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ENGINEERING DESIGN IN INTEGRATED PRODUCT DEVELOPMENT
Design Methods that Work

DESIGNING DESIGN

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Abstract: O*ngoing work at the University of Strathclyde to model, control and improve the design development process is presented. Design Co-ordination has stimulated a number of initiatives to facilitate and support design development performance improvement. Ten elemental frames are discussed and a number of approaches for designing design outlined. Two computer based co-ordination systems have been used in industrial case studies with savings of up to 64% in process execution time and 45% resource cost reduction. Improvement needs can be identified and used as a basis for continuous improvement through re-design; craft, parametric and process optimisation. Significant improvements have been witnessed in industrial practice and processes optimised with an iteration criteria reduction of up to 83%. Future research will attempt to consolidate the work into a holistic approach to designing design and performance improvement.*

1 INTRODUCTION

The nature of designing has evolved over the decades encompassing different eras from craft based, "design by drawing", system designing, and design as a socio-technical activity [1].

The impact and importance of design on society is becoming ever more recognised and prominent. Over the decades there has been increased activity in its research, management and application. Over the period 2000-2001 alone there were 3,087 books[1] published with "design" as keywords and 34,782 articles[2]. This is equivalent to over 11 new articles and one new book every hour of every working day and illustrates the degree of material, change and effort now within the design community.

We are generating and carrying out a considerable amount of effort upon design but do we apply what we have learned to design the design process? This notion is not new. Jones described "designing designing" [1] as:

> *"the conscious direction of part of one's activity and energy, while designing, into the meta-process of designing the process of design. At any one point one should be aware of 'what you are doing' and 'why'."*

The focus of Jones's proposition is upon individual designers being more aware and creating their design process as they are designing, that is, real-time design of the design process. The work at the University of Strathclyde builds on this basic idea by taking a broader and more pro-active, tactical as well as operational, approach than just focussing upon the activity of designing. That is, "designing design" where the latter is to reflect not only the activity of designing but many other aspects involved in enhancing the activity, process, outcomes and a variety of other factors involved.

This paper presents ongoing work being carried out at the University of Strathclyde to model, manage, control and improve the design development process [2]. Design Co-ordination is presented as the impetus and foundation upon which much of the work has been stimulated. The main elements involved are discussed. Two computer-based systems are then outlined, the Design Management System and the Design Co-ordination System, which provide support for

[1] Source: the British Library Public Catalogue in the British Library http://blpc.bl.uk/
[2] Source: BIDS http://www.bids.ac.uk/

tactical and operational co-ordination. An approach, PERFORM, to identify the needs of the design development owners (customers) is then presented. The fundamental aspects of performance, efficiency and effectiveness, are then discussed along with the distinction between goals, activities and tasks. A fundamental model of a design activity is outlined which defines the relationship between the activity of design and its management. This forms the basis to determine and design the behaviour in order to meet the processes' functional and performance requirements. The paper then provides an overview of some of the activities being carried out to design the design development process. Craft, parametric and process optimisation approaches are outlined to illustrate the need for continual improvement and re-design. A number of examples are provided to illustrate the gains to industrial design development practice.

2 DESIGN CO-ORDINATION

To support the designing of design one must understand the elements involved. Since 1992 Strathclyde has been working with a group of European academics and industrialists concentrating upon design co-ordination [3, 4]. The focus of the group was:

> *To provide the foundation for a quantum leap improvement in the product development process by developing a sound formalism of Design Co-ordination for improved design practice.*

The argument for Design Co-ordination is that, to optimise design, activities should not necessarily be carried out "concurrently" but in a way that achieves optimum performance. Design Co-ordination has been defined as [5]:

> *a high level concept of the planning, scheduling, representation, decision making and control of product development with respect to time, tasks, resource utilisation and design aspects.*

This suggests that to achieve a step improvement in design development is the effective utilisation of resources in order to carry out the right tasks, to give the right results, in the right place, at the right time, for the right reasons. That is, the focus of co-ordination is upon timeliness and appropriateness.

The purpose of Design Co-ordination is to manage and control the complexities of the design process and to provide designers with an environment that enables them to tune their product development process to an optimal overall performance. It makes use of Concurrent Engineering principles, such as carrying out activities simultaneously and multi-functional teamwork, but its focus is not on concurrence, but on optimisation.

To achieve effective co-ordination we must not only know the elements involved, but more importantly how they relate and can be managed and controlled. In response, the group developed a hypothesis in the Design Co-ordination Framework, shown in Figure 1, to support co-ordination of various aspects in design development [6]. The framework consists of a set of frames, each of which represents a model showing the state of the design, plans, resources, tasks, etc. Design Co-ordination focuses on the interaction between these models.

Frame 1 - *Model of Product Development***.** Models of product development show the activity phases/stages, their relationships and milestones in the process from the identification of the need for a particular product to its market introduction. This model supports planning of the product development process within the wider business context.

Frame 2 - *Model of Decomposition.* The product decomposition model represents the product breakdown structure in terms of entities and relations. Such a model must provide a representation of the product in a variety of forms to satisfy the needs of different users.

Frame 3 - *Model of Disciplines/Technologies.* One of the complexity factors relating to the artefact is the disciplines, such as mechanical and electrical engineering, required for its development and the different technologies incorporated within it. The model could be used to support decisions on the feasibility of a project according to the company's available technologies and for planning resources in relation to disciplines.

Frame 4 - *Product Life Model*. This model constitutes a map of the product in terms of the life phases, such as design, production and servicing, a particular product goes through. The model aids evaluation and decisions towards the implementation of new design features or alterations by providing information on the requirements derived from the anticipated life phases.

Frame 5 - *Synthesis Matrix*. A principle of Concurrent Engineering is the development of the product in parallel to the development of product related systems such as the manufacturing system. The synthesis matrix models this parallel development process and helps planning and controlling of the activities to be performed.

Frame 6 - *Life Phase System Model*. A life phase system model represents a system which the product interacts with in a particular life phase. It models how the product is effected by the life phase activities and in turn how the life phase is effected by the product.

Frame 7 - *Goal/Result Model*. The product development process is driven by goals and sub-goals, which are specifications of the artefact to be created.

This model supports decisions on design alternatives by comparing design goals with design results and it aids the solution generating process by providing the designer with clear objectives.

Frame 8 - *Task Model.* The task model represents the structure and logical breakdown of tasks that are to be carried out by a variety of agents related to product development. Tasks may be on the achievement of specific product feature related goals or on goals which relate the product to the company's business as a whole. The model helps decision making, by relating the design process to the business process, and also the controlling of resources, i.e. allocating tasks.

Frame 9 - *Activity/Plan Model.* This model represents the details of activities, contained within phases of the product development model, in relation to a time scale. The product development model, discussed earlier, can be used as a master plan, giving an overview of the activities to be carried out in certain stages. The detailed plan is used for controlling team/individual activities and to support the allocation of resources .

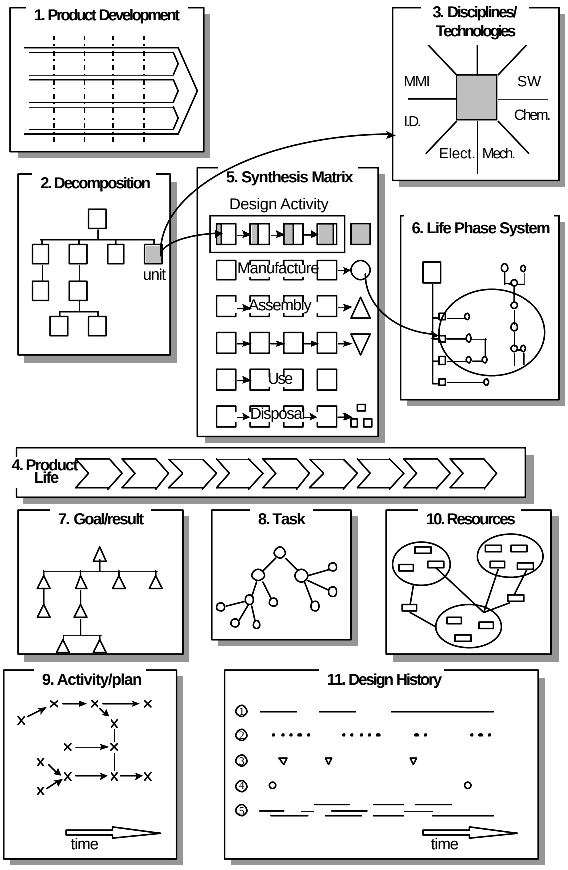

Figure 1: *Design Co-ordination Framework [6]*

Frame 10 - *Resource Model.* Resources in engineering design are any utility that can facilitate design, such as knowledge, skills, people and tools. The resource model represents the structure of the available resources, their state and their relations with each other. Such a model could support the identification, utilisation and control of resources.

Frame 11 - *Design History Model.* In the course of design development knowledge is used and generated. This knowledge can be re-used in future projects if it is recorded and stored effectively. The design history model is a register which records the various states of all framework models during a project and is thus the foundation for knowledge re-use and continuous improvement.

Many interdependencies exist between the frames of the framework, which are complex and dynamic. These links must be identified, managed and controlled to realise a co-ordinated environment. That is, design co-ordination addresses the interactions between these frames rather the frames themselves.

Two computer based systems have been developed, based on the framework, to realise co-ordinated design and facilitate designing design.

2.1 Tactical co-ordination

The Design Management System was constructed to co-ordinate the design activity of an agent-oriented design process with respect to managing design tasks, information, goals and rationale, and facilitating the decision making process [7, 8]. The system addresses the planning and management of design co-ordination at a tactical level.

Design tasks are defined, inter-linked and resources (in this case agents) associated with them to fulfil particular goals, through an interactive interface (Figure 2). Inter-active re-configuration [9] allows the performance of the design process, through the sequences of interlinked tasks, to be improved. The approach is craft design oriented using trial and error design evolution.

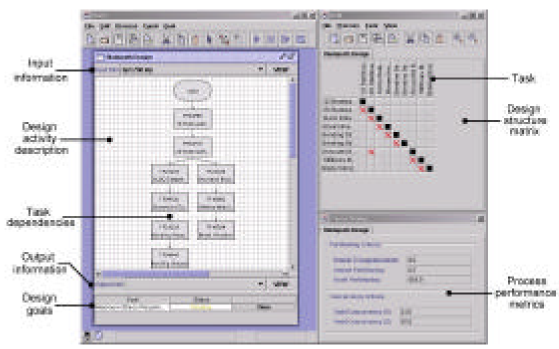

Figure 2: *Design Management System [7]*

The system has been evaluated using an industrial case study that had a well-established design process. The case study investigated the interactions between two designers. In each case significant improvements were made with respect to timeliness compared with the manual enactment. A number of configurations were considered, finally demonstrating that process execution times similar to the time for the critical path could be obtained for both designers corresponding to a 64% reduction in process execution time [8].

2.2 Operational co-ordination

The focus of the Design Co-ordination System is upon operational co-ordination for real time control and "provisional" co-ordination. The former addresses the execution and control of the design process after it has been defined or designed. The latter supports designing design through the computer based simulation of the process, its outputs and iterative design improvements. That is, the system can be used as a simulation based design tool. Design changes are made and the resulting process behaviour simulated. Through an iterative systems type design process the design process itself can be designed.

In three industrial case studies different combinations (designs) of resources and activity configurations were investigated with savings of over 50% reduction in process execution time, the identification of a lack of resources (2 electrical engineers) with 28% reduction in process time, and in team modelling a 45% resource cost reduction and over 50% time reduction [10].

3 CUSTOMER NEEDS

In designing an artefact the identification of a need plays a paramount part. Applying this analogy to *designing design*, how do we identify the needs for improving our design activity?

In addition to the general needs of making improvements with respect to time, cost and quality there are others specific to the particular customer, i.e. business, company, group or individual. The PERFORM approach [2] has been developed and applied to a number of companies over a 5 year period. The overall approach is depicted in Figure 3 and outlined below.

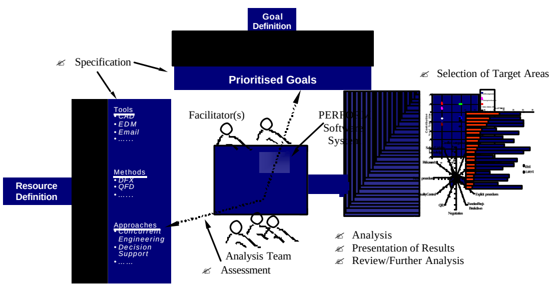

Figure 3: *PERFORM approach [2]*

1. *Specification*: Which results in the definition of the scope of analysis, the goals related to this scope and their priorities, and the resources that are currently used or may be used to support these goals.
2. *Assessment*: Where the exploitation of the resources is defined and the relationship between the resources and the achievement of goals (i.e. the impact) is established.
3. *Analysis*: Which involves the use of a matrix approach and specific analysis measures to provide a number of different analyses on the effectiveness of the resources.
4. *Presentation*: Where the results of the analysis are transformed to a graphical format (Figure 4).
5. *Review*: The results are reviewed and discussed by the participants in the analysis to identify any errors that may have been made in earlier phases, revise the data if necessary and carry out *what-if* scenarios.

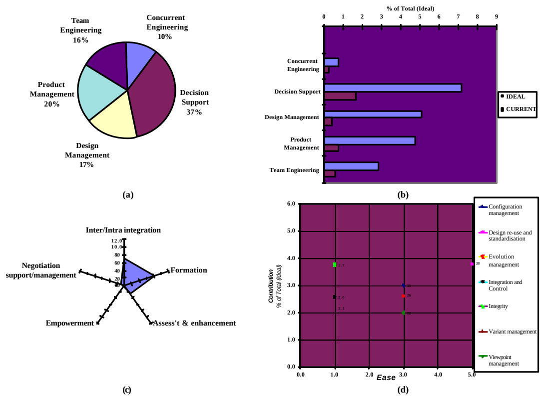

Figure 4: *Graphical output*

The outcomes of the approach include a set of prioritised design development goals along with a targeted set of requirements. From these a variety of means can be "designed", or considered, and implemented to better meet the goals.

4 PERFORMANCE ANALYSIS

An element of designing is being able to determine behaviour prediction. Such prediction can be through a variety of techniques, such as simulation (section 2.2 and [11]), testing and parameter modelling (section 5.2). To perform the latter requires defining the appropriate parameters or metrics and being able to model their behavioural relationships.

Although there is widespread use of efficiency and effectiveness to describe performance there are a variety of interpretations of these terms when applied in design and development. Efficiency *(?)* and effectiveness *(?)* are fundamental elements of performance which may be used to fully describe the phenomenon. That is:

Design Performance
? Efficiency *(?)* and Effectiveness *(?)*

The E^2 model has been defined to clearly formalise the phenomenon of design performance and allow efficiency and effectiveness to be distinguished and related [12]. Efficiency is related to input, output and resources, while effectiveness is determined by the relationship between output and goal(s). These elements are presented within the E^2 model providing a fundamental representation of activity performance.

4.1 Efficiency

In general, the efficiency of an activity is seen as the relationship (often expressed as a ratio) between what has been gained and the level of resource used. Assuming design as a knowledge processing activity (A_k) (Figure 5), the difference between the output (O) and the input (I) defines the knowledge gain from the activity (K^+). The cost[3] of the activity may be determined by measuring the amount of resource knowledge used (R_U). Therefore, the efficiency of this activity may be depicted as in Figure 5 and formulated as a ratio:

$$?(A_k) = K^+ : R_U \quad \text{and} \quad K^+ = O - I$$

Where:

$?(A_k)$	*: Efficiency (?) of an Activity (A_k)*
I	*: Input (Knowledge)*
O	*: Output (Knowledge)*
K^+	*: Knowledge Gain*
R_U	*: Resource (Knowledge) Used*

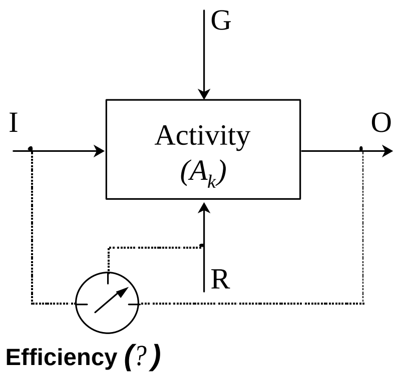

Figure 5: *Efficiency (?)*

This formalism assumes that a quantitative comparison of the input and output knowledge can be carried out that results in a description of the level of knowledge gained in the activity. Similarly, it is assumed that the level of knowledge used in the activity may be measured and that the relationship between both quantities may be expressed in a meaningful form.

In practice a variety of metrics are used to determine efficiency, reflecting different aspects of the input, output or resource knowledge. For example the cost of using a designer within an activity may be measured to reflect the amount of financial resource used in utilising this knowledge source. Efficiency of an activity is considered here to exist irrespective of whether it is measured or not, i.e. it is an inherent property of the activity. The selection and application of metrics to determine efficiency allow particular views of efficiency to be created, e.g. cost or time based efficiency. That is, the determination of efficiency facilitates the measurement of an activity's performance effectiveness.

4.2 Effectiveness

Activities are generally performed in order to achieve a goal, i.e. have a desired effect. However, the result obtained from performing an activity may not always meet the goal. The degree to which the result (output) meets the goal may be described as the activity's effectiveness and expressed as:

$$?\,(A_k) = r_C\,(O\,,G$$

Where:

$?\,(A_k)$	*: Effectiveness (?) of Activity (A_k)*
r_C	*: Relationship (Comparative)*
O	*: Output (Knowledge)*
G	*: Goal (Knowledge)*

This formalism assumes that the output knowledge (O) and goal knowledge (G) may be described in a manner which allows a direct comparison between them, and a relationship to be determined which indicates how closely they match.

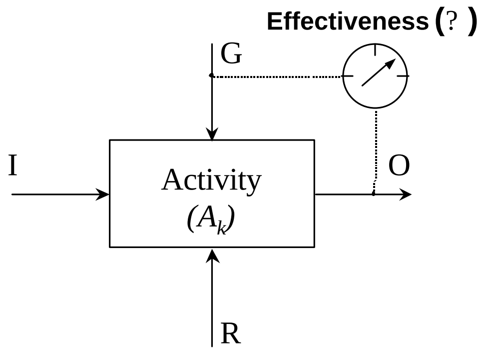

Figure 6. Effectiveness (?)

4.3 Goals, activities and tasks

For clarity it is worth presenting here the relationship between a goal, an activity and a task. A goal reflects a desire, need and/or requirement. For example, a customer's requirement.

An activity is taken to be a physical or cognitive action that creates an outcome. Thus, it has a starting state, condition or input, and an outcome. An activity is carried out by a resource of some kind. In some ways an input and a goal can be considered resources. However, the distinguishing feature is that the resource is the means to carry out the activ-

[3] Cost is used here as a general metric to describe the level of time, money, material, etc. used in the activity.

ity while the other inputs provide the conditions or elements upon which the means act. That is, the resources facilitate the activity where as the inputs and goals are used in the activity.

Definitions of tasks often become entangled with activities and goals. A task is not considered here as an activity or a goal, though they are closely related and hence possibly one of the reasons they are often confused. A task is taken to be an undertaking specified *a priori* [10]. It reflects the desired or expected output or outcome that is required to meet the goal. It is not in itself the goal, as the output shall meet the goal to a degree of effectiveness. Of course there is a strong relationship between the goal, output and task. The desired output reflects the goal and consequently defines the task. Neither is a task an activity, as the activity is the action carried out to create the output or outcome, and consequently meet the task. These relationships are depicted to a degree in Figure 7.

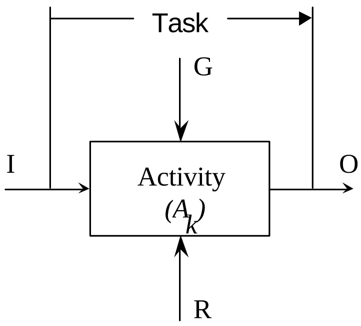

Figure 7: *Goal, activity and task relation*

The difficulty or degree of a task depends on the relation between the activity's input and output. The more inappropriate the input the more difficult it becomes to achieve the desired output or outcome. Similarly, the less appropriate the resource, for carrying out the activity in order to meet the task, the more difficult that task shall be for that resource to complete.

4.4 A managed activity

The knowledge goal *(G)* may be related to either the *design artefact (DG),* e.g. reliability, aesthetics, or the *design activity (DAG)* involved in creating that design, for example time consumed, labour costs, resources consumed. The design and design activity goals may be managed intuitively by the designer in what has been presented above as one activity. However, there are two types of activity taking place; *design activities* (A_d) and *design management activities* (A_m). Design activities are focused on the design goals *(DG),* while design management activities are concerned with design activity goals *(DAG)* and managing the trade-off between achieving design and design activity goals to ensure best overall performance.

At a design project level these activities are often defined separately and are generally carried out by different people, e.g. the designer or design team and the design manager. However, the distinction between these activity types exists even at the level of individual design activities. For example, during sketching a designer may glance at their watch to evaluate the time elapsed in relation to an implicit or explicit time goal before proceeding.

The Design Activity Management model represents a *managed activity,* i.e. any activity in design aimed at achieving design and design activity goals. The categories of input *(I),* output *(O),* goal *(G)* and resource *(R)* knowledge, presented above, are decomposed to reflect categories related to either design or design management activities as follows:

I	?	*DI and DAI*
O	?	*DO and DAO*
G	?	*DG and DAG*
R	?	*DR and DAR*

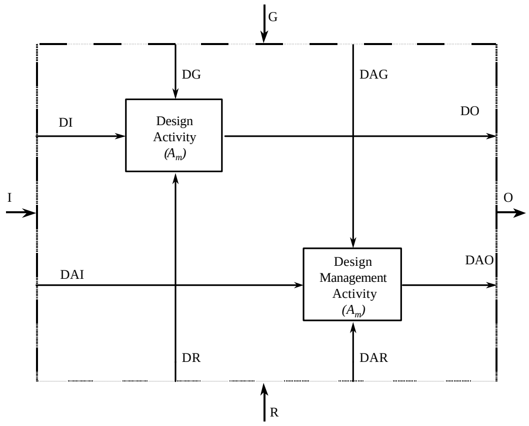

Figure 8*: Design Activity Management model*

The managed activities described above are the fundamental elements of the design process. That is, the design process consists of a number of managed activities with relationships such as those based on information dependencies. The overall effectiveness of designing is composed of *design effectiveness,* illustrating how well the design goals have been met, and *design management effectiveness,* indicating if the design activity goals, such as resource cost, have been met.

In an informal sense, a designer will continually evaluate the effectiveness of his/her activities, e.g. checking their watch to assess time elapsed (design management effectiveness), or evaluating the aesthetic strengths of a particular concept (design effectiveness), as intimated in the comment by Jones (section 1). More formally, effectiveness may be reviewed through simulating product behaviour and evaluating results at specific stages of milestones.

4.5 Relating Efficiency and Effectiveness

Efficiency and effectiveness focus on related, yet contrasting performance elements. The efficiency is inherent in the behaviour of a particular activity/resource combination. It may be measured without any knowledge of the activity goals, although the goals may influence the behaviour of resources used in the activity and consequently the level of efficiency that results from their use.

Effectiveness, in contrast, cannot be measured without specific knowledge of the activity goals. As is the case in measuring efficiency, the measurement of effectiveness involves the analysis of the activity output (*O*). However, effectiveness is obtained through analysing a specific element of the output knowledge, i.e. that which relates to the goal(s) of the activity.

In certain cases there exists a direct relationship between effectiveness and efficiency. This relationship exists when the specific element of the output knowledge, which is evaluated to establish effectiveness, also describes an element of the resource used. For example, an activity may have a specific cost related goal of minimising the activity cost, i.e. G_j: C = Min. Therefore the element of the output knowledge (*O*) which must be evaluated is the cost knowledge (O_C). However, determining the cost based efficiency of the activity also involves the analysis of cost incurred (R_{U-C}) in carrying out the activity as part of the overall resources used (R_U). In this particular instance the element of output knowledge used to establish effectiveness is the same as that used to establish efficiency. Therefore, an increase in the cost based efficiency of the activity will also result in an increase in the cost based effectiveness of the activity, given an activity goal of minimising cost. In cases such as this one the efficiency of the activity can provide insight into why a particular level of effectiveness has been obtained.

In other cases a direct relationship between efficiency and effectiveness is not evident. Such cases exist where the specific element of the output knowledge that is evaluated to establish effectiveness has no relationship to the resource knowledge used in an activity. For example where the goal of a design activity may be to maximise the dimensional accuracy of the artefact, $G_{(s)}$ = Max(s), the element of the output knowledge *(O)* which must be evaluated is the knowledge of the dimensional accuracy *($O_{(s)}$)*. It is clear that this knowledge provides no indication of the resource knowledge *(R)* used in the activity. Therefore an increase in dimensional accuracy will give increased effectiveness with respect to this goal but there is no direct relationship with efficiency in this case.

There are a variety of inter-relationships and resulting control steps within a managed activity. For further reading and indications of some *axioms of performance* the reader is referred to [13].

5 DESIGN DESIGNING

The understanding gained from the performance analysis work is being used to define, implement and measure design development metrics within three industrial companies. These metrics can then be used for craft, parametric or optimisation oriented design.

5.1 Craft oriented

Having an understanding of the customer requirements and performance metrics it becomes possible to carry out craft type design by analysing the needs, implementing "designed" changes and measuring the results, on an iterative basis as depicted in Figure 9.

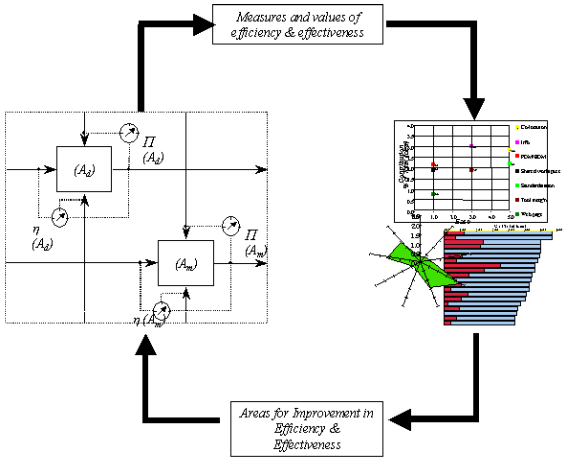

Figure 9: *Craft oriented performance improvement*

In the approach illustrated in this figure the E^2 model is used to measure the efficiency and effectiveness of the actual design development activity. A PERFORM analysis (see section 3) is then carried out to compare the customer needs and the most appropriate means to meet those needs. Areas for improvement are then identified and corrective design and implementation actions taken. Thus, new design process models, methods or computational tools can be designed, developed and implemented, as reflected in Figure 10. These are then introduced back into the company and any improvements measured through the performance metrics. Iterative cycles of this approach supports continual performance improvement.

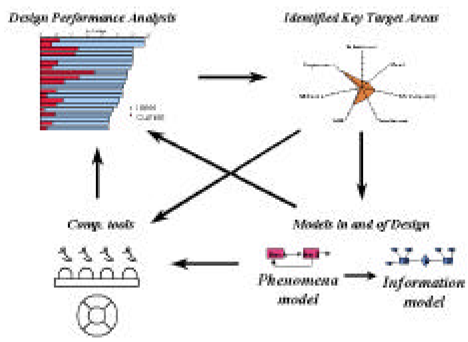

Figure 10: *Craft oriented continuous improvement*

Figure 11 illustrates improvements to a company's design development activities made over a three year period using this approach.

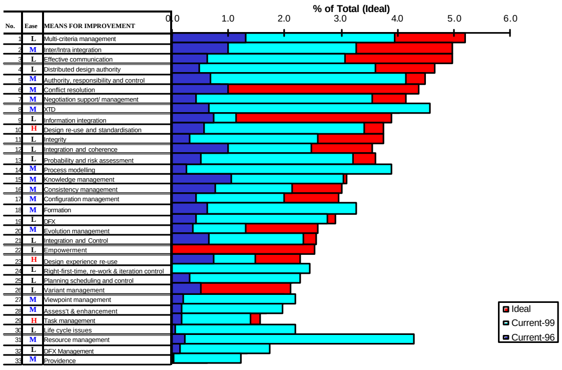

Figure 11: *Required improvements*

5.2 Parametric oriented

As in parametric product design, parametric process design needs a model that not only defines the parameters (descriptors) but also their behavioural relationships. Thus, an additional challenge to determining the most appropriate and reflective parameters (metrics) is not only how to define their relationships but to do so in such a way as to predict their behaviour.

Our approach is to employ Knowledge Data Discovery and Data Mining techniques [14]. Within two of the industrial companies we are currently gathering the necessary data for extracting the implicit behavioural relationships to define "performance models". These models will then be used to design, primarily through parametric analysis, new solutions to design development. It is intended that a number of the solutions shall be implemented. Their actual performance will then be compared to that predicted, and a process of continuous improvement adopted (see Figure 12).

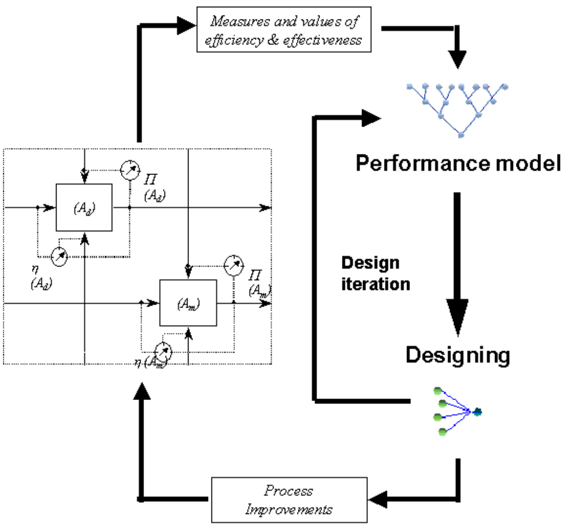

Figure 12: *Parametric oriented design*

5.3 Process optimisation

A number of algorithms exist that may be applied to the optimisation of design process problems including simulated annealing [15], Genetic Algorithms (GA) [16] and Tabu search [17]. The optimisation algorithms tend to have a number of parameters that affect their performance and are intrinsically linked to the problem domain [9], for example, the annealing schedule for simulated annealing.

The Dependency Structure Matrix (DSM) [18] has been used as the dependency modelling technique due to its generic applicability, ease of representation within a computer-based system, and, its quantifiable nature.

The DSM, also known as the Design Structure Matrix, has been extensively used to represent concepts such as: tasks, resources and parameters, as well as the inter-concept dependencies. The DSM is generic in nature, but due to its compactness, easily quantifiable nature, and ability to represent most design activity relationships, has seen considerable use in the analysis and management of the product development process [18-22].

The DSM consists of a list of concepts (e.g. activities, tasks, components) that are represented in the same order in both the row and column of the matrix. The matrix part represents the dependencies between the concepts. A DSM modelling and analysis system (Figure 13) was constructed with the focus of providing mechanisms to enable the optimisation of the order of tasks with respect to a predetermined optimisation criterion [9].

The system allows the creation of a matrix containing any number of activities with the matrix changing size automatically as activities are added or removed. Selecting a cell within the matrix will change the state of the dependency between activities from either independent or dependent. The user may also change the weight[4] of the dependency, which is reflected by its colour.

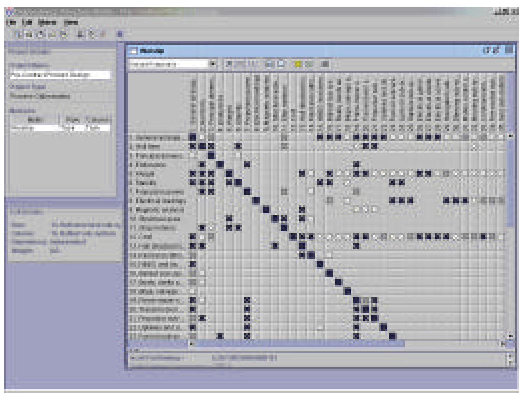

Figure 13. *Dependency Structure Matrix system.*

[4] Indication of the "strength" of the relationship between the concepts.

The order of the activities within the matrix may be managed manually by dragging either of the rows or columns into a new position. The value for the clustering criterion is simultaneously re-calculated, assisting the user in the determination of an improved design process. Alternatively, the design process may be optimised using one of the optimisation algorithms available within the optimisation module. The system can simultaneously manage the optimisation of multiple design processes although this will obviously take longer on a computer with a single processor.

Applied within a warship pre-contract design process, involving 52 activities, the DSM achieved a 75% reduction with respect to the Scott[5] criteria [9]. The before (a) and after (b) matrices are illustrated in Figure 14.

(a) (b)

Figure 14: Optimised pre-contract design process

Similarly within a design and drawing process, involving 54 activities, the system achieved an 83% reduction with respect to the same criteria. Work is currently ongoing to translate this into performance metric improvements through the implementation of new processes within the industrial company. Thus, a similar continuous improvement approach to that indicated above shall be carried out.

6 CONCLUSION

Over 20 years ago Jones highlighted the need for designers to design their design process [1]. The work at the University of Strathclyde adopts this concept but applied to the broader arena of design development.

The focus of Design Co-ordination is upon timeliness and appropriateness and has formed the foundation and motivation for much of the work presented. The Design Co-ordination Framework includes ten "active" elemental frames; product goals, disciplines and technologies, life-cycle model, design synthesis model, life-phase models, goals and results, activity plans, tasks and resources. Two systems have been developed based upon the framework, the Design Management System and the Design Co-ordination System. Both have been applied to industrial case studies with savings of up to 64% in process execution time and 45% resource cost reduction.

Performance is defined to consist of efficiency and effectiveness. Efficiency is seen as the relationship between what has been gained and the level of resources used. Effectiveness reflects the degree to which a goal has been met.

A distinction between a goal, activity and task was presented. A goal is considered to reflect a need, an activity an action with a resulting outcome that can meet the goal to some degree, and a task as *a priori* specified undertaking.

A design activity and a design management activity are presented as being inextricably linked and grouped within a managed activity. The inter-relationships, performance and control links within the managed activity were considered outwith the scope of the paper and are presented elsewhere [13].

A number of cyclic approaches of design designing are presented as a basis for continuous improvement; craft, parametric and process optimisation. The craft oriented approach is a trial and error iterative process, with significant improvements witnessed within industrial practice over a three period. Work is ongoing to build a performance behavioural model that can be used as the basis for parametric design. Two industrial processes, each with over 50 activities, have been optimised using a genetic algorithm with reductions of 75% and 83% (with respect to an iteration criteria).

Work is currently being carried out to implement new design development processes into three industrial companies to determine the overall effects on performance.

It is the intention to bring the slightly fragmented work presented in this paper into a holistic approach to support designing design and facilitate continuous performance improvement in design development.

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