Chapter 1
Collaborative Design Approach in Product Design and Development

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Abstract This chapter presents an integrated framework for distributed and collaborative environment, which could assist organizations to achieve integrated design goals. The proposed system emphasizes the integration of the software tools and the resources involved in the design process to collaborate the geographically dispersed design teams and vendors. The advancement in information technology (IT) is the driving force for the development of this environment. Also, the early participation of vendors in the design process is considered critical in order to improve the product quality and reduce the development cycle time.

Advances in IT have enabled designers to more effectively communicate, collaborate, obtain, and exchange a wide range of design resources during development [1]. Many manufacturing companies are publishing their product information on the Internet. The network-oriented design environment is a new design paradigm for product development. An integrative framework that enables designers to rapidly construct performance models of complex problems can provide both design insight and a tool to evaluate, optimize, and select better alternatives. Furthermore, a design problem constructed from modeling components made available over Internet might facilitate the collaborative development of analytical system models in addition to the exchange of design information. A well-defined integrated model will predict the required product properties and evaluate alternative solutions in order to meet the defined design objectives and performances.

Key to the analysis of any problem is the identification of what functions are performed and the relationships between them [18]. A collaborative engineering development process includes a set of activities and functions arranged in a specific order with clearly defined inputs and outputs. Each activity in the process will take a set of inputs and transforms it into an output of some value. The process is considered efficient, when the output of the process satisfies the general customer and product requirements and meets management objectives and cost. New technologies and tools along with advancement in IT are helping these organizations in several ways [2, 17]. However, there is no established generic implementation model for wide range of industries.

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Software vendors may provide "custom" software packages for individual firms. Different industries have different product development strategies, which demand a generic framework that will help them collaborate efficiently irrespective of their product, organizational structure, and/or geographical location. Two of the more important elements in this changing environment are increased product sophistication and variation. Minimizing the total costs and being quick to develop and market new products is the key for survival. Product development is a complex process requiring expertise from several fields. This will demand integrating the diverse functional areas of an organization on a common platform [22].

In this chapter, an integrative framework that would enable the design teams rapidly construct performance models of complex design problems is presented. This framework can provide both design insight and a tool to evaluate, optimize, and select better alternatives. Interaction between the elements at every level of design is a critical issue. The framework should not be limited only to internal function integration but it should also consider the external functions such as vendors. The vendors have precise and detailed knowledge for their items. This expertise should be incorporated in the main development system to ensure and optimize the product as a complete system. The templates for different processes and/or procedures should be designed systematically to assist in evaluating and optimizing the design alternatives through proper integration and analysis.

1.1 Integrated Product Development

Integrated product development (IPD) is recognized as a critical part of the development of competitive products in today's global economy. As a company grows larger and products become more complex, hierarchical organizations are established to master the increasingly large organization size, the technical complexity, and the specialization that evolves to master this complexity. This growth also results in the geographic dispersion of people and functional departments. These factors inhibit many of the informal relationships that previously provided effective communication and coordination between functions. A hierarchical organization structure with enterprise activities directed by functional managers becomes incapable of coordinating the many cross-functional activities required to support product development as the enterprise moves toward parallel design of product and process and a focus on time-to-market. Product development teams (PDTs) are a way to address this complexity by organizing the necessary skills and resources on a team basis to support product and process development in a highly interactive, parallel collaborative manner. Some of the basic principles and guidelines for an IPD are as follows:

1. *Understand Customer Needs and Manage Requirements:* Customer involvement increases the probability of the product meeting those needs and being successful in the market. Once customer requirements are defined, track and tightly manage those requirements and minimize creeping elegance that will stretch out development.

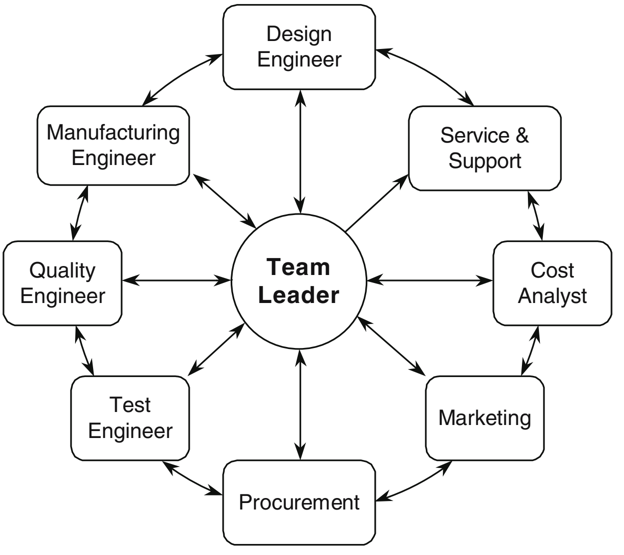

Fig. 1.1 Integrated and collaborative team environment

2. *Plan and Manage Product Development:* Integrate product development with the business strategy and business plans. Determine the impact of time-to-market on product development and consider time and quality as a source of competitive advantage.
3. *Use Product Development Teams:* Early involvement of all the related departmental personnel in product development provides a multifunctional perspective and facilitates the integrated design of product and process.
4. *Involve Suppliers and Subcontractors Early:* Suppliers know their product technology, product application, and process constraints best. Utilize this expertise during product development and optimize product designs.
5. *Integrate CAD/CAM and CAE tools:* Integrated CAD/CAM/CAE tools working with a common digital product model facilitate capture, analysis, and refinement of product and process design data in a more timely manner. Feature-based solids modeling, parametric modeling, and electronic design frameworks facilitate the downstream interpretation, analysis, and use of this product data.
6. *Simulate Product Performance And Manufacturing Processes Electronically:* Solids modeling with variation analysis and interference checking allow for electronic mock-ups. Analysis and simulation tools such as finite element analysis (FEA), thermal analysis, network computer (NC) verification, and software simulation can be used to develop and refine both product and process design inexpensively.
7. *Improve the Design Process Continuously:* Reengineer the design process and eliminate non–value-added activities. Continued integration of technical tools, design activities, and formal methodologies will improve the design process.

Figure 1.1 illustrates the scope of the integrated design team environment.

1.2 Collaborative Design and Development

Design refers to the activities involved in creating the product structure, deciding on the product's mechanical architecture, selecting materials and processes, and engineering the various components necessary to make the product work [26]. Development refers collectively to the entire process of identifying a market opportunity, functional requirements, and finally testing, modifying, and refining the product until it is ready to manufacture. The development of a product is time-consuming, lengthy, and costly.

In a typical product development process the design occurs largely before final full-scale manufacturing. In most of the cases this design is later altered or refined for the manufacturing difficulties, which leads to increased cost and time. The manufacturing department is responsible for estimating the feasibility, cost of building the prospective new product, and modifications, if necessary. If the decision has been taken to outsource some of the components in the final product, the *vendors* come into direct consideration. The vendors become a part of the design team, as they will be contributing toward the development of the final product. Hence, it is very important to consider the vendors' involvement in the design process beginning from the initial stages of the design and development of the product. Thus, in any product design and development scenario the interaction among marketing, engineering, manufacturing, and, in most cases, the vendors is very important. This requirement is met by the application of collaborative product development (CPD) [6, 13, 16, 29].

In the CPD process, the feasibility [25] for product life cycle is analyzed during the early stages of the design process. The expertise from several fields is considered absolutely essential at every stage of the development process. The expertise is grouped in different teams. Each team is responsible for its contribution throughout the process. In the current market trend such teams are mostly dispersed geographically. The need for integration continues when the design enters the preliminary and detail design phases. In an integrated, collaborative design environment, designers interact by sharing information. By considering proper integration and interaction from the beginning, the problems with the final integration of activities can be significantly reduced. In this context, an integrated system is desired to reduce the overall design cycle time by eliminating the repetitive calculations to obtain optimum results. The important stage of collaboration is breaking the barriers among departments and individuals. This open environment increase groups productivity.

CPD practices are recognized as critical to the development of competitive products in today's dynamic market. A hierarchical distribution of work is essential for large organizations and complex products. This structure also results in the geographic dispersion of people and functional areas. The typical integrated environment is shown in Fig. 1.2. PDTs are formed with personnel from various functional departments to support different stages of the development process including the production and services.

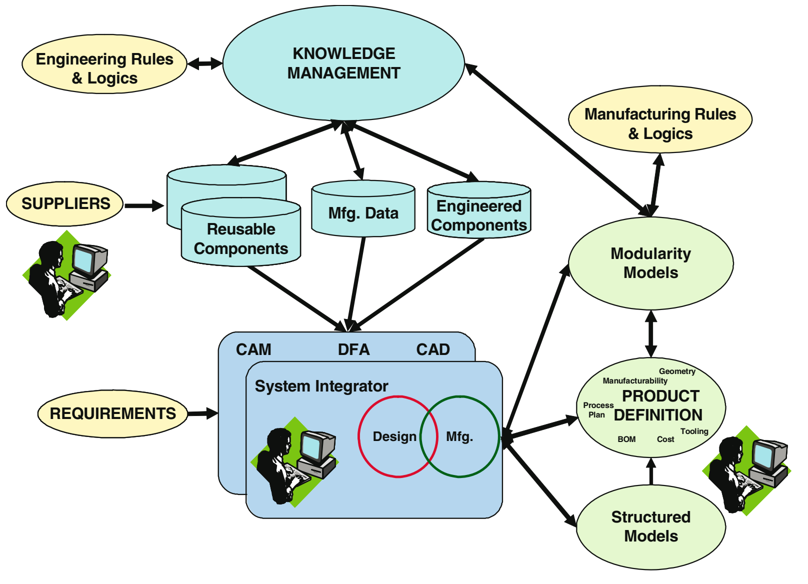

Fig. 1.2 Design team distributed geographically

This early involvement will result in a complete understanding of all the requirements and a consensus approach to the design of both the product and its manufacturing and support processes. PDTs promote open discussion and innovative thinking resulting in superior products, more efficient processes, and, ultimately, a more satisfied customer [12]. The focus of the team will be to satisfy the external customer's product and support requirements as well as the internal customer (functional department) requirements related to factors such as producibility, cost, supportability, and testability.

For an effective distribution of activities among the design teams, the structured approach is very important. The distribution process should start with the product definition and end with manufacturing of the product. The first step toward effective IPD is the understanding and management of customer requirements. The product definition and the structure should be based on the well-understood customer requirements. These requirements should be evaluated and refined considering the expected time-to-market and quality of the product. The early involvement of all the related departmental personnel in the development process provides a multifunctional perspective. This helps reducing and/or eliminating the redundancies of data and manufacturing issues. Today's dynamic market demands more outsourcing from vendors. The utilization of this expertise could help in improving product quality, optimize the product at the system level, and reduce the cycle time [24].

Along with the expertise from different fields and the vendors, the distribution and integration of the resources is also critical. The integration of different CAD/

CAM/CAE tools could shorten the development process and optimizes the design. The use of common electronic product model reduces the chances of redundancy and errors. The feature-based solids modeling, *parametric modeling*, and electronic design frameworks facilitate the analysis and use of product data among participating teams. With the advancements in information technology IT, it is possible to electronically simulate product performance, interface checking, and manufacturing feasibility. This helps in refining the product and the processes from manufacturing perspective [14]. This overall development process should not be set as standard and needs to be improved as it progresses. Figure 1.3 illustrates an example of how design is done using a heterogeneous environment [27, 28].

Central to the design of this system is the interlinking mechanism of the data from different data resources. This link allows for transmitting results from one module to another. The second important part of this design is the parametric databases. Creating the databases is one of the crucial parts in the design of this integrated environment. The databases are built using information (parametric data, models, etc.) supplied by different vendors, design rules, manufacturing, and other pertinent data. Using input module(s) designers participate in the design and analysis process. Designers can input variables and perform necessary calculations and integrated analysis. Figures 1.4 and 1.5 illustrate the scope of integration for the I/O modules and databases.

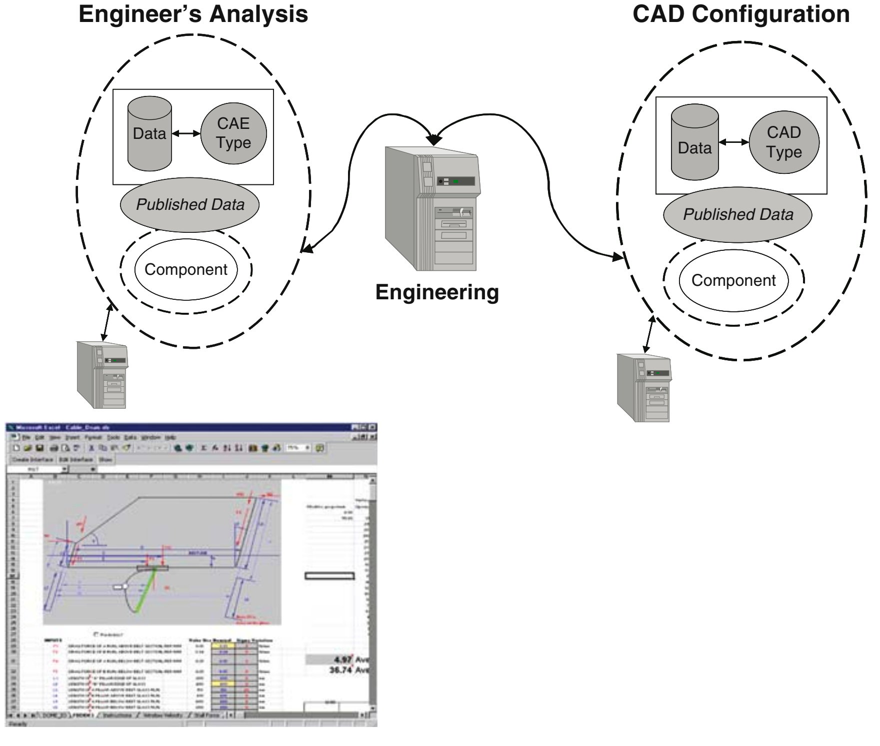

Fig. 1.3 Sample integrated design model

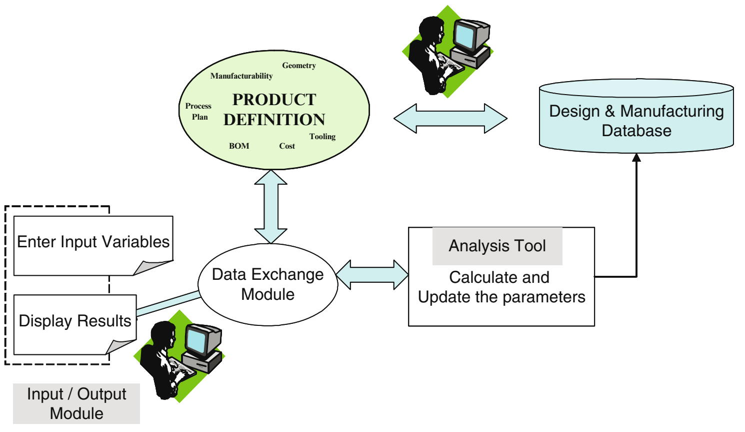

Fig. 1.4 Integration of the I/O modules with the analysis tool

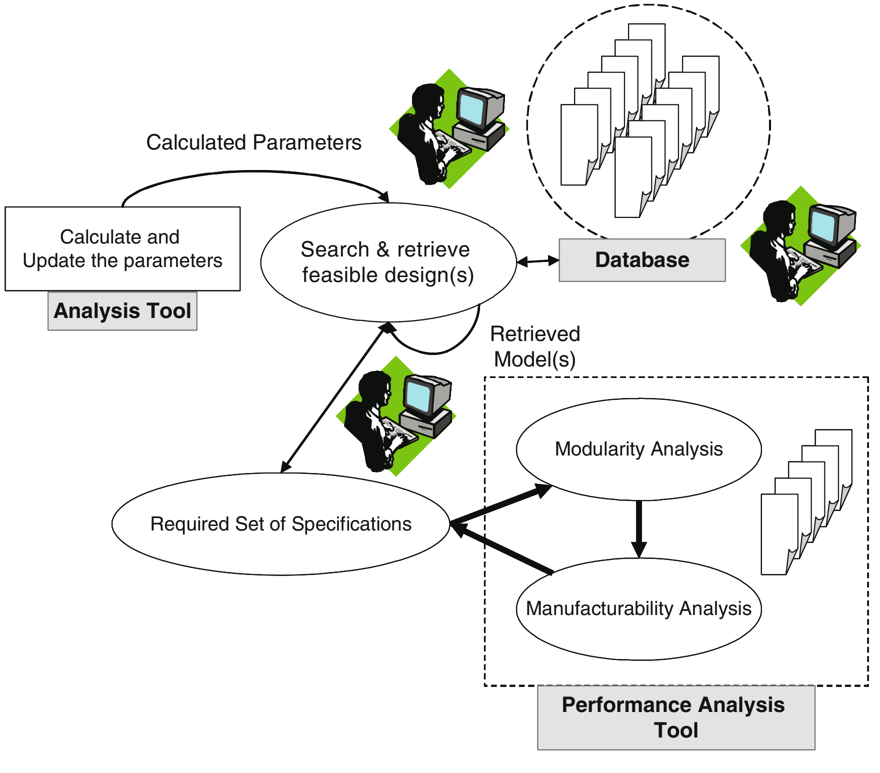

Fig. 1.5 Integration of the analysis tool, databases, and the performance analysis tool

Many researchers are working on developing the technologies or infrastructure to support the distributed design environment. Some are working on providing a platform for sharing or coordinating the product information via the World Wide Web [10, 11].

Others are developing the framework that enables the designers to build integrated models and to collaborate by exchanging services [4, 5, 7, 19–21, 23, 27].

1.3 Case Study: Design of Single-Stage Spur Gearbox

The design problem is decomposed into modules such as physical components, design constraints, parametric models, analysis procedures, and CAD modeling. The important aspect of the framework is an integration of these modules used during the design process in the collaborative environment. The proposed collaborative framework allows the integration, which is capable of revision for the functional model at that instance with any changes made by individuals. The tools used during the product development process vary with the design teams and the vendors. Problems may arise in sharing the information in different forms. Also, sometimes it is very difficult to convert the data or information from one form to the other. This necessitates the *vendors'* involvement at early stages of the development process. The developed system allows the designer to collaborate with the vendors and other team members to optimize the design process considering the relationship within these modules.

1.3.1 System Overview

The problem of gearbox design is decomposed and distributed among the different design teams. At the system level the gearbox design problem has the requirements in terms of design variables and the required output performance characteristics. Along with the design variables there are design constraints like low weight and low cost. Table 1.1 shows the decomposition and distribution of the problem.

The distribution of tasks is done on the basis of the tools used. For this particular design problem different tools and modules considered are analysis tool, optimization team, vendor catalogs, and CAD modeling. These phases represent different design teams that are geographically dispersed. The original equipment manufacturing (OEM) team is the final user of the system. The OEM user enters or changes the design variables and constraints according to the product requirements. The user interface is illustrated in Fig. 1.6.

These variables and constraints are mapped to the *analysis tool* with the use of file wrappers. The *analysis module* is the team of individuals who compose the design problem. The analysis module team performs the numerical analysis and generates the possible alternatives. The design problem and the alternatives are then evaluated at the *optimization module*. The optimization module retrieves the catalogs from the vendor(s) and generates the results in the form of best configuration of the system components.

Table 1.1 Problem decomposition and task distribution

	System level	Subsystem level	Component level
Design variables	Input power Input speed Output power Output speed	Minimum output performance characteristics	
Constraints	Lightweight	Compact design	Gears – Face width – Outer diameter – Shafts diameter
	Low cost	Material Overall size	Material cost Use of standard items
Results	Possible alternatives Overall performance Assembly CAD models	Possible alternatives Trade study	Geometrical detailing Force/stress analysis CAD models

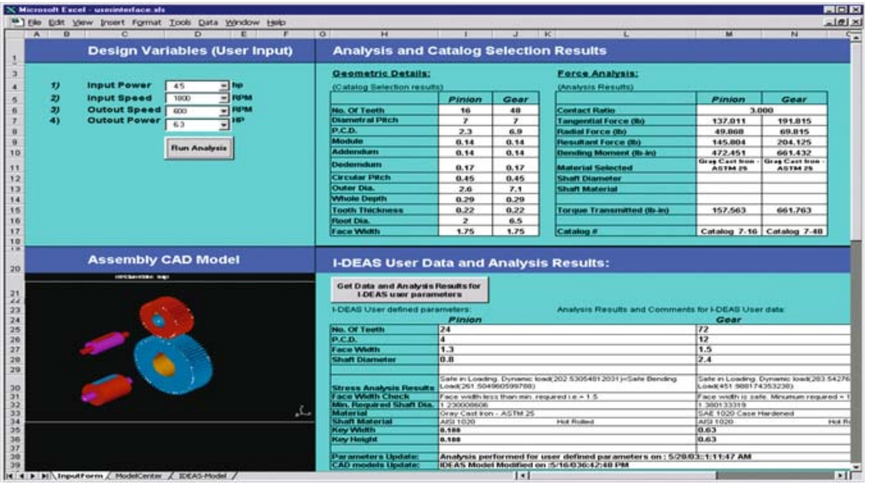

Fig. 1.6 User interface

The *optimization tool* put the catalogs in every instance of the design procedure and evaluates against the design problem and constraint. "Vendor A" is the supplier for the gears and has the set of design catalogs for different gears [*3*, *8*, *9*].

The catalogs are the replaceable modules containing technical specification of the components. The CAD modeling group is responsible for creating the parametric models for the system components. The optimization group sends the results to the CAD station. These results include the geometric details, material specifications, and the analysis data. The CAD modeling group then generates the solid models on the basis of these results. If there are any modifications, the new parameters are sent back to the analysis module for the analysis.

This cycle continues until all the groups approve the design and it meets the functional requirements. Once the design is finalized, the CAD models are created and sent to the user interface.

1.4 System Structure and the Components

The proposed framework is shown in the Fig. 1.7. It consists of five phases: analysis tool, collaborative environment, optimization module, CAD modeling, and vendors' catalogs. An *integrated product* design approach for the design of single-stage speed reducer with a pair of spur gear is structured using the developed system. The design problem is composed of analysis for performance characteristics, catalog selection for vendor supplied items, and CAD modeling for selected alternatives. The product is decomposed into the primary functional system, subsystems, and the components. Maintaining interdependency among these subsystems and components is very important so as to work as a system. It is also important to consider the attributes such as standardization, modularity, future changes, and ease of manufacture and assembly. For the outsource components, the vendors have to contribute with associated design and engineering. In the detail design process, further engineering is done for individual components in the system. The automated generation of

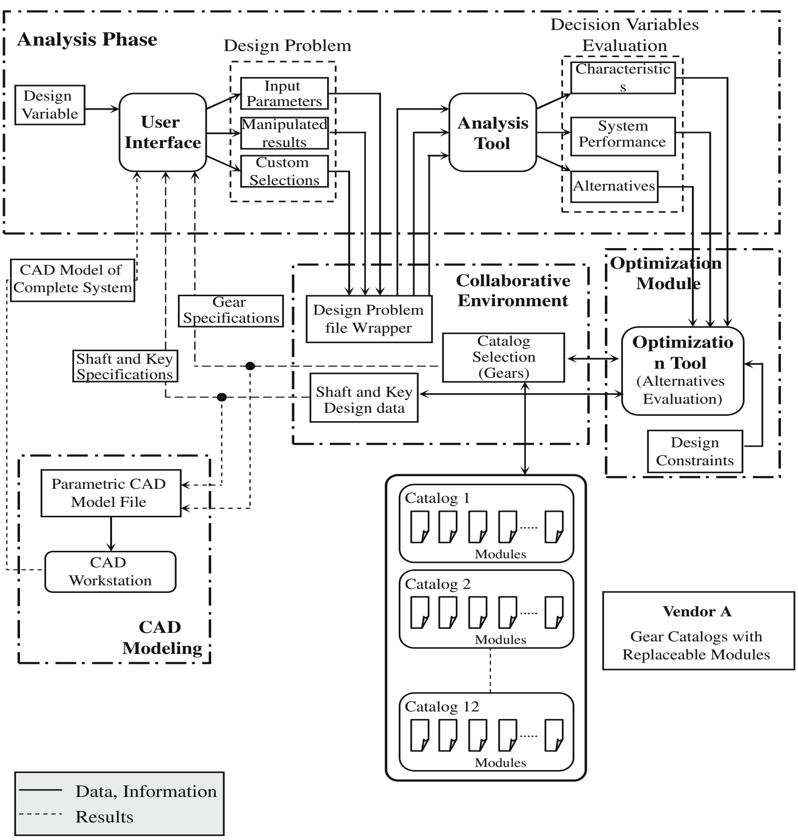

Fig. 1.7 Data and information flow in the proposed integrated system

3-D computer models for different alternatives can serve as unique data model throughout the development process and eliminate and/or reduce the changes of redundancies.

1.4.1 Collaborative Environment

Software integration is a complex process that requires a courtly solution. There has been significant advancement in the data-sharing techniques. The critical issue is maintaining the relationships and dependencies among the different types of data. The data and the information in the proposed system are categorized and defined as modules. The collaborative environment is the integration of all the *modules* and the *catalogs*. The ModelCenter® is used as a service protocol, which connects different modules and catalogs keeping the corresponding relationship as shown in Fig. 1.8.

ModelCenter® is an application that allows users to graphically interact with the modules and generate links between dissimilar applications. During the assembly and the integration of these modules, the design teams can perform the analysis, the optimization, and the trade studies of system level parameters. AnalysisServer® is another application by Phoenix Integration, Inc., that integrates these models by wrapping techniques over the network. The parameters defined in the design problem are the elements of these models.

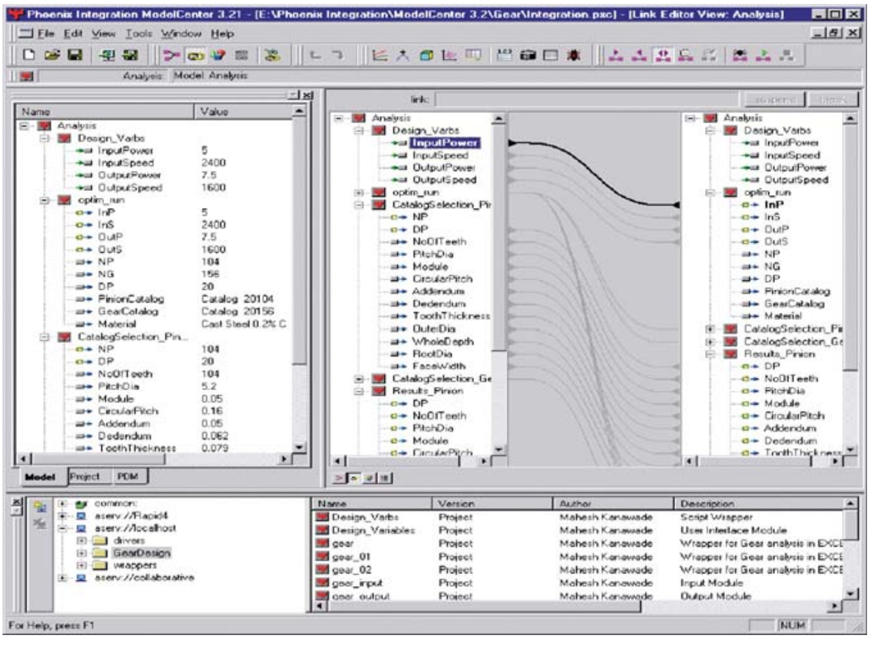

Fig. 1.8 Graphical integration of components

The file wrappers are created to link the input data file (user interface) and the analysis tool. Once the analysis tool calculates the preliminary parameters, the file wrapper maps these values for the optimization module. The results of optimization are returned to the user interface where the user can comprehend these for further changes.

Concurrently, this set of results is sent to the CAD modeling module. Solid models are automatically generated for different components of the product.

1.4.2 Analysis Phase

The design problem is composed of input parameters entered by the user. These are the input and output performance characteristics for the design analysis. The design problem is mapped to variables and synchronized with the analysis tool using the ModelCenter® wrapper file. The analysis tool is introduced to set the decision variables and their evaluation. This application anatomizes the design problem and gives feedback in terms of the performance requirements for different elements in the system. When the user enters/changes the parameters and run the analysis, the wrappers map these as variables and the AnalysisServer® updates the associated variables in the model file. The analysis tool evaluates these parameters and generates the possible alternatives. These alternatives are then further analyzed along with the optimization criterions.

1.4.3 Optimization Phase

The catalogs are the structured databases at the vendors' site. The optimization module team can retrieve these catalogs on limited access basis. Here "limited access" means that the optimization module team can only retrieve the specific information but cannot modify it. During the optimization run the queries are created which retrieve only a particular catalog from the vendor station. It eliminates some of the issues for the information security. The optimization tool maps these replaceable modules from the catalogs for every instance and places them in the current design alternative until the suitable match(s) is found. The optimization module selects the components from the catalogs and returns to the user interface as *results*. This gives the user the detailed specifications for the product and its elements. The results obtained are the parameters obtained from the catalogs, which gives the optimum performance for the given design requirements and constraints. A sample code is listed in Fig. 1.9.

The results obtained from the analysis tool gives theoretical values for the parameters that are acquired from empirical relations. The optimization model is developed to get the configuration, which satisfy the given constraints optimally. The relationships are imposed between the design variables from the design problem and the constraints from the modules. The optimization tool runs an iterative

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For Each DP In DPrange
 Worksheets(1).Range("C14") = DP
 Calculate
    For Each So In materialRange
     Worksheets(1).Range("C23") = So
     Calculate
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      Worksheets(1).Range("C18") = NP
      Calculate
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Fig 1.9 Visual Basic optimization code for gear selection

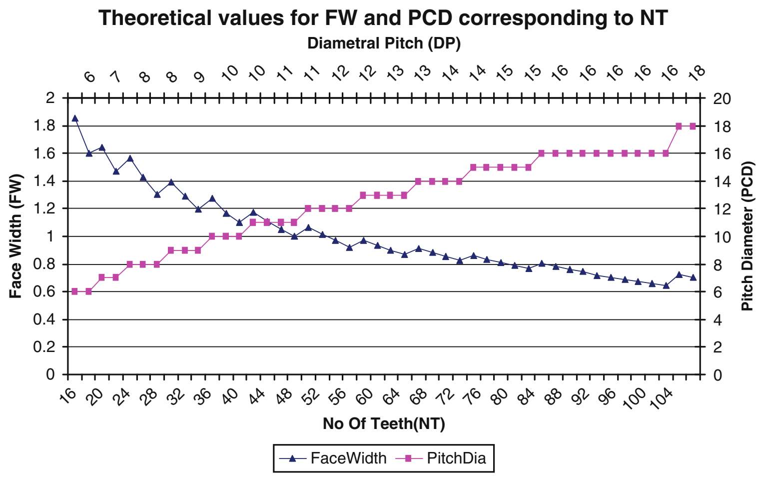

Fig. 1.10 Possible alternatives with expected results

procedure. The modules from the catalogs are retrieved and placed into the current design instance. The modules that satisfy the design constraints and the available components from the vendor catalogs are then selected as alternatives. The graphical comparison of these alternatives is presented at the user interface, which helps the user to trade off for size and cost. Depending on the requirement, the user can then manipulate the design variables to get the best possible configuration. Once the configuration is finalized, the *program files* for CAD modeling are created automatically to generate the solid models of the components. In this case study, a pair of gear is selected from the catalogs and then evaluated for load, power, and other characteristics defined in the design problem. Figure 1.10 illustrates the comparison chart used by the engineer in order to evaluate the alternatives.

1.4.4 Parametric CAD Modeling

Another important module of the proposed framework is *parametric CAD Modeling*. The parametric models for different components are created (Fig. 1.11). The results obtained from the optimization module are used to create the 3-D solid models of each element in the system. These CAD models assist the designer to visualize the interaction of the components for a given configuration. An automated design dramatically reduces the time spent in generating the results for several alternatives.

It also serves as a basis for generating detailed documentation for the manufacturing. A Visual Basic code is used to edit the program files with the newly calculated variables. The parametric models are created for each component in the system for optimized configuration. IDEAS is the CAD tool used in the system. However, any CAD software can be used. For the synchronous, real-time application, parametric models are created [15]. The parametric model allows the user to update the model

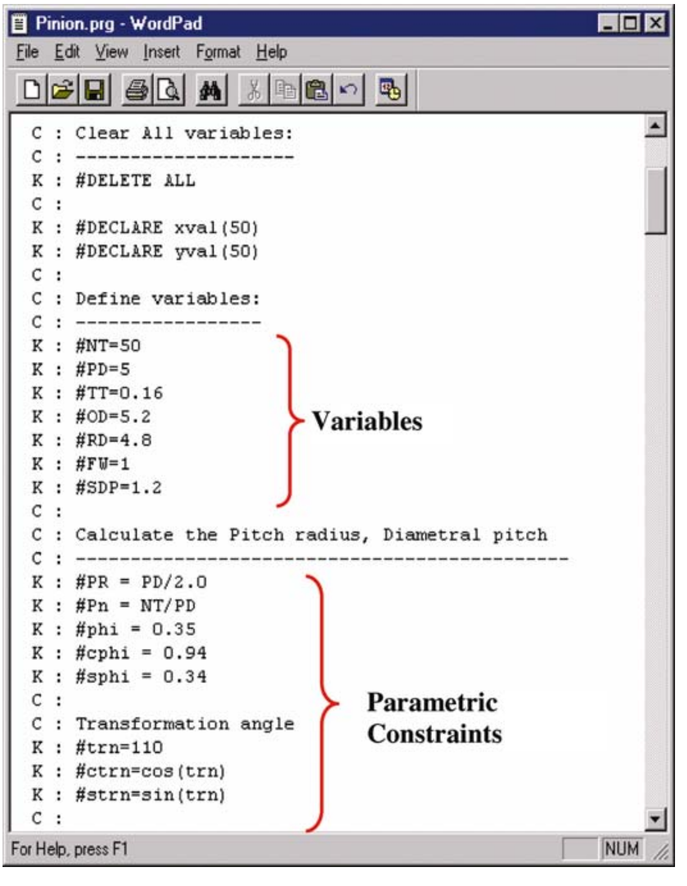

Fig. 1.11 IDEAS macro program file for gear parametric model

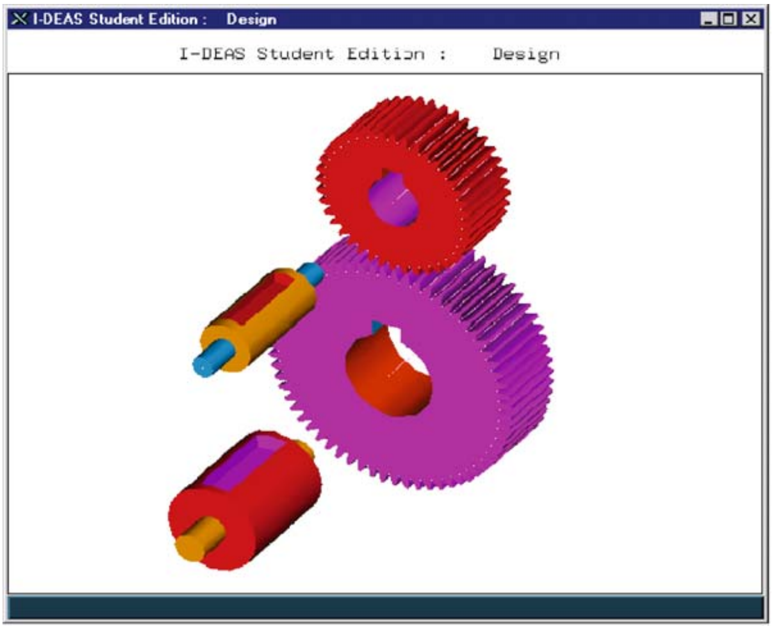

Fig. 1.12 CAD models for the gears and the shafts

according to any change in the design process. For the gear models, pitch circle diameter is a reference dimension and all the other geometric dimensions are constrained and defined using the equations. Once the optimization module generates the alternatives and the results, they are conveyed to the parametric models. The change in pitch circle diameter updates the geometry. The solid models of the components are generated and can be displayed at the user interface in picture format. Solid model for a gear and the respective shaft is shown in Fig. 1.12.

For every change in the design process, the users can retrieve the corresponding CAD models. This gives the designer a chance to visualize the different alternatives and the optimum configuration of the component.

The proposed framework provides the means of integrating software tools that enables the designers to foresee the overall product and enterprise fulfillment during development phases. It will reduce the time required for repetitive analysis for different alternatives. Thus the designer can evaluate more alternatives and can obtain the optimal solution. This integrated system allows the designers to participate in the design process irrespective of geographical location. The developed system provides the capability for design of templates for catalog-based design. Vendors can participate in the development process with their items as catalogs. The optimization phase offers the designers a chance to evaluate different alternatives and the trade-offs.

1.5 Conclusions

Today's manufacturers encounter various difficulties involved in the product development process and these must be overcome for international competitiveness. The obstacles include shortened product life cycle, high-quality product, highly diversified and global markets, and unexpected changes in technologies and customer needs. Any delays in development and you run the risk of losing revenue to your competition. Also the companies are heading toward vendor-based manufacturing (i.e., the manufacturers are trying to get most of the work done by the vendors so as to minimize the time-to-market). Hence it is essential to utilize a computer-aided system in designing, manufacturing, testing, and distributing the products to minimize the time-to-market. For the integration of information at every stage of product development there is need for collaborative technology for job collaboration. As the assistant of the design and development of new products, integrated design technology plays a very important role. The described framework confirms design assumptions and predicts product performance in the early stages of the design process. This results in a faster product development cycle—with lower associated costs—achieved by eliminating the need to constantly build, test, and redesign.

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