

<http://www.lboro.ac.uk/idater/downloads92/flood92.pdf>

Failure modes and effects analysis: its possible application to National Curriculum Technology

J M Flood

Department of Design and Technology, Loughborough University of Technology

Abstract

The first part of this paper describes a technique used in industry to evaluate products at the design stage in order to improve reliability and to minimise potential failure. The second part of the paper explores the extent to which this technique might contribute towards an appropriately structured approach which might enable students to evaluate artefacts and systems as part of an iterative process of design. A justification of this approach is offered and suggestions are made for activities which might be appropriate to different Key Stages of the National Curriculum.

It is arguable that, until recent years, British manufacturing often worked on the basis that some consumers would experience failures in terms of the performance or life-expectancy of products. If sufficient consumers complained then the product might be improved in order to avoid the effects of failure, namely customer dissatisfaction, the cost of repair or replacement and the effect on repeat sales. With the increasing competition from countries in east Asia¹ which have placed the emphasis on the reliability of products, British manufacturers, in common with most European manufacturers, have adopted Japanese design management methods which aim to get products 'right first time'². One of the techniques by which this is achieved is the use of Failure Modes and Effects Analysis (FMEA). It is interesting to reflect on how the National Curriculum might have been different had it been subjected to Failure Modes and Effects Analysis before publication!

The cause of failure is commonly diagnosed from the effects precipitated; for example, the effect of distortion in the casing of a model of a hair drier might be the basis of diagnosing that the heating unit is too highly rated or that an incorrect choice of material has been made. FMEA is the reversal of the cause and effect sequence of diagnosis in that the method is based on establishing the relative importance of effects from possible causes before they occur. This method advocates that the designer or design team introduces an ongoing form of evaluation by speculating, at each stage of a design process, on the potential causes of failure and the possible effects that these might have. The effect of each potential mode of failure is given a weighting; the weighting is a subjective numerical value but the decision on this is likely to be informed by experience and possibly some investigation based on primary sources; for example, a survey of user responses. In giving a weighting to the effect of the failure mode the designer must aim to assess the effect on the potential purchaser. The percentage weighting of the failure modes identifies areas of potential weakness which need to be addressed at the design or re-design stage.

Figure 1 in the appendix shows an example of FMEA applied to a paper stapler. The analysis shows that the main areas of concern to be addressed by the designer are those of staples jamming in use and ease of re-loading.

In this example the failure modes are correlated with design functions of the product to highlight the key areas the designer needs to address in order to improve the product. The FMEA matrix can also be used to compare alternative design concepts under consideration. A similar use of the FMEA matrix can be used at the detail design stage to correlate each component with possible failure modes; this identifies potential weaknesses in each component and the way in which these might contribute to a particular mode of failure. This latter aspect of the use of FMEA can influence the choice of material and methods of manufacture and assembly. More complex, computer based, three dimensional, matrices can be used to correlate functions, components and failure modes. Such matrices are analogue models of the way in which failure might occur.

A simple model of designing is that of an iterative two stage process, the compositional stage and the evaluative stage 3. These two stages are repeated until an acceptable fit with the specification evolves.

It is important to emphasise that FMEA is an analytic process, applied at both the compositional and evaluative stages of design, and that can be part of the iterative process by which a design evolves. The application of FMEA could, for example, result in the identification of a weakness in a design which necessitates a change in the product design specification, and therefore the concept which could evolve; alternatively it could result in a change of material specified, the method of manufacture and assembly or the colour and texture of surface finishes. FMEA is applied to the design of computer software and to the total design management of a product from concept to the point of sale. It is applied to the design of systems and environments as well as products. For example British Home Stores applied FMEA to the design of their computerised stock handling system and the redesign of their stores in 1989⁴.

The structured, iterative and analytic mode of evaluation described above, contrasts sharply with the practice in schools. Although models of design processes offered in school text books and by GCSE examination boards, stress the iterative nature of the procedure and the need in particular for evaluation to be a key part of the iterative process, it is still identified in examiners reports as a main area of weakness⁵. Students at both GCSE and A Level tend to leave the evaluation until the product is complete; there is often little time given to user evaluation and rarely is there evidence of changes made in response to the analysis drawn from an evaluation. Although it is still too early to assess the extent to which this might also be a weakness in student's work within the National Curriculum (or the way in which teachers direct students), it seems reasonable to suppose that it might be, especially since some early reports⁶ indicate the tendency of teachers to start a design project with Attainment Target 1 (Identifying needs and Opportunities) and proceeding through Attainment Targets 2 (Generating a Design) and 3 (Planning and Making) to Attainment Target 4 (Evaluating): it is the evaluation which tends to be squeezed in at the end of a project rather than being a core part of the design process. Although The Non-Statutory Guidelines for the National Curriculum in Technology emphasises that all of the Attainment Targets can provide appropriate starting points for a design project, it does not explain how, for example, evaluation can play an ongoing part in the development of a design.

It seems reasonable therefore to suppose that a structure for evaluation, based on FMEA, might

provide teachers and students with an appropriate interpretation of the model of the design process upon which the National Curriculum in Technology is predicated. This is not to suggest that schools should slavishly follow industrial practice; this would be inappropriate; the method needs adapting to the different conceptual abilities which are implicit in Key Stages 1 - 4. However the context of 'Industry' is identified as an important one in the National Curriculum and FMEA could provide insights into industrial and commercial practice.

This next section suggests ways in which FMEA could be interpreted and applied at different Key Stages and levels, mainly for Attainment Target 4 but, if used in an iterative manner, with implications for Attainment Targets 1 - 3 and the related Programmes of Study. A reading of the Statements of Attainment for Attainment Target 4 shows them to be at a high level of generality with no suggestions as to how the procedures might be implemented. Similarly the Non-Statutory Guidelines offer no help with methods of evaluating design projects at different stages.

Key Stage 4 (levels 4 - 10)

It seems reasonable to suppose that students at levels 9 and 10 could use a version of FMEA similar to the one shown in Figure 1. in order to "demonstrate that they have applied knowledge and understanding from evaluations of their own and others' technological activities." (9b). Level 10b requires students to "evaluate artefacts, systems or environments to show the interaction of influences in the development and use of knowledge in their own work". An interpretation of this level might be that students would be able to define the important functions of the artefact system or environment, to consider the failure modes, to justify weightings and to draw perceptive conclusions from the process. An appropriate use of Information Technology would be for the students to set the matrix up on a spreadsheet in order to show the effect of different weightings. The levels students are at here could be judged by the quality and perceptiveness of the analysis drawn and the effect of it throughout the project.

Students at levels at 6 - 8 could use a framework similar to that used in Figure 1. but omit the multiplication by the correlation coefficient and the relative percentage weighting. Simply adding the raw scores (see Figure 2) would still give a ranked order of importance. This would seem an appropriate way of students being able to "devise and carry out ways of testing the extent to which the product satisfies the design specification." (level 6b): and at level 8 "present an evaluation of their activities including suggestions for improvements, and a discussion of: (i) the relationship between the materials chosen and the procedures, techniques and processes used, (ii) justification of the possible improvements". It is likely that the levels individual students are at could be judged by the degree of help necessary to get them to define the functions and failure mode weightings.

Key Stage 3 (levels 3 - 7)

At these levels 4 - 7 it is likely that students will, in the same class, be tackling a project as a group rather than working on individual projects. In this case FMEA could be undertaken at different stages of the project, as a group, under the direction of the

teacher. A further simplification of the FMEA matrix would be to correlate failure modes with only the main function of the artefact, system or environment (see Figure 3). The level a student had reached could be judged by the conclusions she or he was able to draw from it and the extent to which it could be seen to influence the final design.

Key Stages 1 - 2 (Levels 1 - 5)

Evaluation at these levels is likely to be based more on judgements expressed by pupils than on quantitative methods. However asking pupils about how their artefact, system or environment could 'fail' is likely to provide a focus for imagining, at the design stage, how it could be made 'better'. For example, pupils designing shelter for a pet or planning to raise money for charity by making and selling biscuits could be asked to think about (and possibly record) the problems they anticipate and the action they could take to prevent them occurring.

Summary

At present, evaluation, as a part of the design process, is a weak aspect of students' work. The National Curriculum in Technology and the supporting material do not provide sufficient guidelines for teachers (and therefore students) in the use of evaluative procedures. Failure modes and Effects Analysis has the potential to provide some structure for using evaluation as an iterative part of the design process; it can provide a focused activity which students and teachers can engage in purposefully at different Key Stages. Teachers who are interested in applying a more structured approach to the design of artefacts, might also examine Morphological Analysis, Weighted Objectives and Value Engineering⁷ as a basis for providing students with conceptual tools with which to get to grips with 0000000Attainment Targets 1 - 3.

References

1. Wray, G R *Some lessons from more successful competitors*. Inaugural Professorial Lecture. Loughborough University of Technology, (1990), pp 6 -7.
2. Taguchi methods *in*: Pugh, S *Total design*, Section 11.6, Addison Wesley (1990). 3. Design task *in*: *Living with technology*, Block 1, Section 12, Open University (1988).
4. British Home Stores and its point-of-sale system, *in*: *Living with technology*, Block 2, Section 3, Open University (1988).
5. *GCSE examiners reports for design and technology* (1987 - 1990).
6. Including, for example, an unpublished report by HMI on the National Curriculum in Technology.
7. The Morphological Chart Method, The Weighted Objectives Method and The Value Engineering Method *in*: Cross, N *Engineering design methods*, John Wiley and Sons(1989).

Bibliography

Cross, N *Engineering design methods*. John Wiley and Sons(1989).

Deiter, G E *Engineering design*. McGraw Hill (1983). Pugh, S *Total design*. Addison-Wesley (1990).

Schonberger, R J *Japanese manufacturing techniques*. The Free Press (1982).

Technology in the National Curriculum. DES (1990).

Non-Statutory Guidance: Technology. DES (1990).

Figure 1
Failure Modes Analysis Matrix for a Paper Stapler

Failure Mode Function	Function weighting	Staples jam	Difficult to refill	Awkward to use	Poor aesthetics	Score	Percentage
Fastening paper together	10	9 90	3 30	3 30		150	47
Refill with staples	8	3 24	9 72	3 24		120	37
Fit with desk environment	4			3 12	10 40	52	16
Totals						322	100

Correlation weighting →

9
90

← Correlation weighting x function weighting

Procedure:

1. List the main functions of the product or system on the Y axis.
2. Establish a relative weighting for each function; a 10 - 0 scale is useful with 10 being more important than 1.
3. List the potential failure modes on the X axis.
4. Establish a weighting for the degree of correlation between the function and failure mode on a 9,3,1 scale. This is a standard scale to use; 9 represents a high correlation, 3 a low correlation.
5. For each correlation multiply the function weighting by the correlation weighting, add the scores and calculate the percentage scores.

Figure 2

Simplified version of the above matrix using correlation weightings only

Failure Mode Function	Staples jam	Difficult to refill	Awkward to use	Poor aesthetics	Score
Fastening paper together	9	3	3		15
Refill with staples	3	9	3		15
Fit with desk environment			1	9	10

Function			