Automotive Product Development

A Systems Engineering Implementation

VIVEK D. BHISE

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by

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Preface

The development of a new automotive product requires an understanding of the integration of knowledge from a number of disciplines. In this book, I have provided material that was generated and used in teaching the automotive product development process to graduate students in Automotive Engineering over many years at the University of Michigan-Dearborn.

The material provides the basic background, principles, techniques, and steps that I found to be useful in understanding the complex and coordinated activities that need to be undertaken to ensure successful development of the "right vehicle" that customers will enjoy driving. Proper implementation of the process should make the product development team members feel very proud of their accomplishments. It should enhance the reputation of the company for creating exciting new vehicles and thus, lead the company to achieve financial success beyond its imagination in terms of revenues, profits, and return on investments.

The formula for creating successful automotive products lies in the creation of a well-coordinated product development process, using the right tools and techniques, a dedicated team of highly motivated multidisciplinary professionals, and very supportive senior management.

This book is about understanding "the big picture" of how automotive products need to be developed with the sole purpose of satisfying their customers. The book resulted from my deep desire to understand how automotive products are developed, to understand the many challenges facing the auto industry, to study the methods currently used in designing automotive products, and to make our future automotive engineers realize that their main job is to satisfy the customers who use their products.

We teach our engineers to be proficient in applying specialized techniques in narrowly specialized areas such as structural analysis, vehicle dynamics, powertrain efficiency analysis, aerodynamic drag reduction, and electrical architecture design. But they need to realize that the customer buys the "whole" car, not just a collection of systems and components that they helped design, such as four wheels, a steering wheel, pedals, seats, vehicle body, lamps, wiring harnesses, and fuel tanks. All vehicle systems and their subsystems and components must "work together" to provide the "desired" feel to the customer—so that he or she is either "completely" or "very" satisfied with the vehicle.

Engineers working in the automotive industry may claim that they currently have the necessary knowledge in areas such as system design specifications, design tools, verification test procedures, test equipment, and subsequent data analysis methods. However, many cars and trucks currently satisfy only about 60%–80% of their customers; that is, the vehicles do not achieve the high scores, such as over 90%, desired by the customers and the senior management of the automobile companies. This gap between the high levels of customer satisfaction "desired" by the customers and the management and those "actually achieved" by the current automotive products in various market research surveys is largely because of failure to understand customer needs, to translate these needs into design specifications, and to confirm that the designed products are indeed the right products for the customers.

The objective of the book is to provide the necessary background for future engineering graduates and practicing engineers in the industry to ensure that they understand the automotive product development process, the issues challenging the industry, and the applications of various approaches and tools available to conduct the necessary steps in design, analysis, and evaluation to create products that will satisfy their customers.

This book is divided into three parts. The first part provides an in-depth understanding of the various phases of the product development process and the steps involved in implementing the systems engineering process. Strict and thorough implementation of the systems engineering process is a prerequisite for achieving success in any automotive product program. Otherwise, the vehicle development program may exceed its budget or time schedule, and/or the designed product may fail to meet its customer satisfaction target. The second part of the book covers many important tools and methods used in the vehicle development process. The third part provides many examples and case studies generated during the past several years of my teaching graduate courses in the Automotive Systems Engineering program at the University of Michigan-Dearborn.

The auto industry is facing fierce competition and unending pressure to reduce program timings and costs. This results in further pressure to minimize or even to eliminate many of the systems engineering tasks, and thus, endanger the successful completion of vehicle programs. The complexity of the vehicle programs is also increasing due to rapid advances in technologies, the large number of variables considered in many analyses, and our inability to measure a number of key variables, which still rely on subjective judgments. Subjective measures are used in evaluations of many vehicle attributes, such as styling, drivability, performance feel, ergonomics, interior spaciousness, and quality. It is hoped that this book will help in addressing many of the challenging issues facing the industry.

WEBSITE MATERIALS

The following files are in the Download section of this book's web page on the CRC Press website (http://www.crcpress.com/product/isbn/97814987068100).

A. Computer programs and models
   1. Automotive Product Development Chart with Present Value Calculations
   2. Program for Cost Flow by Months
   3. Program for Cost Flow by Quarters

B. Slides for Chapters 1 to 25

Acknowledgments

This book is a culmination of my education, experience, and interactions with many individuals from the automotive industry, academia, and government agencies. While it is impossible for me to thank all the individuals who influenced my career and thinking, I must acknowledge the contributions of the following individuals.

My greatest thanks go to the late Professor Thomas H. Rockwell of the Ohio State University. Tom got me interested in human factors engineering and driving research. He was my advisor and mentor during my doctoral program. I learned many skills on how to conduct research studies and analyze data, and more importantly, he introduced me to the technical committees of the Transportation Research Board and the Society of Automotive Engineers, Inc.

I would like to thank the late Lyman Forbes, Dave Turner, the late Eulie Brayboy, and Bob Himes from Ford Motor Company. Lyman Forbes, manager of the Human Factors Engineering and Ergonomics Department at the Ford Motor Company in Dearborn, Michigan, spent hours with me discussing various approaches and methods to conduct research studies on crash-avoidance research and development of motor vehicle safety standards. Dave Turner, director of the Advanced Design Studios in the Ford's Design Staff, got the Human Factors Engineering and Ergonomics department firmly anchored in the automotive design process. He also helped establish a Human Factors Group within Ford of Europe when he was the director of Ford's European Design Centre. Eulie Brayboy, chief engineer, Design Engineering in the Corporate Design, always provided support in implementing human factors inputs into the automotive design process. Bob Himes, chief engineer of the Advanced Vehicle Engineering staff, helped in incorporating ergonomics and vehicle packaging as a vehicle attribute in systems engineering implementation in the vehicle development process.

The University of Michigan-Dearborn campus provided me with unique opportunities to develop and teach various courses. Our Automotive Systems Engineering and Engineering Management programs allowed me to interact with hundreds of graduate students, who in turn implemented many of the techniques taught in our graduate programs when solving problems within many other automotive original equipment manufacturers and supplier companies. I would to thank Professors Pankaj Mallick and Armen Zakarian for giving me opportunities to develop and teach many courses in the Automotive Systems Engineering and Industrial and Manufacturing Systems Engineering programs. Roger Schulze, director of our Institute for Advanced Vehicle Systems, got me interested in working on a number of multidisciplinary programs in vehicle design. Together, we developed a number of vehicle concepts, such as a low mass vehicle, a new Model "T" concept for Ford's 100th anniversary, and a reconfigurable electric vehicle. We also developed a number of design projects by creating teams of our engineering students with students from the Product Design and Transportation Design department from the College for Creative Studies in Detroit, Michigan. I must also thank my students for working on a number of research projects—developing test setups, recruiting subjects, and collecting and analyzing data—over many years.

Over the past 40-plus years, I was also fortunate to meet, and discuss many automotive design issues with, members of many committees of the Society of Automotive Engineers, Inc., the Motor Vehicle Manufacturers Association, the Transportation Research Board, and the Human Factors and Ergonomics Society.

I would like to also thank Cindy Carelli from CRC Press—a Taylor & Francis Company—for encouragement in preparing the proposal for this book, and her production group for turning the manuscript into this book.

Finally, I want thank my wife, Rekha, for her constant encouragement and her patience while I spent many hours working on my computers, writing the manuscript and creating figures included in this book.

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During 1973–2001, he held a number of management and research positions at the Ford Motor Company in Dearborn, Michigan. He was the manager of Consumer Ergonomics Strategy and Technology within the Corporate Quality Office, and the manager of Human Factors Engineering and Ergonomics in the Corporate Design of the Ford Motor Company, where he was responsible for the ergonomics attribute in the design of car and truck products.

Dr. Bhise is the author of recent books entitled *Ergonomics in the Automotive Design Process* (ISBN: 978-1-4398-4210-2. Boca Raton, FL: CRC Press, 2012) and *Designing Complex Products with Systems Engineering Processes and Techniques* (ISBN: 978-1-4665-0703-6. Boca Raton, FL: CRC Press, 2014.)

Dr. Bhise has taught graduate courses in Vehicle Ergonomics, Vehicle Package Engineering, Automotive Systems Engineering, Management of Product and Process Design, Work Methods and Industrial Ergonomics, Human Factors Engineering, Total Quality Management and Six Sigma, Quantitative Methods in Quality Engineering, Energy Evaluation, Risk Analysis and Optimization, Product Design and Evaluations, Safety Engineering, Computer-Aided Product Design and Manufacturing, and Statistics and Probability Theory over the past 36 years (1980–2001 as an adjunct professor, 2001–2009 as a professor, and 2009–present as a visiting professor in post-retirement) at the University of Michigan-Dearborn. He also worked on a number of research projects in human factors with the late Professor Thomas Rockwell at the Driving Research Laboratory at the Ohio State University (1968–1973).

His publications include over 100 technical papers on the design and evaluation of automotive interiors, parametric modeling of vehicle packaging, vehicle lighting systems, field of view from vehicles, and modeling of human performance in different driver/user tasks.

Dr. Bhise has also served as an expert witness on cases involving product safety, patent infringement, and highway safety.

He received the Human Factors Society's A. R. Lauer Award for Outstanding Contributions to the Understanding of Driver Behavior in 1987. He has served on a number of committees of the Society of Automotive Engineers, the Transportation Research Board of the National Academies, and the Human Factors and Ergonomics Society.

Section I

Automotive Product Development Process

1 Introduction *Automotive Product Development*

INTRODUCTION

Complex Product, Many Inputs, Many Designers and Engineers

Designing and producing an automotive product is a horrendously complicated undertaking. The automotive product itself is very complex. It involves many systems: body system, powertrain system, suspension system, electrical system, climate control system, braking system, steering system, fuel system, and so on. All the systems must work together under all possible combinations of road, traffic, and weather conditions to satisfy drivers and users with varied characteristics, capabilities, and limitations. The automotive product development (PD) process requires many resources over several years and includes many intricate, coordinated, and costly design, evaluation, production, and assembly processes. The complex automotive product must also meet hundreds of requirements to satisfy customers, applicable government regulations, and the goals and needs of company management.

Developing a new automotive product requires the efficient execution of a number of processes, and the implementation of systems engineering is essential to coordinate varied technical and company management needs. The proper implementation of systems engineering ensures that the right product is developed within the planned timing schedule while avoiding costly budget overruns. To understand the complexity in the PD process, we will begin this chapter with a clear explanation of processes, systems, and systems engineering and then proceed with the details of the automotive PD process.

BASIC DEFINITIONS OF PROCESS, SYSTEM, AND SYSTEMS ENGINEERING

Process

A process is where the "work gets done." A process generally consists of a series of steps, tasks, or operations that are performed by people (i.e., human operators) and/or machines (e.g., robots, computers, or automated equipment) using a number of inputs (e.g., information, raw materials, energy sources). People may also use one or more tools (e.g., hand tools, power tools, or software applications) in performing any of the tasks. The process can be studied and also defined by following a component (e.g., a part, an assembly, a transaction, a tracking paper, a drawing, a computer-aided design [CAD] model), or a person (e.g., one who moves from a workstation to other workstations and performs one or more tasks at each workstation) through a series of steps or tasks. The beginning and ending points of each process must be clearly defined. The purpose of the process, that is, the reason for the creation of the process, and its function, that is, what work is performed in the process, must be also clearly defined and documented.

To create (i.e., to design and produce) a product (e.g., a vehicle), many processes are required (e.g., the customer needs determination process, the vehicle concept development process, the detailed engineering process, the systems verification process, the production tools development process, and the vehicle assembly process).

System

A system consists of a set of components (or elements) that work together to perform one or more functions. The components of a system generally consist of people, hardware (e.g., parts, tools, machines, computers, and facilities), or software (i.e., codes, instructions, programs, databases) and the environment within which it operates. The system also requires operating procedures (or methods) and organization policies (e.g., documents with goals, requirements, and rules) to implement its processes and get its work done. The system also works under a specified range of environmental and situational conditions (e.g., temperature and humidity conditions, vibrations, magnetic fields, power/traffic flow patterns). The system must be clearly defined in terms of its purpose, functions, and performance capability (i.e., abilities to perform or produce output at specified level in a specified operating environment).

Some definitions of a system are

1. A system is a set of functional elements organized to satisfy specified objectives. The elements include hardware, software, people, facilities, and data.
2. A system is a set of interrelated components working together toward some common objective(s) or purpose(s) (Blanchard and Fabrycky, 2011).
3. A system is a set of different elements so connected or related as to perform a unique function not performable by the elements alone (Rechtin, 1991).
4. A system is a set of objects with relationships between the objects and between their attributes (Hall, 1962).

The set of components has the following properties (Blanchard and Fabrycky, 2011):

1. Each component has an effect on the whole system.
2. Each component depends on other components.
3. The components cannot be divided into independent subsystems.

Systems Engineering (SE)

Systems engineering (SE) is a multidisciplinary engineering decision-making process involved in designing and using systems and products throughout their life cycle. The implementation of SE is very beneficial, as without it, the likelihood of creating the "right system or product" that the customers really want (in terms of its attributes, such as performance, safety, styling, and comfort) within the targeted timings and costs can be substantially reduced (see INCOSE [2006], NASA [2007], and Kmarani and Azimi [2011] for more information on SE).

Systems Approach

The word "systems" in "systems engineering" is used to cover the following aspects of different systems in an automotive product:

1. An automobile product is a system containing a number of other systems (e.g., body system, powertrain system, chassis system, and electrical system).
2. Thus, the design of the whole automobile will involve designing all the systems within the automobile such that the systems work together (i.e., the systems are interfaced or connected with other systems, and each system performs its respective functions) to create a fully functional vehicle and meet customer needs.
3. Professionals from many different disciplines (e.g., industrial design, mechanical engineering, electrical engineering, physics, manufacturing engineering, product planning, finance, and business and marketing) are required to design (i.e., to make decisions related to the design of) all the systems in the vehicle.
4. The vehicle has many different attributes (i.e., characteristics that its customers expect, such as performance, fuel economy, safety, comfort, styling, and package). Simultaneous inputs from professionals from many disciplines and specialists with deep knowledge about each of the vehicle systems are required to make decisions about proper consideration of levels of all the attributes and trade-offs between the attributes in designing all the systems within the vehicle.
5. The automotive product is a component of other, larger systems (e.g., one or more vehicle platforms [which may be shared with other vehicle models], the highway transportation system, the petroleum consumption and fuel distribution system, the financial system, and so forth).
6. The automobile works within different environmental and situational conditions (e.g., driving on a winding road at night in a thunderstorm).
7. All phases of the life cycle, from conceptualization of a new automotive product to its discontinuation (i.e., its disposal, scrappage, recycling, replacement, plant dismantling or retooling), must be considered during its design.

Thus, the systems approach comprises simultaneous consideration of many systems, many attributes, trade-offs between the attributes, life cycle, disciplines, other systems, and working environments in solving problems (i.e., decision making). The systems approach is thus a primary and necessary part of SE.

Multidisciplinary Approach

SE is a multidisciplinary approach, that is, it obtains inputs from people from many different disciplines working together and considering many design and operational issues and trade-offs between different issues, to enable the realization of a successful product or a system. It is important to realize here that even when one discipline, such as electrical engineering, has the primary responsibility for designing an electrical system, other disciplines can raise a number of issues related to the design and operation of the system and thus assist in the design of the system by simultaneous consideration of multiple views and issues.

SE involves both technical and management activities from the early conceptual stage of a product (or a system) to the end of the life cycle of the product (i.e., when the product is removed from service and disposed of). The management activities help ensure that all requirements and design considerations are taken into account along with the key goals of meeting the product performance, developmental schedule, and budget of the product program.

Customer Focused

SE begins with an understanding of customer needs and development of an acceptable concept of the product (or system). It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and proceeding with the design synthesis and system (product) validation while considering the problem as a whole (INCOSE, 2006).

The objective of SE is to ensure that the product (or the system) is designed, built, and operated so that it accomplishes its purpose of satisfying customers in the most cost-effective way possible by considering performance, safety, costs, schedule, and risks.

Basic Characteristics of SE

The basic characteristics of the SE approach are

1. *Multidisciplinary*: SE is an activity that knows no disciplinary bounds. It involves a collection of disciplines throughout the design and development process. It involves professionals from different disciplines working together (simultaneously and preferably co-located under one roof), constantly communicating, reviewing the design issues, and helping each other on all aspects of the product. The types of disciplines to be included depend on the type and characteristics of the product and the scope of the product program.

   For example, SE application for developing an automotive product will require personnel from many disciplines, such as engineers (including many specializations within engineering, e.g., mechanical, materials, electrical, computer and information science, chemical, manufacturing, industrial, human factors, quality, and SE), scientists (e.g., in physics, chemistry, and the life sciences) for research related to the design and production of new technological features of the vehicle, industrial designers (who define the sensory form and craftsmanship characteristics of the vehicle, i.e., the look, feel, and sound of the interior and exterior of the vehicle, such as the styling and appearance of surfaces of the vehicle, the touch feel of the surface and material characteristics, the sounds of operating equipment, and the smell of materials), market researchers (who define the customers, market segment, customer needs, market price, and sales volumes), management (e.g., program and project management personnel, including product planners, accountants, controllers, and managers), plant personnel involved in manufacturing and assembly, distributors, dealers, and even insurers to ensure that costs associated with fixing a vehicle damaged in an accident can be reduced and covered by the insurer.

It is important to get inputs from all the disciplines that affect or are affected by the characteristics and uses of the vehicle at the early stages of the PD. This ensures that their needs and concerns, and trade-offs between different multidisciplinary issues, are considered and resolved early, and costly changes or redesigns in the later phases are avoided.

2. *Customer Focused*: SE places continuous focus on the customers; that is, the product design should not deviate from satisfying the needs of the customers. The customers should be identified and involved in defining the vehicle specifications and designing the vehicle, and in subsequent evaluations, to ensure that the vehicle being designed will meet their needs. The customer needs are translated into vehicle attributes, and attribute requirements are developed to ensure that each vehicle attribute is managed (i.e., reviewed, verified, and validated) during the life cycle of the vehicle program. The vehicle attribute requirements process is described in Chapter 2.
3. *Product-Level Requirements First*: SE places concentrated effort on initial definition of the requirements at the overall product (i.e., the "whole" vehicle) level. For example, at the product level, the requirements for an automotive product will be based on all the basic attributes (derived from the needs of its external and internal customers) of the vehicle, such as safety, fuel economy, drivability (ability to maneuver, accelerate, and decelerate, and cornering or turning), seating comfort, thermal comfort, body-style, styling, costs, size, and weight.

   It is important to realize that the customer buys the vehicle for his/her use as a "whole" product, not as a mere collection of the many components that form the product. (Note that an automotive product typically contains about 6,000–10,000 components.) Thus, the requirements for the systems, subsystems, and components of the product should be derived only after the product-level requirements are clearly understood and defined. This issue of cascading of the product-level attribute requirements to the system and lower-level entities is covered in Chapters 2 and 9.
4. *Product Life-Cycle Considerations*: SE includes considerations of the entire life cycle of the product being designed—through all stages from "Concept Development to Disposal of the Product" (from lust to dust). Thus, it is the applications of all relevant scientific and engineering disciplines in all the phases of the product, such as concept development; designing, manufacturing, testing and evaluation; uses under all possible operating conditions;

service and maintenance; and disposal or retirement from service, that the product encounters throughout its life cycle.

5. *Top-Down Orientation*: SE takes a “top-down” approach, which first views the product (or the entire system) as a whole and then sequentially breaks down (or decomposes) the product into its lower levels, such as systems, subsystems, sub-subsystems and components. Thus, the lower-level systems are designed to meet the requirements of the higher-level systems. (Note that if a manufacturer decides to use a carryover [i.e., existing] component or system in a new product, the top-down approach will need to be modified. This issue is covered in Chapter 2.)
6. *Technical and Management*: SE is both a technical and management process. It involves making all the technical decisions related to the product during its life cycle as well as management of all the tasks to be completed in a timely manner to implement the SE process and apply the necessary techniques.
7. *Technical Process*: The technical process of the SE is the analytic effort necessary to transform the operational needs of the customers into a design of the product (or system) with proper size, configuration, and capacity (e.g., performance level). It creates a documentation of the product requirements and drives the entire technical effort to evolve and verify an integrated and life cycle–balanced set of solutions involving the users and the product in its usage situations.
8. *Management Process*: The management process of the SE involves assessing costs and risks, providing needed resources, integrating the engineering specialties and design groups, maintaining configuration control, and continuously auditing the effort to ensure that cost, schedule, and technical performance objectives are satisfied to meet the original operational need of the product and the product program.
9. *Product and Organization-Specific Orientation*: The details of the SE implementation (such as steps, methods, procedures, team structure, tasks, and responsibilities) depend on the program objectives, the product being produced (i.e., its characteristics), and the organization (company) producing it (i.e., different companies generally have somewhat different processes, timings, organizational responsibilities, and brand-specific requirements).

PRODUCT DEVELOPMENT

The majority of PD programs do not involve designing a product from “scratch” (i.e., a totally new product) or a product of a type that did not exist before. The process of designing a product is therefore typically called the *product development process* in most industries (including the automotive industry) rather than the *product design process*. However, the terms *product development* and *product design* are interchangeable and are used in the same context in many industries. (After the product has been designed, the process of producing the product [i.e., manufacturing various systems and assembling the systems to create the whole product] is generally called the *production process* [see Figure 1.1].)

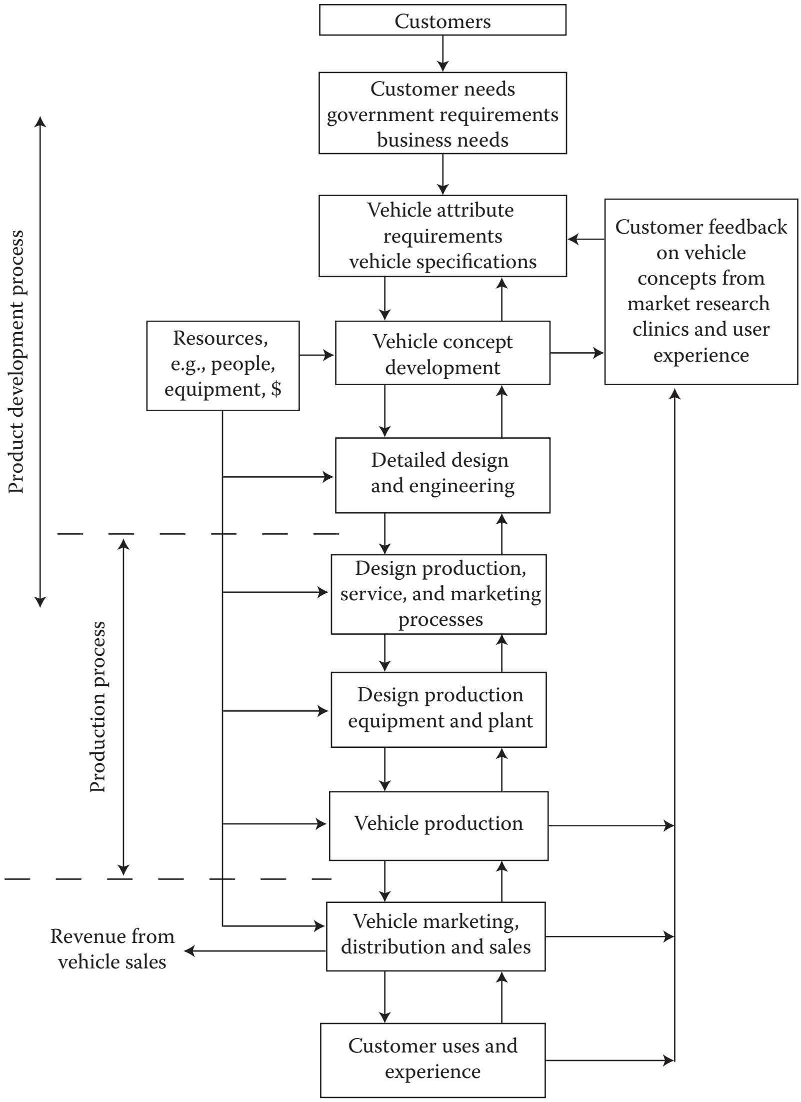

FIGURE 1.1 Flow diagram of automotive product development and production processes.

Processes and Phases in Product Development

It is important to realize that any work is generally performed by using one or more processes. A process usually involves inputs (e.g., raw materials, energy), equipment (one or more workstations with tools, machines, robots, or computers), and human operators that are configured in a sequence of steps (operations or tasks) to produce a specified output. Designing a product is also performed by using a process (defined earlier as the PD process). The PD process, depending on the complexity of the product, can involve many processes within and outside the organization (e.g., suppliers) responsible for developing the product. PD processes vary due to differences in the products (i.e., their characteristics, functions, features, and demand volume), the type of PD program (e.g., refreshing an existing product or designing a totally new product), and the design organization (or company).

A generic process of product creation and use involves the entire product life cycle, which generally includes the following phases:

1. Pre-concept or pre-program (pre-program planning)
2. Product concept exploration (alternative concepts development)
3. Product definition and risk reduction (feasibility analyses, preliminary design, and risk analysis)
4. Engineering design (detailed engineering design including testing)
5. Manufacturing development (process, tooling, and plant development)
6. Production (manufacturing and assembly)
7. Product distribution, sales, marketing, and operational support
8. Product updating or discontinuation and disposal

The first five of the above phases can be defined as the PD process, and the fifth and sixth phases can be considered as the production process. It should be noted that the fifth phase of manufacturing development can be considered as the transition from PD to manufacturing. It is very important to include product manufacturing considerations (e.g., applications of "design for manufacture" and "design for assembly" methodologies) very early during the product design (i.e., during Phases 1 to 4, by implementing simultaneous [concurrent] engineering) to ensure that the transition in the fifth phase (involving designing of manufacturing processes and the creation of required tools and equipment in the manufacturing plants) occurs seamlessly without changes in the PD in the later phases to meet production needs.

The work in each of these phases is performed by undertaking specialized processes. For example, the pre-concept phase can involve a process of understanding the customer, corporate needs, and regulatory requirements to decide on the type and characteristics of the new product (i.e., product specification) and preparing a plan for the subsequent activities.

Ulrich and Eppinger (2015) described the generic PD process with the following phases:

1. Planning
2. Concept development
3. System-level design
4. Detail design
5. Testing and refinement
6. Production ramp-up

It should be noted that Ulrich and Eppinger (2015), in their fourth "detail design" phase, included detailed component design (e.g., part geometry, material selection, and specification of tolerances), definition of production processes, tooling design, and beginning of tooling procurement. The fifth phase involves all product verification tests (i.e., performance, reliability, and durability) and refinements of assembly processes, including training of the production workforce. The production ramp-up phase involves the evaluation (validation tests) of early production outputs and the beginning of full operation of the production system.

AUTOMOTIVE PRODUCT AS A SYSTEM

An automotive product is considered as a system that involves a number of lower- (or second-) level systems: the body system, the chassis system, the powertrain system, the fuel system, the electrical system, the climate control system, the braking system, and so on. Each of the systems within the automotive product can be further decomposed into subsystems, sub-subsystem, sub-sub-subsystems, and so on, till the lowest-level components are identified. For example, the body system includes the body frame subsystem, the body panels subsystem, the closure subsystem (which includes the hood sub-subsystem, the doors sub-subsystem, and the trunk or liftgate sub-subsystem), the exterior lamps subsystem, the seats subsystem, the instrument panel subsystem, the interior trim components subsystem, and so forth.

Table 1.1 illustrates the major systems, subsystems, and sub-subsystems or components within a typical automotive product. The definitions and contents of the various vehicle systems illustrated in this table can vary somewhat between different vehicle makes and models. Further, the implementation of different technologies used in performing different vehicle functions can have a major effect on the design of any vehicle system. In fact, one of the challenges facing vehicle engineering groups is how to divide the entire vehicle into different systems, subsystems, sub-subsystems, and so on and to assign design responsibilities to various engineering teams. This issue of division or decomposition of an automotive product for management of various PD activities and their interfaces is covered in Chapters 7, 8, and 12 and Appendix I.

The key tasks of systems designers are to ensure that each system performs its functions and that the systems, through their interfaces with other systems, work harmoniously to meet the customer needs of the whole product. Thus, the task of designing the vehicle requires a lot of understanding of systems and coordination between systems, their functions, and trade-offs between vehicle attributes to come up with a balanced vehicle design, This issue is covered in more detail in Chapters 2 and 8.

AUTOMOTIVE PRODUCT DEVELOPMENT PROCESS

What is Automotive Product Development?

The automotive PD process involves the designing and engineering of a future automotive product. The automotive product (i.e., a vehicle) can be a car or a truck or a variant such as a station wagon, a sports utility vehicle (SUV), or a van. The manufacturing and assembly operations are generally assigned to different groups. However, selected representatives from manufacturing and assembly operations must actively participate in the teamwork during the PD process.

TABLE 1.1
Major Systems and Their Subsystems in a Typical Automotive Product

Vehicle System	Subsystems of the System	Sub-Subsystems or Components of the Subsystem
Body system	Body-in-white	Body frame, cross members, body panels, front and rear fascia/bumpers
	Closures system	Doors (door frame, exterior panels, hinges, latches, inside trim panel power window mechanisms, door handles, window and mirror controls), hood and trunk-lid (or liftgate)
	Seat system	Driver's seat, front passenger seat, and rear seat(s)
	Instrument panel	Instrument panel fascia, instrument cluster, switches, glove box, brackets (for other components such as climate controls, entertainment and navigation controls and displays, passenger airbag) and trim components
	Exterior lamps	Front lighting system (headlamps and front signal lamps), rear signal system (tail lamps, stop lamps, turn signal lamps, back-up lamps, license plate lamps, rear reflectors), and side marker and clearance lamps
	Glass system	Windshield, backlite, side window glasses (also called *glazing surfaces*)
	Rear vision system	Inside mirror and outside mirrors, camera systems, and rear and side target sensing systems
Chassis system	Underbody frame work	Front subframe, rear subframe (cradle), cross members for mounting other chassis systems such as steering system and brake system
	Suspension system	Front and rear suspensions (includes arms, links, knuckles, joints, springs, shock absorbers)
	Steering system	Steering linkages, steering column, steering wheel and stalk controls
	Braking system	Brake disks/drums, brake pads and actuators, master cylinder, and pedal linkages
	Wheels and tires	Wheels and tires
Powertrain system	Engine	Engine block and cylinder heads, power conversion system (pistons, connecting rods, crank shaft, bearings), intake and exhaust system, fuel supply system, engine electrical and control system, cooling system, and lubrication system
	Transmission	Transmission casing, gears and shafts, clutches, valves and linkages, sensors, lubrication and oil cooling system
	Shafts and joints	Drive shaft, universal joints, convel joints and bearings
	Final drive and axles	Differential casing, shafts, gears, and bearings

(*Continued*)

TABLE 1.1 (CONTINUED)
Major Systems and Their Subsystems in a Typical Automotive Product

Vehicle System	Subsystems of the System	Sub-Subsystems or Components of the Subsystem
Fuel system	Fuel tank	Tank, fuel system module (fuel pump, pressure valve, fuel filter, fuel level sensor), carbon canister, filler pipe and fuel cap
	Fuel lines	Fuel lines, hoses, and connectors
Electrical system	Battery	Battery
	Alternator	Casing, rotor, and stator
	Wiring harnesses	Wiring harnesses, connectors, and clips
	Power controls	Switches, sensors, relays, electronic control units, fuse box and fuses
Climate control system	Heater	Heat exchanger, blower, air ducts, valves, and hoses
	Air conditioner	Heat exchanger, compressor, valves, tubing, hoses, and refrigerant
	Climate controls	Controls and displays (for setting temperature, fan speed, and mode)
Safety and security system	Air bag system	Air bag units, sensors and actuators, wiring, electronic control units
	Seat belt system	Seat belts, belt anchors, belt buckles, belt movement control mechanisms, sensors, and wiring
	Wiping and defroster systems	Windshield wipers, wiper motors, wiper control system, defroster system, and defroster control system
	Security lighting and locking systems	Exterior courtesy lamps, door locks, locking mechanisms, theft protection system, wiring and control units
	Driver assistance systems	Collision avoidance systems such as automatic braking, lane-departure warning system, driver alertness system, and adaptive cruise control system
Driver interface and infotainment system	Primary and secondary vehicle controls and displays	Driver controls and displays, wiring, and connectors
	Audio system	Audio controls and displays, audio chassis and circuit board, antenna, wiring, USB port
	Navigation system	Microprocessor, display, wiring, antenna, map database, and data ports
	CD/DVD player	CD/DVD player chassis and mechanism, microprocessor, wiring, USB port

Automotive products are generally produced in large quantities (about 10,000 to 700,000 vehicles per year per model and at rate typically of about 40–70 vehicles/hour on an assembly line), shipped to dealers in many locations, and sold to customers to meet their transportation needs. The vehicles must be safe, efficient, economical, dependable, "fun to drive and use," and "pleasing" to the customers. The vehicles also must have necessary characteristics such as performance (i.e., operating capabilities), styling/appearance (form), quality (customer satisfaction), and craftsmanship (perception of being well made). The customers must "enjoy owning the vehicles"—that is, the vehicles must have all the necessary attributes and the right features to meet their lifestyles.

Flow Diagram of Automotive Product Development

The vehicle development process generally begins with understanding customer needs and ends with the customers providing their feedback after using the vehicle. Figure 1.1 shows the major phases in the vehicle development process along with the production, marketing, sales, and vehicle usage phases. Based on an understanding of customer needs, government requirements, and the business needs of the company, a design team consisting of members from different disciplines (e.g., industrial designers, product architects, engineers, manufacturing personnel, product planners, and market researchers) generally develops attribute requirements at the vehicle level and creates the vehicle specifications. The information is used by the team to develop one or more vehicle concepts (in the form of sketches, drawings, CAD models, mock-ups, or bucks). The vehicle concepts are iteratively improved by using customer feedback and suggestions by different team members and are market researched to determine whether a leading concept can be selected for the detailed design and engineering work. Based on the selected product design, manufacturing processes and suppliers are selected. The production equipment and plants are designed and built or modified for manufacturing and assembly. Marketing, sales, and distribution plans are developed. The early production parts and systems are assembled into prototype vehicles. All entities, from components to major vehicle systems, are tested to verify that they meet their respective requirements. The assembled systems are installed into vehicle bodies, and prototype vehicles are created. These prototype vehicles are further tested to verify and validate vehicle-level requirements. Final approval to produce the vehicle is given by senior management, and the vehicle is "launched" (i.e., production begins). The produced vehicles are shipped to the dealerships for sale. As the purchased vehicles are used by the customers, feedback from the customer experience (i.e., data from field operating performance, customer likes/dislikes, vehicle repairs, and warranty work) are continuously collected and provided for improving existing products and designing future products.

To support the entire vehicle development process, resources (e.g., dollars, people, equipment, and facilities) are needed. Budgets and schedules are created to manage the entire PD process. The organization begins to make money from revenues generated from the vehicle sales. The program management and financial analysis issues are covered in Chapters 12 and 19.

Timing Chart of Automotive Product Development

Figure 1.2 provides a timing chart illustrating various activities during major phases of an automotive PD program. The length and location of the horizontal bars indicate duration and beginning and ending times of each activity within each program phase.

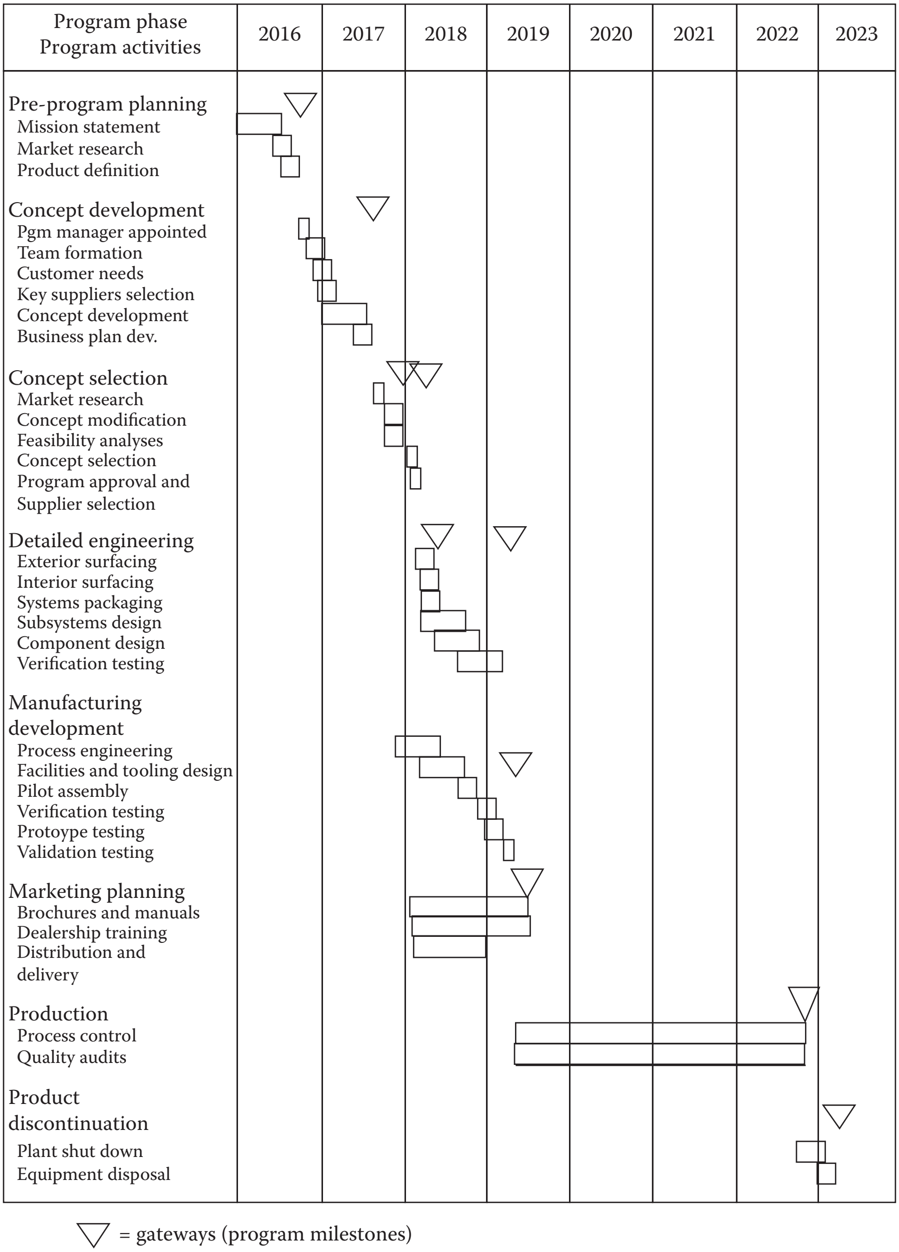

FIGURE 1.2 Timing chart of a vehicle program.

Automotive PD and subsequent life-cycle processes typically include the following major phases, shown in Figure 1.2:

1. *Pre-Program Planning*: This phase involves (a) development of a mission statement for the vehicle program, (b) determination of customer needs for the proposed vehicle, and (c) creation of basic specifications for the proposed vehicle. Market research is conducted to determine market potential, customer needs, and characteristics of the proposed vehicle. The vehicle definition is refined and provided to the vehicle development team.
2. *Concept Development*: As soon as the vehicle development decision is made, the program manager and team members for vehicle development are selected. The team gathers customer needs data, selects suppliers for key vehicle systems, and develops several alternate concepts (or theme vehicles). The vehicle attribute requirements and a business plan providing more detailed information about the proposed vehicle are developed (see Chapter 5 for more information on the business plan).

   The design department develops a number of alternate concepts of the proposed vehicle by creating many exterior and interior sketches and CAD drawings or models. The package engineering department provides engineering support in terms of values of important exterior and interior dimensions to ensure that adequate space is provided for accommodating people, vehicle systems, and luggage/cargo areas. To enable better visualization of alternate concepts, mock-ups and full-size exterior and interior bucks are created.
3. *Concept Selection*: The results of market research clinics and observations from various management and technical reviews of the alternate concepts (including feasibility analyses) are discussed with the company senior management, and a vehicle concept is selected for detailed development in the subsequent phases.
4. *Detailed Engineering*: All engineering design, analysis, and testing work is conducted to ensure that all vehicle systems can be configured and designed to fit within the exterior and interior surfaces created in the selected vehicle concept. Detailed design and engineering of all systems and their lower-level systems and components are completed, and verification tests are conducted to ensure that all attribute requirements are met.
5. *Manufacturing Development*: Manufacturing processes are finalized, and all tools, equipment, and facilities needed to produce the vehicles are designed and constructed. Installation and testing of production and assembly equipment in plants are completed to ensure that all entities within the vehicle can be manufactured and assembled to produce vehicles at the planned production rate and high quality (e.g., meeting all manufacturing tolerances and fit and finish requirements). Early prototype/production vehicles are used for validation testing to ensure that the right product was produced.
6. *Marketing Planning*: Marketing plans are created, and dealerships are provided with the necessary information and training for sales, marketing, maintenance, and repair work of the vehicles.

7. *Production*: Early production vehicles are tested to verify and validate that the vehicles meet all the attribute requirements. Customer and management reviews are completed. Plant equipment calibrations and production output quality are monitored during production. The plant output is adjusted on an ongoing basis to match the vehicle demand through dealer orders and sales forecasts.
8. *Product Discontinuation*: Plant is shut down to discontinue production and retooled for the next vehicle model. Obsolete and unneeded equipment is removed and disposed of.

Preparation of vehicle and systems development timing plans is a very important activity in managing vehicle programs. A proper amount of time must be allocated to accomplish the hundreds of tasks performed by various design and engineering departments. The tasks must be carefully analyzed and selected to ensure that they are needed, and the time required for each of the tasks should be estimated by experienced and specialized professionals from each activity. The product planning department generally takes the time estimates from all key design and engineering activities and creates an overall program timing chart, such as the one shown in Figure 1.2.

UNDERSTANDING CUSTOMER NEEDS

The SE work begins with the definition of the vehicle to be developed. The vehicle definition should include a description of its type (body-style), size (overall dimensions), and market segment (i.e., the market location and customer characteristics). The description should be as detailed and specific as possible, as it will be used by all the team members (designers and engineers) involved in the vehicle development process.

For the vehicle to be successful in the market, the vehicle definition should be based on the needs of its customers. This means that its prospective customers should be identified, and their demographic and ergonomic characteristics and needs for specific vehicle characteristics and features must be determined and used during the vehicle development process. The description of the customer needs should be comprehensive and complete, in the sense that all aspects of the vehicle covered by all the attributes of the vehicle must be obtained. The customer needs should be focused on the vehicle as a whole and not on its lower-level entities. Chapter 3 provides more information on how customer needs and other needs arising from government requirements and corporate business needs are obtained and used in the PD process.

PROGRAM SCOPE, TIMINGS, AND CHALLENGES

Scope of Vehicle Development Programs

An automotive PD program is initiated to modify and improve an existing vehicle design or to replace it with a totally new vehicle. The modifications or changes can range from minor refreshments to an existing vehicle to replacing the existing vehicle with a completely new vehicle design. Vehicle development programs can thus be classified as follows:

1. *Minor Refreshment Program*: Small changes in vehicle exterior (e.g., changes in exterior colors, wheels, rear lamps, grill and headlamps, interior colors, interior materials, and/or graphics in displays)
2. *Program with Medium Changes*: Changes in appearance of some body panels and functionality of some vehicle systems (e.g., restyling shapes of hood, fenders, lamps, instrument panels, and performance improvements in selected systems or subsystems)
3. *Program with Major Changes*: New powertrain, changes in vehicle body and chassis, adding variations in vehicle body-styles (e.g., adding a coupe and/or a station wagon to an existing sedan)
4. *Totally New Design*: Replacing an existing vehicle with a completely new vehicle, which usually involves a new vehicle exterior (body), new powertrains and chassis, and a new interior (instrument panel, door trim panels, consoles, and seats)

The scope of the vehicle program has a direct effect on the number of tasks, timings, and costs associated with the program.

Program Timings

An automotive PD program generally extends over 12 to 48 months, depending on the scope of the program and how the beginning and end points of the program are defined. A large PD program may involve developing a totally new vehicle platform, a new powertrain, and one or more product variations, for example, similar body-style but different exterior panels and interior components for different corporate brands (e.g., Chevrolet, Buick, and Cadillac; Toyota and Lexus; Ford and Lincoln), or adding more body-styles or variants (e.g., sedan, coupe, hatchback, station wagon, and SUV). A large vehicle program may thus extend over several years. A small program may involve merely refreshing an existing vehicle with minor changes to vehicle exterior, such as changes in front fascia, grill, wheel covers, exterior colors, headlamps and tail lamps, and other minor changes to the interior, such as changes in audio components, graphics, and interior materials and colors. A small vehicle program may take from a few months to about 18 months to complete its vehicle development activities.

No two vehicle programs (in terms of tasks to be performed), even within the same automotive company, are alike (because of differences in people working in various program activities, constraints related to time and budget, changes in customer needs, technology-related changes, etc.). Thus, vehicle programs can be very different between different vehicle manufacturers in terms of differences in design tasks, phases, timings, test procedures, organization, and management style.

A major vehicle program can cost upwards of a billion dollars over several years and involve about 600–1200 professionals from different disciplines; many design and engineering computer systems with specialized software; hardware fabrication shops, laboratories, and test facilities with specialized equipment, tooling, and fixtures; design and building shops; and modifications to manufacturing and assembly plants.

Depending on the program size, the vehicle development program timing plan can range from a few months to several years. The timings of the vehicle program are estimated from a list of all the tasks that need to be accomplished and the time and resources needed to complete the tasks. The costs for each of the tasks are estimated and added to come up with the estimates of total time needed, program timings, and program costs. These cost-related issues are covered in Chapter 19.

The success of an automotive company primarily depends on development of the "right" products that its customers truly want. Thus, PD is probably the most important process in an automotive company. The objective of the PD process is to develop one or more products that will be purchased by customers to meet their transportation needs. A successful product not only increases revenues and profits but raises the company's reputation and status, that is, how it is perceived in terms of its image, brand value, and prestige.

Important Considerations in Managing Vehicle Programs

Vehicle programs are influenced by the priorities of various customer needs and approaches used by the company management in developing the vehicle. Important considerations in managing the vehicle programs are

1. *Implement Co-Located Product Design Teams*: Co-location involves moving the offices, design studios, and test facilities of all key team members into one building. The co-location facilitates more frequent interaction between team members. It also eliminates transportation time, as team meetings are held in the same building.
2. *Enable Constant Communication*: More opportunities for communications (formal planned meetings and informal discussions) between team members allow quicker identification and resolution of problems.
3. *Ensure Availability of Latest Vehicle Design, Program Status, and Reference Materials*: Online access and availability of latest data on vehicle design, program changes, and reference information from common data bases (e.g., benchmarking data, design standards, test procedures, and government requirements) to all team members reduces delays in obtaining information on the latest changes and thus reduces rework or duplication of effort.
4. *Adopt Simultaneous/Concurrent Engineering Methods*: Simultaneous development involves performing many tasks within overlapping time intervals (i.e., reducing sequential scheduling of tasks). Concurrent engineering does not only reduce overall program time; it also reduces major rework and improves quality by communicating on issues being resolved using concurrent inputs from many disciplines.

5. *Minimize Number of Design Changes after Program Definition*: Any design change made after the product specification has been approved generally results in more changes (in all entities affected by the changes) and rework. This is especially true because automotive products are complex (i.e., they involve many systems, subsystems, and components that have many interfaces).
6. *Use Computer-Aided Methods to Reduce Costs of Physical Model Building and Testing*: Computer-aided methods do not only reduce time (by use of functions such as copy, paste, mirror, and extrude); they also reduce errors in data transfers and facilitate conducting many design iterations to optimize the design.
7. *Use Carryover Parts*: If existing components can be used (i.e., reused) in developing a new product, this can reduce design, engineering, and manufacturing time and costs. The carryover components, however, reduce design flexibility and the possibilities of incorporating innovative design ideas. The carryover content can range from reuse of a few selected components or systems from an existing vehicle model to use of an existing vehicle platform (i.e., a collection of a large number of systems and large body and chassis parts that determine the characteristics of major tools and fixtures used in manufacturing and assembly plants).
8. *Use "Book-Shelved" Technologies*: A book-shelved entity (i.e., a component or a system) is one that has already been studied, researched, and developed and is ready to be incorporated in a future complex (automotive) product. This eliminates time required to design and develop the new entity.
9. *Incorporate Design Reviews throughout the Program*: Design reviews facilitate additional critical reviews and analyses by experts and managers from different disciplines and departments, which may not have been directly involved during the earlier design work. The design reviews thus help in identifying and fixing problems in the vehicle design and related processes early.
10. *Define and Follow Gateways*: Gateways are important points (or events) in the program timeline. Gateways are also called *milestones* in some organizations. The gateways indicate when certain key events are projected to occur. They are used to guide and coordinate all activities in PD to ensure that the vehicle program progresses according to the pre-developed timing plan. They are usually tied to events such as completion of certain activities (e.g., completion of concept development, engineering steps, management reviews and approvals). Some important gateways are presented in Table 2.1. The definitions and number of gateways vary widely between different programs of different auto manufacturers. The definitions and timings of gateways are usually developed by the program planning departments with constant communication between all major areas (e.g., design, engineering, manufacturing, finance, and marketing). Gateways for each major activity, such as design, engineering, and manufacturing, will include additional lower-level gateways to coordinate their more detailed activities

with the overall program timings. Chapter 2 presents the gateways used in a vehicle development program in relation to the SE process used in the program.

Some Frequently Asked Questions during Vehicle Development

The team members involved in an automotive PD program face many questions. A few commonly asked questions are

1. Are we designing the right vehicle? (Does the vehicle have the characteristics and features that its customers truly desire? Would the vehicle sell well?)
2. Can an actual vehicle be created with the same characteristics as shown in the vehicle concept? Would such a vehicle concept be feasible, considering engineering and manufacturing challenges and tasks?
3. Can this vehicle compete well with its toughest competitors when it is introduced, many months from now?
4. Can we build the vehicle with the required level of quality and within the planned price range?
5. Do we have the capabilities, plant capacity, and resources to build such a vehicle?
6. Can we meet the program timings and stay within the budgeted resources?

Decision Making during Product Development

It should be noted that many decisions are made during each step of the PD process. Some examples of questions related to decisions involved in PD are: What type of product to make? What should be its dimensions? What type of power source would be planned for the vehicle? What should be the capacity of the power source? What types of materials should be used for each component? What types of joining or assembly methods would be used? What should be the height of the seat from the vehicle floor and the ground? What fields of view would the driver need to drive the vehicle safely? In which assembly plant would the vehicle be produced?

Making the right decisions at the right time during the PD is very critical to meet the timings of the vehicle program. Early decisions usually involve the selection of characteristics related to the basic type and configuration of the vehicle (e.g., sedan vs. SUV, front-wheel drive vs. rear-wheel drive). If any of the key parameters of the vehicle configuration, such as the type of powertrain or the wheelbase, are changed in the later phases of the vehicle program, then many other design decisions and parameters that are dependent on the key parameters will also change. The changes generally require redesign of many systems, and they can be very time consuming and costly, especially when the changes are made during the later phases of the program. Thus, all important disciplines need to be involved during the early decision making to avoid late changes.

DISCIPLINES INVOLVED IN AUTOMOTIVE PRODUCT DEVELOPMENT

Development and production of an automotive product requires professionals from many disciplines. In addition, professionals with work experience in past vehicle programs can provide a lot of knowledge during the resolution of a number of issues. The professionals from specialized disciplines (e.g., mechanical engineering, structural engineering, vehicle dynamics, aerodynamics, and electronics) needed in different functional areas are

1. Product planning (mechanical engineers, market research specialists, business management specialists, economists, operations researchers, financial planners)
2. Market research (market research specialists, business management specialists, economists, operations researchers, financial planners)
3. Industrial design (studio designers [interior designers and exterior designers], studio engineers, CAD modelers, graphic artists, color and trim specialists, craftsmanship specialists, clay modelers, computer-aided surfacing modelers, buck builders)
4. Body engineering (mechanical engineers, package engineers, CAD modelers, computer systems engineers, structural engineers, safety engineers, materials engineers, aerodynamics engineers, lighting design engineers, electrical engineers)
5. Powertrain engineering (mechanical engineers, CAD modelers, electrical and electronics engineers, chemical engineers, environmental and emissions engineers, materials engineers, fuel systems engineers, aerodynamics engineers)
6. Chassis engineering (mechanical engineers, suspension engineers, CAD modelers, vehicle dynamics engineers, brake engineers, tire engineers, electrical and electronics engineers)
7. Electrical systems engineering (electrical engineers, electronics engineers, computer systems engineers, telematics specialists, mechanical design engineers, audio engineers, display technologists)
8. Human factors engineering and ergonomics (industrial engineers, engineering psychologists, ergonomists, human factors engineers, mechanical engineers)
9. Climate control engineering (mechanical engineers, thermodynamics engineers, aerodynamics engineers, electrical and electronics engineers)
10. Manufacturing, production, and assembly engineering (mechanical engineers, manufacturing process engineers, materials engineers, metallurgists, numerical control specialists/programmers, industrial engineers, plant engineers, tool designers, tool engineers, ergonomists, industrial hygienists, safety engineers)

SELECTING THE PROGRAM LEADER

Selecting the leader for the vehicle program is probably the most important decision faced by the senior company management. The vehicle development process involves making many decisions related to the characteristics of the vehicle being

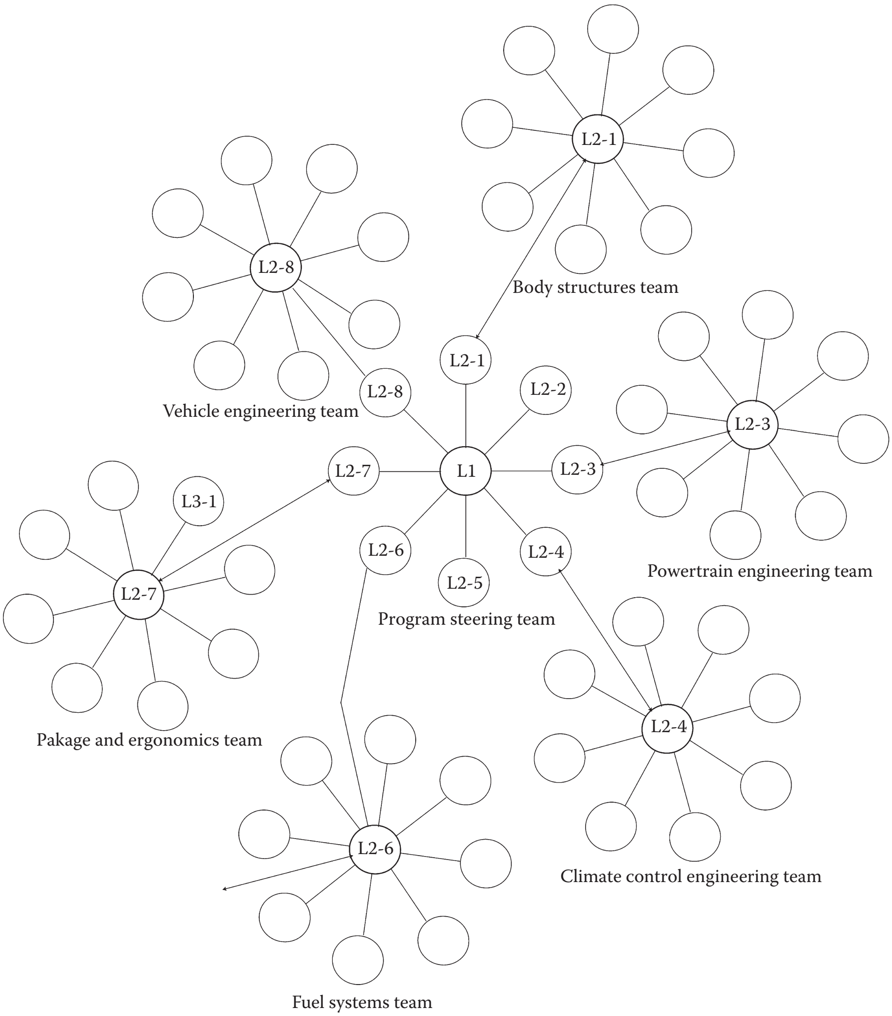

FIGURE 1.3 Illustration of linked team structure (only partial team structure is shown).

designed. The program leader (or program manager) must oversee the vehicle development activities and make all key decisions. The program leader should be a big-picture thinker and must have the skills to perform many roles, functioning as an integrator, a decision maker, a time and cost controller, a team builder, a coach, a motivator, and a communicator.

Womack et al. (1990) have compared the leadership issues in Western auto companies with Toyota and found that the reduced PD cycles and better quality in Toyota vehicles in the 1980s were due to implementation of the *shusha* concept. The shusha (or chief program engineer) is given the complete authority to make all decisions on the vehicle and its program management. Additional information on the program management tasks are provided in Chapter 12.

ROLE OF EARLY VEHICLE CONCEPT DEVELOPMENT

In most automotive companies, early vehicle concepts (i.e., before a vehicle program is officially approved and launched) are developed to understand the integration and development aspects of many issues involved in the development of a new vehicle. The outputs of such activities are typically concept vehicles (working or nonworking vehicle bucks or prototypes). These concept vehicles are typically shown in various auto shows in different automotive markets to gauge the interest in such vehicle concepts from customers, experts, and critics in the industry.

Many automotive companies have formally assigned functions and dedicated staff within design and engineering activities—commonly labeled as *advanced design studios*, *advanced vehicle engineering* departments, or *advanced product concepts* research projects—to create future vehicle concepts. Such vehicle concept development exercises help in understanding many strengths and weaknesses of the concepts, engineering challenges, and risks that need to be resolved before such a concept is further developed and implemented in a formal vehicle program. A formal vehicle program is generally created after the company's senior management is convinced about the need and marketing potential; that is, the consensus is formed among key decision makers within the company that an actual vehicle can be developed from the concept and will sell well.

FORMATION OF TEAM STRUCTURE AND TEAMS

The development of an automotive product requires many people from different disciplines and specializations. The number of people and teams required will depend on the scope of the vehicle development program and the automotive company. However, about 400 to 1200 engineering personnel from different specializations, such as body engineering, chassis engineering, electrical engineering, and powertrain engineering, are needed in a typical vehicle program in a Western automotive company. The entire design project is usually organized by using many teams, each undertaking the design of a certain portion or systems or subsystems of the vehicle. The structure of each team, with team leader and number of team members, technical qualifications of each team member, responsibilities of each team member, progress reporting, and problem resolution and communication methods, is strictly enforced to ensure that all vehicle systems and interfaces between the systems can be designed to meet all identified engineering requirements.

The highest-level team in a vehicle program is typically headed by the vehicle program manager, and the membership of the team consists of high-level managers of major activities and chief engineers of major engineering offices. In some auto companies, this is called the *vehicle program steering team*. The organizational structure of the vehicle program steering team, with the top level (Level 1) and next level (Level 2), is illustrated in Figure 1.3.

Vehicle program steering team:

L1 = Vehicle program manager (Level 1)
L2-0 = Program management manager (Level 2)

L2-1 = Body engineering chief engineer (Level 2)
L2-2 = Chassis engineering chief engineer (Level 2)
L2-3 = Powertrain chief engineer (Level 2)
L2-4 = Climate control chief engineer (Level 2)
L2-5 = Electrical engineering chief engineer (Level 2)
L2-6 = Fuel system chief engineer (Level 2)
L2-7 = Package and ergonomics engineering chief engineer (Level 2)
L2-8 = Vehicle engineering chief engineer (Level 2)
L2-9 = Manufacturing engineering chief engineer (Level 2)
L2-10 = Chief designer (Level 2)
L2-11 = Vehicle attribute engineering chief engineer (Level 2)

The next-level teams, headed by each Level 2 chief engineer with membership of Level 3 managers, can be illustrated as follows:

Body engineering team:

L2-1 = Body engineering chief engineer (Level 2)
L21-1 = Body structural engineering manager (Level 3)
L21-2 = Body closures engineering manager (Level 3)
L21-3 = Body safety systems manager (Level 3)
L21-4 = Body electrical engineering manager (Level 3)
L21-5 = Body lighting engineering manager (Level 4)
L21-6 = Instrument panel engineering manager (Level 3)
L21-7 = Seating systems engineering manager (Level 3)
L21-8 = Body trim components engineering manager (Level 3)

Vehicle attribute engineering team:

L2-11 = Vehicle attribute engineering chief engineer (Level 2)
L211-1 = Vehicle dynamics engineering manager (Level 3)
L211-2 = Aerodynamics engineering manager (Level 3)
L211-3 = Thermal management engineering manager (Level 3)
L211-4 = Noise, vibrations, and harshness engineering manager (Level 3)
L211-5 = Craftsmanship engineering manager (Level 3)
L211-6 = Weight engineering manager (Level 3)
L211-7 = Vehicle cost management manager (Level 3)

Similarly, the next-level teams headed by each of the Level 3 managers with membership of Level 4 supervisors are

L21-2 = Body closures engineering manager (Level 3)
L212-1 = Hood engineering supervisor (Level 4)
L212-2 = Front doors engineering supervisor (Level 4)
L212-3 = Rear doors engineering supervisor (Level 4)
L212-4 = Trunk/liftgate engineering supervisor (Level 4)
L21-5 = Body lighting engineering manager (Level 3)

L215-1 = Front lamps engineering supervisor (Level 4)
L215-2 = Rear lamps engineering supervisor (Level 4)
L215-3 = Side marker and courtesy lamps supervisor (Level 4)

Depending on the issues being covered in any meeting of any of the above teams, other team members and specialists are invited to help resolve the issues.

TREATING SUPPLIERS AS PARTNERS

It is important to realize that depending on the automotive company, about 35–75% of the content of the automotive products is produced and supplied by supplier companies. Thus, the quality of the vehicle depends on the quality of the entities supplied by the suppliers and how these entities interface and work together with entities supplied by different suppliers and produced by the automotive company. Many of the suppliers are selected early, and their personnel are asked to participate in the PD process (as team members in different teams related to their supplied entities) and are given the tasks of designing the entities that they will produce. Thus, the suppliers should be treated as partners during the entire PD, production, and automotive assembly processes.

It is therefore very important to select the right set of suppliers. Supplier selection criteria typically include (a) expertise in SE and specialized disciplines needed to develop the entities, (b) production capability in terms of required levels of quantities with specified quality and price, (c) demonstrated flexibility in quickly incorporating engineering changes during early design stages, (d) dedication and responsiveness in meeting key product requirements (e.g., high fuel economy), (e) ability to incorporate innovative methods and technologies, and (f) ability to support globally (on products marketed in many countries).

OTHER INTERNAL AND EXTERNAL FACTORS AFFECTING VEHICLE PROGRAMS

Automotive PD programs are affected by many factors. The program management needs to be constantly on the lookout to determine whether these factors will affect various attributes of the vehicle, program timing, and costs. Major factors related to issues both internal and external to the automotive company that can affect the vehicle programs are listed in the following subsection.

INTERNAL FACTORS

1. Constant change due to the iterative nature of the PD process
2. Company's senior management directives and decisions related to the program (e.g., budgets, cycle plans, preferences for certain vehicle features)
3. Balancing costs, manpower, and timings across all vehicle programs within the company
4. Availability of manpower with required qualifications and expertise
5. Ability to select suppliers and integrate their involvement in the vehicle program teams

6. Ability to outsource design and production work and manage the supply chain
7. Ability to maintain confidentiality of information related to product plans and designs
8. Program management (organization, communication, and control)
9. Commonality and shared entities: platforms, systems, and components
10. Ability to meet quality characteristics of the product, including variety of expected features and delights

External Factors

1. Political changes and other situations (e.g., adverse weather) in the vehicle-producing country
2. Economic conditions, such as employment levels, tax, interest, and inflation rates
3. Changes in government regulations affecting the product
4. Availability of energy and materials sources related to the vehicle performance needs and prices
5. Global factors such as political and economic conditions affecting other countries and markets related to the product
6. State of competitors and their product plans (e.g., new products introduced by the competitors)
7. Trends and changes in vehicle design and related technologies
8. Supplier abilities to meet quality, cost, and timing targets

IMPORTANCE, ADVANTAGES, AND DISADVANTAGES OF SYSTEMS ENGINEERING

Importance of Systems Engineering

SE, with assistance from the other engineering disciplines, establishes the vehicle configuration, allocates functions and requirements to all vehicle systems and their lower-level entities, establishes measures of effectiveness for ranking alternative concepts/designs, and integrates the design with all specialty disciplines. SE is, thus, a "glue" that bonds together all the vehicle systems and the disciplines required to create a vehicle that the customers want.

SE is responsible for verifying that the developed vehicle (with all its systems) meets all the important requirements defined in the vehicle attributes and systems specifications. SE also plans for all necessary analyses that need to be conducted and ensures that design reviews are conducted to meet program timings. Thus, products developed with the application of SE principles, processes, and techniques will benefit from the following:

1. The right products will be developed, because the SE will make sure that (a) the customer needs are obtained and translated into requirements, (b) the requirements are used by multidisciplinary teams for PD, (c) the best

product configurations are selected through iterative and recursive refinements, (d) all product entities are verified to ensure compliance with their requirements, and finally, (e) the whole product is validated using customers and pre-selected test procedures. Thus, the customers will like the products and will be very satisfied.
2. PD time can be reduced by avoiding costly delays.
3. Costly redesign and rework problems will be reduced.
4. The product will remain on the market for a longer time.

Advantages and Disadvantages of the Systems Engineering Process

The major advantages of the implementation of the SE process in the development of a complex product program are

1. It will help in reducing costs and time overruns.
2. It will help in creating products that the users want (i.e., it ensures customer satisfaction).

The disadvantages of the incorporation of SE functions in a PD program are

1. It adds people (systems engineers) to the payroll and thus increases the costs of the program.
2. It creates an additional documentation burden with the SE management plan.
3. It creates more work for the team members in communicating with the SE personnel and following the activities incorporated in the SE management plan (see Chapter 12).

CONCLUDING REMARKS

Undertaking a vehicle development program is very challenging due to the complexity of managing many tasks performed by many professionals from many disciplines to design all the vehicle systems and making sure that all the vehicle specifications and requirements are met. Vehicle programs are also affected by a number of unforeseen and uncontrollable internal and external factors. The competition between many vehicle manufacturers is also very fierce, and vehicle development teams are pressured to reduce development times and budgets under fast-paced technological changes. The subsequent chapters present the concepts, methods, and processes used to meet the design challenges.

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2 Steps and Iterations Involved in Automotive Product Development

INTRODUCTION

Systems engineering implementation is an iterative process. The iterations are necessary because many decisions that are made during the vehicle development process require consideration of alternative configurations of systems and system characteristics. The type of technologies used in the operation of each of the systems also affects their characteristics and configurations and trade-offs between vehicle attributes. Many trade-offs between vehicle attributes, such as performance versus costs (e.g., acceleration capabilities of the vehicle vs. powertrain costs), vehicle weight versus performance, energy consumption versus performance, and performance versus packaging space, need to be carefully considered to ensure that the systems meet their attribute requirements, work together, and fit within the vehicle envelope. Further, many of the design issues are dependent on the importance of each of the vehicle systems and its features to customers. And many unexplored combinations of system characteristics require extensive analyses and evaluations (e.g., testing) to determine which of the design alternatives would be feasible and most economical and would best meet customer needs.

Systems engineering implementation also involves simultaneous consideration of inputs from professionals from many disciplines. Simultaneous (or concurrent) engineering requires constant communication between professionals from all disciplines to ensure that requirements for all vehicle attributes and trade-offs between the attributes are considered. The communications between professionals occur in many informal and formal information exchanges and design review meetings. The product visualization in the design reviews is facilitated through reviews of drawings, computer-aided design (CAD) models, and physical models (e.g., mock-ups, bucks, prototypes). Physical properties or three-dimensional CAD models with fly-through views (i.e., camera views from different locations or paths) are particularly useful in visualizing the space available to package all affected systems within the vehicle space when studying configurations, interfaces, interferences, and clearances between different vehicle systems (see Chapter 13 for more details).

For example, powertrain packaging involves understanding the spaces required to package the engine, transmission, suspension system, steering system, wheels and tires, shafts, final drive, and braking system within the vehicle body and chassis systems. The vehicle body system is configured to accommodate the needs of the occupants and requirements for vehicle attributes such as styling, aerodynamics,