Product Element Interaction Chart.

		1.	2.	3.	4.	5.	6.
CCD	1.		S	-	E	S	EI
Carriage	2.			-	E	S	EI
Focus image	3.				E	-	EI
Provide power	4.					E	E
Position carriage	5.						E
Control process	6.						

Where the defined elements are plotted against one another in a matrix format. The area where the elements coincide defines the interaction and the interface type is denoted by a simple key based upon Crosfield Electronics and Pimmler & Eppinger's work (1994), where:

M = Material Interaction. E = Energy Interaction. I = Information Interaction.
S = Spatial Interaction. = Fundamental or critical interaction.

It may be beneficial in certain cases to define degrees of the various interactions, such as fluid, or gaseous material interactions.

Cluster Elements of the Schematic.

Once the agreed schematic elements and interactions are finalised, the elements should be assigned to a module. This process is one that must be done purely intuitively by the team but there are a number of points that can be used for guidance.

- The level of modularity that was defined earlier provides a guide to the number of modules that will be acceptable.
- The easiest process is to start with a schematic of one element per module and then group elements where advantageous.

There are also a number of factors in deciding if grouping is advantageous:

- ***Interactions:*** Some interactions will be more critical than others, and some may be easier to perform over a distance. Any interactions between elements that is critical may benefit from the elements being grouped as may interactions utilising mechanical movement which is not sympathetic to being made to function over long distances. The benefit is also seen in manufacturing as the process will be simplified if complex interactions are not split over module interfaces. Interactions that utilise digital signals can be easily separated and may allow for benefit from being in separate modules, as in multiplexed systems.
- ***Geometric location:*** Integrating elements that require geometric alignment between them will benefit from being in the same module, as control of the alignment is done in a localised area or by a single component. This will influence the ease of manufacture especially in low tolerance areas, and will thus effect quality and repeatability, or reusability of the modules.
- ***Function deployment:*** When a single element can implement a number of functional elements of the product the elements can be grouped. This simplifies manufacture i.e. design for assembly (DFA) but may inhibit flexibility as integrated elements will be restricted for use in other products. However there is the possibility of redundancy if advantageous.
- ***Supplier capability:*** A regular supplier to the company may have specific expertise, elements in this area may be grouped to utilise the capability of a supplier to the maximum.
- ***Natural Modules:*** Groups of elements that naturally complement each other and benefit little from being separate are termed natural modules, such as power supply units and electronic packages. They ease the design process and provide additional advantages to manufacturing. They also benefit quality by preventing the split of closely related functions.
- ***Core Business:*** The grouping of elements into modules that contain features, functions and expertise that fall outside of the core business allows them to be provided by a supplier.
- ***Localisation of change:*** If change is anticipated in certain elements through, wear, use, obsolescence or fashion, these elements should have their own modules, such that they may be altered, replaced or serviced without effecting the whole, as in printer toner cartridges.
- ***Configurability:*** Elements should be grouped such that the company may combine modules in differing ways to provide variety if desired.
- ***Standardisation:*** Elements that maybe useful in a range of products should be grouped so that modules can be standard to the product range. These standard modules may form a generic platform or architecture. A generic architecture provides a standard proportion for each product in a family, and introduces benefits for product design and manufacturing through flexibility. In this regard it is recommendation that design of a product should not only include ideas from previously designed products but also bear in mind future products and how they may be integrated with current designs, components, processes, modules, facilities, and tooling etc.

- ***Manufacture:*** Elements that can be combined into a single module by a different manufacturing process such as injection moulding or casting can be grouped, as can elements that require the same manufacturing technique. This can be further extended to the grouping of elements composed of similar materials, not only for ease of manufacture but also for recycling purposes. Elements that can be grouped to provide modules that encapsulate the key features of the product (i.e. not the generic modules) will aid manufacturing if the design allows for these to be introduced to the assembly process late on. This will also speed delivery time as generic architectures can be made up independent of orders and only customised into the ordered products at the last possible moment.
- ***Failure modes and effect analyses:*** If FMEA studies are carried out early on, or previous data is available, the results may be used to group elements with a view to minimising the failures and their consequence.

Determine Nature and Type of Module Interactions.

Once a satisfactory grouping of elements into modules has been performed the nature and type of interactions between modules must be identified. It cannot be taken that the interactions will purely be combinations of those between elements determined previously. The interactions that we are considering here are those at a higher level than the element interactions and will arise due to the physical implementation of the functional elements or due to the geometric arrangement of the modules. These interactions will probably not appear on the schematic and must be identified to ensure that any detrimental effects may be removed.

These interactions will occur at interfaces between modules and these interfaces should be kept to one discrete location for each module to module connection wherever possible. Interfaces should transmit all necessary function between modules and should be designed such that they can readily be assembled and disassembled. Their ease of connection will aid in assembly of the product initially but also at a later date for upgrade or service.

It is strongly suggested that a set of standard interface types and standard interface locations are determined that will be used wherever possible through the product range, and in future products. Thus carry-over modules will have a set of defined interactions associated with them. Standard interfaces ensure that new and existing product modules are compatible, if only in physical connection. It also provides economies of scale, reduced stock holding, and ease of manufacture and assembly. Standard interface locations can aid in the flexibility of the product by allowing changes to the product through upgrade to be simply introduced. There is a further effect that provides a degree of manufacturing flexibility in that tooling for different products can be common if assembly operations occur at the same points.

Figure .7.
The Product Module Interaction Chart.

		1.	2.	3.	4.	5.	6.
Top skin	1.		S	S	S	S	-
Bottom skin	2.			SE	SE	S	S
System board	3.				SI	-	-
Power supply unit	4.					E	-
Fans	5.						E
Drive & Platform	6.						

The interactions are defined using the product module interaction chart. Where the defined modules are plotted against one another in a matrix format. The area where the modules coincide defines the interaction and the interface type is denoted by the key as before.

Create a Rough Geometric Layout of Modules.

Once the elements of the schematic are grouped into modules and the interactions determined, a geometric layout should be created using drawings, CAD, or foam mock-ups. This model forces the team to consider if the groupings can be realised geometrically, and to optimise the manipulation of the modules with respect to the interactions, and to many of the criteria highlighted in the grouping of elements. As with the schematic a number of layouts should be made in order to try out differing solutions. Depending on the results of these layout trials, the process of grouping the elements may have to be revised.

Test Modules Against Criteria.

Having determined the rough module list, modules are tested against the criteria defined earlier. This acts as a check to ensure all desirable criteria are included or considered in the module design. This is especially important in complex products where addressing the details may make the team loose sight of the overall desires. Those modules not meeting the criteria must be looped back and the process performed again. Any particularly advantageous grouping that is in conflict with criteria may also require the criteria to be addressed. If modules contradict a non-essential criteria there may be compromise in the interest of the overall product.

Module and Interface Specification.

When the grouping of elements has formed modules, the modules have been checked against the criteria and the interactions between modules defined, detail specifications must be drawn up for both the modules and the interfaces. These specifications will form part of the standard product design specification but will document the detail regarding a modular architecture.

Interactions documented in the specifications are very important and may be used to structure and manage the remaining development activities. Modules that have many interactions should be developed by a single or few groups that are closely tied. Modules that have few or no interactions can be developed by an independent team or by an outside supplier. If a module is to be developed in isolation there must be strict specification of interfaces with other modules. A number of general good practice points should also be considered.

- Modules should be as simple as possible whilst adhering to the specification.
- Modules must use as many standard parts and subassemblies as possible.
- Modules must be testable independently.
- Separate specifications should be drawn up for each module.
- Use should be made of bought in modules when a module falls outside of the core business.
- Modules should always bear in mind ease of manufacture and assembly.
- Modules should be capable of assembly without adjustment.
- Modules should make use of standard locating features.
- Modules should make use of existing standards, wherever they are appropriate.

Software Considerations.

Software is increasingly a highly functional element of product design. Many products derive a fundamental degree of functionality through their software. Reflecting this, there are a number of points that need to be considered when developing products that have a software element.

Software development should be addressed vary carefully. It is often a feature that is considered to be effectively free, infinitely adjustable, changeable at the last minute and an ideal way to compensate for shortfalls in the basic design. In reality software complexity increases rapidly with the complexity of the problem and, due to temporal dependencies in real time systems, can have extremely complex failure mechanisms. This requires a very rigorous design and test philosophy based around software modularity and it is very important that software requirements are treated with as least as much care as mechanical or electronic systems.

During the **document key elements** phase ensure any software considerations are included, this will then become part of the **module criteria**. The criteria for a software element may in turn have its own criteria. When **determining the nature and type of element interactions** it may be beneficial to highlight those interactions that are made or controlled by the software element. This will allow the domain of the software’s influence to be clearly identified. This boundary can then be used during software development to indicate the interactions with the product modules and the personnel responsible.

When the process of **clustering elements of the schematic** is being carried out a subset of the ***Interaction*** factor may be the desirable feature of grouping elements that are controlled by software to do complimentary functions or to perform simultaneously. There is an advantage to be gained from linking the product architecture to the software architecture, such that changes to software functionality may be mirrored through localised changes to the product modules.

When product modules are determined any software requirements should be included as a module themselves. So that it may be developed in parallel, analysed for interaction with physical modules, and finally integrated with greater efficiency.

Though the software elements are very important they are generally beyond the scope of this process to address significantly here. For further information there are a number of standards related to this area, a good example of which is: BS 5750 Part 13. 1991. Guide to the application of BS 5750 Part 1: to the development, supply and maintenance of software.

The Legacy Factor.

It is unlikely that a company considering the use of a modular strategy for one of their products is embarking on their first product design project. The implications of this are that the company will have it's own experiences and their own existing products, preferred components, systems and suppliers. This section will provide some guidance on dealing with the legacy of previous products and how to manage this legacy for future products.

From the outset this workbook was developed to be integrated into an existing product development process through the generic PIP. The reasons for this are to combine the familiar and useful elements already in place with the improved Holonic Product Design process. This methodology is also taken to the product level where existing elements that are useful or desired are identified for the modular design. *Section 5*, A6 & A7 provide some analysis of the existing product and manufacturing features.

Typically the product and manufacturing legacy presents two attributes that are both constraints and yet possibilities. Existing products that have to be supported constrain the development of new products to maintain compatability between old and new systems. Constraints may also be due to the level of resources invested in specific engineering and manufacturing capability ensuring that a new product greatly different from the 'known' status of previous products is not viable. The possibility is that of self imposing a form of backward compatibility in terms of a generic or common approach to the product.

Backward Compatibility.

Backward compatibility provides a severe constraint upon product development, yet provides a clear possibility for success if the user does not have to replace their existing system on the basis of a new incompatible product. A modular design provides an ideal platform from which to deal with this constraint and maximise its potential. A number of guidelines can be followed to allow maximum freedom for design whilst maintaining the important backward compatibility.

During the **document key elements** phase ensure all compatibility issues are documented fully. If there are elements in the older products that may form a module, develop modules that may in future be used to retro-fit older products and allow a step-change to update them. For example; use new PCB's that have the same footprint as older generations so that they may be used to repair or upgrade old models with the new components, features or interfacing elements. Identify any **module criteria** that will provide flexibility in the product range. Try to provide backward and forward compatibility, this will turn the constraint of backward compatibility into a possibility for a common element for the new and future products.

When **creating a product schematic** clearly identify those elements that will interface to older products. Also maintain this when **determining the interactions**, so that when the **clustering of elements** is performed, those that provide compatibility may be formed into a module. This realises the possibility to supply products that do not need the compatibility, simplify changes to compatibility dependent areas, and ensure that interaction is localised thus easier to ensure full compatibility. Also **cluster elements** to group components, processes and features that are traditionally used so future products may easily replace them if economic circumstances allow.
Try to break the dependency. By using the above suggestions or others that may be specific to your case, move away from being dependent on support of previous products. This will allow greater flexibility in development, reduced problems when there are issues with procurement difficulty, etc. and allow the 'possibly redundant but necessary for compatibility' elements to be phased out at a later date.

Generic Features.

Generic or common elements to products provide a constraint on product development, but with care turn the constraint into a possibility for savings in development time, work, space, and cost. The key to using this feature to advantage is getting it right early on, and also providing flexibility for the unpredictable situations that can, and do present themselves.

Generic elements build upon common features to provide a generic module, platform or architecture that is a physical building block for all products within a range. It embodies the concepts of commonisation and rationalisation. It provides economies of scale such that development, manufacturing, and procurement costs are spread over many products. It eases and speeds development, manufacture, procurement, test, and maintenance, by reducing the number of procedures and features that staff have to be comfortable with. It presents a philosophy that can meet the customers needs for variety, yet through the generic element make the proposition economically viable for the developer.

When developing a product to take advantage of a generic element start by **defining the level of modularity** that suits the product and takes account of a generic platform. Ensure that the concept for a generic element is part of the **key elements** and state if an existing or new module is to be used. **Module criteria** must also give consideration to forward compatibility so that the generic element will have as long a life as possible before modification.

When **creating the schematic** the generic element must be included and carefully considered for the **determination of interactions**. If the nature of the generic element is known (i.e. being used from another product) the process will continue as though two products are being developed that must closely interact and only give the overall required function when combined. When **creating a geometric layout**, try to ensure that a range of module geometries can be combined with the generic element.

Balancing It Out.

It is possible that such a radical change from a conventional integrated architecture product to a modular one may have some disadvantages. There may also be situations when modularity is not always justified for a product or for a specific part of a product. *Section 5* provides a number of analyses on determining suitability and lessening the impact of disadvantages In general the main disadvantages of a modular strategy can be summarised as follows:

- Increase in number and complexity of interfaces.
- Possible increase in part numbers due to redundancy requirements, and extra interfaces.
- Possible increase in assembly operations. (A 6 part product requires 12 operations if assembled serially, three modules of 2 parts require 16 operations plus more fixtures.)
- An increased ‘perceived’ work load and cost through greater resource requirement up front.
- The management of change to the modular strategy.
- Possible increases in weight and size.

The majority of modularity disadvantages can be lessened or removed by careful consideration and implementation of the surrounding framework and support. For example, modularity may cause an increase in part numbers, though is likely to be quite low and could easily be negated by use of DFA techniques. Size and weight also fall into this category, overall reduction in part numbers, and closer product tailoring to user requirements potentially realise a product of equivalent or reduced size and weight. Also, due to the front loaded effort required for modularity, initial project costings and time commitments may look discouraging. However this increased ‘perceived’ work load is easily outweighed by the downstream benefits of such an approach.

Regardless of the specific details of the process to be implemented it is likely to have significant impact upon the company. Of course implementation is likely to be an extremely specific task relative to the organisation in question. The management of change is always difficult no matter the change involved. A management perspective must see the potential and be prepared to overcome teething troubles and re-education of staff in order to achieve long term benefits.

The increase in interfaces should be seen as a key opportunity rather than purely a disadvantage. By modularising and thus decomposing the system, module interfaces will become a priority. This priority will force consideration of the function of the system as a whole. Novel interface solutions and standardisation will aid the assembly and configurability of the modular product.

There will be situations when the application of modularity comes into question. However it can be argued that no matter the constraint it is likely that modularity will not adversely effect the product or its development, as a modularity process is inherently a combination of best practices. This leads to the conclusion that the application of modularity is not a black and white decision. Instead modularity will provide benefit to almost any application no matter the constraints, the issue that must be addressed is the level to which the product is modularised.

MANUFACTURING STRATEGY FOR MODULAR PRODUCTS *Section 4*

AIM >> The aim of this section is to provide guidance on the manufacturing strategy for modular products. The methodology is maintained to promote integration of specific points into an existing manufacturing strategy to compliment the new design process for modular products.

The Manufacturing Advantage.

Manufacturing is fundamental in providing a competitive advantage to the company. The influence of manufacturing is wide spread and often directly affects the customer. These influences include: high quality production, rapid order fulfilment, keeping delivery promises, timely introduction of innovative new products, providing a range of products to satisfy customer requirements, flexible production volumes and delivery dates to customer demands, and the company's ability to offer products at the right price. The implications of this are that the manufacturing function is central to providing competitiveness, and that through a modular strategy, each one of the influences of manufacturing may be facilitated in meeting the five performance objectives of: quality, speed, dependability, flexibility and cost (Slack 1991).

Quality.

This is the objective of not making mistakes. Products must be produced that meet all of the known requirements and are free from errors. There are many initiatives and techniques that aim to provide this capability such as Kaizen, 'right first time' and 'zero defects'. By doing this manufacturing provides a *Quality Advantage* to the company. The influence of a modular product, the manufacturing strategy, and manufacturing's input into the design can help to achieve a high level of quality through modular simplification and parts reduction, ease of assembly, the buying in of non-core modules, simplified and reduced verification and test, and the structured approach to the design and manufacture of the product.

Speed.

This is the ability to minimise the elapsed time between the onset of manufacturing and the customer receiving the product ordered. This provides a *Speed Advantage* to the company. The influence of a modular approach facilitates the *Speed Advantage* through ease of assembly, reduced tooling, parts inventory, part count, and a reduction in process operations. The ability to produce a product that is simpler and has been designed for manufacture and assembly reduces quality problems and increases efficiency and speed of the overall process. Modularity also improves the production time by allowing parallel production and test of modules.

Dependability.

Not only should manufacturing be fast, but also be able to keep delivery promises. Thus, manufacturing should be able to meet customer or self imposed delivery dates with consistency. In doing this manufacturing gives the company a *Dependability Advantage*. A modular approach has a number of characteristics that provide this consistency:

- Simplified assembly of modules implies that the process will have a consistent throughput.
- Modules can be produced in parallel and configured to an individual order in final assembly.
- Modules cab be tested prior to final assembly, moving the impact of test upstream.
- Products are all analogous, thus production times are similar and new products will be relatively easy to plan as they will typically be a new modules on a common framework.

Flexibility.

Manufacturing should be flexible in order to vary and adapt the operation to meet changing customer needs, changes in the production process or supplier changes. Not only must manufacturing be able to change, but it is important that the change is far enough and fast enough. The ability to do this gives the company a *Flexibility Advantage.*

Flexibility is a key feature in a modular approach. The use of modules facilitates manufacturing flexibility through the flexibility of the product. A modular design provides manufacturing with the ability to easily meet design changes for customer requirements by meeting specific customer requirements through a limited number of modules. Thus changes are limited to the manufacturing processes that deal with these modules leaving the rest of the process unaffected. In addition, planned redundancy in modules or interfaces allows for changes with no modification to manufacturing. Finally, a modular approach deals with the issue of flexibility up front in the life cycle of a product so changes are anticipated and allowed for.

Cost.

This means achieving a price that is lower than a competitor can manage. Meaning that resources must be obtained cheaper and they must be converted more efficiently than the competition. In doing this manufacturing provides a *Cost Advantage* to the company. A modular approach can influence the cost of a product by allowing suppliers to produce non-core modules. Thus removing needless capability, the burden of investment in technological expertise, time and effort in production and test, and by providing suppliers with responsibility. Though responsibility may mean some increase in part cost it will ultimately lead to company-supplier loyalty and a greater likelihood of reduced overall costs. Secondly, modular production allows the company to meet the previous four performance objectives and through improved quality, faster production and greater flexibility cost can be maintained at a low level.

These objectives are the building blocks of a competitive advantage from manufacturing. A company should be able to rank the importance of these objectives and how they perform against each of them. Achieving a high level of performance in each of the objectives should be a major priority of any manufacturing strategy.

A Generic Manufacturing Strategy Structure.

Below is a generic structure for a manufacturing strategy (Greenhalgh 1991), and its key elements. The nature of the manufacturing strategy should essentially be dynamic, updated regularly to meet the changing needs of the company, and the markets it serves. The strategy must also be given a time period over which the statements and assumptions are made.

1. **Background**
   a. Function definition
   b. Current situation
2. **Basis for competitive advantage**
   a. The key factors for success in the markets in which the organisation competes
   b. On the basis of the business key factors manufacturing will contribute to the success of the organisation through the following.
3. **Key issues**
4. **Strategic aims**
   a. What must to be done to address the key issues.
5. **Strategic initiatives**
   a. How the strategic aims are to be met.

The manufacturing strategy will now be used as a basis on which to highlight the key points and considerations related to the manufacturing strategy for modular products.

Background.

The aim of this section is to provide a statement as to the precise role of manufacturing over the time period considered, and to provide a perspective for the strategic aims and objectives. The **function definition** and **current situation** sections should also include specific references to the implementation of modular products and modular assembly processes. In order to successfully incorporate a modular design into a manufacturing system, there must be a clear statement of the current situation and the functional aims of manufacturing.

Basis for Competitive Advantage.

When identifying the basis for competitive advantage a list of **key factors for success in each major market in which the company competes** should be developed. The layout of these factors should highlight the influence of a modular product. Highlighting the influencing region provides a focus for defining the **contribution of manufacturing** to the success of the modular product and the success of the company. In addition the influence of the modular product allows the company to avoid allocating resources to areas which have no real impact on success.

Key Issues.

This section covers events, trends, facts or realities which are likely to have, or have had a significant impact on the company and manufacturing in particular. They can be summarised as the issues that have to be dealt with to ensure the long term effectiveness of manufacturing. Identifying and defining the key issues is paramount and requires a thorough and multi-disciplinary analysis. A number of key issues should include the management of change to a modular approach and its implications to manufacturing and to the company. Furthermore key issues should be identified that are influenced by a modular approach in order that the appropriateness of the level of modularity and commitment to this approach may be optimum.

Strategic Aims.

The strategic aims provide direction as to *what* must be achieved within the time period considered and are in direct response to the key issues. The aims are not necessarily a one-to-one correlation with the key issues but it is important to a modular approach that there are a number of issues that must be dealt with. A number of strategic aims include:

- To ensure the maximum benefit from the possibility of parallel production of modules.
- To provide an infrastructure and climate which encourages the work force to contribute to the development of the modular concepts and their production.
- To ensure that module assembly is as simple, responsive and flexible as possible.
- To investigate the possibilities for outsourcing all non-core modules.
- To ensure manufacturing input into module development as early as possible.

Strategic Initiatives.

The strategic initiatives are the statements as to *how* the relevant strategic aims are to be met. These statements must be qualified with an explanation and example of what is to be done. Examples of the initiatives that may be relevant to a modular approach are:

- Elimination of non-value adding activities. This covers the need to address outsourcing of modules but also calls for a tightening and refining of operations in manufacturing.
- Training of shop floor employees. This must be done to educate the workforce as to the new products and manufacturing processes associated with them.

Manufacturing Organisation.

Cellular Manufacturing.

Cellular manufacturing (CM) is an organisational framework that allows a modular approach to system design (Alford 1994) and facilitates the introduction of programmes such as computer integrated manufacture (CIM), just-in time (JIT) and total quality management (TQM). CM expands upon the theory of group technology, grouping products with the processes and personnel required to produce them. These groups form the basic cells from which the whole production process is structured. A cell may be defined by the processes that go into it, and the particular products that require those processes, or by a recognisable product, such as a subassembly, encompassing some part of the production process. The distinction gives the cell its identity, where a process based cell can produce different products yet retain its identity. A product based cell would be linked to that particular product, modification to the processes would not effect the identity of the cell, yet removing the product would remove the cell.

CM has advantages in both of it’s forms but the product based organisation is one that would be complimentary to a modular product. A manufacturing system structured to a cellular form in which cells are linked to modules of the products it produces would maximise the benefit of parallel production, and aid in the planning of production and scheduling tasks. This manner of organisation also provides continuity throughout the enterprise where module design teams will relate to module production teams in the cells of the manufacturing system, and should provide greater links throughout the system and simplified organisation.

It is recommended that a cellular manufacturing organisation of product based cells be given serious consideration. The use of product based cells for individual modules or a strategic selection of similar modules could be integrated with cells that form hierarchies of cells depending on the level of modularity, the size of the manufacturing organisation and the available resources. A high level cell may represent a common platform of a product range which is composed of a number of individual modules and therefore cells. Cells would operate in parallel and feed into a final assembly line or cell. Final assembly would then be responsible for assembly of modules to modules to form the finished product. This system would be fast and responsive allowing generic products to be easily tailored with the specific modules to meet customers need through the introduction of variety late on in the manufacturing process. The late introduction of variety, the ability to buy in complete, pre tested modules, together with simple final assembly all lead to an efficient manufacturing process.

After Manufacturing.

To reflect a total view to product realisation it is important to consider the impact of the product after it has been manufactured. Servicing and maintenance of products and also take-back, recycling and reuse all require serious consideration during the development phase. A modular design allows for the maximum utility to be made of these aspects. Modules can be specified that localise service or maintenance, allowing easy removal and replacement in the field. For the end of the life cycle, recyclable and reusable elements can again be grouped in a module. In fact, modules extend the possible life of a product by allowing common modules to be reused and upgraded, and modules added that contain the new features or technology.

SELF ANALYSIS *Section 5*

AIM >> This section aims to begin a process which allows the generic HPD process to be tailored to individual requirements through analysis of the current situation, the clarification of aims, and the derivation of some metrics, in the form of goals or benchmarks. The self analysis will look at both the business and the product in order to provide a clear basis for a HPD framework.

The following analysis should be carried out honestly. This process is an attempt to provide the maximum benefit to the user and accurate answers will aid in this process. It should ideally be carried out by a multifunctional team, or as a minimum by a senior staff member who has views of both general company, and specific product details.

A1. Qualification analysis - to ascertain if the product is suited to a modular architecture.
A2. Advantage analysis - to ascertain the key business issues to which modularity is to be used.
A3. Implementation analysis - to ascertain the LOM most suited to the product and company.
A3. Groundwork analysis - to ascertain if basic groundwork requirements have been met.
A4. Driver analysis - to provide tailored guidance based on the reasons or drivers for modularity.
A5. Product analysis - to ascertain the possibilities for modularity, and highlight key elements.
A6. Manufacturing analysis -to ascertain how current facilities and practices may effect modularity.

Qualification Analysis (A1):

Please ring as appropriate.

correlation is?	strong	moderate	neutral
1. Does the product to be modularised require an integrated architecture?	3	1	0
2. Is the product sensitive to functional interfaces?	3	1	0
3. Is the product uniform in substance or formed through continuous processing?	3	1	0

Qualification Review: Your responses to the **qualification analysis** are weighted in importance according to the three responses. The summation of the three responses provides a qualification metric. A qualification metric in the range 0-3 indicates that the proposed product will be acceptable as a modular product. A further aid to qualification is the use of the manufacturing grids shown in **Figure 8**. Complexity refers to the variety of products, components, processes, sources of supply etc. Uncertainty is about the volume and stability of demand and the degree to which the product design is static. The shaded area represents the suitability of modular products:

Figure .8.
Modularity Manufacturing Grids (adapted from PA Consulting Group 1989).

Modularity Classification
Complexity

Uncertainty	**High**	**Low**
High	Sophisticated capital equipment	Fashion
Low	Consumer durables	Commodities

Modularity Classification
Complexity

High	**Low**
Aerospace Defence Ship building	Cosmetics Jobbing builders Packaging
Automotive Machine tools Consumer durables	Simple components Paper Commodity tools

Advantage Analysis (A2):

Please ring as appropriate.

correlation is?	strong	moderate	neutral
1. Is the efficient deployment of customer requirements an important issue for your company?	3	1	0
2. Is the rationalised introduction of new technology an important issue for your company?	3	1	0
3. Is a structured approach to dealing with complexity an important issue for your company?	3	1	0
4. Is flexible or agile manufacture an important issue for your company?	3	1	0

Advantage Review: Your responses to the **advantage analysis** are summed to provide the advantage metric. An advantage metric in the range 8-12 presents an excellent opportunity for advantage through modularity, 3-7 an opportunity, and 0-2 little opportunity.

Implementation Analysis (A3):

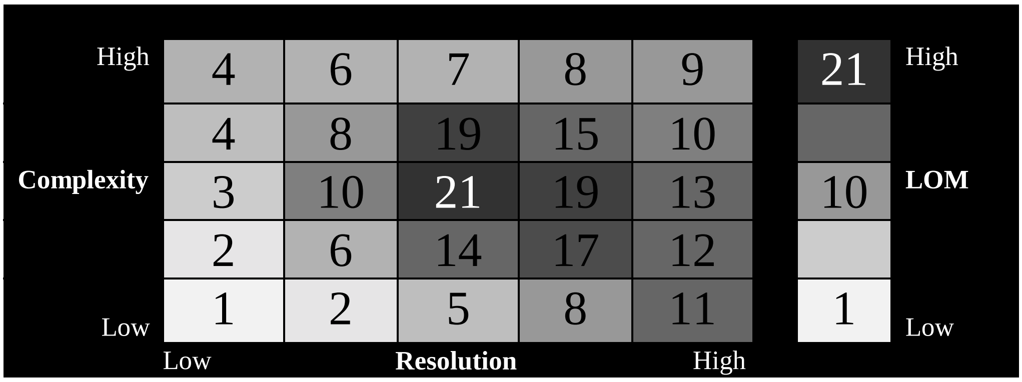
Please ring as appropriate.

correlation is?	strong	moderate	neutral
1. To what extent will the user desire / require configurability of the product?	3	1	0
2. What is the degree of possible commonality between the product and any other?	3	1	0
3. To what extent is the product likely to be modified / updated in the future?	3	1	0
4. How complex is the product and project undertaken?	3	1	0
5. To what extent is the product constrained by manufacturing strategy and processes?	3	1	0
6. To what extent will the product include elements requiring regular service or replacement?	3	1	0
7. What is the degree of possible recyclable / reuseable elements within the product?	3	1	0

Implementation Review: Your responses to the **implementation analysis** are a guide to determine the appropriate level of modularity for your product. The summation of the responses provides the level of modularity metric. A LOM metric in the range 17-21 corresponds to a very high level of modularity, 11-16 a high level, 5-10 a moderate level, and 0-4 a low level. The LOM metric can be related to a broad level of complexity, resolution, and composition, using Figure 9. as guidance.

1. *Complexity* - this is the functional level of modularity for each module. A module can contain anything from a single function to a combination of functions.
2. *Resolution* - this is the number of modules in the product. The number of modules relate to the complexity, where high numbers of modules will likely have low individual functionality
3. *Composition* - this is the degree to which complexity varies within a single product, and whether the product is a hybrid of an integrated common modules and variant modules.

Figure .9.
Level of Modularity Graph.



A further aid to the determination of the LOM is the **permutation chart**. The permutation chart is based on a morphological matrix and is a simple graphical method of exploring the possibilities for module levels and module standardisation. Possible solutions are marked in each column and the desired combination built up by linking solutions from row to row. However, this particular analysis is very subjective and should only form part of an important discussion on the level of modularity suited to the company's products.

Figure .10.
Permutation Chart.

Factors \ Solutions	1	2	3	4
Composition	No common element, all variant modules	Integrated common element	Modular common element	Only a common layout principle
Complexity	Low level of complexity in all modules	Medium level of complexity in all modules	High level of complexity in all modules	Mixed complexity levels in modules
Resolution	Only a small number (2-4) of variant modules	A medium number (5-10) of variant modules	A high number (10+) of variant modules	A variable number of modules to meet requirements

Groundwork Analysis (A4):

Please ring as appropriate.

correlation is?	strong	moderate	neutral
1. Does your company run an active concurrent engineering programme, using multi-functional teams?	3	1	0
2. Does your company have a defined product introduction process in place?	3	1	0
3. Does your company have a clear view of their corporate strategy and objectives?	3	1	0
4. Does your company have a clear product plan?	3	1	0
5. Does your company organisation allow for easy; use of multi-functional teams, communication, adoption of ideas?	3	1	0
6. Does your company know it's reason for developing a modular product?	3	1	0
7. Is your companies product suited to a modular architecture? (See analysis A1.)	3	1	0
8. Is your company committed to providing up front effort and accommodating the changes required for this process?	3	1	0
9. Have you an idea of the level of modularity suited to your product? (See analysis A3.)	3	1	0
10. Have you analysed your current situation in terms of products and future plans / corporate strategy and how they fit with a modular philosophy?	3	1	0

Groundwork Review: Your responses to the **groundwork analysis** are summed to provide the groundwork metric. A groundwork metric in the range 25-30 is acceptable and much of the structure and ground work has been provided to allow a modular design programme to be undertaken However, a perfect score of 30 is desired. These initial questions are to ascertain the readiness of the company for this work, the indication that there are some areas that are lacking requires further work to be done. All responses < 3 should be addressed before any further action is taken.

Driver Analysis (A5):.
Please place in order of preference.

Relating to the questions in A3, your desires for modularity are for:

1. Configurability	
2. Commonality	
3. Modification	
4. Complexity	
5. Manufacture	
6. Service	
7. Recyclability	

Driver Review: Your responses to the **driver analysis** will be used to provide a focus on the different benefits that may be derived from a product with a modular architecture. In addition, though all *Section 7* guidelines are important, specific implementation phase guidelines of interest are highlighted.

1. Configurability:

Module variety, simple assembly, flexible interfaces.
Consider:
- Ensuring modules are easy to assemble and disassemble.
- Placing user specific features in variant modules.
- Provide a generic architecture / module that is common to all products and combines the minimum basic features of the product.
- Ensuring modules are self contained.
- Providing flexible interfaces to allow modules to be combined without modification.
- Guideline numbers: 8-12, 15, 17-22, 25, 27, 32-33, are especially pertinent.

2. Commonality:

Common modules and interfaces, carry-over modules, generic architectures.
Consider:
- A generic ‘platform’ module or modules.
- An open design that allows the greatest flexibility for future product specifications.
- Redundancy to provide the degree of functionality to meet all requirements from a standard.
- Standardising from the bottom up; look at part standardisation, service standardisation, configuration and architecture standardisation.
- Guideline numbers: 8, 10-13, 15, 16, 19, 20, 24, are especially pertinent.

3. Modification:

Localised areas subject to change, common interfaces, upgrades.
Consider:
- Modularise areas that are liable to change through customer requirement or new technology.
- An ‘open’ interface design to provide flexibility for possible future designs.
- Allowing flexibility in the physical size and location of modules for future upgrades.
- Allocating customer specific features to single modules.
- Building in greater potential functionality than may be initially required.
- Guideline numbers: 10-12, 15, 18-22, 27, are especially pertinent.

4. Complexity:

Product complexity and project complexity management.
Consider:
- Utilising module teams to decompose the design project.
- Ensure the total view is maintained and consider systems engineering approaches.
- Linking product module development to manufacturing cell development.
- Decomposing complex systems into modules that combine for a common purpose.
- Use variety modules to minimise complexity, diverting it to configuration for the customer.
- Standardising wherever possible, from components to architectures.
- Guideline numbers: 2-4, 8-9, 12-13, 17, 19-20, 23-24, 28, are especially pertinent.

5. Manufacture: Reduced part numbers and part variety, self location, standardisation.

Consider:

- DFA techniques, look to reduce part numbers, part variety, make parts easy to locate, align and insert.
- Treating complete modules as parts in an assembly, look to make modules self locating, easy to align, and easy to insert.
- Ensure final assembly is all modules. Avoid introducing parts at this late stage.
- Linking modules to manufacturing cells to localise change.
- Introducing variety only during final assembly for maximum order flexibility.
- Guideline numbers: 10, 14, 17, 19-24, 28, 31-38, are especially pertinent.

6. Service: Self contained features that require maintenance or replacement.

Consider:

- Locating serviceable elements in accessible locations.
- Serviceable modules that are self locating for ease of disassembly and re-assembly.
- Grouping all serviceable elements into a single or limited number of modules.
- Guideline numbers: 10, 12, 15-16, 18-20, 22, 26, 35, are especially pertinent.

7. Recyclability: Recyclable or reuseable modules, ease of disassembly.

Consider:

- Modularise recyclable materials by material type.
- Modularise recyclable elements.
- Modularise reuseable or refurbishable elements.
- Ease of disassembly of recyclable modules as this will affect their reuse.
- Guidelines: 10, 16, 18, 27, are especially pertinent.

Though not directly part of the driver analysis the following guidance is presented relating to some popular drivers for modularity. Though they are actually derived from the seven drivers of A5 they are presented as additional guides for convenience.

A. Project management: Divisioning and deploying of responsibilities and work loads, parallel working.

Consider:

- Using separate multifunctional teams for separate modules.
- Decomposing the project into modules that exist around product modules.
- Ensuring modular design is a clear focus from the outset of a new product.
- Guideline numbers: 1-9, 12, 30, are especially pertinent.

B. Lead time to market: Parallel development and manufacture, reduction in reengineering.

Consider:

- Developing separate modules with separate teams in parallel.
- Manufacture modules off the main line, so that final assembly is just assembly of modules.
- Those points for Manufacture and Modification.
- Introduce variants late, so products are not dedicated to specific orders until late as possible.
- Guideline numbers: 3, 4, 7, 12, 15, 17, 31, 38, are especially pertinent.

C. Bought in modules: Bought in modules tested and ready for assembly.

Consider:

- Isolate any areas of non-core business and modularise them.
- Get modules to be fully tested by the supplier, to your specifications.
- Working to a JIT principle with the delivery of modules.
- Guideline numbers: 5, 10, 25, 30, are especially pertinent.

D. Consistent quality: The control of quality in manageable modules with defined traceability.

Consider:

- Keeping critical features of quality in single modules.
- Adopting principles of dimensional control where appropriate.
- Testing modules when complete, prior to final assembly.
- Guideline numbers: 4-6, 10, 14., 23-25, 29, are especially pertinent.

Product Analysis (A6):

Using your existing or precursor product, or prototype:

1. Begin by drawing a schematic or retrieving an original, and listing the functional blocks.
2. Relate the functional blocks to physical groups of components / sub-assy's in the existing product?
3. Identify the boundaries between the *physical* blocks of the product.*
4. If components do not satisfactorily fit into a block, create a new one and link it into the schematic.
5. If there are obvious secondary groupings of blocks in the product, identify these on the schematic.

Having related the product to it's schematic we now begin to identify modularity possibilities.

6. Identify the functional blocks that are necessary in the new product.
7. Identify the functional blocks that would be advantageous in the new product.
8. Identify the functional blocks that would be a possibility in the new product.
9. Ensure that those blocks that have not been identified above have no use in the new product.
10. Starting with necessary blocks, check to see if they can physically cohere as separate assemblies.
11. Further identify the secondary groupings of blocks that can cohere as assemblies.
12. Identify any blocks that may form a secondary grouping once freed from the existing product.

The modules, or basis for modules that can be carried over have now been identified.

13. Identify any blocks or secondary groupings that may form a generic element to a range of products.
14. Identify any blocks key to backward compatibility.

* All components in the product must belong to a block.

Product Review:

Your findings in the **product analysis** can be used to provide valuable material for the new product development. The blocks or secondary groups can be used as modules in the new product with a varying degree of modification. The goal is to make use of as many modules as possible with as few a modifications as possible. The modules should be worked through in order, from necessary to possible, placing them directly into the new product schematic or placing them on the key elements list. Opportunities should be sought to standardise on the interfaces that will likely be poor on the identified blocks.

Manufacturing Analysis (A7):

1. Identify the structure of the manufacturing organisation and obtain the results from A 6.
2. Identify the links between the blocks from A 6. and the manufacturing processes that produce them.
3. Identify any corresponding grouping of processes to the blocks.
4. Aim to mirror the block structure (modules) by grouping processes that manufacture them (cells).
5. Ensure that the processes related to any generic element are grouped separately.
6. Group assembly operations into workstations for the modules.
7. Identify modules that are non-core business and aim to procure them as a total package.

Manufacturing Review:

Your findings in the **manufacturing analysis** will allow the existing facilities and processes to be adapted to maximise the benefit from a modular product architecture. The degree to which this can be done is related to the size of manufacturing operation. Large organisations can aim to mirror the modules by manufacturing cells such that changes to the product are localised in manufacturing and will not effect other parts of the product. Smaller organisations must look toward identifying modules that can be procured totally from one vendor, and to rationalising vendor usage by grouping similar components and materials for procurement.

Assembly should be grouped about modules where possible. This provides efficient assembly by having workstations that run in parallel, leave the definition and thus variety of the product till late on, provide completed modules, allow modules to be tested individually, and provide interesting work and responsibility for the assembly workers. The modules then go to final assembly which can be used to define the final product.

AIM >> This section presents a number of checklists to be completed by those employees involved (programme team) with the HPD methodology. Their function is to aid the application of HPD principles by acting as a framework for the many activities of the programme, a focus for effort, and a visual reminder of the status of the programme. They should be completed and kept in a central location (database / server) to allow all employees involved access to their status.

It is important that these checklists are customised with user specific questions, and preferably linked with a number of further checklists that relate to product development stages not included in this workbook such as, marketing, distribution etc.

Holonic Product Design Checklist.

Checklist 0.

Due Date	On Schedule	Person Responsible		Number
			1. Programme fundamentals complete?	Checklist 1
Item 1 to be completed prior to 2-5.				
			2. Timeliness of overall project: on schedule?	Checklist 2
			3. Self analysis complete?	Checklist 3
			4. Modular design (by team) on target?	Checklist 4
			5. Manufacturing strategy on target?	Checklist 5

Programme Fundamentals Checklist.

Checklist 1.

Due Date	Date Complete	Person Responsible	
			1. Purpose and objectives for modularising product noted?
			2. Benchmarks set and being measured?
			3. Business strategy statement documented and agreed?
			4. Schedule for programme agreed and set?
			5. Total elapsed time required for module definition set?
			6. Adequate staffing to assure schedules?
			7. Vendor participation planned?
			8. End user / customer participation planned?
			9. Team members and leader identified?
			10. Management signoff on modularity vision, levels and spec?

HPD Schedule Timeliness Checklist.

Checklist 2.

Due Date	Date Complete	Person Responsible	
			1. Modularity / Design reviews held per plan? Percent to plan?
			2. Key elements identified?
			3. Module criteria identified?
			4. Internal documentation on schedule?
			5. Hardware module design on schedule?
			6. Software module design on schedule?
			7. Manufacturing tasks on schedule?

Self Analysis Checklist.

Checklist 3.

Due Date	Date Complete	Person Responsible	
			1. Qualification analysis performed and completed?
			2. Current modularity problems / bottlenecks analysed?
			3. Advantage analysis performed and completed?
			3. Implementation analysis performed and completed?
			4. Permutation chart complete?
			5. Groundwork review performed and completed?
			6. Driver review performed and completed satisfactorily?
			7. Product review performed and completed satisfactorily?
			8. Manufacturing review performed and completed?

Module Design Checklist.

Checklist 4.

Due Date	Date Complete	Person Responsible	
			1. Team members identified, and Chair?...................................
			2. Regular team meetings scheduled and attended by team? %..
			3. Team communication channels established?
			4. Level of modularity agreed and understood?
			5. Key elements collected and deployed?
			6. Module criteria documented with traceability?
			7. Rough product schematic drawn up and agreed?
			8. Element interaction analysis performed?
			9. Elements clustered into modules?
			10. Module interaction analysis performed/
			11. Rough geometric layout of modules performed?
			12. Modules tested against criteria?
			13. Module sign off when adherence to criteria satisfactory?
			14. Module specifications drawn up in full?
			15. Interface specifications drawn up in full?
			16. Standard modules identified?
			17. Standard interfaces defined?

Manufacturing Strategy Checklist.

Checklist 5.

Due Date	Date Complete	Person Responsible	
			1. DFMA conceptual analysis performed on modules?
			2. Tolerance studies performed to guarantee assembly fit?
			3. Close tolerances self locating?
			4. Modules designed with location tooling considered?
			5. Benchmark set for ease of module assembly (B-D) %...........
			6. Benchmark set for ease of upgrade?
			7. Benchmark set for ease of service?
			8. DFMA analysis performed on final assembly modules?

AIM >> These guidelines present a comprehensive explanation of many of the principles of the HPD methodology. They are related to the checklists and where relevant should be used to explain the checklist points in greater detail. In addition, the guidelines can serve as a stand alone document for reference of the desired requirements to lead to a successful modular product design and associated manufacturing process.

Concept Phase Guidelines.

1. **A definition of the purpose for modularising the product must be determined.**
   This definition will force a close examination of why modularity is deemed necessary in the new product development, and will act as a benchmark and focus for development

2. **The current situation must be documented to allow mapping to the new objectives.**
   The decision has been made to develop a modular product. What in the current system (product / design process) does and does not match the objectives for the new development system and new product? This identification of factors will aid in tailoring the change

3. **Working practices that may inhibit the change to modular design must be identified.**
   Any part of the product development process must be identified if it may not be suited to the new corporate objectives, and objectives for modular design. These areas can then be modified to allow modular design to take place

4. **A product must be committed to modularity from the beginning.**
   The decision to modularise the product must be made from the earliest possible moment and must then be a key element in the products development. Modularity fundamentally changes the traditional method of integrated design and cannot be done lightly.

5. **The commitment to modularity must include an acceptance of change.**
   For many companies modularity and its implications will be considerably different from their current processes. This transition may cause issues within the company to arise and thus the smooth and flexible handling of these will be essential for the technique to work.

Feasibility Phase Guidelines.

1. **A product must be assessed at to whether a modular architecture is beneficial.**
   A seemingly good product for modularisation may, in fact, be extremely difficult to define into modules and arrange suitable interfaces to other modules. The product in question may also be degraded by a modular architecture. Highly integrated systems where performance is the prime requisite are not suitable for modularity.

2. **A definition must be made as to the level of modularity required, and a limit placed on the degree of modularity, based upon the purpose for the modular product**
   The level of modularity ranges from one module per function; providing flexibility in function configuration but also high complexity and reliability issues. To, one module for a number of functions; providing less flexibility but also less complexity and greater robustness. In-between, standard products with modules for variants provide a balance of these properties. A decision must be made for suitability and then adhered to.

3. **The key elements of existing and planned products must be identified for assessment of module requirements.**
   The key elements of the product range can be targeted for modular design to allow new technology or innovation to effect the market edge of the products in a rationalised manner, without effecting the rest of the product adversely.

4. **Products that exhibit beneficial features must be identified.**
   Any product that has ‘good’ features can be built upon if modular or identified as an area to work around if integrated.

Implementation Phase Guidelines.

Project Management.

1. **The project must be assigned a multifunctional project team to provide expertise from all concerned departments.**
   In addition to the general good practice of using multifunctional teams there is the need for this approach due to the degree of parallel thinking required in complex modular problems.

2. **Modular design should be met by module teams being managed separately.**
   The project can be naturally broken down into smaller more manageable parts. These parts will relate to modules and thus personnel of appropriate fields may work on appropriate modules. Work may also be carried out simultaneously, thus interface problems that will always address more than one module can be worked on from both sides.

3. **The module teams must be multifunctional.**
   Module teams have responsibility for getting the module to meet all its criteria concerning the customer, design and manufacturing. The team must therefore include representatives from all relevant departments and suppliers so that all issues are dealt with at an early stage.

4. **Both project and module teams must have extremely good communication concerning interfaces.**
   Interfaces have special consideration within these guidelines and the process of design must reflect this. The interface definition and communication for interface decisions must be good. This may include a greater number of team meetings at an early stage.

5. **The purpose and definition derived at the concept phase must be deployed into objectives for the team.**
   The initial job of the team is to deploy the high level decisions into objectives for the development of the new product. This initial stage will provide focus for the team in specific design terms which relate to business goals.

6. **The results of the feasibility phase must be integrated into the team objectives.**
   Information from the feasibility phase must be used to provide the basis for the new development. Concerns with existing products can be integrated and built upon, and issues with the development process can be modified to meet the strategic objectives.

7. **Modules must be planned, designed and developed in parallel.**
   Modular design allows for parallel design and development of individual modules and also of the associated processes. Advantage must be taken of this ability to reduce lead times.

8. **Modules must be defined as early as possible within the development process.**
   The work on defining modules is done early on so that major decisions are made before any factors are agreed upon. Thus changes cannot interfere with work done previously. Also increased up front effort will reduce problems downstream.

Process.

9. **Each module must be assigned a number of functions based on the level of modularity.**
   The number of functions per module will be determined by the degree of modularity required, but this factor is very important when defining the modules as it will impinge on the complexity and structure of the modules and product.

10. **Modules must be self contained.**
    The required functionality of a module must be contained wholly within the module. There must be no components that do not belong to a module. A module must be able to be manufactured as a stand alone sub assembly.

11. **Avoid concentrating on a particular product when designing.**
    The team must be aware of variants or possible areas of commonality between other products, existing or future. This insight provides the broadest possible base for standardisation and flexibility throughout a product range or family.

12. **Generic architectures should be determined for all products, and new products should be based on this platform.**
A generic architecture will provide product and manufacturing flexibility. It will provide a framework for new products that will therefore be easier to design to be compatible, and be easier to manufacture with the maximum of reuse of components and equipment.

13. **Standard modules must be used as much as possible to standardise across products.**
HPD gives the advantage of a theoretically large product range with only a relatively small number of specific modules. The use of standard modules can be exploited fully to reduce stock holding, tooling, part variety, etc.

14. **Design to natural modules.**
Modular design does lend itself naturally to existing divisions, such as those between electrical, and mechanical areas. Designing to natural features will improve design quality.

15. **Develop modules for the areas likely to change in future products / revisions.**
If modules can be developed for areas of the product that are likely to change, a number of benefits are gained. A proportion of all products is standard. Instead of total redesign, upgrades and modifications may be made to a limited number of modules, so change to both the product and manufacturing system is limited. This is especially useful to parts the customer sees, or functional areas such as engines (same car, different engine). This is important for highly complex products or products constantly in a state of flux, such as those in high technology industries, where upgrades in products happen very frequently.

16. **Modules must be defined for any parts that are consumable, or that may be removed at a later stage.**
For consumables such as toner, bearings etc. and toxic or recyclable materials, should be contained in a module to allow easy service, removal and replacement, or disassembly.

17. **Modules must be designed such that variety can be introduced late on.**
The use of modules in a products design allows standard modules to be manufactured and then introduced to the final assembly. Thus individual variations are only assembled at the very end of the line, prior to shipping.

Interfaces.

18. **Modules must be designed with great care and attention to interfaces.**
Module use highlights the problem of interfacing the individual modules to one another. Normally these interfaces would not be so well defined, and would not be designed to come apart so readily, or indeed go together so readily thus the new interfaces must consider making all relevant connections between modules at purely one fixed set of interfaces.

19. **Standard interface locations should be determined wherever possible.**
The use of standard interfaces for modules will increase the flexibility of module usage by allowing easier interchange of variant or upgrade modules.

20. **Standard interface types should be determined wherever possible.**
Interface types, connector types and communication standards should all be consistent. This allows easier interchange or replacement of modules, negates incompatibility problems, eases assembly, reduces stock holding, and makes the designing of modules easier through only having to meet a limited number of interface criteria.

21. **Interfaces must provide transmission of all function required between modules.**
Interfaces must allow the required communication and transmission between modules at that discrete point / surface. Interfaces will be a key element in the functioning of the product. The interface cannot be made up from, or enhanced by, components not part of a module.

22. **Interfaces must allow easy connection / disconnection of modules.**
The interface design must allow modules to be assembled and disassembled with ease. The ease of these operations will benefit the functioning of the modular design in terms of upgrade, service, and recycling.

Good Practice.

23. **Modules should be as simple as possible whilst adhering to the number of functions defined earlier for each module.**
    The use of simple modules will avoid problems with reliability, manufacturing costs, servicing, and provide a greater chance for standardisation of modules between products. Even though it may be decided to have some highly integrated modules, these should still be developed with simplicity in mind.

24. **Modules must use as many standard parts and subassemblies as possible.**
    The use of standardised parts, reduces stock holding overheads, eases assembly and servicing, and reduces complexity.

25. **Modules must be testable independently.**
    Modules must be designed so that their function may be tested as a separate unit. The ability for modules to be pre tested gives a greater level of product quality by products being tested in individual areas and not just as whole products, thus allowing systems to be more robust and faults found easier.

26. **Modules must be designed to facilitate maintenance and servicing.**
    Modular products allow easier access to restricted locations and easier removal of individual units for service, reconditioning or replacement. There are also the advantages for simple operations such as lubrication, refilling, and the like, that may not come under service.

27. **Modules must be designed for ease of disassembly.**
    The modular product will provide natural decomposition into manageable units for requirements such as recycling or servicing.

28. **Both the product and the manufacturing process must be designed simultaneously.**
    Modules allow easier design of product and process simultaneously, by considering simplified individual units rather than a complex complete product. Thus when a module is being designed, the requirements for its manufacturing, assembly, and test facility and tooling can be drawn up. It is then a much simpler task to design the main assembly line where module combinations are assembled.

29. **Separate specifications must be drawn up for all modules.**
    The use of modules will not only require one overall product specification, but individual specifications for each module within the product. Across the range of specifications details will have to be standardised, and thus the actual management of such material will be increasingly difficult, due to individual groups responsible for individual modules. Specifications will also be more complex having to define interfaces and what will be required to ensure continuity.

Manufacturing and Assembly.

30. **Make use of bought in modules whenever a module falls outside core business.**
    Standard modules may be bought in directly from a supplier, pre-tested and ready for assembly. Thus benefits are gained through reduced assembly costs, material handling costs, and quality control.

31. **Modules must be designed with manufacturing issues in mind from the earliest point.**
    The use of multifunctional teams for product development will aid in the simultaneous engineering of the product, but manufacturing must be part of this process. Failure to address manufacturing concerns will prohibit much of the benefit from modularity.

32. **Modules must be designed for ease of assembly and manufacture.**
    Modularisation of a design can provide a platform for the use of other techniques such as DFA and thus promote reduction of parts and part variety within the product. Part reduction and DFA are integral parts of a modular strategy. If modules are designed to be easy to assemble with one another, much utility will be derived for the assembly process, the servicing of the product and the ease of customer upgrade.

33. **Modules must be assemblable without adjustment.**
Modules must be designed to assemble to one another without adjustment such that modules may provide easier assembly, easier replacement at a later date, and remove quality / reliability issues with adjustment.

34. **Modules should be designed with standard locating features.**
Standard locating features allows easier assembly and replacement of modules, and benefits the automated assembly of products. Thus transport systems can be used without modification for different modules.

35. **Modules must be self locating.**
Self location aids assembly and replacement of modules.

36. **Modules should be designed with the capability for automated assembly, if automation is commonly used or desired by the company.**
A modular strategy promotes the use of automation by simplifying assembly, using standard parts, and by grouping of similar types of operations within the same team work area.

37. **The plant layout should reflect the modules of the product.**
The grouping of module manufacturing into self-contained cells allows for easier planning of factory layout, and improves communication between key areas. A factory organised into these cells can operate with greater efficiency by running in parallel and thus do not suffer from a problem in an individual cell halting production.

38. **Modules should be assembled off the main line.**
By assembling modules independently of the main line, the main line is not tied to assembly of individual components, only modules to one another, and is thus more flexible. This set up also allows modules to be assembled in parallel.

REVIEWING THE PROCESS *Section 8*

This section is to be added in a future version, through consultation with users and analysis of feedback. It will address any issues with the HPD methodology when it has been implemented and has been running for a short while. It is aimed to provide some guidance on any areas that may require modification or tuning.

References.

ISO 9001 'Quality Systems' Part 1, 1994. *Model for Quality Assurance in Design, Development, Production, Installation and Service*. London: BSI.

BS 5750 'Quality Systems' Part 4, 1990. *Guide to the Use of BS 5750 Parts 1, 2, & 3.* London: BSI.

BS 7000, 1989. *Guide to Managing Product Design*. London: BSI.

BS 7000, 'Design Management Systems' Part 2, 1997. *Guide to Managing the Design of Manufactured Products*. London: BSI.

Alford, H., 1994. Cellular manufacturing: the development of the idea and its application. *New Technology, Work and Employment,* **9**(1), 3-18.

Greenhalgh, G.R., 1991. *Manufacturing Strategy: formulation and implementation*. Sydney: Addison-Wesley Publishers Ltd.

John, V., 1990. *Macmillan Dictionary of Materials and Manufacturing.* London: Macmillan.

Kidd, P.T., 1994. *Agile Manufacturing: forging new frontiers.* Wokingham: Addison-Wesley Publishers Ltd.

Koestler, A., 1967. *The Ghost in the Machine.* London: Hutchinson.

Slack, N., 1991. *The Manufacturing Advantage: achieving competitive manufacturing operations.* Didcot: Management Books 2000 Ltd.

Pimmler T.U. & S.D. Eppinger, 1994. Integration Analysis of Product Decompositions. *Design Theory and Methodology.* **68**(1), 343-351.

Walker, M., 1997. Systems Engineering in the Product Lifecycle. *In: Loughborough University Automotive Systems Engineering Framework Module 2.* pp. 1-33.

Recommended Further Reading.

BS 5750 'Quality Systems' Part 13, 1991. *Guide to the Application of BS 5750 Part 1. to the Development, Supply, and Maintenance of software.* London: BSI.

Marshall, R., 1998. *Design Modularisation: A Systems Engineering Based Methodology for Enhanced Product Realisation.* PhD Thesis, Loughborough University.

Voss, C.A., 1992. ed. *Manufacturing Strategy: Process and Content.* London: Chapman and Hall.

GLOSSARY

BS 5750 / ISO 9000	Quality systems standard that comes in a number of parts. The parts used in this document are: Part 1. ISO 9001 - Specification for design / development, production, installation and servicing, and Part 4. ISO 9004 - Guide to the use of BS 5750 : Parts 1, 2 & 3.
BS 7000	Design management systems in four parts. The parts used in this document are : Part 1 (1989). - Guide to managing product design, and Part 2 (1997). - Guide to managing the design of manufactured products.
Conceptual design	Preliminary research and design studies to establish design alternatives that merit further development.
Cellular manufacturing	The smallest natural grouping of manufacturing personnel and/or equipment producing a family of products typically defined by group technology, clustering or production flow analysis (John 1990)
Design brief	Statement that describes the purpose and required performance of a product or service. NOTE. The statement includes time and cost to complete the design. Product cost and investment targets are also included.
Design specification	A document that defines the requirements and restraints of the product design to those responsible for design. NOTE. A design specification differs from a design brief in that it contains only definitive design requirements whereas a design brief also contains project requirements, e.g. time scale, and is usually less prescriptive.
Design trigger	That which sets into motion a new product or design programme.
DFA - Design for assembly	A technique aimed at improving the design efficiency for assembly of a design. This is done by reducing the number of parts, part variety and providing guidance in the most efficient way of assembling components.
Detail design	The process in which the precise shape, dimension and tolerances are specified, the material selection is confirmed and method of manufacture confirmed for every individual part of the product.
Dimensional management	A system of accepting the existence of variation in assembly and learning to manage that variation. Often associated with a software solutions (such as VSA or Valisys) for manipulating assembly sequences to achieve the best stack up of tolerances or moving the variation to less critical areas.
Feasibility study	Examination of a possible design concept / proposal to determine whether it can realistically meet the specified requirements.
General arrangement design	The stage in the process where all the elements are brought together to establish physical relationships and practicality.
Holon(ic)	The word holon (Koestler 1967), is a combination of the Greek word *holos* meaning whole, with the suffix *on*, as in prot*on* indicating a part. The use of the word holon and holonic is an attempt to indicate something which is simultaneously a whole and a part of a whole. Thus a self contained module is a whole in such that it has a function and can operate on its own, but at the same time it combines to form a greater whole and thus can be seen as a part.
HPD - Holonic product design	A design framework aimed at employing systems concepts and modular design to providing efficient and effective product designs and manufacturing systems. The term HPD is used to provide an indication that the key to design is keeping the full complexities of interactions in view while dealing with specific sub-systems (Kidd 1994).
Interface	Boundary common to two or more systems, or other entities at which information flow takes place, or that have physical contact.
Just in time (JIT)	A manufacturing methodology whereby facilities are only presented the product on which to perform their operations when they are ready. This effectively negates stock holding as all components are called for or ‘pulled’ by the impending operation. The principle can be extended to JIT delivery of components from suppliers, and forms the backbone of a lean production process.
Modular products / design	Modules are independent units of function that are self contained. Combinations of these modules can be used to form products where different combinations alter the functions of the product. Modular design is the discipline of designing products in modules as oppose to an amorphous whole.
PIP Product introduction process	This is the total product development process from the product trigger to product availability. Embodied within this series of events is the design, development, and manufacture of the product.
Robust design	a) A design that is created with the intention or ability for future evolution. b) Design of a product that is insensitive to variations in its manufacturing or use.
Total quality management (TQM)	TQM has two main components; customer service and individual employee responsibility for quality. Customers are anyone to whom a service is supplied and includes internal departments. Each area strives to better understand their customer’s needs and deliver a better service. The responsibility issues means that performance targets should be in place and if employees are expected to meet these targets they must be trained and consulted in developing the goals. Thus emphasis on team work, training, communication, and breaking down of barriers.

APPENDIX

Revision History.

Version 0. 21/05/96.

0. 19/06/96.

0.1 01/08/96.

0.11 10/09/96.

- Self analysis refined, tabular questions added and simple analysis presented.
- Guidelines arranged to format of HPD process.
- Format and presentation changes.
- HPD refined and details regarding modular design moved to the appropriate section.
- Designing for modular products refined and improved, more explanation, and focused on interactions.
- Glossary added.
- Manufacturing strategy for modular products conceived.

Version 0.2 13/11/96. **Major update.**

- Customising the HPD process dropped.
- Self analysis highly improved and focused.
- Checklists arranged to format of HPD process. Checklist items improved.

Version 0.3 22/11/96. **Major update.**

- Minor presentation and format improvements.
- Software considerations added.
- Manufacturing strategy for modular products added.
- References added.

Version 0.4 06/12/96. **Major update**

- Major presentation changes.
- Manufacturing strategy now includes cellular manufacturing.
- Self analysis improved and now includes a more detailed analysis of the LOM
- Glossary updated.
- Revision history added.

Version 0.5. 16/12/96. **Minor update**

- The legacy factor added.
- Balancing it out added (r).
- Self analysis modified, questions all in positive logic (r), LOM graph added.
- Manufacturing strategy now briefly includes after manufacturing.
- Implementation guidelines further subdivided for ease of use (r).

Version 1.0. 24/01/97. **Minor update**

- Product and Manufacturing reviews added.
- The legacy factor and Balancing it out completed.

Version 1.1. 16/06/97. **Minor update**

- Numerous small modifications (r)

Version 1.2. 12/09/97. **Minor update**

- Overhaul of self analysis section.
- Formatting changes.

(r) modifications denoted thus are due to feedback from industry.