

THE ISSUES AND BENEFITS OF AN INTEGRATED APPROACH TO SYSTEMS DESIGN WITH STANDARD COMPONENTS – AN INDUSTRIAL CASE STUDY

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Abstract

The efficient and economical transformation from a design schema to an embodied design solution containing real components is essential for the success of a product. The ability of the designer to explore an optimum solution is severely frustrated by the analytically intensive and time-consuming aspects of embodying a concept. This is particularly the case where standard components are considered. This paper summarises a new modelling approach that supports the designer during the transformation of a concept to an embodied solution and describes the process of constructing a system model, specifying the desired performance characteristics and what is known as system resolution. In particular an industrial case study is used to demonstrate the capabilities and benefits of the new approach.

Keywords: computer systems, mechanical product design, competitive products, industrial case study

1 Introduction

For the majority of components in a machine system, it is generally more effective and economical to procure components from a third party supplier [1, 2]. Because of this, the role of standard components in achieving high-quality low-cost design solutions is particularly important. As a result of this, the ability of the system to achieve all of the desired requirements depends largely on the ability of the designer to identify and procure the most appropriate mix of third party components. More often, the procedure for sizing and selecting mechanical components involves supplier catalogues, standard literature or computer based support tools. This selection process is shown in relation to the overall design process in figure 1 and demand up to 20 to 30 percent of the designer's time [3]. In contrast, emerging technologies for computer aided component specification remove much of the analytically intensive, time-consuming and routine tasks, and replace them with sophisticated equations which better match an individual component to the performance requirements entered by the designer. The benefits of such technologies are widely documented [4, 5].

However, the specification of mechanical components cannot (or should not) be conducted in isolation. In order for effective system configuration and in particular, optimal design, the system of components must be considered as a whole [6, 7]. Whilst many of the approaches for component procurement improve the selection of individual elements they do not support the consideration of the system as a whole. In fact, because of the many and varied data formats used, and the different proprietary software standards, these tools can frustrate a systems approach. The inevitable consequence of this, is that many of these emerging electronic selection tools are used in isolation. This requires the designer to manipulate

selection or performance data between software tools, which can be a recursive and very time-consuming activity in an already highly iterative process.

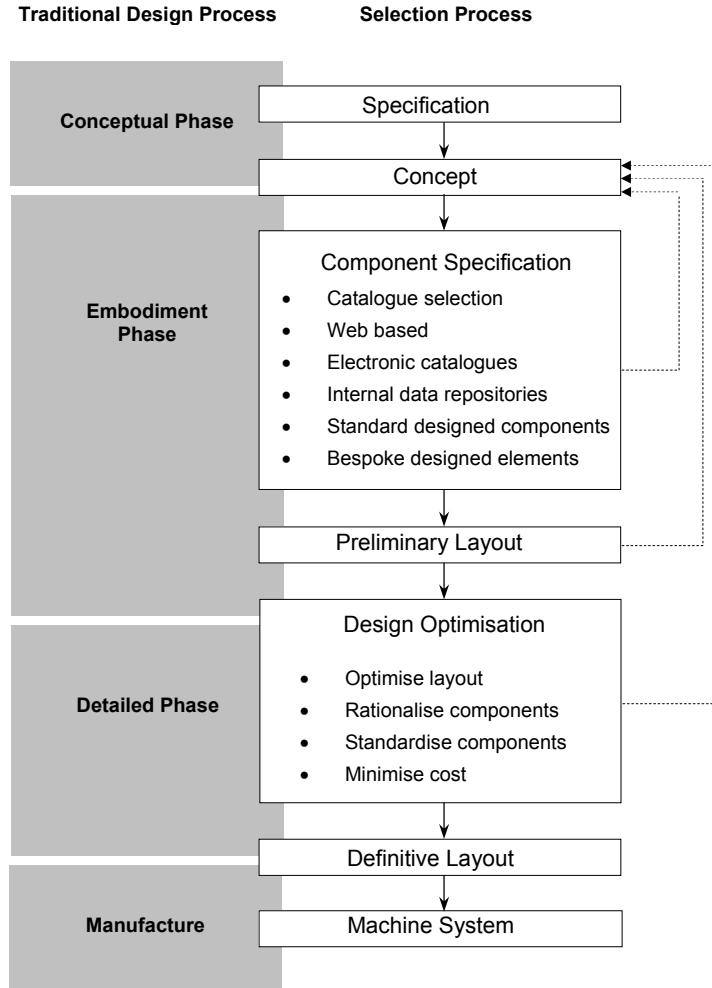


Figure 1. Selection design process for the sizing, selection and specification for a standard component.

During the embodiment of mechanical systems and in particular machine systems, the consideration of both performance and geometry is necessary in order to ensure that components are physically connectible (fit together) and satisfy essential performance requirements, such as speeds, loading and torques. This process is highly iterative because standard components follow a discrete, finite range of possible sizes. The process involves interrogating component representations, arbitrating conflicting parameters and assimilating and manipulating component selection data, all of which occupies a large proportion of the designer's time. This process also frustrates design optimisation where the designer must consider system attributes such as cost, mass and the spatial envelope. Furthermore, changes in a single component later in the process can have a serious impact on many other components. This may demand that the designer return to the iterative selection process to determine a compatible system.

In order to better enable a systems approach for the embodiment of engineering assemblies with standard components a modelling approach has been created. This approach integrates

the varied and disparate technologies for electronic component representation and automates the key tasks of the selection process. These include data manipulation, data arbitration and the interrogation of electronic representations. This enables the designer to spend more time on generating and refining design solutions. This paper summarises the fundamental elements of an integrated modelling approach and a computer based modelling environment for machine systems. A more detailed description of the modelling environment is given in [8, 9 & 10]. The major aim of this paper is to demonstrate the approach and illustrate its capabilities and its benefits. To support this, the application of the computer based modelling environment to an industrial case study is described in detail.

2 An Integrated Modelling Approach

The development of computational methods for component identification and selection through performance modelling of systems has been hampered in the mechanical domain by a number of problems. These include extensive hard coding and bespoke software, combined with the diverse range of models, levels of model abstraction and programming/modelling languages necessary to represent a single mechanical component [11]. Furthermore, where standard components are considered, more often than not only an abstraction of the representation is used within the modelling environment. This is a serious limitation, because ‘real’ mechanical components which are the closest match will have to be sought later in the process. In this work, ‘real’ components are those elements that may already exist, have been previously used and have predetermined or predefined properties. In addition to these limitations, many modelling approaches only provide for a fixed predetermined assembly structure or a limited number of components. This is very restrictive and frustrates the ability to explore alternative configurations or layouts and more importantly restrict the types of mechanical elements that a designer may consider.

One of the fundamental issues addressed in this overall work is the ability to consider a system of individual components as a whole. To address this issue, a modelling approach has been created that represents the performance of mechanical systems for their embodiment with a set of mechanical components. The key elements of the modelling approach are depicted in figure 2. These elements include system representation, the handling of interactions and system resolution [8, 9 & 10].

2.1 System representation

In engineering design, systems are often considered to be a hierarchy of assemblies, sub-assemblies and components [12, 13]. The definition of these terms and the extent to which they encompass elements are held largely in the minds of the individual. Whilst the designer may distinguish between assemblies and subassemblies, the modelling environment considers the complete machine system and each of its included elements. For the purpose of the system being dealt with, *primary elements* are those mechanical components that provide the overall transmission requirements of the system. *Secondary elements* are designed post selection of the primary components and may include housings and casings.

In order to achieve the necessary level of flexibility and completeness, no predefined structure or order of arrangement for the system is imposed on the designer. The modelling environment generates an abstraction of the system referred to as the template. This includes the relative arrangement and connectivity of components in the system and is extrapolated from the schematic layout constructed by the designer, an example of which is shown in part (a) of figure 3. In addition to this, individual elements and the extents of their connections are

evaluated, and categorised as either a unitary, binary or core element [8]. This latter aspect is needed for system resolution. In the example shown in Figure 3 the unitary elements are the mounts and inputs/outputs, the binary elements are bearings and the core element is a shaft.

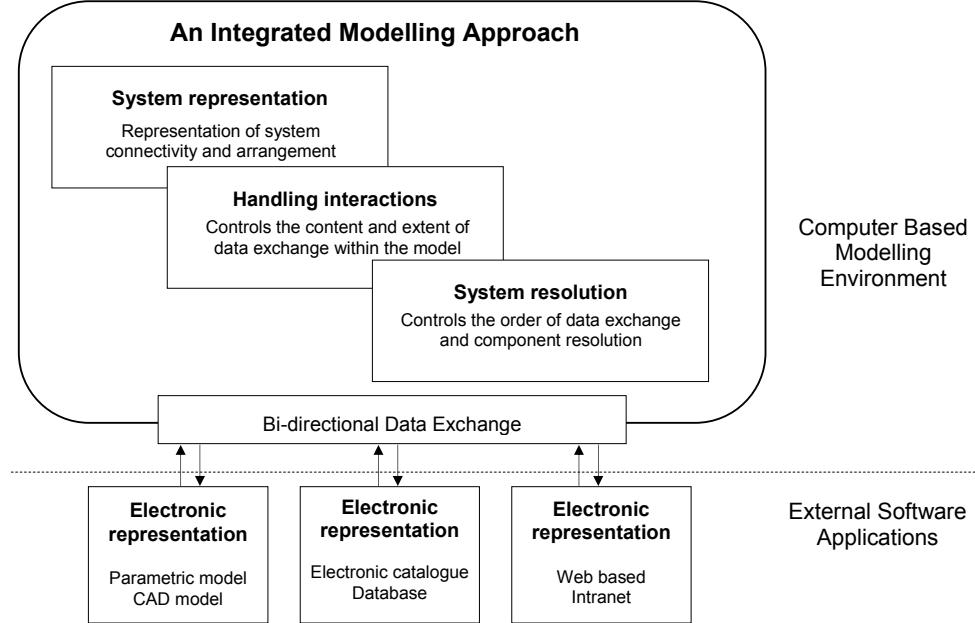


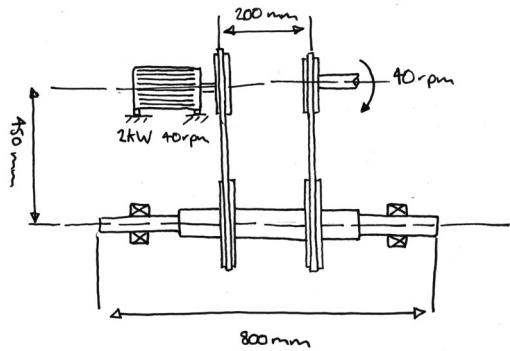
Figure 2. The key elements of an integrated modelling approach.

2.2 System resolution

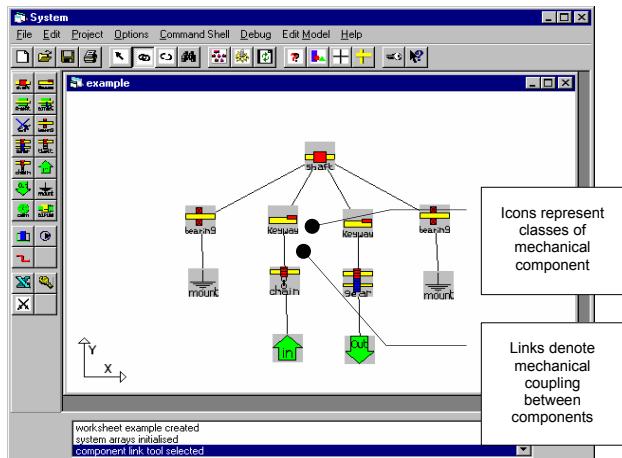
In order to achieve the requirements for data propagation within the system model, the modelling environment implements a relatively complex resolution cycle. This resolution cycle commences at the unitary elements, sequentially resolving binary elements until a core element is reached. Following this, a second phase of resolution initiates from each core element through the binary elements, until either a unitary element, core element or a previously resolved element is reached. The resolution cycle is derived from the system template, which creates a command list for the modeller. This list contains information on the type of electronic representation, the location of the electronic representation, the type of component(s) to which it is connected and an identifier for the relative connection(s). This identifier relates to the ‘local blackboard’ which is associated with every connection in the system model. The primary function of the system resolution is to ensure that the data necessary for the effective execution of each electronic representation is available. The majority of this data is imposed by interactions with connected components and in the modeller the content and extent of this data is governed by the protocol for handling interactions.

2.3 Handling interactions

During the embodiment of a machine system the designer has to evaluate constrained parameters between connected components, these include speeds, loads, torques and geometric attributes. In order to automate this process, a protocol that communicates all necessary parameters between related components has been developed [9]. These parameters provide the basis on which selection data for individual components can be generated and the overall system performance evaluated.



Part (a) Concept sketch



Part (b) System schematic constructed in the modeller

| ID | Parameter | Value | Units | Flag |
|----|----------------|------------|-------|------|
| 78 | I/p gear spe | 10 | rpm | 0 |
| 79 | O/p gear sp | 20.00 | rpm | 0 |
| 80 | Facewidth | 40 | mm | 0 |
| 81 | Power | L020943951 | kW | 0 |
| 82 | Shaft separa | 300 | mm | 0 |
| 83 | Safety Factc | 2 | n/a | 0 |
| 84 | Material Yield | 30 | Mpa | 0 |
| 85 | I/p gear pitc | 400 | mm | c |
| 86 | O/p gear pit | 200 | mm | c |
| 87 | Mass | 25.03 | kg | 0 |
| 88 | Cost | 121.88821 | £ | 0 |

Part (c) Component attributes

Part (d) Constraint specification

The screenshot shows the 'System attributes' dialog box. It contains a table with four columns: No., Attribute, Minimum, and Maximum. The table has three rows:

| No. | Attribute | Minimum | Maximum |
|-----|---------------------|---------|----------------|
| 1 | Working environment | null | null |
| 2 | Temperature range | -20 | 50 degrees |
| 3 | Life | 1000000 | 2000000 cycles |

A callout box points to the 'Minimum' and 'Maximum' columns with the text: 'Minimum and maximum permissible values for attribute'. Another callout box points to the 'Attribute' column with the text: 'Attribute name used in the global array'. At the bottom, there are buttons for 'Edit attributes' (disabled), 'Add', 'Update', 'Delete', 'Close', 'Cancel', and 'Apply'.

Part (e) System attributes

The screenshot shows the SolidWorks System Information dialog box. The left panel displays assembly properties:

- Assembly Mass: 21.00
- Assembly Cost: 522.0
- Assembly x-dimension: 800
- Assembly y-dimension: 578
- Assembly z-dimension: 154

The right panel shows a 3D view of a mechanical assembly consisting of a blue horizontal shaft and two yellow vertical supports. Red rectangular callouts point to the 'Shaft' and 'Key' components in the list.

| Index | Comp | Shaft | Key |
|-------|---------|-------|-------|
| 1 | | | |
| 2 | | | |
| 6 | | | |
| 3 | | | |
| 7 | | | |
| Chair | | | |
| Beari | | | |
| 10 | | | |
| 11 | Bearing | 0.53 | 43.00 |
| 4 | Input | 0.00 | 0.00 |
| 5 | Output | 0.00 | 0.00 |
| 8 | Mount | 0.00 | 0.00 |
| 9 | Mount | 0.00 | 0.00 |

Part (f) Solid model and attributes of resolved system

Figure 3. An integrated modelling environment.

Component attributes are classified into three classes; global, local and intrinsic attributes. These classes differentiate component attributes according to their method of formulation, and relate their dependency on the system, connected components and intrinsic properties of the component itself. Attributes in the global, local and intrinsic classes are therefore dependent on system data, data from coupled elements, or data that is particular to the component type respectively. Within the modeller local attributes are conveyed by ‘local blackboards’ assigned to each connection. These allow information to be acquired and consigned. Global attributes are held at a system level in a global data field, whilst intrinsic attributes are held within an individual data field for each component.

2.4 Modelling a machine system

The overall steps involved in configuring a system model are illustrated in figure 3. Firstly the solution principle needs to be determined, represented as the concept sketch shown in part (a). Following this, a schematic is constructed which represents the connectivity of the considered system, shown in part (b). Individual components, represented as icons, are placed on to the worksheet and linked to form the mechanical structure, i.e. the system configuration. Once completed, electronic representations that govern the design/selection of each mechanical component need to be specified, shown in part (c). This is effected for all but the core elements, for the example shown in figure 3, the core elements are the shaft components. In order to select a governing electronic representation for a core component, knowledge describing all the connected component types must be available. Hence, prior to selecting a governing representation for the core element(s) the system template is generated by the modeller. From this template it is possible to examine the number of elements, their type and their relative order of connectivity to the core component. This order of connectivity can be manipulated by the designer, say for example to alter a configuration from bearing A, gear, chain drive, bearing B; to bearing A, gear, bearing B, chain drive. Furthermore, in the case of a core element such as a shaft, the designer can control the properties of the individual nodes to which elements are connected.

After the selection of governing electronic representations and the specification of desired values for element attributes, system constraints need to be set and any performance and physical requirements for the system may be specified. The former might include lubrication types whilst the latter may include system attributes such as life or working conditions. This phase of the modelling process is shown in parts (d) and (e). Once complete, the system model may be resolved. This resolution process automatically determines a system of real, compatible mechanical components that satisfy the desired performance requirements for the system. The modeller handles the many different attributes and relationships between connected components, manipulates and arbitrates the selection data for each component, and automatically interrogates the various electronic representations during resolution. The resolution process culminates with the determination of a fully embodied design solution. In the resolved system all components are matched in terms of their geometry and performance capabilities and the system best meets the overall performance and physical requirements of the design specification. A solid model of the resolved system is shown in part (f) of figure 3.

3 Industrial case

This case study involves the reconfiguration of a drive train for an industrial overwrapper. The overwrapper uses two cam and linkage assemblies to perform the wrapping of the film around the product. These assemblies are mechanically coupled by the drive train. The current

configuration comprises two layshafts located 500 mm to either side of a drive shaft, which is powered by an electric motor that is geared to the drive shaft. The layshafts are each driven by identical chain drives, shown in the upper portion of figure 4.

The company for whom the case study has been undertaken are embarking on a program of redesign and wish to alter the machine assemblies which perform two supplementary operations. In order to achieve this, additional space in the central/upper portion of the machine must be created. Furthermore, in an effort to reduce the out-of-balance forces it is desirable for the cams to rotate in opposite senses. In order to achieve this, a solution is proposed which involves shifting the drive shaft towards the lower layshaft and replacing the chain drive with a gear pair, shown in the top portion of figure 5. This increases the free space in the central/upper portion of the machine, allowing the redesigned assemblies which undertake the supplementary operations to be incorporated into the machine.

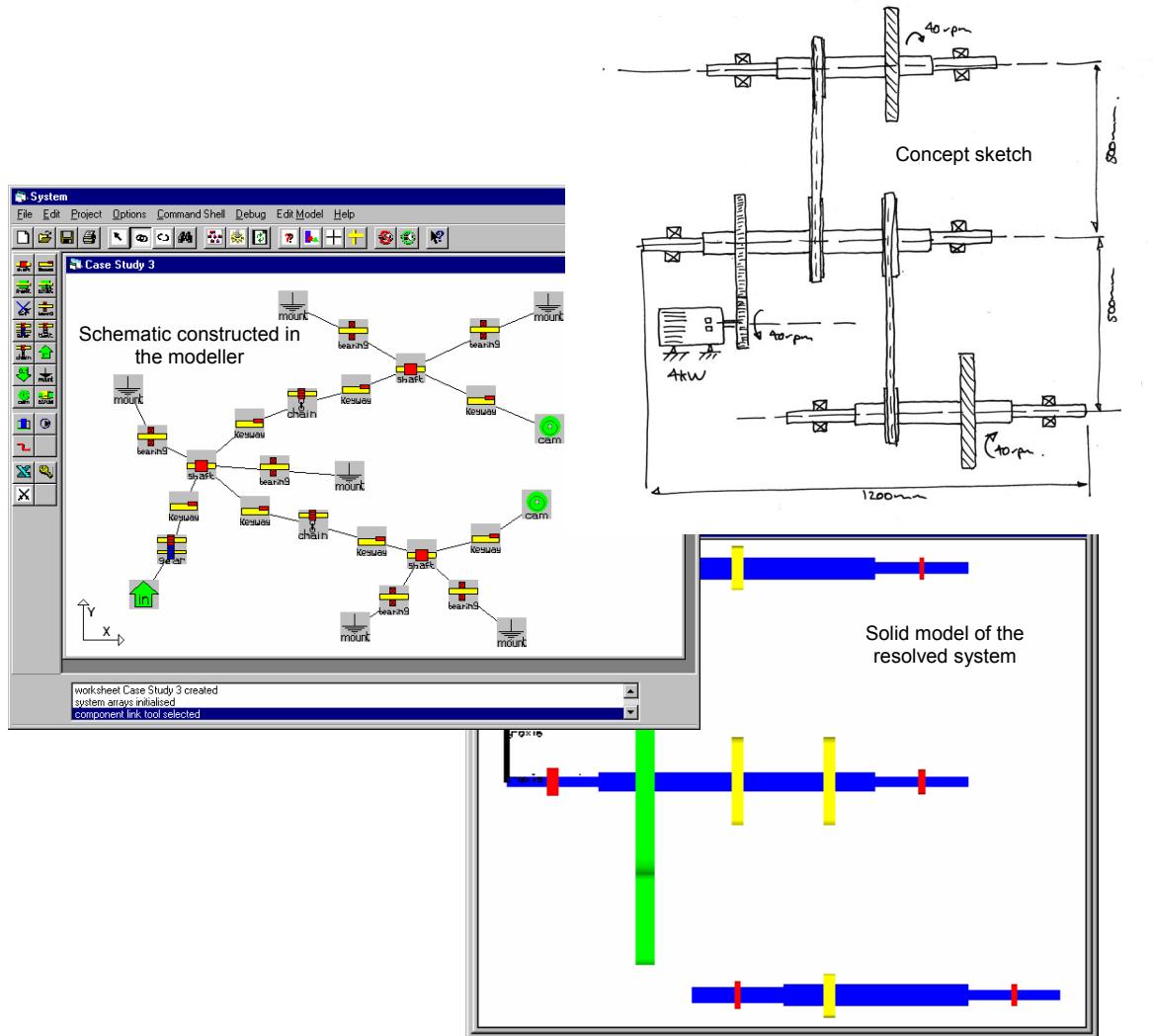


Figure 4. Current overwrapper transmission.

In order to investigate the revised drive train, modelling episodes for the current layout and the revised layout were undertaken. A schematic or connectivity model of the current configuration created in the modelling environment is depicted in figure 4. The required values for the centre distances of the chain drives, the loading and the shaft dimensions were

entered. The system model was then resolved and a set of components determined. The geometry of the system is also shown in figure 4 and a summary of the system attributes is given in figure 6. This process is repeated for the revised drive train, except one of the chain drive components is replaced by a gear pair and the centre distances for the upper chain drive and the gear pair are altered to 750 mm and 250 mm respectively. The schematic and the geometry of the system are shown in figure 5, whilst a summary of the system attributes is also given in figure 6.

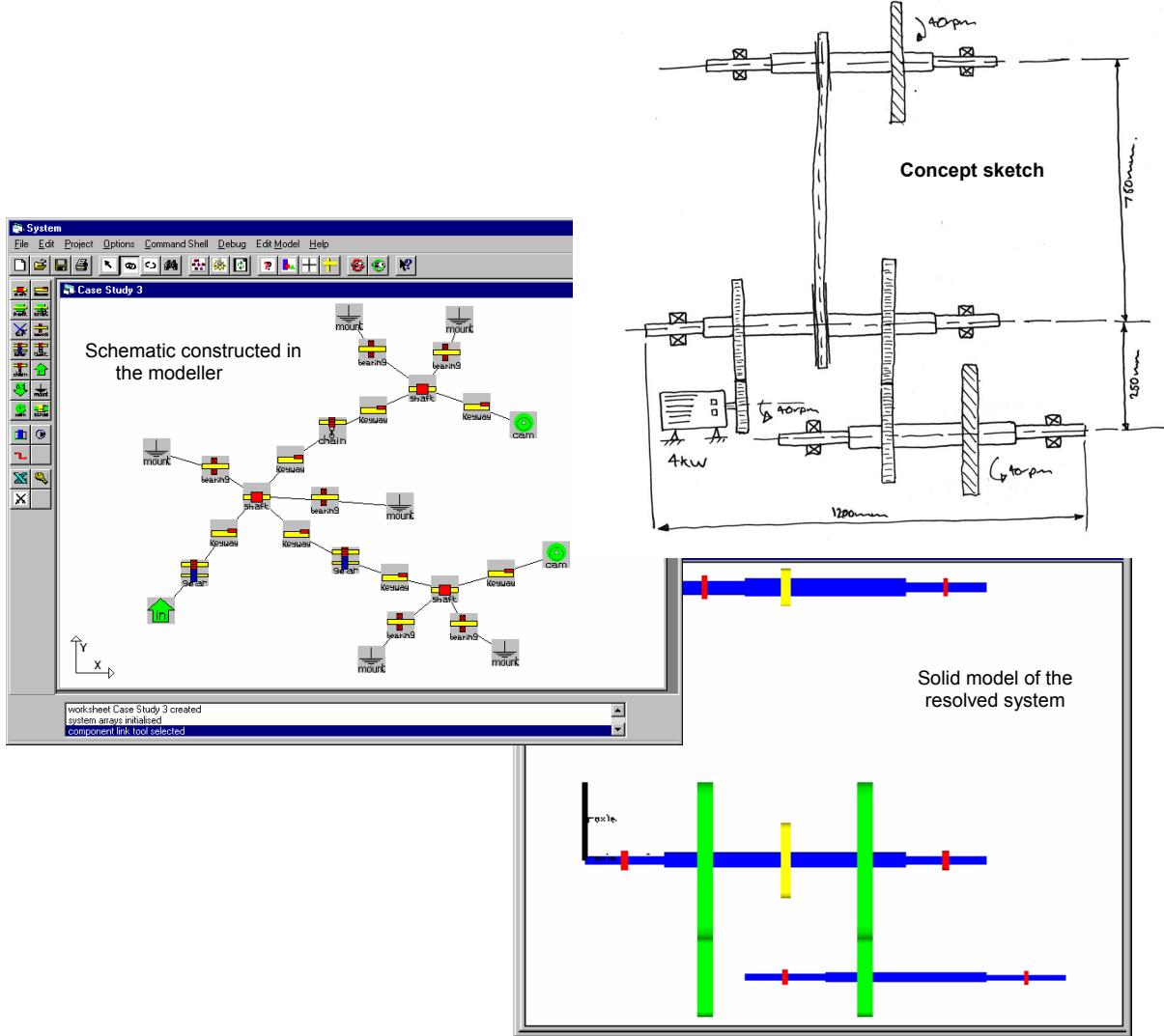


Figure 5. Revised overwrapper transmission.

The ability to determine key system attributes provides a means for comparing the revised layout and the current layout, these are summarised in figure 6. In particular, the mass of the system is reduced as well as the cost. This is due to the introduction of the second gear pair. This reduces the forces in the lower layshaft, enabling a slightly reduced specification for the shaft and the bearings. Furthermore, the gear pair is slightly cheaper than the current chain drive assembly. However, the cost of the chain drive on the upper layshaft has risen due to an increase in the centre distance and hence the chain length. The overall spatial envelope of the assembly does not really change, although there is a slight increase in the y-dimension due to the large gear that has replaced the sprocket on the lower layshaft. The modelling episodes

show that there are no significant changes in the system attributes and that the altered configuration is feasible. Furthermore, the impact on the system geometry can be investigated by inspecting the solid models of the layouts (figures 4 & 5). This provides a mechanism for evaluating aspects such as clearances, arrangement, internal space and mounting points.

The case study comprises twenty-eight components, each of which possesses between ten and twenty-four different attributes, an example of component attributes is shown in part (c) of figure 3. If a system of this size were embodied manually by the designer, the process could take many hours, involving a number of analytically intensive and error prone tasks. However, the modelling approach is capable of handling and analysing such a system in only a fraction of the time. This case study demonstrates the capability of the modelling approach to handle large systems and evaluate the effect of changes to particular assemblies or components on the overall machine system. Furthermore, all the components that are specified by the system during resolution are ‘real’ components sourced from third party representations, and can be procured exactly as specified. From this real data the system geometry and system attributes are determined. This provides a reliable means to evaluate the revised layout and compare changes to the internal space, the mass and the cost.

| | Current transmission | Revised transmission | Percentage improvement |
|--------------------------|----------------------|----------------------|------------------------|
| No. of components | 28 | 28 | - |
| System mass (kg) | 36 | 33 | 8 % |
| Cost (£) | 757 | 681 | 10 % |
| Leading dimension x (mm) | 1200 | 1200 | - |
| Leading dimension y (mm) | 1026 | 1068 | 4 % |
| Leading dimension z (mm) | 200 | 200 | - |
| Shaft mass (kg) | 23.68 | 16.76 | 29 % |

Figure 6. System attributes for the current and revised overwrappers.

4 Conclusions

The new modelling approach enables both the performance and geometry of a machine system and each component to be considered. The approach provides a flexible and unrestricted representation of the system both in terms of its size and structure. Furthermore, because existing (third party) electronic representations are integrated in the modelling approach ‘real’ mechanical components are considered, which is essential for effective system design. This computer based embodiment of machine systems can be undertaken in a fraction of the time when compared to more traditional manual methods. This enables the development of a more refined design solution and ultimately more fully informed decisions to be taken at an early stage in the design process.

An industrial case study is considered. This case study comprises twenty-eight components, each of which possesses between ten and twenty-four different attributes. It is clearly not possible to weigh up the impact and interaction of around 500 component attributes. If a system of this size were embodied manually by the designer, the process could take a very long time, involving a number of analytically intensive and error prone tasks. In reality it is likely that the designer would stop once a feasible solution, balancing all the different component attributes, has been achieved. However, the modelling approach is capable of handling and analysing such a system and considering all the potential schemes.

The case study demonstrates the capability of the modelling approach to handle large systems with multiple assemblies. The modelling environment can automatically embody different configurations or design concepts for the same or similar performance requirements. In addition to this, the ability of the approach to evaluate the impact of changes to particular assemblies or components on the overall machine system is shown. In particular, the modelling tool provides an indication of the changes in system mass, cost and geometry that are brought about by incorporating an altered assembly or changed part. Because these measures are generated from component data contained within the various third party electronic representations they afford a reliable basis for decision-making.

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