Modular Function Deployment (MFD), Support for Good Product Structure Creation.

Gunnar Erixon
Centre for Industrial Engineering at Dalarna University and KTH, Stockholm

ABSTRACT

Modularity based on the use of *module drivers* enables the set up of independent manufacturing units for each module that can be precisely adapted to the requirements of the actual module. Thus, a module workshop in which, for example, a carry over module resides can permit heavier investments due to longer life-cycle then the rest of the product. In the same way a variant module workshop needs focus on a highly flexible material handling system. The concept of module drivers gives a direct link between the design requirements on a module and its manufacturing system.

This contribution will present the MFD (Modular Function Deployment) method for product structuring, using the concept of "module drivers", which supports the designer in the elaboration of a good product structure, where e.g. diversity, assemblability, life cycle and re-use considerations are supported.

The method described gives any company the opportunity to specify its own special grounds and systematically choose the modular design that corresponds to them.

MFD consists of 5 steps:

1. Clarify product specifications.
2. Analyse functions and select technical solutions.
3. Identify possible modules.
4. Evaluate concepts.
5. Improve each module

MFD will be explained in a pedagogical example showing the method applied in practice.

1. INTRODUCTION

Diverse customer requirements lead to a wide variety of products. As a consequence production becomes complex and difficult to plan and control. Greater part of a manufacturing company's ability to create variety resides with the structure of the product (1).

Figure 1 shows how a factory can be organised when the entire assortment of products have been divided into modules, each manufactured in a so called "assembly module workshop".

In the same way as modules are "Products in the Product", "Factories in the Factory" are formed as a result. The traditional final assembly line does not exist anymore. Modules are assembled separately and supplied to the main flow, where they are attached to one another. Short feedback links for failure reports can also be secured if modules are tested before delivery to the main flow.

With an early fixation of the interfaces between modules, product and manufacturing system development can proceed in separate, and parallel projects, one for each module.

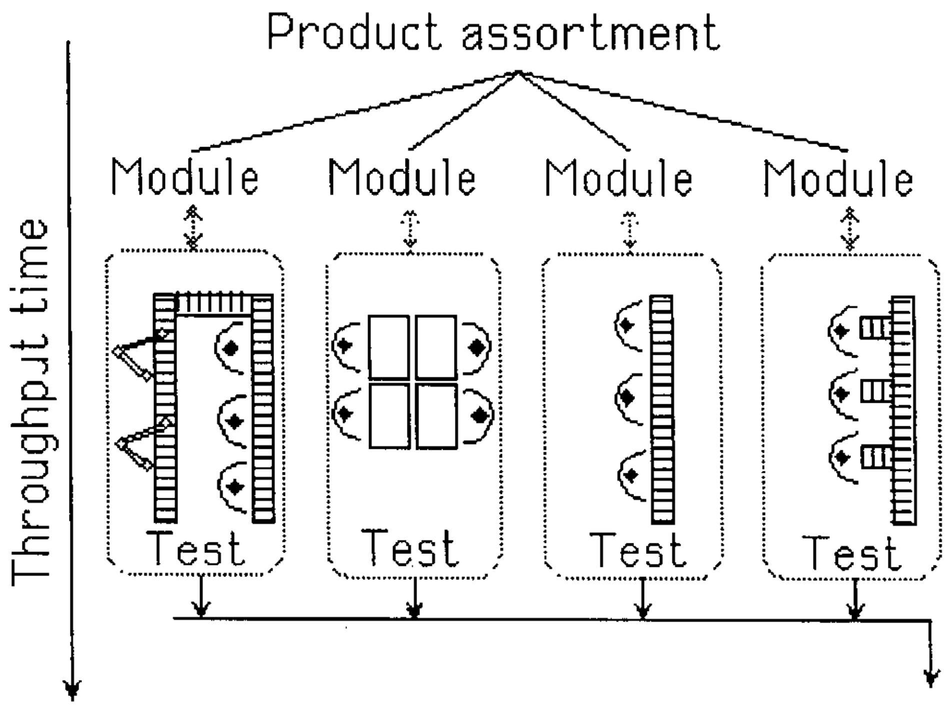


Figure 1. Manufacture of a modular built product, principle.

2. THE CONCEPT OF MODULE DRIVERS

In order to create an "ideal" factory like this, the reengineering of the product and the factory has to proceed concurrently and follow a consistent procedure, enabling product features to be easily linked to manufacturing parameters. Thus, when a product is modularised, the factory has to be reorganised accordingly.

Our research has shown that this can be done using the concept of *module drivers*. Module drivers are a number of different criterias behind modularisation, along the entire product life cycle (2).

These drivers can be seen as generic but may be complemented by company specific ones such as: strategy, financial limitations, legal restrictions, etc.

A carry over is a part of product or a sub-system of a product that can be re-used (carried over) from an earlier generation of a product to a new generation or from one product family to an other. This possibility should be examined throughout the entire company and corporation. It should also be assessed if and how eventual carry overs will influence the company image, etc.

Technology push means that a part or a sub-system is likely to go through a technology shift during its life cycle because customer demands will change radically; the technology itself will evolve i.e. from mechanical to mechatronic, new material, etc. A rapid change and development of competitive products point in this direction.

When a part is a carrier of specific features the product planning might indicate a change at a specific time.

In order to handle product variation and customisation effectively one should strive to access all variations in technical specification to one or a few parts of the product and not let the variations spread throughout the entire product. Also it will be advantageous to make the variation adaptation as late as possible in the manufacturing chain. Parametrisation in one or a few of the modules may be one way of doing this.

Some products are strongly influenced by trends and fashion, others have part(s) that are strongly connected to a brand or trademark. Here it will be advantageous to create what can be called a styling module that may be altered more freely without causing disruptions in the whole product.

Although an increased customisation means a high degree of variation, it is still possible to find parts and functions that can be common units and used throughout the entire assortment of products. Common units can be found by comparing assembly drawings of several product types or by checking already existing sub-assemblies. Parts that contain the basic function(s) are possible candidates.

Smaller areas where a team work organisation can be formed around a module and the shop floor work can be organised in different ways in the different module areas. Work content, responsibility and authority, technical level etc. can be varied, thus giving a development opportunity for the shop floor employee, leading to increased work satisfaction. This also improves the possibility for automation since similar types of operations can be placed in the same team work area. An improved process and working organisation like this is easier to re-use and is therefore a driver for modularity.

If each module can be tested before it is supplied to the main flow, immediate feed back on quality can be supplied to the operators giving the resulting module increased quality mainly due to the reduced feed back times.

Modularity also gives the possibility to purchase complete standard modules (black box engineering) instead of individual parts. This of course reduces purchasing work. From the standpoint of material cost, modularity means that fewer parts are needed to build up the assortment. This means less material to ship and consequently lower logistical costs. Dealing with one big supplier instead of many small ones also makes the administration part of the logistic cost lower. Modularity also gives a simpler product structure with a high degree of similarity between different departments and makes it possible for instance to use the same computer system for product specification (sales), purchasing and spare parts.

Quick service and maintenance in the field are an important factor for many companies and they point out the unique ability the product modules offer for fast service. One damaged module can be replaced by a new one. Then the damaged one can be repaired at a service centre.

Modularity also offers the possibility to upgrade products if necessary. Rebuilding products for other purposes than the original one can also be achieved. Several companies have used the well defined structure that product modules give, to support simple sale tools so that the salesmen can give a detailed price faster.

To enable a high degree of recycling, the number of different materials can be limited in each module and environmentally hostile material can also be kept in the same module so that disassembly will be easier.

3. MODULAR FUNCTION DEPLOYMENT, MFD

Based on the module drivers, a methodology for product and factory reengineering has been developed. The methodology gives any company the opportunity to specify its own special reasons and systematically choose the modular design accordingly. The MFD methodology (Modular Function Deployment), a systematic procedure for creating modular product design consists of 5 steps:

Step 1: Clarify product design specification using the QFD matrix (3), with "modularity" put in as the first design requirement.

Step 2: Analyse functions and select technical solutions.

Step 3: Identify possible modules using the MIM (Module Indication Matrix, explained below).

Step 4: Evaluate concepts by testing the interfaces between the modules.

Step 5: Improve each module using known DFX methodology (4) and the MIM as a pointer for what is important for each module respectively.

4. PEDAGOGICAL EXAMPLE

In this paragraph the MFD methodology will be explained with the help of a pedagogical example showing how the methodology is applied in the modularisation of a domestic vacuum cleaner. The example is a "dummy", but have been elaborated in co-operation with personnel from Electrolux. It has also been used at numerous training work shops for modular design training.

A complete MFD procedure contains, as earlier said, 5 steps. In this example however step 1 and 5 are not used. Step1, *Clarify Product Design Specification,* can be left out when the product is mature and the design team is fully aware of the design specifications. One have however to be aware of the risk that all customer requirements on the product may still not be totally clear. Also Step 2, *Select Technical Solutions*, has been limited to a decomposition of *existing* technical solutions.

4.1 Functional decomposition, step 2

Decomposition of a mechanical system is common activity in engineering design and many systematic procedures exists. In this case we use the methodology of Suh (5), incorporating a hierarchical mapping between the Functional Domain (Functions) and the Physical Domain (Means/Technical Solutions/Function Carriers). Figure 2 shows the first level of decomposition.

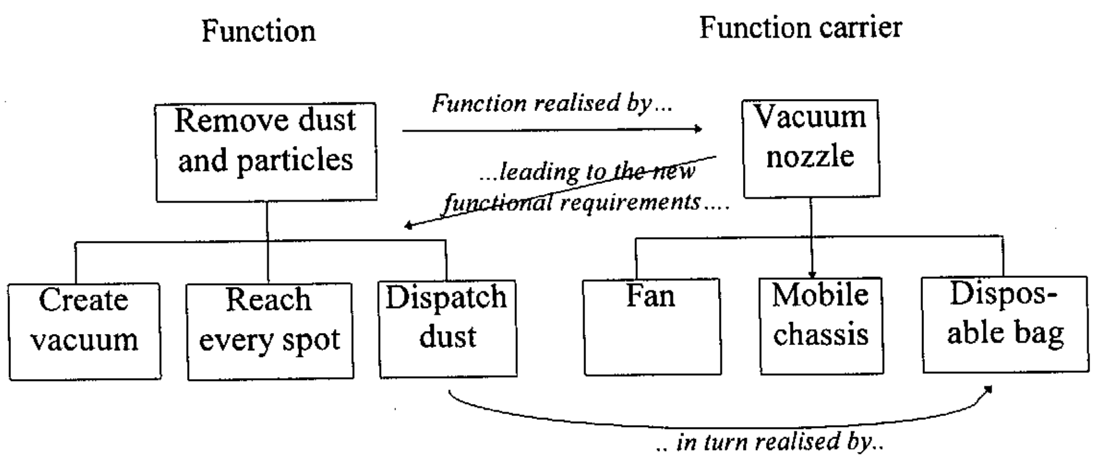


Figure 2. First levels of the functional decomposition of a vacuum cleaner.

The decomposition will be carried out down to a practical level. "Bolts and nuts" level is usually to detailed as long as a good modular structure is the objective. Experiences have shown that, with this objective, it is better to stop too early in the first attempt and then, in an iteration, go one step further in the decomposition.

All function carriers from the completed decomposition for the vacuum cleaner are transfered to the MIM matrix, explained below.

4.2 Identify possible modules with the Module Indication Matrix (MIM), step 3

The Module Indication Matrix, MIM, is a QFD alike tool, where the *function carriers* (technical solutions) are assessed one by one against every module driver, for each column vertically down through the matrix. Every function carrier is weighted in a scale, 9 (= strong driver), 3 (= medium driver) and 1 (= some driver) according the importance of the respective reasons to be a module. To support the work with the MIM, a questionnaire is developed (see appendix). The completed MIM for a vacuum cleaner is clear from figure 3.

Module driver \ Function carrier		Fan	Noise absorbent, fan	Electric motor	Damper	Noise absorbent, motor	Chassis	Bag	Filter	Triristor+knob	Switch+knob	Housing	Wire+contact	Grip	Rear wheel	Front wheel	Accessories	Bumper	Cover	Indicator	Seal, cover	O-ring	Wire collector	Bag lock	Brake+knob
Design and Development	Carry-over	●		●						●	⊘		⊘			●	○			●			●		⊘
	Technology push							●	●																
	Product Planning																								
Variance	Diff. specification	○	○	○					○	○	○		⊘												
	Styling									●	●	●		●	○				●						●
Manuf.	Common unit	⊘	⊘	⊘	●	●	●	●	⊘	⊘	⊘		○		⊘	●	●	●		●	●	●	●	●	⊘
	Process/Org.	●		●			●	●				●													
Quality	Separate testing			●							○														
Purchase	Black-box engineer.								●	●			●												
After sales	Service/maint.			⊘					○	⊘	○														
	Upgrading								●																
	Recycling			●			●					●											○		
● =9 ⊘ =3 ○ =1	Weight of Driver vertically summarised	22	4	43	9	9	27	27	32	34	18	27	16	9	4	18	10	9	9	18	9	9	19	9	15
	Module candidates	√		√			√	√	√	√		√											√		

Figure 3. Completed MIM for the vacuum cleaner.

There is an ideal number of modules which equals the square root of the average number of parts in one product variant (6). The same number of function carriers can now be picked out as *module candidates*.

The number of parts in the vacuum cleaner is estimated to be 70 pcs giving an ideal number of modules of eight. The eight candidates, marked in figure 3, are:

Fan
Electric motor
Chassis
Bag
Filter
Triristor+knob
Housing
Wire collector

This far ve have treated every single function carrier as a separate module and we run the risk of getting a not optimised product (a "pile" of functions). If the markings in the MIM are followed horizontally, it will be clear which of the carriers have the same or not contradictory module drivers. *Grouping or integration* of function carriers to the module candidates can now be executed. Function carriers not among the module candidates should be considered in first place.

At this stage total product concepts should be created and sketched. Grouping or integration possibilities are often reduced by physical limitations. This horizontal assessment can give the basis to value appropriate integration, but can also draw attention to problem areas within the product.

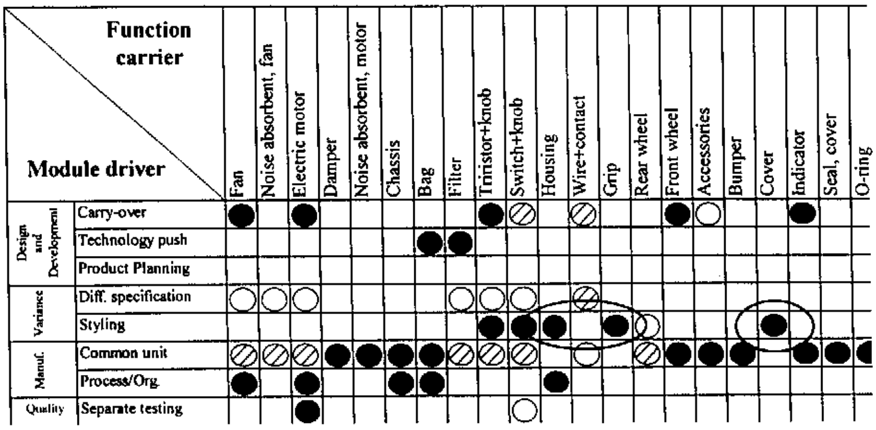


Figure 4. Grouping or integrating with module candidates.

The chassis and the housing have similar markings in the MIM, figure 4. What differs is the fact that the chassis has a strong driver for *Common unit* and the housing has a strong driver for *Styling*. An integration of these two would lead to a need for early fixation of variety creation in the process, resulting in increased administration costs. It might be possible that this integration should be done for other reasons, but now the problem has been opened for discussions.

Table 1 shows the modules that was chosen for the vacuum cleaner. The modules can be given names that clarifies the properties of the module and make the module driver profile transparent, i.e. *Styling module* - housing.

Styling module	housing, grip, cover
Panel	triristor-knob, switch-knob, brake-knob
Electric motor	electric motor, triristor, switch
Chassis	chassis, rear wheel, front wheel,bag lock, bumper, accessoires
Bag	
Filter	
Wire collector	
Absorbent	
Fan	
Standardised parts	

Table 1. Finally chosen modules.

4.4 Evaluate concepts

The interfaces have a vital influence on the final product and the flexibility within the assortment.

An interface might be fixed, moving or media transmitting. Fixed interfaces only connect the modules in a product and transmit forces. Moving interfaces transmit energy in the form of rotating, alternating forces etc. Media can be fluids, electricity etc.

A matrix as per figure 4 gives a good overview of the interface connections. (E) stands for moving (energy transmitting) and media transmitting force, inertia, electricity etc and (G) for solely geometrical specification in the connection. The assembly operation times could also be entered to complete the picture.

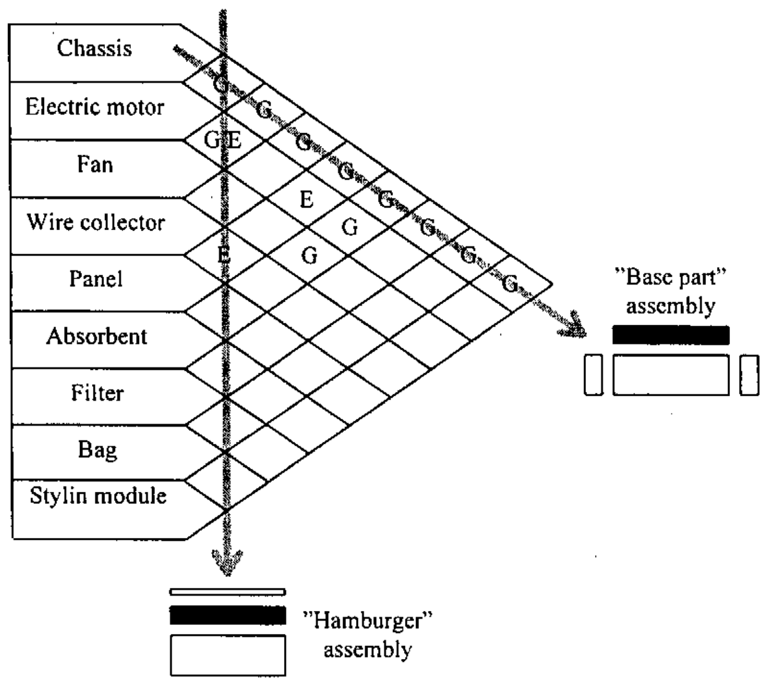


Figure 4. Evaluation of interface complexity.

In figure 4, interface principles preferred have been marked with arrows. All markings outside the areas marked show not wanted connections and should be avoided and/or be made the subject of improvements. The matrix serves as a pointer for the interfaces that have to be observed and eventually improved.

4.5 Improve each module, step 5

Improve each module using known DFX methodology and the MIM as a pointer for what is important for each module respectively. E.g. a module that is chosen mainly for service and maintenance reasons should be designed to ease disassembly.

5. DISCUSSION

The product development procedure has a major impact on the result and also on the working process itself. A systematic work procedure is needed throughout the entire flow, from the identification of the customer requirements to the delivery of a satisfactory product fulfilling these requirements.

It is well known today that DFX-tools are very efficient in product design. However most DFX-tools only handle the product structure and component level. Company studies have shown that efforts on the product range level give further effects in ease of manufacturing and assembly. Andreasen (7) claims that the effect of the assembly principles derived on the product range, product structure and component level is in the ratio 100:10:1.

Unlike DFMA, MFD is a tool applicable across the entire product range. The concept of module drivers gives a direct link between the requirements on a module and its manufacturing system. Linking sub-functions of a product to "module drivers" has proved to be a powerful tool in this development process. A number of companies which practice the methodology have verified that the concept of module drivers gave quite new and different approaches to development work.

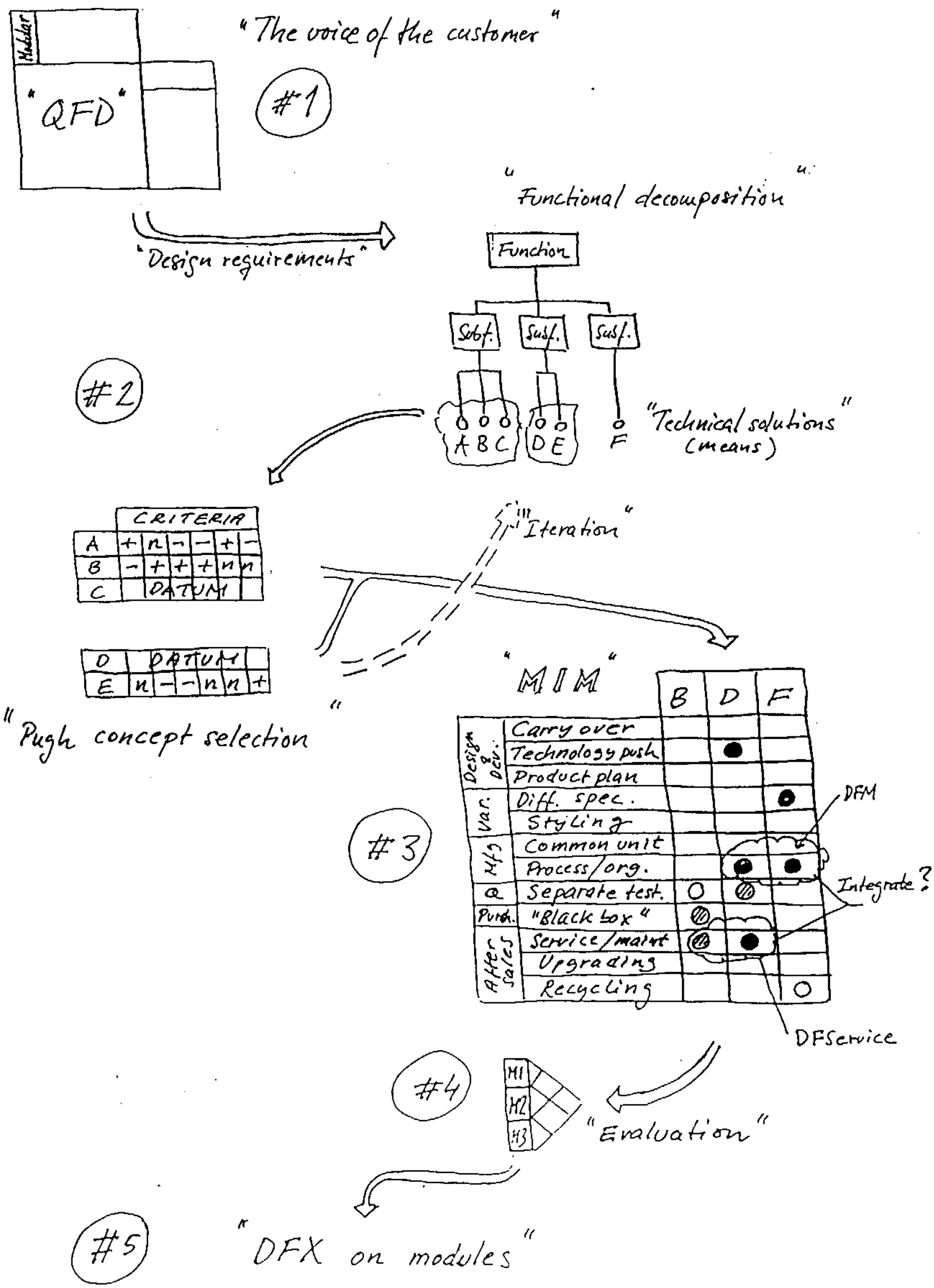
6. REFERENCES

(1) Ulrich, K., 1992, "The Role of Product Architecture in the Manufacturing Firm", WP #3483-92-MSA, MIT, Cambridge, USA.
(2) Erixon et al, 1994, "Modularise your product" (in Swedish), Industrilitteratur, Stockholm.
(3) Akao, Y., 1990, "QFD - Integrating Customer Requirements into Product Design", Productivity Press.
(4) Boothroyd, G. & Dewhurst, P.,1987, "Product Design for Assembly, Handbook", BDI, Wakefield, USA.
(5) Suh, N. P., 1990, "The Principles of Design", Oxford Univ. Press, New York.
(6) Erixon, G. et al, 1993, "Evaluation Tool for Modular Design", Int. Forum on DFMA, Newport, USA.
(7) Andreasen, M M & Olesen, J., 1990, "The Concept of Dispositions", Journal of Engineering Design, Vol 1, No. 1.

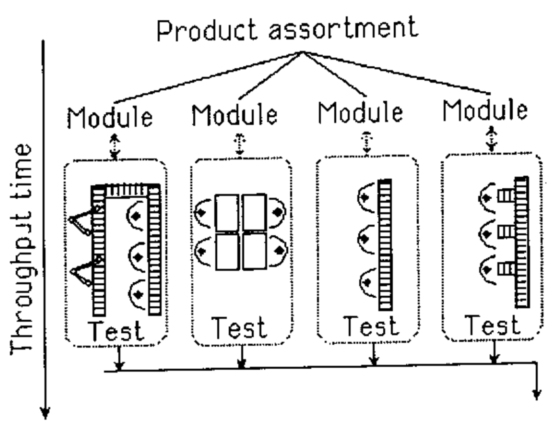
MIM questionnaire.

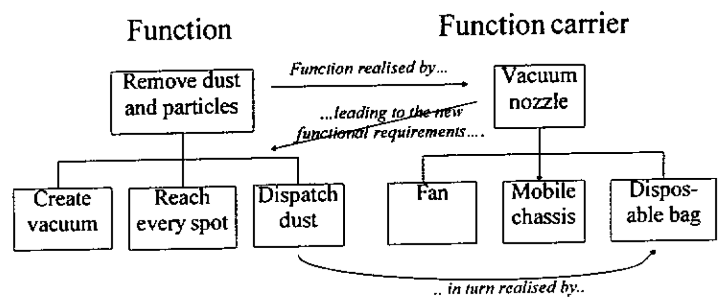
Carry over		
Are there	[ ] strong [ ] medium [ ] any	reasons why this part should be a separate module since it can be carried over from earlier to new product generation?
Technology push		
Is it	[ ] very possible [ ] possible [ ] some poss.	that this part will go through a technology shift during the product life cycle?
Planned design changes		
Are there	[ ] strong [ ] medium [ ] some	reasons why this part should be a separate module since it is the carrier of attributes that will be changed according plan?
Technical specification		
Is it possible to contain	[ ] all [ ] the main [ ] some	variants of the technical specification in this part?
Styling		
Is this part	[ ] strongly [ ] fairly [ ] to some extent	influenced by trends and fashion in such a way that form and/or colour has to be altered?
Common unit		
Can this part be the same in	[ ] all [ ] the most [ ] some	of the product variants?
Process/Organisation		
Are there	[ ] strong [ ] medium [ ] some	reasons why this part should be a separate module because: - it will be an ergonomic part to handle? - it has a suitable work content for a group? - the production accessories (fixtures, tools, etc) can be re-used? - it fits to our special know-how? - a pedagogical assembly can be formed? - the lead time differs extraordinary?
Separate testing		
Are there	[ ] strong [ ] medium [ ] some	reasons why this part should be a separate module because it can be tested separately?
Purchase		
Are there	[ ] strong [ ] medium [ ] some	reasons that this part should be a separate module because: - there are specialists that can deliver the part as a black box? - the logistics cost can be reduced? - the capacity can be balanced?
Service/maintenance		
Is it possible to locate	[ ] all [ ] most [ ] some	of the service repair to this part?
Upgrading		
Is it possible to do	[ ] all [ ] most [ ] some	of the upgrading by changing this part only?
Recycling		
Is it possible to keep	[ ] all [ ] most [ ] some	of the highly polluting material in this part?

MFD



Modular
"QFD"
"The voice of the customer"
#1
"Design requirements"
"Functional decomposition"
Function
Subf.
Subf.
Subf.
A B C
D E
F
"Technical solutions" (means)
#2
CRITERIA
A + n - - + -
B - + + + n n
C DATUM
D DATUM
E n - - n n +
"Pugh concept selection"
"Iteration"
"MIM"
B D F
Design & dev.
Carry over
Technology push
Product plan
Var.
Diff. spec.
Styling
Mfg
Common unit
Process/org.
Q
Separate test.
Purch.
"Black box"
After sales
Service/maint
Upgrading
Recycling
DFM
Integrate?
DFService
#3
#4
M1
M2
M3
"Evaluation"
#5
"DFX on modules"


Product assortment
Module
Module
Module
Module
Test
Test
Test
Test
Throughput time


Function
Function carrier
Remove dust and particles
Function realised by...
Vacuum nozzle
...leading to the new functional requirements....
Create vacuum
Reach every spot
Dispatch dust
Fan
Mobile chassis
Dispos-able bag
.. in turn realised by..

Module drivers

Design and Development
*Carry over *Technology push *Product planning

Variance
*Different specification *Styling

Manufacturing
*Common unit *Process/org.

Quality
*Separate testing

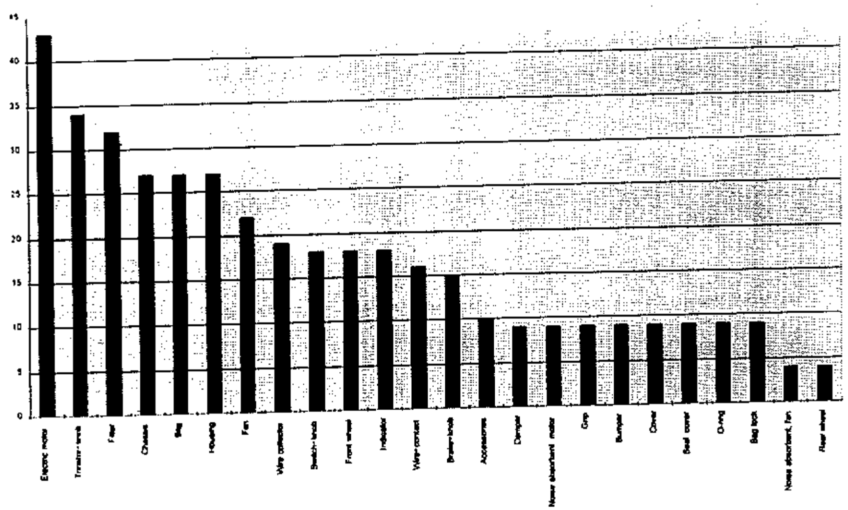
Purchase
*Black-box engineeing

After Sales
*Service/maint. *Upgrading *Recycling

MIM

	Module driver \ Function carrier	Fan	Noise absorbent, fan	Electric motor	Damper	Noise absorbent, motor	Chassis	Bag	Filter	Tiristor+knob	Switch+knob	Housing	Wire+contact	Grip	Rear wheel	Front wheel	Accessories	Bumper	Cover	Indicator	Seal, cover	O-ring	Wire collector	Bag lock	Brake+knob
Design and Development	Carry-over	●		●						●	⊘		⊘			●	○			●			●		⊘
	Technology push							●	●																
	Product Planning																								
Variance	Diff. specification	○	○	○					○	○	○		⊘												
	Styling									●	●	●		●	○				●						●
Manuf.	Common unit	⊘	⊘	⊘	●	●	●	●	⊘	⊘	⊘		○		⊘	●	●	●		●	●	●	●	●	⊘
	Process Org.	●		●			●	●				●													
Quality	Separate testing			●							○														
Purchase	Black-box engineer.								●	●			●												
After sales	Service/maint.			⊘					○	⊘	○														
	Upgrading								●																
	Recycling			●			●					●											○		
● =9 ⊘ =3	Weight of Driver vertically summarized	22	4	43	9	9	27	27	32	34	18	27	16	9	4	18	10	9	9	18	9	9	19	9	15
○ =1	Module candidates	√		√			√	√	√	√		√											√		

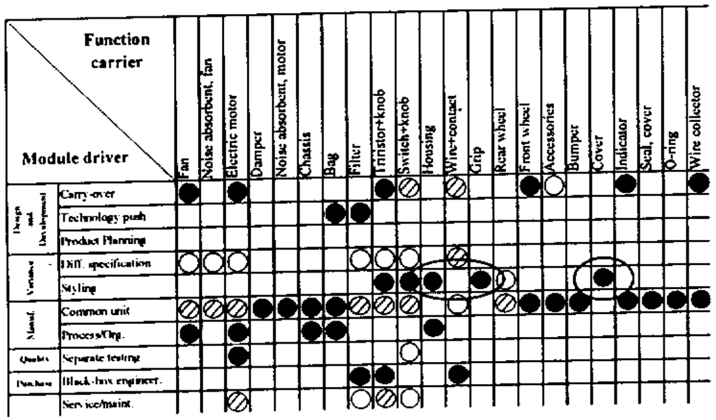
Module profile



Module Candidates

Fan
Electric motor
Chassis
Bag
Filter
Triristor+knob
Housing
Wire collector

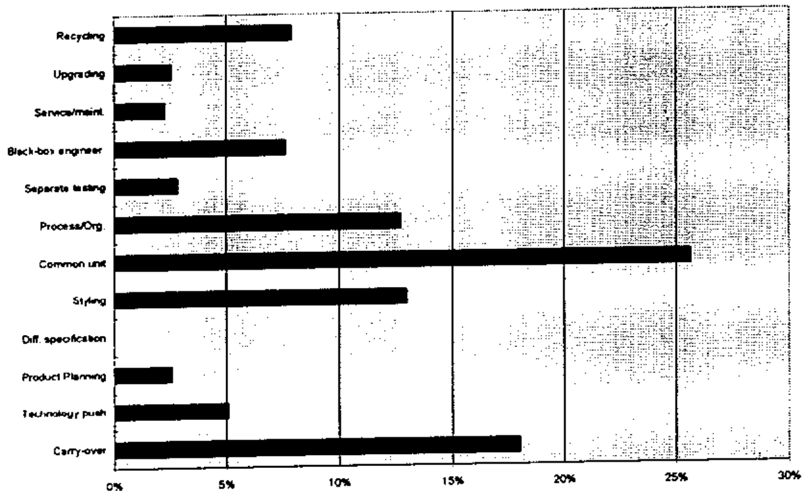
Grouping/Integration



Chosen modules

Module	*Property*	Integrated
Styling module	*styling*	housing, grip, cover
Panel	*styling*	tiristor-knob, switch-knob, brake-knob
Electric motor	*carry over*	electric motor, tiristor, switch
Chassis	*common unit*	chassis, rear wheel, front wheel,bag lock, bumper, accessoires
Bag	*technology push*	
Filter	*upgrading*	
Wire collector	*common unit*	
Absorbent	*common unit*	
Fan	*process/org.*	
Standardised parts		

Driver profile



Evaluation of interfaces