CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The discussions in the previous chapter point to the need for studies that can provide methods to the suppliers of headlamps in the development of passenger cars that can be implemented in the existing design platform. There is a need for a framework that can be developed into a PDM system for reuse of knowledge in the development of headlamp. To know the status of research activities in this area exhaustive literature review was carried out. This chapter deals with research activities reported on product development where the increased application of computer and information technologies are in use and the product development strategy for the manufacturing of headlamps in passenger car application in particular. In the first level, literature on research activities for improving functional requirements of headlamps and the supporting technologies for this purpose, namely, computer aided design (CAD) and knowledge based engineering (KBE) are reviewed. In the second level, research activities reported on various concepts and tools supporting product development activities such as product modelling, product data management (PDM), product lifecycle management (PLM) and collaborative engineering are reviewed. Knowledge gained in the literature survey is briefly explained in the following subsections.


2.2 FUNCTIONAL REQUIREMENTS AND SUPPORTING TECHNOLOGIES FOR DESIGN OF HEADLAMPS

Major considerations in the design of products are various requirements that constrain the design process. The constraints are effectively managed by suitable technologies that support the CAD system. This section deals with the survey of literature published in the areas pertaining to the requirements of performance and aesthetics, which may pose challenges to the designer of headlamp. The literature survey also covers the CAD and KBE technologies that support the design phase of the product development.

2.2.1 Design of Headlamp components for optical performance

Designers of headlamps for passenger car enjoy only a limited amount of freedom on improved stylistic designs due to various constraints imposed by OEMs on mounting height and space without compromising illumination distribution. This issue has been addressed in the work reported by Neumann (1989) wherein the author has proposed a variable focus reflector. The reflector surface is divided into adjacent surface elements with unique focal points. The concept was implemented and improvements in lighting efficiency were reported. The reflected beams have to diverge in horizontal and vertical direction for the proper illumination of roads. Chinniah et al (1995) have used divergent angles for modelling the reflector surface from the incident angle and axis of parabola. The spread specified by the curve can be easily programmed and helps computer aided implementation.

Patow et al (2004) and Patow et al (2007) have reported the development of reflector surface from user defined far field radiance distribution. Nagai (2005) has proposed a method for reducing divergence angle by extending optical path between reflector and light source. The
computer aided design and optimization for reflector has been reported in the work reported by Prasannakumar et al (2006) where a mathematical model for reflector surface is implemented in CATIA V5® and an optimized surface for reflector was generated. Kuhlenkotter and Sdahl (2007) have reported on automated inspection of reflector for car headlamps. Anson et al (2008) have presented a framework for inverse designing rotationally symmetric reflectors given a desired near field of distribution. They have used a Non-Uniform Rational BSplines (NURBS) curve to represent the generatrix of the reflector surface.

The literature survey shows that reflector is a critical component and its role is significant in meeting the performance requirements. Paraboloidal surface for reflector is still under active research. Development of surface for the reflector from the user defined illumination distribution has been addressed by many researchers.

2.2.2 Design of Headlamp components for aesthetics

The domain of CAD has been evolved to cater to the requirements of the automotive and aircraft industries. This has led to the incorporation of aesthetic design options in CAD, which was later developed, to computer aided industrial design (CAID). In this new domain of industrial design, surface modelling is critical. Accordingly, commercial software vendors added user friendly and powerful surface modelling features. For example, CATIA V5 R16 supports better surface modelling and analysis features compared to other modelling softwares. The details of literature survey conducted on surface modelling are discussed here.

A good number of research activities have been reported on surface generation methods. The method of development of surfaces from a set of
profiles can be seen in the applications like, generation of surface for vases by giving its end curves as inputs, surface connecting the turbine blade with its boss, rounded surface created at the corners of bumper of automotives and surface joining fuselage with wings in aircraft. Similar to this, a number of research papers are available on blended surface generation. In both cases, the surface continuity has a major role in providing visually pleasant shapes to the surfaces. In blended surfaces, the boundary curves on the primary surfaces are propagated across the linkage curve and the newly created surface becomes integral with the surface where the primary surfaces exist.

A surface generation method was proposed incorporating aesthetic aspect of design for automotive bodies by Higashi et al (1996). Reflected images are important for visual continuity and are affected by the changes in surface normal. The variation of the curvature is reflected in the variation of surface normals. The desired distribution of such surface normals is attained by generating surface from the evolutes, which are the loci of radii of centres of curvatures. A similar work was reported on a vase design by Zhang and You (2002). Vase is composed of a special class of free form surfaces. The authors concluded that their method was superior to conventional surface modelling approaches for vase design as a fourth order partial differential equation (PDE) was used in their method. However, this method was limited to tangent continuities of surfaces.

A large number of research activities have reported on the blending of surfaces using PDE (Zhang and You 2002; You et al 2004; You and Jian 2005; Du and Qin 2007). The authors have used a general sixth order PDE for curvature continuous blending of surface. However, Zhang and You (2002) have used a fourth order PDE for the design of vase as the surface has basically circular cross section and has position and tangent continuities. But for both curvature continuity between primary and blending surface a sixth order PDE has to be used. In addition, sixth order PDE provides a better shape
control than a fourth order PDE as it has four vector valued parameters and two more boundary curvatures. Similar to vase design a different concept has been used by Aumann (1995) for curvature continuous blending of cylinders and/or cones. The algorithm proposed by them, has a six degree directrix for controlling a ‘ringed surface’ whose radii were a function in five degree Bezier forms. This algorithm was applied to various cylinder and/cone combinations.

Surface patch joining a common point has been analyzed by Peters (1992). An interpolation scheme ensuring up to second order continuity (curvature) on arbitrary boundary triangles was proposed by Hagan and Pottumann (1989) where a side vertex method for triangular interpolation for which a quintic Hermite operator has been proposed. A method of curvature estimation for smooth surface design was also presented in the work using a functional as a standard fairness criterion for surface engineering. Jean (1989) has described triangular and rectangular patches for spline surfaces at various continuity conditions.

Gabrielides et al (2007) have proposed a tangent continuous smooth branching surface construction from cross sections. Many authors have addressed discontinuity of surface mesh for CAD and meshing where identification of tangent \( (C_1) \) and curvature \( (C_2) \) continuities were important. Jiao and Heath (2002) have formulized a set of characteristics of \( C_1 \) continuities. Baker (2004) has used statistical measures to capture global discontinuities. Literature on \( C_2 \) continuity of surface mesh seems to be limited. Yamakawa and Shimada (2005) proposed a method, called polygon crawling, which can identify typical \( C_2 \) discontinuities for stereo lithography (STL) meshes generated from CAD models. Shimada (2006) and Varady et al (2007) have reported automatic mesh generation.
Recently, Jiao and Bayyana (2008) have proposed an algorithm for detecting singularities on surfaces, which can identify $C_1$ and $C_2$ discontinuities of surface mesh. Some authors have addressed surface interrogation of car bodies. Vignesh et al (2007) have reported a method for CAD model generation from sketches and discussed the curve and surface interrogation methods where the development of surface patches from closed 3D space curves and global evaluation has been discussed. (Hagen et al 1992a; 1995) have presented certain tests for convexity, flat points, and continuity of surface and visualization of technical smoothness of surfaces. The paper concludes with an interesting finding that the difference of surface areas of the surface constructed and generalized focal surface with scalar function, \( f = \frac{(k_1^2 + k_2^2)}{(k_1 + k_2)} \), is a measure for the technical smoothness of the surface, where $k_1$ and $k_2$ are the principal curvatures.

Interactive examinations of surface quality by interrogation on car bodies have been proposed by Subner et al (2004). A new technique for tessellation of trimmed surfaces was proposed in this work. (Choi and Lee, 1996) have reported work on evaluation of automobile body surface proposing reflection mapping for surface evaluation at global level and focal surface method for the local evaluation of surface.

Principal normal curvature is one of the widely used intrinsic properties for surface generation as well as surface interrogation. The centre of curvature is an efficient tool for surface evaluation interactively. Evolutes are the loci of centres of curvature and can provide knowledge on surface quality. The application of generalized focal surface has been used for surface interrogation in many research works (Hagan et al, 1992b; Choi and Lee, 1996; Elber 2001). The radii of the principal curvatures create a line segment on the normal (line congruence). The loci of such radii of curvatures create
two surfaces in such a way that the line of congruence touches both the surfaces.

Ye (1996) has developed the Gaussian and mean curvature criteria for curvature control. Gregory (1989) has surveyed geometric continuity concepts for parametric curves and surfaces and proposed two concepts for continuity. Yu et al (2007) have used a pair of associated focal surfaces for interpreting differential geometry of smooth 3D surfaces. The application of CATIA V5 R16 for the development of car body surfaces and its analysis has been discussed by Vignesh et al (2007).

The research activities surveyed here on optical design of reflector seems to have not attempted to integrate aesthetic aspects of car body in their work. It is evident from the survey conducted that the most of the researches have eluded out their research on aesthetics aspects in the design of headlamps. The totally integrated shape for headlamp exteriors could be developed by a curvature continuous surface from the car body profiles. The generalised focal surface can be used to evaluation of surfaces and can be implemented in CATIA V5 R16.

2.2.3 Knowledge based engineering of Headlamps

Knowledge based engineering (KBE) is another area of research which strives for effective implementation of computer integrated manufacturing (CIM). KBE basically supports CAD system by using object oriented programming and/or rule based methods. Design knowledge is captured, processed and disseminated or shared by these methods. Parametric design and feature based design are the two primitive knowledge approaches adopted by CAD systems. Literature survey was conducted on the role of KBE in CAD systems.
Since 1990, the domain of CAD was extended to decision-making, design analysis and case based reasoning which has happened in the passenger car design as well. Knowledge based passenger car design has been discussed in the paper reported by Kochan, (1999) where a method of knowledge based headlamp design along with other areas of passenger car design was proposed.

Use of manufacturing knowledge in design reduces the number of engineering change required. Saeed et al (1993) have reported a design method focused on manufacturing knowledge. (Choi et al 2002 and Mun et al 2003) have developed history based parametric approach enabling exchange of product data as macro files. The authors have introduced a set of modelling commands for standardizing the methods. Parameters were used for capturing engineering decisions for driving collaboration. The idea was implemented in simultaneous engineering change management (ECM) within a PDM system developed by Roubiah and Caskey, (2003) where the parametric concept supports integration between suppliers and OEMs. Many engineering parameters are geometrically related. Since the well known and frequently used CAD systems can handle parametric design, a mechanism has been developed to link the parameters in the CAD systems to the parameters in the PDM system by Yang et al (2004) which was used to control product development. Similarly, Jonathan et al (2005) have adopted this concept for capture of knowledge in PLM domain, design automation and customization.

Object oriented approach to modular design was introduced as design with modules (DwM) by (O’Grady and Liang, 1998). DwM provides each product a distinct functionality, feature and performance level. The authors have applied the concept of design with object (DwO) where the objects represent both physical objects such as parts, products, etc. and non-physical objects like order, supplier, etc (Liang and O’grady 1998). The
concept of object orientation imparts computability, exchangeability and reusability in designs. The background to design process model has been reviewed in research work reported by Wen-Yau and Peter (1998). The authors have described object oriented approach to design process. Gorty et al (1998) have reported a knowledge representation model using a shared object model. Knowledgebase and database modelling for an intelligent concurrent design has been reported by Xue, et al, (1999). The authors have presented a mathematical and system model where features are the basic primitive for PLM models.

The research work reported here are parameter based, feature based and object oriented. The commercial software packages can handle these primitives. Parameters are used to instantiate parts from a template or feature class. Features can convey information in the best manner across domains semantically. In the design of headlamps, both parameter based and feature based approaches have been used. It is difficult to make distinction between these two approaches. The application of these primitives would be discussed in the chapter 6 (Multiple view product modelling for development of headlamps). The design of PDM system has adopted the object oriented approach for managing artefacts.

2.3 DEVELOPMENT OF INFORMATION SYSTEM SUPPORTING PRODUCT DEVELOPMENT OF HEADLAMP

Previous section has covered the literature survey on state of the art CAD application practised in industries and reported research. The current section discusses the research on basic approaches for developing an information system connecting the various domains of product lifecycle. This includes product modelling, manufacturing, product data management,
collaborative design, concurrent engineering and product lifecycle management.

2.3.1 Product modelling

This part of the literature survey focuses on research papers published in various contexts of product modelling. The various contexts are first, product modelling in a generic approach where the requirements are mapped from one domain to the other. Second level is multiple perspective product modelling where each actor makes a decision on his own views and all the views are integrated. The third context is the multiple view feature modelling, which is based on the features used in design.

Product is modelled in two different interrelated domains namely functional domain and physical domain. Tay and Gu, (2002) have proposed a product modelling method for conceptual design support wherein product information is organized as functional and physical domain using object oriented approach. Product modelling manages various technical and market requirements. Non-technical requirements mainly include market requirements. Harding et al (2001) have presented a market driven design approach. The authors have discussed an intelligent framework for balancing customer requirements with product characteristics so that customer requirements are better addressed in design. Last few decades have witnessed a number of research efforts on CAD/CAM integration. Many researchers have addressed the issue through product modelling context.

An Innovative design process model for computer based engineering design have been reported by Yan, (2003). The model is based on the concepts of multiple perspective product modelling and integration of multidisciplinary design systems. Song et al, (2005) have proposed a
framework for design and manufacturing integration. Sudarsan et al. (2005) have focused product modelling for information management throughout the lifecycle of product where as Petrinja et al (2007) and Horvath and Rudas (2007) have focused on data management aspects on product modelling. Information exchange across the various product development domains suffers information losses, interoperability problems and ineffective data management support. These issues are targeted by developing a generic framework for product modelling by Xie et al (2008). All the above discussed researches on product modelling deal with information system design and integration only at system levels and were of metadata based.

Most of the researchers argue that feature based approach do convey product semantics in a better way and can be used as means of integration of domains of product development. Feature modelling has become the most popular means of product modelling (Wong and Wong 1995). Both geometrical information and functional information can be stored in a feature model. More detailed explanation on feature modelling can be found in the research reported by Bronsvoort et al (2006). Parameters and constraints together can represent product model effectively. The feature based design by constraints has been proposed by Jaque et al (1991) for integration within the manufacturing industry. The application of UML in feature modelling at preliminary level can be found in Chen et al (2004) and more detailed UML based representation was given by Jha and Gurumoorthy (2000).

There may be association between two feature elements, which is active only in a specific context of product development phase. For example, in an injection mould die design, association of the faces of core and cavity halves with the parting line propagates the changes in the in the parting line. Associative feature modelling for concurrent engineering has been reported
by Ma and Tong (2003). The associative feature modelling has been explained in the work with an example of cooling channel design in injection molding. Recently, the associative feature modelling method has been applied for change management in PLM perspective in the work reported by Ma, et al (2008). All the above works confined to few phases of product development. However, Bronsvoort and Noort et al (2004) have worked on multiple view feature modelling for integral product development covering all lifecycle phases. The paper also gives a review on various approaches reported on multiple view feature modelling. Nyirenda and Bronsvoort (2009) have presented new surface feature modelling facilities for creation of user defined freeform surface features, model specification and model variation.

It can be observed that the above two streams of research, namely, product modelling and feature modelling have common objectives. Feature modelling can be considered as a subset of product modelling at the same time it is a higher level representation. Research on product modelling has largely adopted metadata approach of integration of systems. In feature modelling methods, features are the means of exchange. The meta-data approach is suited for data exchange as the activities involved in the exchange are interested in preserving just the syntactic aspect of the exchanged data and manage the semantics locally. This is true for administrative or commercial data for instance. The feature approach performs better in applications where the feature concept has a clearly established meaning. However, feature modelling approach supports exchange of information more semantically (Mostefai, et al 2004). Modern 3D modelling software packages support feature based designs and using application program interfaces (APIs) integration with external system is possible.

The research work reported here support the use of the feature primitives in product modelling for more meaningful representation of
product. Most of the research works deal with simple features like hole and slot, which are relevant in manufacturing. Multiple view product modelling can be used to model product with features relevant to aesthetics, design, manufacturing and assembly.

2.3.2 Manufacturing Strategy

The literature survey on manufacturing systems is aiming two aspects, namely, manufacturing process discrimination, that is determination of the best manufacturing process from shape information and manufacturing system which is rapidly adaptable to the requirements of shape changes of products. Mechanical CAD artefacts have a physical realization of a variety of manufacturing processes. Ip and Regli, (2006) have proposed a method to automate the process of classification of 3D mesh based models according to manufacturing process.

Many researchers have focussed the reconfigurable manufacturing systems (RMS). Mehrabi, et al, (2000) have reviewed manufacturing techniques and introduced the re-configurable concepts in manufacturing. The product functionality is the key decision criterion of product characteristic, which in turn influences manufacturing decisions. Flexibility in manufacturing is a key requirement in products with aesthetics. Reconfigurable moulding has been focused by (Mehrabi, 2000, Walczyk and Hosford 2003; Kelkar et al 2005). Kelkar et al (2005) have proposed a geometric algorithm for reconfigurable mould manufacture. Recently, Nagahanumaiah et al (2008) have reported a methodology for rapid tooling process selection and manufacturability evaluation for manufacturing of injection moulding dies. The work does not address the scope of selecting other competent processes. Study of dependency of feature modelling on the manufacturing strategy is important. This work compares the feature
modelling with different degree of flexibility in manufacturing systems. Dynamic model and analysis for capacity scalability of RMS using control approaches have been reported by Deif and Elmaraghy (2006). Zaletelj et al (2008) have reported a conceptual framework for collaborative modelling of networked manufacturing systems.

Producibility of designs is the measure of effectivity of CAD CAM integration. It is the process of continuous improvement in manufacturing system (Priest, et al 2001). It helps industries adapt most viable manufacturing strategy. Manufacturing is basically a heterogeneous and rigid phase in product development. When it requires changes in shapes, associated set up time and cost are high.

Thermoforming or vacuum forming is the process which can be integrated with the RMS. Throne, (1996) has reported the technology of vacuum forming in detail. The literature review on the manufacturing systems shows that reconfigurable systems are suited for the manufacture of lens.

2.3.3 Product data management

Modern engineering industries are becoming increasingly aware of the use of software technology for effective management of product related information. The evolution of PDM began, in early 1980s, from a standalone software system supporting designer for the storage and retrieval of data. Currently, PDM has become the underlying concept of the modern philosophy of collaborative product development and product lifecycle management (PLM). A large number of researchers have contributed to the enormous progress achieved in this field. Hamer and Lepoeter (1996) have introduced five dimensions for managing design data in CAD framework, configuration management and PDM. The five dimensions are version, view,
hierarchy, status and variant. These are the primary elements in modern PDM systems. Eventhough PDM systems vary in their functionality; they have a few common capabilities such as, repository management and access control, product structure management, change management, configuration management, document management and process and workflow management. The research works reported on these functionalities are discussed in this section.

PDM systems make data valuable and available to users, where database and electronic vaults are the core of the system. These lead to a new risk of security as all users get in touch with the PDM system. A design resource management scheme for managing CAD files using a specific software was proposed by Wang et al (2002), named by them 'model enhancer'. This software coverts CAD models to an enhanced model to which other applications can also access. Leong et al (2003) have reported a security model for the distributed PDM systems. The authors stress the need of product data decoding and install locks for hardware and software. Capture and reuse of heterogeneous design information are important for product development. Bohm et al (2008) have developed a database schema for managing the design information captured. For organising design data in a collaborative product development, Feng et al (2009) have proposed the concept of business components, which are built by the modular analysis of engineering processes.

Product structure is the heart of PDM. It is created during product development, and is used during document delivery for determining the complete set of documentation that should accompany the product. A document can be connected to the product as a whole or to any of its parts. Company has to maintain different views of product structure even within a department (Peltonen et al 1996). Similarly part and product variants are
represented in a product structure. Mapping of product structure data between CAD and PDM reported by Oh et al (2001) has supported exchange of product data between CAD and PDM systems. Eynard et al (2004, 2006) have modelled product structure for design and assembly views for high-pressure compressor rotor example as a part of their research on unified modelling language (UML) based PDM implementation. Janardanan et al (2008) have developed a web based product structure manager enabling viewing and modifying product structure and annotation of 3D models. In PLM systems, product structure is used for structurally connecting modules, items and information of a product (Schuh, 2008).

An engineering change (EC) is a modification to a component of a product, after that product has entered production (Wright 1997). The author has reviewed engineering change process and its implications to product design. The tools used for engineering change are highly system dependent while the methods and management strategies could be described within a generic framework. Engineering change order (ECO) is one of the critical product development processes consuming lot of time and cost. Terwiesch and Loch (1999) have identified five key contributors to lead time of ECO namely a complex approval process, snowballing changes, scarce capacity and congestion, setup and batching and organizational issues.

A framework for assessing EC in manufacturing sector, where the implication of change is critical, is proposed by Taskinen and Smeds (1999). The role of design changes in digital versus paper based industries has been compared by Kidd and Thompson (2000). Engineering change management (ECM) problems have been addressed by researchers in different knowledge perspectives such as parameter, feature, function and requirements. A parameter based change management system, which was termed as ‘intelligent ECM’, and its implementation within a PDM system has been
reported by Rouibah and Caskey (2003). The elementary engineering decisions in a design process are captured as parameters and are used to identify the collaborators. This allows the design collaborator to learn the impact of design changes. The changes in design parameters may lead to subsequent changes in parameters within the part and associated parts.

Tay and Gu, (2002) have reported a function based product modeller supporting conceptual design with the help of user interface to solid modeller and was supported by a database. Based on knowledge modelling an information system has been proposed by Merlo and Girald (2004). Collaboration is the next issue which needs system or object support to information exchange. Collaboration among the designers and collaboration with the downstream phases are important; they termed as horizontal and vertical collaboration respectively. Data consistency is important in design models. It shows the ability of the model to be used in varying conditions. A framework with data as a prime objective for conceptual design has been proposed by Giguere et al (2003).

All the studies discussed so far report the concepts of knowledge based design in a generic way. However, application of knowledge at relatively low levels can address better the specific product design issues. A parameter based design method supporting standardization of products for manufacturing of tire mould was reported by Chu et al (2006). Proper implementation of the changes in design is critical to industries. Industries follow systematic procedures and maintain documents of changes. Peng et al (1998) have reported a data model for managing changes and product structure. The authors have developed data models using EXPRESS modelling language for a set of six functionalities, which includes engineering change.
Configuration management (CM) is a formal discipline, which envisages engineering change control, including software used for product development. It includes identifying and controlling product structure, as well as maintaining revision control and history of all changes made to a product and its associated documents. CM was first introduced by the U.S department of Defence in the year 1992. For configuration management and version control Miles et al (2000) has proposed an object oriented database integrated with AutoCAD® using Autolisp as an interface with executable C++. Recently, Shiau and Wee (2008) have reviewed the research activities on configuration management.

Management of document is one of the main functionalities of PDM systems. It insures the availability of latest version of documents. Peltonen (1996) have presented the general requirements of document management in product and delivery processes. PDM systems allow users to check out documents and modify and upload (check in) the documents. Management of changes in document is essential for document management. Bae et al (2004) have reported a change management system for documents. Liu et al (2006) have proposed decomposition of documents so that engineers need to use only relevant portion of documents.

Aziz et al (2005) have adopted an object oriented approach by extending functionality of system to include management of knowledge in ontology. Document structure defines the elements in a document and the way they are organised. Documents with well-defined structures enable consistency, which is required to be maintained in a company and integrity of communication between its members (Erdmann and studer 2001). Information retrieval (IR) is one of the functionalities, which is strongly supported by the document management systems. Structured document retrieval (SDR) is the current area of research in document management system. Liu et al (2008)
have conducted a survey on the application of SDR for document management and suggested it as a widely accepted method of information retrieval.

Workflow system generally records the details of work done, instruct users what are to be done according to predefined procedures and react to different events. PDM system may implement work flow directly, or the system can be integrated with external work flow systems as suggested by Kovacs et al (1998). Huang et al (2000) have worked on a workflow system for collaborative product development through internet. The network includes a decision support system for product development. Workflow system effectively coordinates the team work of the participants. Workflow is essential for managing complex business process. Bae et al (2004) worked on a version management for documents in a complex business process. While merging different business processes, a requirement arises for merging of concerned workflows. Merging of workflows of different types such as sequential, parallel, iterative and conditional are described by Sun et al (2006).

The literature survey shows that PDM is still evolving with the support of the developments in IT. However, the integration among the various domains is not addressed effectively. A data management system tailored to a specific application can perform better, rather than implementing general purpose commercial software.

2.3.4 Information modelling for PDM

The literature discussed so far in this section covers research on different PDM functionalities. When developing a PDM system, it is important to decide what data, when, how and where the data should be available. Therefore, PDM system is to be developed from a data model. Vroom (1996) has developed a meta-model with three objects and eight
diagrams for representing product and process information in a structural form. An integrated product data base and six functional modules were presented by Peng and Trappey (1998) for product structure and change management. CAD-PDM integration has been studied by Oh et al (2001) using UML based integration between CAD and PDM. The application of UML on the development of an information system for distributed applications was reported by Costa et al (2001). Again, for developing a PDM architecture, (Shu et al 2003; Berenbach 2004) have used UML. For the product structure and work flow for a PDM system, UML has been tried by Eynard (2004). Meta modelling of production systems using UML has been reported by Ghazel et al (2004). An authoring framework for simplified customisation of PDM system using UML has been proposed by Song et al (2008).

The research papers surveyed here show the extensive research efforts made in the area of integration of systems. The PDM system specification has been attempted by meta-modelling and later the methods based on UML are applied. For modelling PDM system, this thesis uses the UML based approach.

2.3.5 Collaborative Product development and concurrent engineering

Information system supporting designer of headlamp must support collaborative product development and concurrent engineering methods eliminating time and space barriers. Literature reported in this subsection extends to these philosophies. Kao and Lin (1998) have developed a collaborative CAD/CAM system enabling the extension of the application of a standalone CAD/CAM system to a multi-location CAD/CAM application. This system helps the geographically dispersed users to work together
simultaneously. It was built in a two-tier architecture, supporting asynchronous collaboration.

Lee et al (2000) have presented a web based collaborative environment for the feature based design. The authors have demonstrated the application of simple features and their representation in a process centric collaborative design. For a collaborative product development system, appropriate use of information and communication technology (ICT) is vital. Web technologies like Extensible Markup Language (XML) and PHP hypertext pre-processor (PHP) are the standard formats used for dynamic processing of information, Virtual reality markup Language (VRML) and Java 3D are dynamic viewing software while STEP is used for information exchange. Eynard et al (2005) have briefly introduced these technologies and have proposed an asynchronous web supported cooperative work supporting collaborative design. Multiple view feature modelling concept has been applied for developing a collaborative framework for part and assembly modelling by Bidarra et al (2002). Zhang, et al (2004) have reviewed the internet based product information sharing and visualisation.

Different product life aspects such as design, manufacture, and inspection are supported by specific database and product libraries wherein each user works on a single product model class. The users communicate via internet. This idea has been presented by Xue and Xu (2003) for collaborative concurrent design. Fujita and Kikuchi (2003) have applied this concept on aircraft design. Common manufacturing application middleware was proposed by Mervyn et al (2004) for integrating design and process activities with product model.

Nahm and Ishikawa (2004) have reported an agent based approach for collaborative product and process modelling framework where the
hierarchical and non-hierarchical dependencies between decomposed smaller design problems were addressed. Similar work has been reported by Huang (2004) focusing on modular approach for design. A process driven framework has been suggested for conceptualizing the collaborative product development by Sharma (2005) based on the three factors namely, collaboration, product development and innovation. A conceptual framework towards seamless interoperability in a collaborative competitive economic networked environment is described by Chituc et al (2009).

Sayah and Zhang (2005) have proposed a model for on-demand business process where process based collaboration is used. Han (2006) also has proposed a conceptual model of a collaborative product development management system based on object-oriented philosophy while Framling et al (2006) have presented an agent based model for managing product information of complex products at component level. Project, Product, process, participant, cost and collaboration are the six modelling views identified for the collaborative product development management systems. Open source, Peer-to-peer tools based approach for collaborative product development using a decentralized architecture has been reported by Aziz et al (2005).

Integration of systems is achieved by two methods, namely, transfer file integration and database integration (Saaksvuori 2002). In the case of transfer file integration, information is managed as files of any formats, which are managed using metadata. Metadata includes the information about data like the type, location and file format. Database integration is often carried out through an APIs provided by the software packages. For heterogeneous databases, Wang et al (2005) have proposed a metamodel for enterprise integration using XML technologies.
Dynamic data sharing is important for distributed systems integration. Kim et al (2006); Lee et al (2006) and Roubiah, (2007) have reported dynamic database application in product development systems. Multi-level data sharing among collaborators according to the requirements of user in a collaborative design process has been reported by Kim et al (2006). The web and associated technologies are the backbone of the collaborative product development. Web technology resembles PDM technology in many ways. Liu and Xu (2001) have reviewed literature on PDM technology and studied the integration aspects of PDM technology using web architecture. They have subsequently proposed a web based collaborative concurrent design. (Xu and Liu 2003).

The three tier architecture for PDM consists of PDM user interface at the first tier, PDM logic server in second tier and PDM database repository in the third tier. Rezayat (2000) has recommended the use of web in product development for the reason that the web is easy to use, can function as a universal interface, and uses open standards. A web based PDM system using Java and Java 2 enterprise edition (J2EE) has been proposed by Huang et al (2004). The last decade has witnessed an emergence of component-based software, which offers improved flexibility, security, stability and maintainability. Sung and Part (2007) have researched on developing a component based PDM (CPDM) using the J2EE technologies.

2.3.6 Product lifecycle management

PLM aims to provide a shared platform for effective capturing, representing, organizing, retrieving and reusing product lifecycle information across companies. PLM supports the integration of the existing software systems, including CAD/CAM/CAE and enterprise resource planning (ERP) / customer relationship management (CRM)/ and supply chain management
(SCM) (Ball et al 2008). According to this concept of PLM, the management of a product from inception to disposal is the strategic initiative that will define the 21st century product development (Stark 2004).

Gao et al (2003) have described the methodologies aimed at overcoming the lack of analyzable product information at the conceptual stage of product design and manufacturing evaluation, along with the integration of such a concept design tool within a distributed environment. The authors have proposed a software methodology and architecture for the integration of supply chain, manufacturing and costing functions at the conceptual design stage. They have also stressed the necessity of standards for ensuring interoperability across functional domains.

Subrahmanian et al (2005) have identified the lack of facilities for interoperability across tools as one of the barriers to the software developers to the PLM arena. The authors have compared PLM softwares of different vendors and concluded that vertical integration of functions have not adequately addressed by the existing PLM softwares. Recently, Rachuri et al (2008) have developed a typology of standards relevant to PLM support that addresses the hierarchy of existing and evolving standards and their usage. They have also identified a suite of standards supporting the exchange of product, process, operations and supply chain data. The information within PLM systems can be classified as form information, functional information and lifecycle information. Currently, standardisation is relatively matured in the form information using STEP standards. However, the level of standardisation is incomplete in functional information system whereas the standardisation of lifecycle information is in the evolving stage.
2.4 SUMMARY

Automotive manufacturers especially passenger car manufacturers experience immense pressure to reduce time-to-market. Design phase of product development has become increasingly complex due to proliferation of product data, reduced lifecycle of products and difficulties in integration of systems. Present manufacturing system for passenger car also poses challenges to product development due to the lack of flexibility and heterogeneity of systems. Numerous research efforts are being reported on these demands from automotive industries. However, these efforts basically are the implementation of a generic solution which may not exactly be the solutions needed.

It was learnt from present scenario that, the OEMs of passenger cars outsource the development of functionally critical units like headlamp. The suppliers of headlamp may not have powerful data management systems as in the case of OEMs. Instead, the use of domain specific CAD/CAM softwares is expected with the supplier. The literature survey revealed the fact that research activities, supporting the designer of headlamp to meet the challenges posed by OEMs, seems to be limited. In order to bridge this gap, this thesis focuses on development of a systematic design methodology for design and manufacture of headlamps with the support of a data management system for making relevant data available to the right user of the product development process. Next chapter presents the objectives of this study.