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MULTI-ENTERPRISE CONCURRENT ENGINEERING THROUGH INTERNATIONAL STANDARDS

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ABSTRACT

Concurrent engineering involves the integration of people, systems and information into a responsive, efficient system. Integration of computerized systems allows additional benefits: automatic knowledge capture during development and lifetime management of a product, and automatic exchange of that knowledge among different computer systems. Critical enablers are product data standards and enterprise integration frameworks. A pioneering assault on the complex technical challenges is associated with the emerging international Standard for the Exchange of Product Model Data (STEP). Surpassing in scope previous standards efforts, the goal is a complete, unambiguous, computer-readable definition of the physical and functional characteristics of a product throughout its life cycle. The use of STEP will lead to higher, integrated levels of automation based upon information standards and frameworks. Concurrent engineering, through information technology and standards, represents the power of a new industrial revolution.

KEY WORDS

Automated manufacturing; concurrent engineering; information standards; manufacturing standards; PDES; product data engineering; product data sharing; product data standards; STEP

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I. INTRODUCTION

In our increasingly global economy, digital information technology has become critical to international competitiveness. From computers to telecommunications to military systems to consumer electronics, the future of a nation's economic and worldwide influence depends on its excellence in digital information technology. Just as the industrial revolution changed the world order, the information revolution will too. Just as steel, ship, and computer technology affected the balance of economic and military power in the past, information technology will too.

Concurrent engineering is one of the applications of information technology that will be pivotal and will provide unique economic opportunities. Concurrent engineering will stimulate and maintain increased diversity in an entrepreneurial environment by expanding access to knowledge. It will force a global optimization among all of the product life cycle processes within a design and production system.

Concurrent engineering empowers decisions, decisions that take into account all the possible impacts and outcomes. Concurrent engineering is the use, in each phase of a manufacturing activity, of all the available information about that activity, as well as other life cycle activities. It represents the totality of knowledge applied to a manufacturing goal.

In principle, concurrent engineering does not have to be an automated process; it could be people interacting directly with other people. In practice, in today's manufacturing environment, the complexity of products and processes and the use of computerized systems preclude sole reliance on people-to-people concurrent engineering. Today, the approach to concurrent engineering has to be through the automatic sharing of knowledge by computerized systems. This can be thought of as automated concurrent engineering, or computer-aided concurrent engineering.

Concurrent engineering achieved through the integration of computer systems can create a cooperative environment within a company, as well as among companies. It can result in bringing together independently innovative companies without any loss of independence. This could provide the mechanism for a country or economic region to develop its own, unique approach for achieving world-class manufacturing. However, in an automated environment, concurrent engineering is impossible without standards. That is, the full automation and integration of industrial processes is impossible unless standardized hardware and software, especially standardized knowledge and knowledge models, exist to allow intercommunication among all types of computerized systems.

Concurrent engineering, based upon product data standards and enterprise integration framework standards, truly represents a new form of concurrent engineering that can be called "multi-enterprise concurrent engineering" [1]. Multi-enterprise concurrent engineering can be defined as the systematic approach, across industrial enterprises, to the integrated concurrent design of products and their related processes (such as manufacturing and support) through the sharing of product data.

II. CONCURRENT ENGINEERING: TEAMWORK-IN-EFFECT

Concurrent engineering is an old concept. In earlier times when individual craftspeople created individual objects, by necessity they took into account such factors as the properties of the materials, the manufacturability of the parts, and the function and utility of the object. The integration of the product information occurred within the mind of each individual craftsperson.

When factors such as technology led to more complex products as well as specialization and compartmentalization among experts and workers, the integration of all relevant information was no longer spontaneous. Increasingly, the tendency was that the information was made available *sequentially*: the designer designed, then the producer produced, and so forth.

The evolution toward sequential manufacturing was movement away from concurrent engineering. This is because concurrent engineering is an inherently *parallel* process. The integration of the information required for all phases of the life of a product represses serialism and promotes parallelism. A formal definition of concurrent engineering emphasizes this idea [2]:

> "Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements."

A. The Process of Concurrent Engineering

Concurrent engineering is a process that involves the integration of information. In principle, in a concurrent engineering approach, all the available information about a product is accessible at every stage in its design, manufacture, support, and recovery and disposal, as illustrated in Figure 1.

A concurrent engineering approach could be implemented by assembling a team of (human) experts, each of whom is a specialist responsible for one or more stages of the product's life cycle. The team would create and support the product during its life. Access to information would be accomplished either by request for the information by the expert who recognizes the need for it or by contribution of the information by the expert who recognizes its usefulness at the time. The human team is the mechanism for integrating the product information. Examples of product information used by experts in different phases of a product's life cycle are shown in Figure 2.

The human team approach is limited by cultural and organizational practices and by the amount and complexity of the information. An alternative approach that has none of these limitations is automation of the creation-to-disposal process for a product. In this approach, computerized systems access the information and either automatically utilize it or offer it to the appropriate human specialist at the proper time. Therefore, the mechanism for integrating the product information is the totality of interconnected, information-sharing automated systems. This is illustrated in Figure 3.

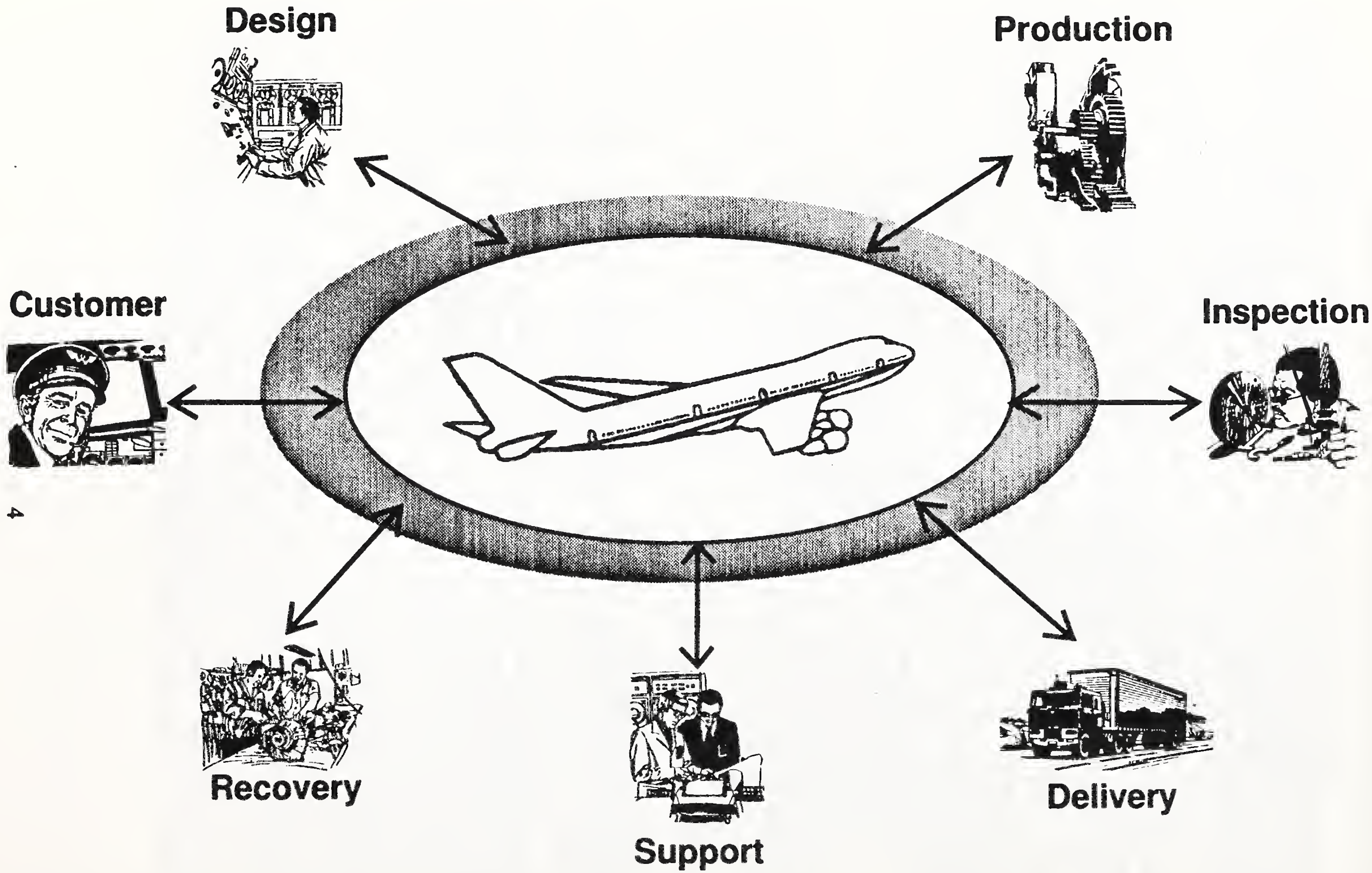

Fig. 1. A "world class" product requires an enterprise-wide commitment to excellence. Examples of various life cycle stages of a complex product--an airliner--are shown schematically.

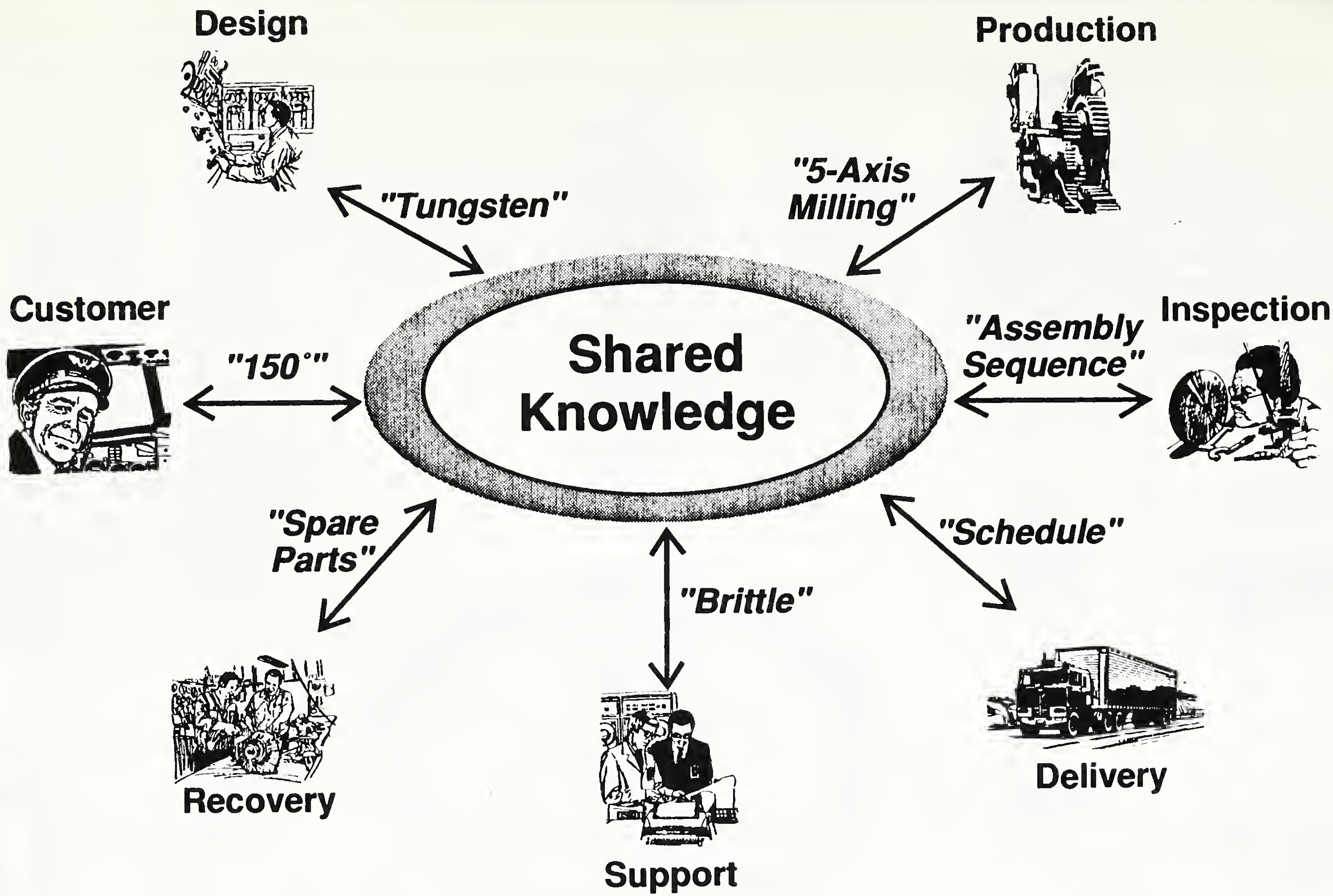

Fig. 2. Examples of knowledge that is needed by the specialists involved in the various product life cycle stages are illustrated. The sharing of the product knowledge leads to concurrent engineering.

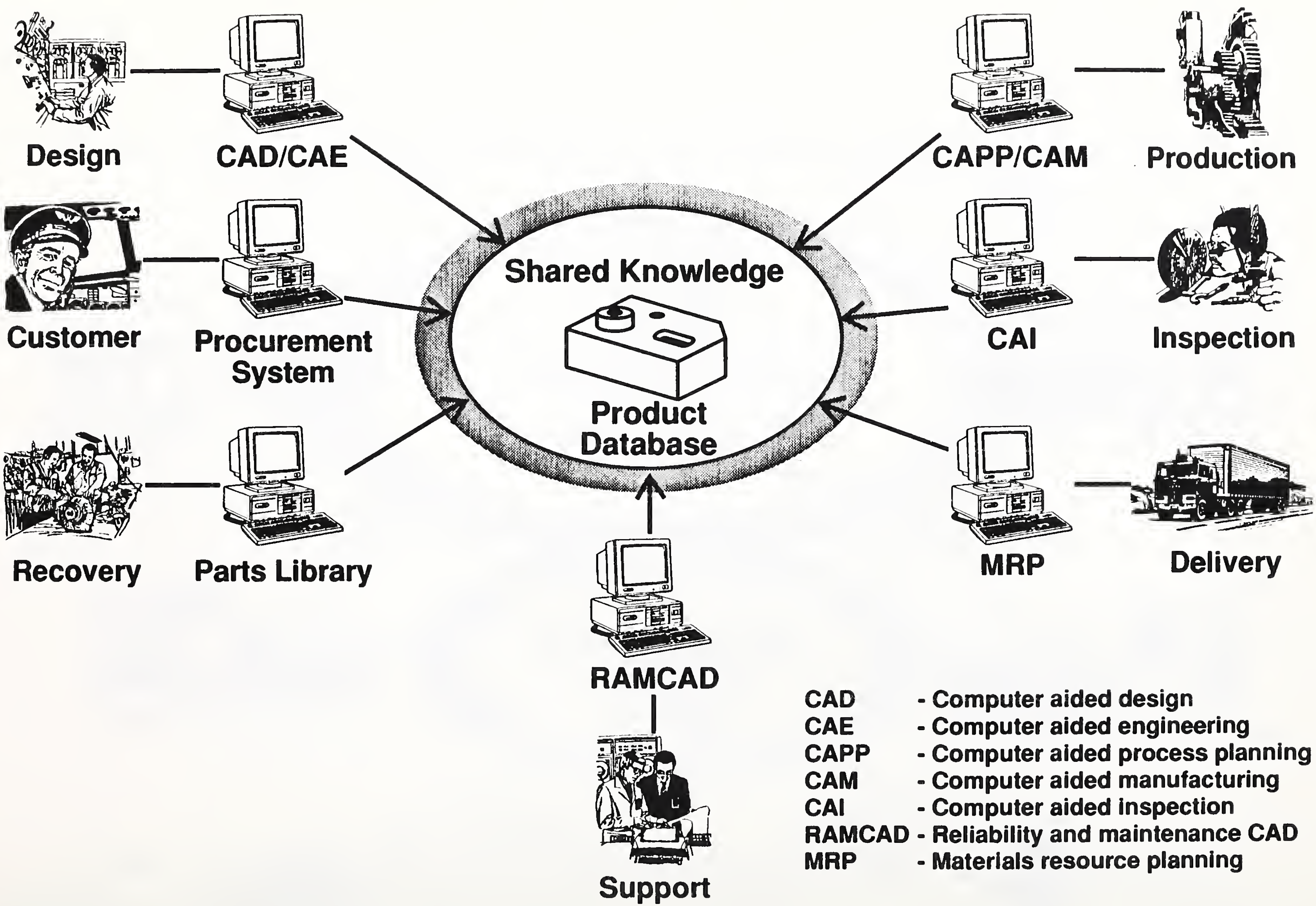

Fig. 3. When the knowledge is shared automatically by computerized systems, the concurrent engineering environment itself becomes automated.

No human team need meet or interact face-to-face. The specialists can be separated both physically and organizationally.

Of course, human specialists must still play a role. They create designs, make value judgements, and make decisions from information provided by the automated systems.

Nevertheless, concurrent engineering truly represents teamwork, even in its automated embodiment, even when an actual team of human experts has not been created. Using a concurrent engineering approach made possible by integrated automated systems, product experts operate as they would in a traditional environment. This is because they (and their computers) utilize information from and provide information to each other as needed. They become a team through their automated systems. Their interactions can be optimized, even though they may not include face-to-face interactions, and the individual team members can perform to the limits of their capabilities without changing their personal or interpersonal styles.

B. The Need for Concurrent Engineering

Competitive success depends on shortening the time between conception and introduction of new technologies and products into the marketplace. To minimize time-to-market, computer-aided tools are used to move the product from concept through design, prototype, manufacture, test, and introduction into the marketplace (from concept to consumption).

Yet, even as pressure is applied to decrease product development time, the diversity of activities and expertise required to bring a product to fruition is increasing dramatically. This is because in addition to meeting functional needs, the product must meet energy, environmental, health and safety requirements, as well as other needs. Such non-traditional requirements are becoming more demanding on manufacturers as the sophistication of our culture advances and as our knowledge of the impacts of human activities on the global environment expands.

Because of the need to minimize the time from conception of a product to its delivery to a customer, and because of the amount and variety of information needed by manufacturers, computers are essential in manufacturing. They are used to design products, plan for their manufacture, control the equipment that produces them, control the equipment that tests them, manage their distribution, and help support their operation, repair and maintenance. Furthermore, because most producers of complex products, for example, vehicles and computers themselves, manufacture only a fraction of the parts in these products, there are needs relating to activities such as inventory control, scheduling, and ordering, as well as the coordination of all the manufacturing activities of the supplier companies. But the needs can be only partially met, and the advantages of using computers only partially achieved, unless the computers can interoperate--that is, share information--so that they can perform their tasks in parallel. In this manner computers and integration naturally point to--even *demand*--concurrent engineering.

C. The "Meanings" of Concurrent Engineering

Concurrent engineering can shorten the time required before a product is marketed. It can improve productivity, profitability and competitiveness. It can lower costs, reduce waste, improve quality, and improve efficiency in all phases of the life of a product [2]. It can allow suppliers and vendors to coordinate their operations. It can enable manufacturers to cooperate in consortia in precompetitive projects. Such coordinated operations increase the resources, lower the cost and reduce the risk for each individual participant. This may allow the participants as a group to be more innovative and risk-taking to produce more competitive products. Therefore, in today's aggressively competitive world market, concurrent engineering may mean the difference between failure and success of an industry.

On another level, the introduction of concurrent engineering to an enterprise through people-to-people interactions may mean unacceptable cultural changes. Because it emphasizes teamwork rather than competition, people-to-people concurrent engineering may be in conflict with a company's culture or management style. Or it may interfere with established relationships among the departments within a company, or among the companies within a group of companies.

To an individual manager, concurrent engineering may represent barriers to be overcome. A manager might conclude that concurrent engineering means:

- Overcoming resistance to teamwork and getting employees in different departments to work together,
- Overcoming competitiveness among workers,
- Retraining specialized workers in new technologies,
- Modifying management style and organizational culture, and
- Developing new types of computer-based tools.

In a sense, these are input- or investment-oriented issues. Looking instead at outputs or benefits, concurrent engineering may mean:

- Lower costs,
- Shorter time-to-market, and
- Greater quality.

These larger benefits can be obtained without many of the difficulties of changing people's behavior by introducing concurrent engineering through the integration of computer systems. Even while the integrated computer systems are sharing information, people can have the choice of how to respond to the information presented to them automatically by their computers. They do have to alter the way they work because they are utilizing greater amounts of information; however, they do not have to alter the way they interact personally with other people.

In this manner, concurrent engineering does not require cultural changes. Although management approaches must be modified to promote the use of more shared information, people and companies can interact and can perform their activities, either individually or collectively, in whatever work style suits them. The entrepreneurial spirit does not have to be stifled by new business-imposed interactions. The key is that the computer systems used by the people and companies interact effectively and automatically.

The concurrent engineering environment will give managers the ability to oversee all activities throughout their enterprise--without any additional bureaucracy. Managers will be able to have the information they need, as it is created, to anticipate, plan, and act quickly. Therefore, concurrent engineering will mean a change in management styles in many enterprises.

Suppliers, partners, and customers can be linked to a manufacturer through an information network. In this way, multi-enterprise concurrent engineering may mean the creation of vertically and horizontally integrated manufacturing entities *de facto*. Although the suppliers would not be controlled by the systems integrator, for example, as they might be in a vertically integrated entity, supplier companies and systems assembly companies might cooperate to their mutual advantage through the sharing of product data and decision-related information.

The important point is that the creation of an automated interconnected computer environment can free people and companies to operate however they please. If information can be shared automatically and the computer systems people use to do their work can interact and the mechanisms are in place to create a concurrent engineering environment, then individuals can perform their activities in their own way. Instead of being constrained by having to interact and cooperate with others, people can, if they choose, be independent and work alone Their data will be integrated, and their ability to retain their individual freedoms would preserve for them the benefits associated with their traditional strengths and diversity. In this way, *the full automation of the industrial environment will provide the needed teamwork.* The entrepreneurial spirit does not have to be stifled by business-imposed interactions. Independent innovators can continue to be independent--at least in the way they operate personally.

III. CONCURRENT ENGINEERING: COMPETITION THROUGH COLLABORATION

There can be little doubt that in today's economic environment, and for the foreseeable future, industries must compete in world markets. Among industrialized nations, international competition is increasing. Yet, as evidenced by trade deficits, many countries are not competing successfully.

Manufacturing technology has been identified as a key to competitive success [3]. However, manufacturing technology is seldom cited as a contributor to a country's poor competitive performance. This may be because the role of technology and its relationship to economic factors may not be well understood. Technology is sometimes viewed only as the creation of new products rather than the improvement or alteration of existing manufacturing practices. Yet technology, in particular the technology that will lead to multi-enterprise concurrent engineering, can provide the means to build a new national economic strength. Concurrent engineering based on integrated automated systems can produce a new basis for competitiveness.

A. The Path From Automation to Concurrent Engineering

Automation in manufacturing has led to impressive economic benefits from improvements in capacity, productivity and product quality. Yet, the benefits that remain unrealized are even greater. They are the benefits that will accrue from the integration of information among automated systems. The benefits include:

Reduced time from concept to commercialization. The efficient sharing of product data among automated systems will eliminate the need to produce hard copy drawings and models. Design details can be tested electronically against physical and engineering constraints using analysis systems and against economic constraints using cost prediction and manufacturing process simulation systems. Design changes can be made rapidly even after initial production has begun.

Reduced costs. Increased productivity will be obtained by the increased efficiency of the design process and by reduced "time to market." Studies have shown that concurrent engineering results in a reduction in the number of design changes and in the amount of material wasted due to defects and rework [2].

Increased responsiveness to customer needs. By improving the flexibility of the bond between design and production, manufacturers can more quickly introduce new products or change existing products. This capability is essential in today's global markets. The demands by customers for both products and services that are characterized by differentiation, customization, and localization, result in a competitive environment where the rewards go to the speediest and quickest to adapt.

Increased cooperation among suppliers and vendors. The ability to communicate and exchange information among suppliers automatically spreads the benefits of integration from within a single enterprise to a network of enterprises. For example, a single design change in one component can cause an unpredictable delay as its effects cascade through all enterprises whose components and processes are required by the product. Today, even the need to evaluate the impact of a design change on the product causes delays as different enterprises communicate and respond. However, integration would not only allow manufacturers to coordinate activities and product changes among all their suppliers to avoid delays, but, even more importantly, it also would allow manufacturers and suppliers to take any required actions automatically and *simultaneously.*

The integration of information means the merging of machines and information into a system that is responsive and efficient--a system that can support concurrent engineering.

However there are technical barriers to achieving the goal of concurrent engineering and the economic benefits it offers. The barriers include not only incompatibility among existing information systems, but also the complex nature of the data that must be shared among systems. The manufacturing data that must be shared is more than just an accumulation of unrelated bits of numerical information. Design data provides a good example; it contains physical and functional information as well as information about the significance of the design decisions that led to the final design. Product data includes not only the design data itself, but also data about its supporting infrastructure and its interfaces with other equipment.

Therefore, the standardization of product data implies more than merely the standardization of product data file formats. For concurrent engineering, information models for product data are needed. The path from automation to concurrent engineering is through standardized product data models.

B. A Higher, Integrated Level of Automation

When the approach to concurrent engineering is through automation, information technology must be applied to create the means for automated systems to communicate and interoperate. For example, within a manufacturing enterprise, computer-aided design systems must be able to share information with analysis systems, manufacturing systems, and distribution systems. Eventually, concurrent engineering can be applied to all business systems, not only manufacturing systems.

Interconnected automated business systems will provide managers, engineers, accountants, marketing specialists, distributors, and everyone involved in a business enterprise with all the information they need to carry out their functions. This includes information they need to make decisions as well as information about how their decisions affect the decisions and activities of everyone else in the business. Plans and actions will be made simultaneously, without the delays experienced in traditional paper communications and face-to-face meetings as projects progress step-by-step in linear fashion.

Key to the goal of concurrent engineering is the ability of manufacturing information systems to capture automatically the knowledge that is generated during the product life cycle. The knowledge can then be used by the designer and others involved in managing the product. For example, knowledge about how a product would be processed or what new materials would be required to meet the functional specifications is made available to the designer as the design is being developed to ensure the best quality product reaches the downstream life cycle managers. In this way the most appropriate and cost-effective materials and processes can be used.

In a sense, two attributes of integration can elevate automation to a higher level:

1. The ability to capture automatically the knowledge gained during designing, producing, commercializing, and managing a product throughout its lifetime, and

2. The ability to exchange automatically that product knowledge among different computer systems.

An integrated level of automation can be thought of as a facilitating or an enabling technology for concurrent engineering.

C. A Shared Database Environment for Concurrent Engineering

Automated systems store product information digitally in a database. The mechanism for sharing the information is a multi-user or "shared" database. In a shared database environment, the product information can be accessed by one or more applications, even at the same time.

Of course, there are many technical issues that must be resolved for such a shared database environment to be implemented. For example, an interface is needed between present computer-aided design representations of a product and other computer-aided systems, such as computer-aided engineering analysis and process planning systems. Production costs and capabilities must be integrated into the database for effective design decisions.

Intelligent processes must have access to geometry data in much the same manner that users query business systems. In addition, it is critical to have a mechanism that allows new knowledge to be added to the database as the intelligent processing operations are being performed.

The technical challenge is the development of the information technology and the associated standards that will define the environment for the representation of product knowledge. This will allow the implementation of a shared-database environment for concurrent engineering.

IV. CONCURRENT ENGINEERING: STANDARDS ARE ESSENTIAL

Even if a multidisciplinary team of engineers were assembled to produce both a product and the procedures necessary to maintain it in use, it is impossible such a team could operate effectively without using automated systems to communicate and share information. In today's manufacturing environment, concurrent engineering means integrated information systems--and that means product data standards are needed.

A. Standards Are Necessary for Integrating Automated Systems

The critical ingredient for the use of concurrent engineering in manufacturing is the integration of product and process data. This integration gives the designer, along with everyone else in the commercialization chain, information about the entire life cycle of a product, as well as information about how their decisions affect all other aspects of the product. In addition, the integration and automation of product and process data provides for meeting the needs of the specialists involved with a product's commercialization by allowing each of them to obtain a particular "view" of the product that is suitable for their specialty and function.

Within a single enterprise, the issue may be one of technology rather than standards. Sometimes a company can choose to use systems from one vendor for all applications, or it can develop the interfaces, translators and other software needed to integrate its systems. But whenever more than one company cooperates or shares information, interoperability of systems becomes the uppermost issue, and that means standards. (Standards do not guarantee interoperability, but they bring it closer to reality.)

The integration of product and process data is not possible unless there is a mechanism that allows the sharing of information among different manufacturing systems. The mechanism must be a standard digital representation for product and process data. That is why standards are the key to multi-enterprise concurrent engineering and why, in today's business environment, *concurrent engineering is impossible without standards.*

B. Standards Create a Bigger Pie

It takes years for companies in an industry to recognize all of the different specialty niches for systems and to develop viable products. For example, although the basic interface specifications for personal computers were established in the early 1980's, new types of hardware and software products are still being developed today. In the same way, the integrated concurrent engineering environment will provide opportunities for new products that cannot be predicted now. In both cases, the enabling vehicles are standards. Standards are essential for concurrent engineering in an automated environment because even if a single manufacturer were to offer a computer that designs, manufactures, and supports a product, these activities may not be carried out at the same physical location using all the same manufacturer's equipment.

Standards are sometimes viewed as inhibiting or constraining change rather than enabling or facilitating innovation and new technologies. Fortunately, standards for enterprise integration are interface standards or "open system standards." Interface standards relate to interoperability, including data exchange and intercommunication, among different hardware and software elements. Interface standards encourage independent development of interoperable products because they specify both the characteristics of critical interfaces and the way in which the information transferred across the interfaces is represented digitally.

Such standards are welcomed by manufacturers because they lower barriers to market entry and they enlarge the market. No manufacturer is comfortable venturing down proprietary paths with the risk that they may one day find themselves at a dead end.

From the customer's point of view, open system standards lead to more intense competition, a larger number of vendors from which to choose, a greater variety of off-the-shelf solutions that are both less likely to become obsolete and more likely to be easily integrated into existing systems, modular systems that can be configured for improved performance in a specific application, and, as a result, lower prices. Everybody wins.

The result of multi-enterprise concurrent engineering is more than just the optimization of a design and production system--it is a broader optimization of an industrial system. The technical challenges are numerous and difficult. Equally challenging is the attainment of international consensus on the methods for achieving the required networking of diverse types of business systems. Nevertheless, international consensus on the means for integrating automated systems--the standards--is essential. No single company, in fact no single country, has enough resources to develop suitable methods applicable to all businesses in all countries. Even if it were to happen that one company developed an integration method, the likelihood of acceptance by everyone else is negligible. Clearly, the best approach is through consensus-based international standards.

But it is not enough for internationally accepted standards to be "best," nor is it enough that everyone agree that standards are essential. Instead, for the rapid realization of international standards, it is critical that participants see real benefits for themselves.

The real benefits of international standards to promote concurrent engineering are the benefits of concurrent engineering itself. For workers, customers, manufacturers, and industries, the benefits were discussed earlier in this paper. However, the participants in the international standards arena are nations. What are the benefits of concurrent engineering for nations?

For some nations, concurrent engineering might provide the cooperation that allows their companies to continue to be independent entrepreneurs. For some nations, concurrent engineering might meld a large number of small, highly specialized, vibrant and dynamic technology companies into a position of global competitiveness. For other nations, concurrent engineering might provide the benefits of vertical and horizontal integration, without undesired restrictions.

However, for all nations, new opportunities will be created. Because these opportunities lead to new and less expensive products, everyone gains in some way. The gain is realized in an improved standard of living.

V. CONCURRENT ENGINEERING: THE FUTURE "*STEP*"

A key international standard, as well as the technology to support it, is under development under the auspices of the International Organization for Standardization (ISO). The developing standard will be designated ISO 10303 and is commonly called The Standard for the Exchange of Product Model Data (STEP) [4].

The reason STEP is important for concurrent engineering is that *the development of STEP is a pioneering effort that includes the research and development of the information technology necessary for the envisioned shared-database environment.* Once STEP and its environment are in place, product data, process data, and all other types of enterprise information can be more easily shared by automated systems, and a concurrent engineering approach can be more easily implemented.

A. The Nature of STEP

To achieve the goals of the STEP effort, a new approach to the standards-making process is underway. This approach facilitates cooperative development of the requirements, the information technology, and the specifications simultaneously--before the existence of commercial systems that can use the capabilities of the standard.

The technology does not yet exist to define a product and its associated properties and characteristics completely in a way that is computer interpretable. Even if this could be done now, the technology does not exist to communicate this information electronically and to interpret it directly by the wide variety of automated systems associated with the product's life cycle. Therefore, only a process for creating standards at the same time the technology is being created will succeed for STEP.

The creation of specifications for the standard representation of product data involves many complex issues. It requires a number of different information and manufacturing system technologies and the experience of many different kinds of technical experts. Industry users and software vendors must cooperate closely throughout the precompetitive technology development and the standardization processes. In addition, it is essential that the standardization process includes rigorous testing to determine that the standards meet the needs of the user communities.

The goal of the STEP effort is the establishment of a complete, unambiguous, computer definition of the physical and functional characteristics of a product throughout its life cycle. As a standard method for digital product definition, STEP will support communications among heterogeneous computer environments. STEP will make it easier to integrate systems that perform various product life cycle functions, such as design, manufacturing and logistic support. Automatic paperless updates of product documentation will also be possible. The principal technique for integrating these systems and exchanging data will be the shared database.

B. The Technical Challenges of STEP

There are four major technical challenges facing the developers of STEP:

- The exchange of information is different from the exchange of data. Data must be transmitted accurately and without any changes. In contrast, information, although composed of data, must be understood and interpreted by the receiver. Furthermore, the receiver must be able to apply the information correctly in new situations. The first challenge is that *STEP is a standard for information, not just data.*

- The need for STEP to be extendable to new products, processes, and technologies, requires a more abstract representation of the information than in previous standards. Regardless of their equipment or process, a user must be able to obtain the information necessary to do something from the STEP representation of a product. Therefore, the second challenge is that *the development of STEP must include the development of an "architecture" or a framework for the exchange of information, not just a means or format for storing data.*

- The wide range of industries and the diversity of product information covered in STEP is beyond that of any previous digital standard. The variety of attributes and parameters, such as geometric shape, mechanical function, materials, assembly information, and date of manufacture, is immense. Also, the industrial base, the number of industries involved, is enormous; even greater is the number of technical specialties that are involved. Moreover, STEP must be flexible and extensible so that new information and additional applications can be added and can be upwardly compatible. Therefore, the third challenge is that *the scope and complexity of STEP is far beyond any previous standards effort.*

- Traditionally, standardization is a process that devises an approach encompassing a variety of existing vendors' options, builds on the best solution available, and avoids penalizing some vendors more than others. In the case of STEP, there is no existing implementation. Thus the fourth challenge: *the technology to support STEP must be developed at the same time the standard is evolving.*

The consensus approach to meeting the above challenges is to start with conceptual information models [5]. STEP will consist of a set of clearly and formally defined conceptual models and a physical exchange protocol based on these models. The conceptual models will be combined into application protocols that have a standard interface to a shared database [6].

C. The "Commercialization" of STEP

STEP will be applicable to all product data for all products and all applications involving products over their life cycles. However, any single practical implementation, such as a computer program for a specific manufacturing-related process (i.e., a specific application) will not require all of STEP. Therefore, STEP developers adopted the concept of application protocols.

An application protocol is a subset of STEP entities that describes the product data requirements for a specific application. STEP application protocols address the issues of completeness and unambiguity of data transfer by specifying what data should be transferred in a particular context. Application protocols are those parts of STEP that are relevant to a particular data-sharing scenario [7].

In effect, application protocols will be standards that define the context, the use, and the kind of product data that must be in STEP for a specific manufacturing purpose in a product's life cycle, such as design, process planning, and NC programming [7]. Application protocols standardize the use of STEP to support a particular manufacturing function.

Vendors will use application protocols to build their products. For this reason, the strategy is to implement STEP through application protocols, and to extend STEP through the development of new application protocols that bring new entities into the standard as their need is identified.

An application protocol consists of [8] [9]:

1. An application reference model that specifies the kind of data required to perform a particular purpose, in terms that are appropriate and familiar to experts in the application area,

2. An application interpreted model that defines how the STEP models are to be used to present the information specified in the application reference model,

3. Documentation that describes how the information is used and exchanged, and

4. A set of conformance requirements. A set of test purposes, will define the actions necessary to perform conformance testing of each application protocol.

The commercialization of STEP is intimately tied into the development and conformance testing of application protocols. The development of application protocols permits the incremental implementation of STEP. There will be many STEP application protocols.

The concept of application protocols allows vendors to build an implementation that can interface with STEP data in a standard manner. In a sense, an application protocol is a standardized way of implementing a portion of STEP for a specific application.

The technical challenges involved in the development of application protocols are central to the use of STEP. Among the technical issues being resolved are:

- How application protocols will communicate with each other and share product data,
- Whether application protocols will be independent of the way in which the product data is used (for example, whether the data is shared or exchanged),
- Whether a commercial application must implement an entire application protocol or if it can utilize a subset of the application protocol, and
- How, and whether, information not already contained in STEP but needed by a new application protocol will be added to STEP.

Application protocol development will force solutions to many of the remaining issues related to the usefulness and practicality of STEP itself.

VI. MULTI-ENTERPRISE CONCURRENT ENGINEERING: THE EXTENSION TO CONCURRENT ENGINEERING

A concurrent engineering approach can help optimize the operations of a manufacturing enterprise. However, the optimization is "localized" to the life cycle--design to production to support--of the enterprise's product. Clearly, concurrent engineering is but one dimension of a bigger idea. That bigger idea is *the optimization of all the enterprise's operations, including planning, marketing, and financial operations, as well as its transactions with its suppliers, distributors, and other business partners.* "Multi-enterprise concurrent engineering" is the term that connotes the broader optimization. This broader optimization is based upon the integration of all the operations within an enterprise and between an enterprise and its business partners.

A. A Framework for Enterprise Integration

The term for the standard architecture that would allow the integration of all activities of manufacturing enterprises is "enterprise integration framework." Just as STEP implies a standard means of representing information about a product *as well as* the infrastructure necessary to access and contribute to that information in a heterogeneous computer environment,

> *Enterprise Integration Framework* includes the structure, methodologies, and standards to accomplish the integration of all activities of an enterprise.

The key is the sharing of all kinds of information that allows for a concurrent approach not only to engineering, but also to accounting, marketing, management, inventory control, payroll, and other activities that are vital to the functioning of an enterprise. Multi-enterprise concurrent engineering through an enterprise integration framework is an approach that can both *guide the integration* of an enterprise's activities and *provide the standardized organization and arrangement* for the integration to occur.

Just as in the implementation of computer integrated manufacturing (CIM) [10], the major technical challenge to an enterprise integrated framework is the design of the integrated system architecture. Beginning with a system architecture, developing the methods to build the models, and then building an integrated framework is the "top down" approach to the integration of all components of an enterprise. A number of architectures have been proposed for CIM [11], but enterprise integration architectures have been studied only recently.

Because every company is unique in the way that it operates and because there are different laws and cultures in different countries that affect how businesses operate, it is essential that an enterprise integration framework be flexible and conceptually broad. This is the realm of enterprise modeling [12].

Enterprise modeling is the abstract representation, description and definition of the structure, processes, information, and resources of an identifiable business, government activity, or other large entity. The goal of enterprise modeling is to achieve model-driven enterprise integration and operation. Also important are modeling techniques for describing the logistic supply chains in an industry, including the business processes that occur among independent but closely cooperating enterprises.

It is also essential that such a large undertaking as enterprise integration framework development be carried out internationally. As explained earlier, the consensus development of international standards for integrating enterprises will help assure that the benefits of concurrent engineering approaches, as well as opportunities for global economic competitiveness, are available to all enterprises.

Open Systems Architecture (OSA) is the description of those computing and networking systems that are based on international and *de facto* public domain standards, rather than proprietary systems. The concept is to be able to create modular information technology components, thus providing for a "plug and play" ability to swap out both hardware and software components among various vendor products. Much of the OSA product planning is precompetitive and linked to standards activities.

In the U.S., a number of government agencies are initiating efforts to define and develop an enterprise integration framework. A major goal is a set of international standards that provide a framework upon which commercial (and government-purchased) information technology-related products could be produced that will support multi-enterprise information systems for industrial applications. It is anticipated that an international consensus can be built for use of this framework as the model for the development and implementation of international standards and for integrating many types of applications and industries. Enterprise integration represents an opportunity to cooperate internationally in a coordinated program to define, develop, and validate a conceptual framework for inter- and intra-enterprise integration based on open systems principles and international standards.

Within the European Strategic Program for Research on Information Technology (ESPRIT), a CIM architecture consortium (ESPRIT Project AMICE) is working to develop a Computer Integrated Manufacturing Open Systems Architecture (CIM OSA) [11] [13].

Recently, a series of workshops were begun to explore the opportunities for collaborative efforts in research and development in information science as applied to manufacturing [14]. The themes of the workshops are product data sharing, multi-enterprise integration framework, and open systems architecture. The participants, who are technical managers, engineers and scientists involved in computer integrated manufacturing research in the U.S. and Europe, advocate the development of a framework for inter- and intra-enterprise integration based upon open systems and international standards.

B. A Vision of the Future

In a sense, just as multi-enterprise concurrent engineering is the next step in the evolution of manufacturing, the enterprise integration framework is the next step in the evolution of engineering standards. As indicated in Figure 4, engineering education will have to evolve also. Perhaps product

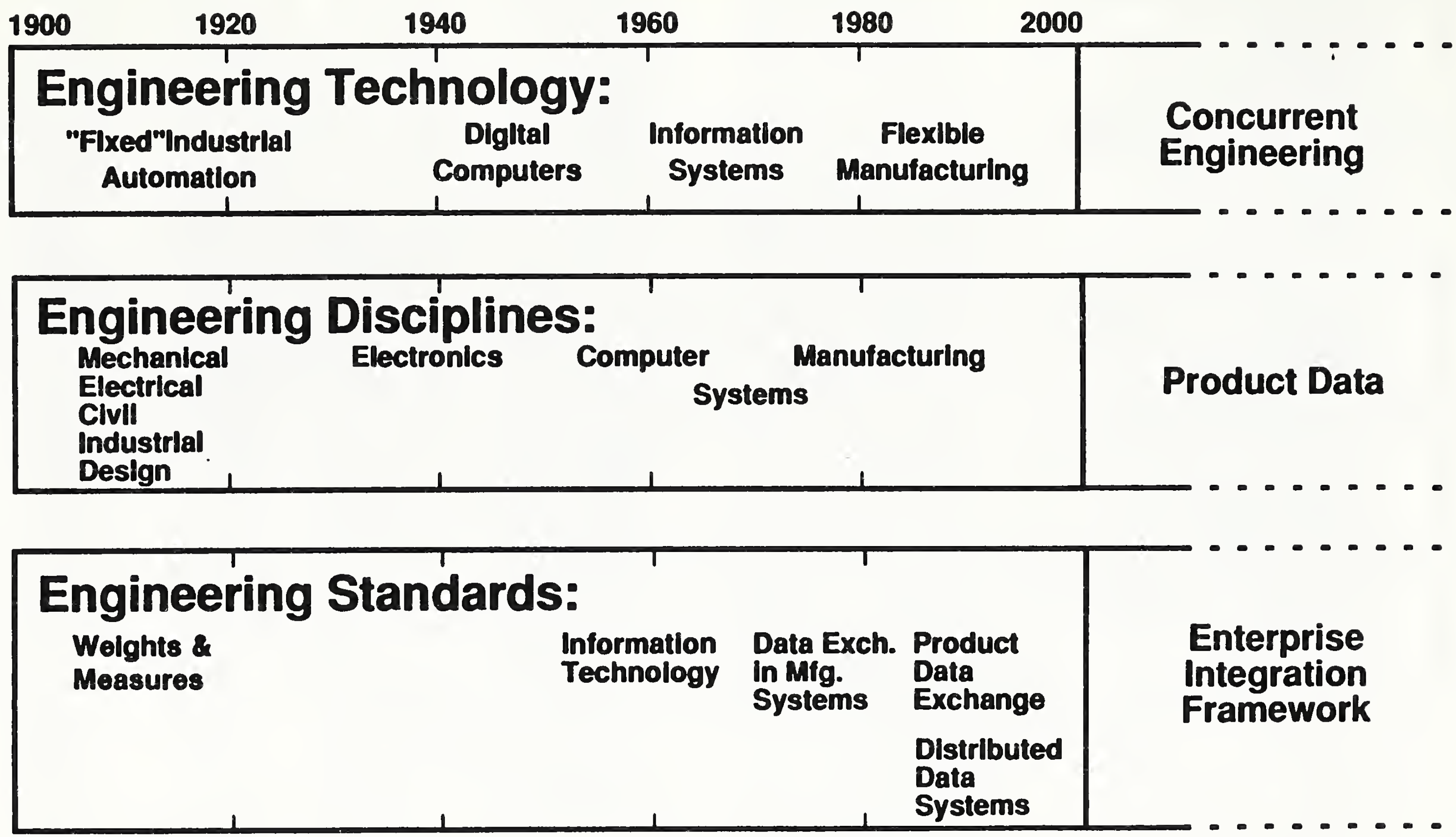

Fig. 4. As the evolution of manufacturing and engineering standards progresses, new engineering disciplines are required. "Product data engineering" may become the next new engineering discipline.

data engineering will become as important as the traditional engineering specialties were in the early part of this century.

A vision of the future manufacturing environment is shown in Figure 5. Independent enterprises operating as suppliers, system integrators, merchants and customers are integrated by an information framework into an effective system. Within each of these enterprises, the various product-related functions and product life cycle stages are integrated through the sharing of product data, although each stage maintains its own view of the product. Based upon standards, the inter- and intra-enterprise integration enables the practice of multi-enterprise concurrent engineering. It is the practice of multi-enterprise concurrent engineering through which the characteristics of world-class products are achieved. These characteristics are short-time-to-market, low cost, high quality, and high functionality.

VII. SUMMARY AND CONCLUSIONS

The primary aim of any manufacturing enterprise is to deliver working products to customers. To this could be added timeliness, cost effectiveness, quality, reliability, and other characteristics that contribute to a competitive product and hence to profits. Nevertheless, the bottom line is simply *working products in the hands of satisfied customers*. Recently there has been increased recognition that concurrent engineering, engineering design, manufacturing engineering practices, and data exchange and interface standards are critical to international competitiveness. These technologies, based upon information technology in general, are the means for providing to customers high quality and reliable products, as well as the support for those products, in a timely and cost-effective manner.

Information technology will provide an integrated level of automation based upon standards and frameworks. It will create a climate in industry in which enterprises can benefit from cooperation, collaboration and interdependence, without sacrificing their individual independence, initiative, and intellectual property rights. Information technology, by enabling such approaches as concurrent engineering, will stimulate the necessary standardization and provide the economies of scale that would not be otherwise provided without drastic changes in the way people behave.

Concurrent engineering, based upon information technology, will initiate a new industrial revolution. Certainly, the bottom line would still be *working products in the hands of customers*, but future products are much more likely to be of higher quality and more reliable, state-of-the-art products at prices that are much lower than they might have been if concurrent engineering were not used.

It is instructive to reflect on the mechanical drawing and the way it impacted the entire manufacturing process in its era. The drawing enabled the practice of designing a product with interchangeable parts. A product could be produced by contractors who could manufacture different components to be assembled. This capability led to a fragmentation of the manufacturing process that exists to this day.

The mechanical drawing became the output of the design phase of the process and the input into the production phase. Drawings were converted into production process plans which were converted into programs or procedures for each of the manufacturing operations. Each step of the

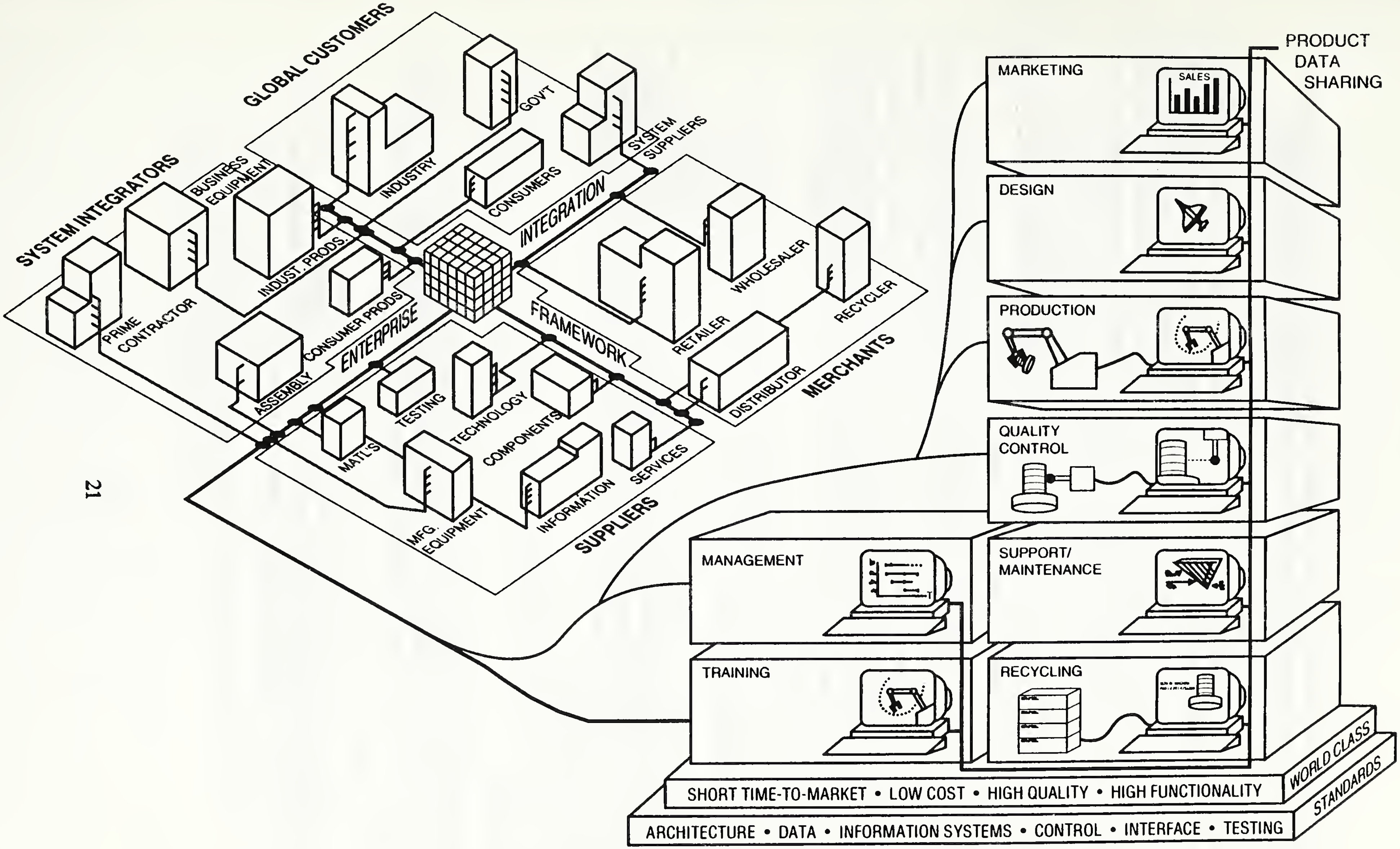

Fig. 5. Through an enterprise integration framework (indicated by the symbolic rectangular framework) enterprises will be integrated into a system that encourages the practice of multi-enterprise concurrent engineering. The structure at the right is an exploded view of one representative manufacturing enterprise that shows how the various internal departments in each enterprise will be integrated through the sharing of product data. Product data standards will allow each functional department to retain its own view of a product.

manufacturing process had its own view of the product data. These dissimilar views make it difficult to return to the designer evaluative or corrective knowledge about the different processes.

Multi-enterprise concurrent engineering will require the ability to store and retrieve product data far beyond the capability of the mechanical drawing. The replacement for the mechanical drawing that will allow revolutionary new engineering technologies is product data sharing. This new capability will make available to the designer knowledge about all other processes. It will process product data through automated computer-based techniques that allow for shared access among the life cycle processes in support of concurrent engineering. It will make available an integrated product data model that allows access to multiple views of the product.

STEP, as well as other new product data, data exchange and interface standards and their supporting technologies, must be implemented for this new product data sharing capability to be successful. *That is why concurrent engineering is impossible without standards.*

The critical concept is this: standards for product data and data exchange are important because they enable and facilitate an automated form of concurrent engineering that can be implemented in a computerized environment. This automated, or computer-aided, concurrent engineering provides a mechanism for multi-enterprise integration. As a result, the automated practice of concurrent engineering among manufacturing enterprises, their customers and their suppliers, including suppliers of technology as well as of materials and components, will create a new kind of *multi-enterprise concurrent engineering.*

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Concurrent engineering involves the integration of people, systems and information into a responsive, efficient system. Integration of computerized systems allows additional benefits: automatic knowledge capture during development and lifetime management of a product, and automatic exchange of that knowledge among different computer systems. Critical enablers are product data standards and enterprise integration frameworks. A pioneering assault on the complex technical challenges is associated with the emerging international Standard for the Exchange of Product Model Data (STEP). Surpassing in scope previous standards efforts, the goal is a complete, unambiguous, computer-readable definition of the physical and functional characteristics of a product throughout its life cycle. The use of STEP will lead to higher, integrated levels of automation based upon information standards and frameworks. Concurrent engineering, through information technology and standards, represents the power of a new industrial revolution.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

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