NISTIR 6006

A Context for Interoperability Standards for the Footwear Industry

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April 1997

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

TECHNOLOGY ADMINISTRATION
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NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
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DISCLAIMER

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ABSTRACT

Emerging technologies for footwear manufacturing in combination with advanced information infrastructure and virtual enterprise technologies have the potential to revolutionize the footwear industry. The developments could create a large market for custom footwear (CF) and greatly expand the availability of custom therapeutic footwear (CTF) for people with foot problems.

To service a customer an array of diverse organizations will work together as a virtual enterprise. To avoid islands of automation, a comprehensive set of complex information must be standardized so that each organization can provide its particular value-added service using its own particular set of systems. Data standards that provide a limited exchange of data between pairs of functions (or services), rather than comprehensive information that is sharable among all functions, runs the risk of requiring multiple iterations to produce the correct product specifications.

A product information model that can enable effective communication of product requirements and design specifications within a virtual enterprise is key to realizing the market potential. The model must be information rich and unambiguous to enable the first-time design of a product that will meet a customer's footwear requirements.

For a product information model to be practical as an industry standard it must apply within a *business context* that is a *sufficiently realistic* representation of the business activities and information flows of the industry. This report proposes a business context for product development of custom therapeutic footwear and will list requirements for a product information model within that context. The information requirements for custom footwear is a subset of the more extensive requirements needed for custom therapeutic footwear.

In addition, practical considerations involved in developing standards, largely derived from experience in the apparel industry, are discussed.

KEYWORDS

custom footwear; footwear manufacturing; interoperability standards; therapeutic footwear

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A Context for Interoperability Standards for the Footwear Industry

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1 INTRODUCTION

Representatives from the American footwear industry have decided that *interoperability standards* will benefit the industry.[1] Interoperability standards specify interfaces between applications to enable information to be exchanged and recognized between them.[2] The industry will benefit because each company can custom configure its operation using the best commercial applications for its needs. The company can reduce its worry that the applications cannot be integrated together (or that the integration effort would be overly expensive).

The awareness that interoperability standards are valuable is not new. Other industries have realized their value and have spent considerable time, effort, and expense to develop them. The metal-parts industry was among the first to recognize the need and to begin developing the appropriate standards. More recently (over the last five years), and more closely related, the apparel industry has begun to develop interoperability standards.

The footwear industry can benefit by the past efforts of other industries. In fact, other industries are developing *generic technologies* for interoperability standards to reduce the effort to develop standards for other applications and for other industries. Not only will effort be reduced, but consistent representations for materials, parts, and products can be achieved. The consistency will enable more sophisticated design systems (as well as other applications) to be created. For example, a footwear design system could utilize the representation of an insole from a potential new supplier without a special data translation required. The representation would be sufficiently complete so that a separate analysis application could help determine the tradeoffs of using the insole from one manufacturer over another.

---

[1]The Footwear Industries of America and the Pedorthic Footwear Association established the Foot Measurement Committee in the first quarter of 1996 to begin developing interoperability standards.

[2]This report focusses on interoperability standards for industry-specific (i.e., the footwear industry) information exchange. Standards required to enable the underlying communication connections and networks are not covered; the standards used by industry at large are sufficient for the underlying communications infrastructure.

Electronic commerce puts additional demands on interoperability standards. Electronic commerce combined with emerging information technologies enable new paradigms for business structures, such as the *virtual enterprise*.[3] However, to fully realize the potential of the virtual enterprise, business and manufacturing applications need to share the same data.

To create suitable standards to integrate the future footwear industry, two prerequisites are needed—a comprehensive business context that specifies the manufacturing activities required and a comprehensive, unambiguous list of the information requirements needed within that context. Based on these prerequisites, an information-rich and unambiguous product information standard can be developed that can serve as the "glue" to integrate the new manufacturing technologies within the business context.

This report proposes a business context based on the product development phase for custom therapeutic footwear (CTF) and lists product information requirements within that context. Subsequently, interoperability standards can be developed that can enable effective communication throughout the footwear enterprise.

The report is organized as a presentation (of *slides*) with accompanying text. If desired, the reader can skim quickly through the presentation, to get a general idea of the ideas and arguments presented. When necessary, the reader can study the accompanying text for further explanation.

The slide on page 3 presents an overview for the main body of this report. The appendix that follows the main body contains tables that specify the information requirements for custom therapeutic footwear (CTF). The CTF requirements are more extensive and complex than for any other type of footwear. The information requirements for all other footwear should fall out as a subset of the CTF requirements.

[3]Simply put, a virtual enterprise is a group of companies acting as one by virtue of computer networks to provide a product. One important advantage is that a particular grouping of companies could be formed quickly to seize a particular market opportunity; and could be disbanded just as quickly, once the opportunity was past.

OVERVIEW

- Lessons learned from the apparel industry
- Unambiguous, information-rich, product data models
- Business context for integration and standards
- Custom therapeutic footwear (CTF) enterprise model (activity and information models)
- Recommendations

The intended audience for this report includes those members of the footwear industry who are interested in interoperability standards.

Section 2, "LESSONS LEARNED FROM THE APPAREL INDUSTRY," immediately follows this overview discussion. The section describes practical issues that arise in the development and use of interoperability standards (based on the actual experience of the apparel industry) and recommends that comprehensive product information should be the basis of those standards.

Section 3, "CREATING A BUSINESS CONTEXT," recommends that a broad industry perspective should be considered, analyzed, and modeled to provide a proper context for the development of interoperability standards. The apparel industry is again used as an example and a technical approach to represent a business context is described.

Section 4, "THE CTF MANUFACTURING LIFE CYCLE," presents a brief overview of custom therapeutic footwear manufacturing as represented by an activity-modeling approach. The activity models presented are proposed as the business context for the CTF industry.

Section 5, "INFORMATION REQUIREMENTS," indicates the type of information model[4] that can support the information flows within the business context presented in Section 4. This section presents specific information requirements to support CTF manufacturing in a graphical representation with accompanying text that describes the requirements. (Additionally, the information requirements are listed along with a description of each in a table format in the Appendix.)

Section 6, "RECOMMENDATIONS," are intended specifically for a footwear standards committee that are developing interoperability standards. The recommendations are derived in large part from the information presented in the preceding sections.

Section 7, "SUMMARY/CONCLUSIONS," briefly summarizes and concludes the main body of the report.

2 LESSONS LEARNED FROM THE APPAREL INDUSTRY

(Refer to the slide on the following page.)

[4]The information model can be derived from the information requirements.

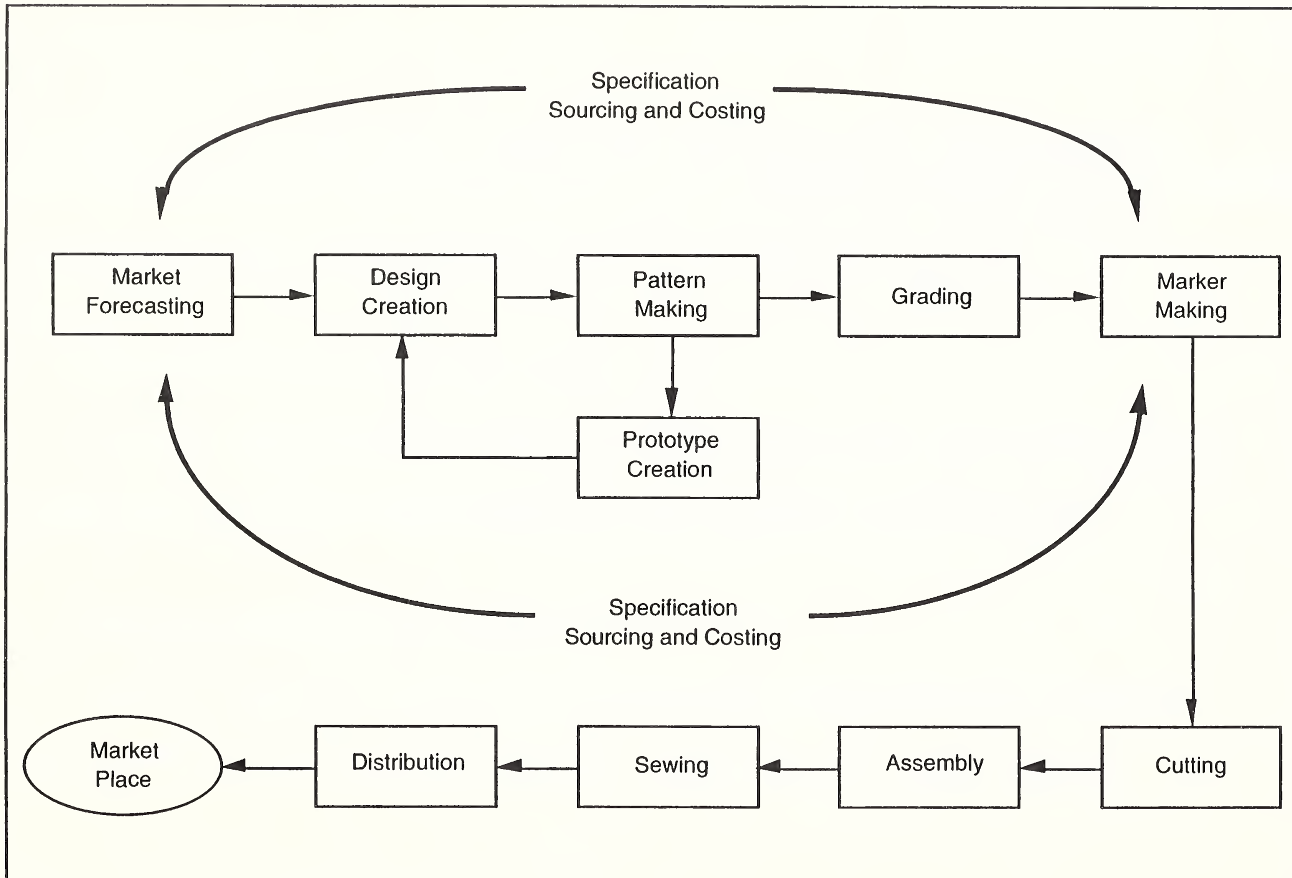
LESSONS LEARNED FROM THE APPAREL INDUSTRY

The apparel industry is following the path that other manufacturing industries have previously blazed.

The footwear industry can learn lessons from the experience gained by the apparel industry in that journey.

The following discourse is taken from lessons learned by the apparel industry that could benefit the footwear industry.

THE APPAREL MANUFACTURING ENTERPRISE



Courtesy of Peter Denno, NIST

The figure on the preceding page traces the activities involved in the apparel manufacturing enterprise [Denno]. The boxes represent the manufacturing activities and the arrows show the direction of information flow among the activities. The top half of the figure, from market forecasting to marker making, can be considered the pre-production phase. That phase is involved in determining the garment requirements based on market analysis, designing the garment, and planning the production of it. As shown in the figure, the pre-production phase is one of iterative refinement, where feedback from succeeding activities is used to refine the design of the garment and to plan its manufacture.

Each manufacturing activity uses information as input and generates new information as output. The more effectively that information can be communicated, particularly among the pre-production activities, the more effectively that a final design and manufacturing plan can be created. Without effective communication, information generated by a manufacturing activity must be manually entered into the next activity. For example, a computer-aided design system might produce a drawing that a pattern maker must interpret to enter the proper information into a computer-aided pattern making system. Without effective communication, it is often necessary to repeat iterations of prototype creation and even final production to finalize the design and manufacturing plans for a garment. Standard interfaces between manufacturing activities enhance effective information exchange and reduce the iterations required.

The ultimate goal of effective communication is to share information among all the manufacturing activities, rather than to transfer information from one activity to the next, so that each activity only needs to be performed once. For example, a final design could be produced on the very first attempt if the design activity correctly took into account all ramifications of the design on succeeding activities. Without the attainment of that ultimate goal, the entire manufacturing process will still be more efficient if the number of iterations through it can be reduced, and particularly if prototype development time can be reduced.

REALIZATION:

American industry and military have recognized the need for standard interfaces between apparel manufacturing processes

- **to communicate to customers/suppliers in a standard, unambiguous way; and**
- **to avoid islands of automation within a company.**

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ACTION:

American Apparel Manufacturing Association (AAMA) initiated an effort to establish interoperability standards (circa late 1980s).

- ☺ **Set up Computer-Integrated-Manufacturing (CIM) Subcommittee to develop interoperability standards**
- ☺ **Obtained recognition from the American National Standards Institute (ANSI) as the standards organization for the apparel industry**
- ☹ **Assigned ad hoc priorities to standards development for point-to-point interfaces (to remove immediate bottlenecks, w/o regard to long-term issues)**
- ☹ **Aimed for lowest-common-denominator data exchange**

The symbols, ☺ and ☹, shown as bullets on the preceding page (as well as on the slides following) represents the author's value judgments concerning each point raised. Setting up a committee to develop interoperability standards for the apparel industry is seen as a positive step. Obtaining recognition from the American National Standards Institute (ANSI) lends respect and credibility to the standards developed. To create an ANSI standard, a formal and comprehensive procedure that requires broad industry consensus is mandatory. Experience has shown that technology vendors are much more likely to implement a standard in their systems if that standard is sanctioned by a reputable standards organization.

On the other hand, the AAMA CIM committee did not consider the entire apparel manufacturing enterprise as a single system of activities and information flows. In the *system approach*, interfaces can be determined systematically to yield the most effective communication among all the enterprise activities. Instead, the committee identified bottlenecks of communication between specific activities and chose to develop standard interfaces to eliminate those bottlenecks. Standards developed in the system approach will enable information sharing among activities. Furthermore, it is then possible to leverage the effort expended to develop one standard to develop the other standards identified. In the *bottleneck approach* it is difficult to develop standards to enable information sharing among multiple enterprise activities, and it is difficult to leverage standards-development efforts.

Also, the committee chose to include in the standards developed only those information entities that all the vendor companies that were represented had included in their products, without any options to communicate entities contained in a subset of the vendors' products. Without those provisions, customization of the *standard* interface will always be necessary to transfer that additional information across the interface. The larger that set of additional information is, the less valuable the standard developed will be.

INITIAL RESULTS :

- ☹ Standards are ambiguous

  (requires additional implementation guidelines; even with standards, integration is not painless)

- ☹ Development for each standard must be started basically from scratch

  (minimal leveraging of effort)

In fact, the *pattern data interchange* standard developed by the AAMA CIM committee proved to be insufficient to define the interface unambiguously between different pattern making systems, and an additional implementation guide had to be created to eliminate the ambiguities.

The knowledge gained by developing the first couple of standards was used to help develop successive standards, but leveraging was not done to the extent that portions of preceding standards could be used as building blocks to create new standards.

PROBLEM:

Will be difficult to maintain standards

Why?

- ☹ No attempt made to plan future evolution of standard
- ☹ Did not look at entire industry/enterprise landscape

Result:

- ☹ Anticipate pressures to update standards

  (against the pressure to maintain existing standard and consequently not match technology advances)

- ☹ But, updating and keeping track of implementation configurations will be difficult

  (which application will contain which version of standard? anticipate spawning of special case standards)

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ISSUES: (resulting in missed opportunities)

(Example taken from pattern data interchange standard as articulated in recent paper by Peter Denno of NIST)

☹ Work needs to be repeated after data exchange to recover knowledge acquired that was not communicated.

☹ Suppliers are kept distant from the initial design process—no leveraging of standards efforts from other industries, that might in fact be suppliers to apparel industry.

☹ New technologies that manage and take maximum advantage of virtual enterprises require additional information incorporated into the product data model.

The slide on the next page shows the solution to the problem and issues indicated above—an unambiguous, information-rich, product data standard. The standard would contain the information shown in the items listed underneath the "Contents of Model." The shaded item indicates the information that is currently contained in the AAMA pattern data interchange standard. However, the other items listed are necessary to include together with the pattern piece information to unambiguously and comprehensively specify the apparel product.

The slide on the page following the "SOLUTION" slide (page 19) shows a table which lists apparel activities under the headings "Producers" and "Consumers." The activities listed under producers generate the information shown in the middle column. Each item shown in the "Information" column is used by the apparel activity shown under consumers. Again, the shaded block of information indicates what is contained within the current AAMA pattern data interchange standard.

The point is that the apparel producer and consumer activities listed are coupled together via an information model that contains all of the information items shown. An effective interoperability standard must ensure that each apparel activity has access to whatever information it needs from the other activities to maximize its potential effectiveness. (Of course, the software application that implements that activity must take advantage of the information available to it.) Such a standard will contain all of the information items shown, including the relationships among those items.

SOLUTION:

unambiguous, information-rich, product data standard

Contents of Model

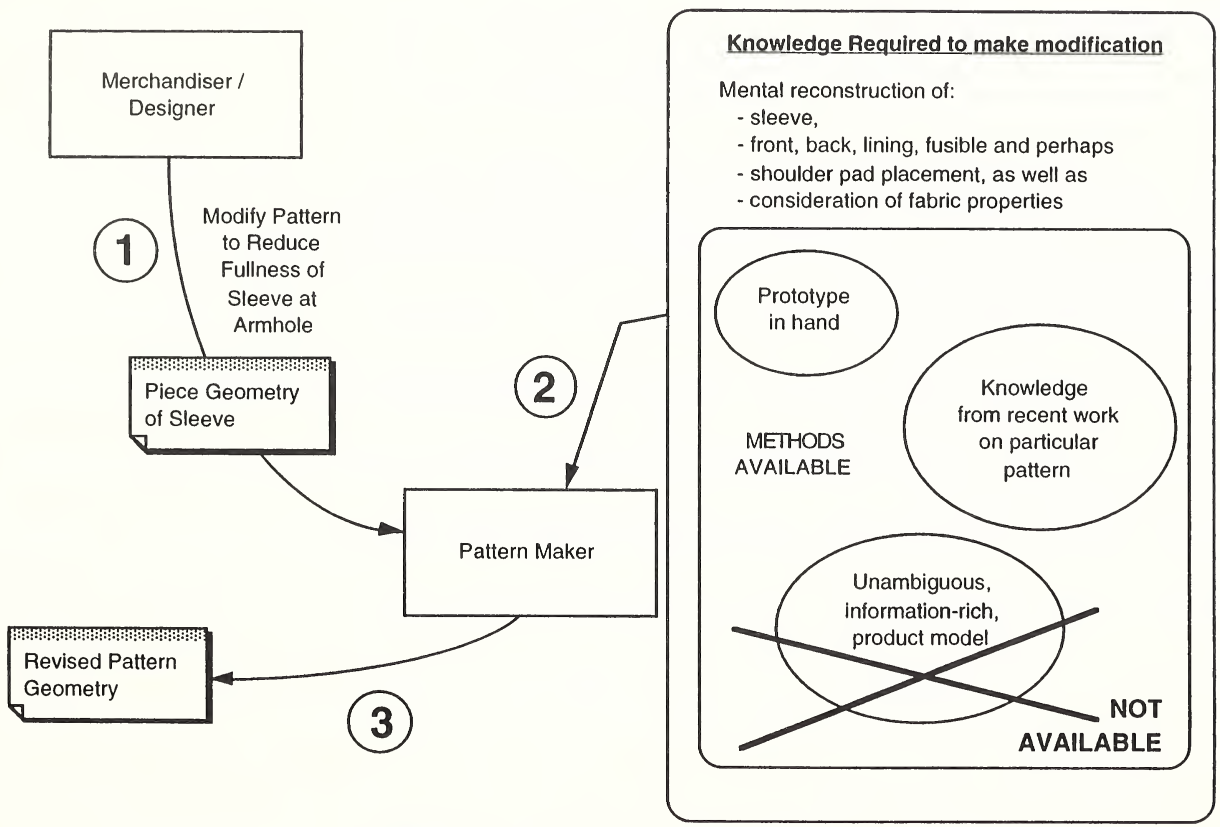
- Specification of pattern pieces (within existing AAMA standard)
- Relationship among pieces
- Relationship between the garment and the body
- Seam types, construction details, fabric and trim specification
- Relationship of seams to pieces, linings to complete garments, fabrics and trims with the garment model

In summary, the standard should contain sufficient information for two manufacturers, using nothing but the model, to produce garments that are indistinguishable.

INFORMATION PRODUCERS & CONSUMERS IN PRODUCT DEVELOPMENT ACTIVITIES

Producers	Information	Consumers
market forecasting	market trend	design, sourcing
	style concept	design
	cost constraints	sourcing
design	style development	pattern making, market forecasting
	selection of trims	sourcing
pattern making	pieces	prototypes, market forecasting, design
	piece geometry (AAMA standard)	grading, sewing
	construction features	grading, sewing
	style features	grading, sewing, design
grading	graded pieces	marker making

THE CASE FOR AN UNAMBIGUOUS, INFORMATION-RICH, PRODUCT DATA STANDARD



Similar case can be made for pattern grading

The above figure makes the case for an unambiguous, information-rich, product data standard for apparel.[5]

A designer decides to modify a pattern to reduce the fullness of the sleeve at the armhole and communicates that request to the pattern maker along with the pattern geometry of the existing sleeve. The "Piece Geometry of Sleeve" can be transferred via the AAMA pattern standard as shown in the figure. Once the pattern maker makes the change, it is specified by the same standard and shown as the "Revised Pattern Geometry" in the figure.

However, the pattern maker needs additional information about the garment to make the change (as shown in the "Knowledge Required to make modification"). Otherwise, the pattern maker must do a mental reconstruction of the sleeve. To make the modification easily, the pattern maker must have recently worked on the garment or else have a prototype in hand. Either alternative is more error prone and less efficient than a stored electronic specification of the garment. Furthermore, the flexibility to substitute workers (or pattern design companies) and the agility to quickly make a design modification without need for a prototype is lost.

---

[5]This example was taken from [Denno].

BENEFITS:[1]

- ☺ Avoids work required to recover complete data after exchange
- ☺ Reduces cost of iterations required to refine a design as it traverses organizations involved in the life cycle
- ☺ Enables improved features for product development software
- ☺ Enhances industry's ability to distribute work in a virtual enterprise[2]
- ☺ Enhances industry's access to labor skill base in short supply

1 of unambiguous, information-rich product data standard

2 group of companies acting as one by virtue of computer networks to provide a product

3 CREATING A BUSINESS CONTEXT

A natural inclination, as observed in other industries, is to form a consortium to advance the technology base of a particular industry; and to come to a quick, subjective decision on which projects to do and in which order to do them, without regard to their true priorities based on a top-level needs analysis. The short-sighted approach often leads to fragmented and redundant efforts that address lower priority needs at the expense of more important needs.

The problem is particularly evident in determining which point-to-point interfaces to standardize on. Unfortunately, the short-sighted approach leads to an interface with no broader context—often, additional information and considerations are realized later that reduce the initial enthrallment with the interface, and may even render it useless. Standards developed in an ad hoc manner rather than a systematic approach usually do not lend themselves to an efficient system solution.

Once standards are in place, even if they are poor, they may still improve the situation from before, and consequently are hard to replace because of the effort required, even though a better system of standards may be at hand. It is best to carefully consider possible standards ahead of time so that a short-term solution for integration needs does not impede long-term industry progress. A better approach is to step back and look at the entire "landscape" of the industry to enable improved planning and prioritizing of succeeding efforts. With that perspective, a *business context* can be developed that can serve as a basis for information exchange, and hence interoperability standards.

Another problem that has arisen in creating a business context for other industries is the proliferation of multiple *solutions*, the creator of each professing his or hers to be the best. The confusion of multiple business contexts for a particular industry causes inefficiency in succeeding industry efforts. To develop "the best" business context is an exercise in futility—it doesn't exist. Instead, the goal should be to do as good an effort as possible and be done with it. That is not to say that the original effort cannot evolve and further improve with time.

Currently, no business context exists in the public domain for the footwear industry. So, a well-backed, industry-based effort to create one is timely and should enable the pitfall mentioned above to be avoided. Also, with the benefit of hindsight, the footwear industry can take advantage of good efforts in other industries and avoid known pitfalls.

A useful business context can be based on a model of the manufacturing life cycle of a product. The approach of using the life cycle has been taken successfully in other industries. A notable example taken from the apparel industry is the Apparel Manufacturing Architecture (AMA), developed by Georgia Tech [Jayaraman]. The AMA is a set of specifications for a computer-integrated apparel enterprise. It consists of an information model, a function (or activity) model, and a dynamics model (that specifies the interactions of the activities over time). The models are specified using IDEF.[6] The AMA is currently being used as a road map for a nationwide collaborative research program, sponsored by the Defense Logistics Agency (DLA), to address technology needs for the apparel industry. Furthermore, the AMA is proving useful to point out the interoperability standards that need to be developed within DLA's program to enable the separate technologies to be integrated properly within the AMA's context.

[6]Integrated DEFinition Language (IDEF) is a representation scheme developed by the Air Force that is used to model the activities, information flows, and dynamics of a complex system or enterprise [USAir1, USAir2].

CONSIDERATIONS FOR DEVELOPING A BUSINESS CONTEXT:

- Broad landscape of industry is required (to avoid locking oneself in to short-term solutions that will cause long-term problems).
- Standards, once instituted, are hard to change even if better solutions become known.
- Multiple business contexts should be avoided.
- "The Best" business context is not required.
- Main concern is consensus, not creating the perfect technical solution.
- After initial consensus, the business context can still evolve over time.

TECHNICAL APPROACH

to develop interoperability standards—iterative refinement

- Determine activities involved in footwear manufacturing.

- Determine what information is exchanged.

- Consider what work is being performed, or can be performed, by product development systems.

- Restructure activities into a "To Be" activity model.

- Develop a "To Be" information model.

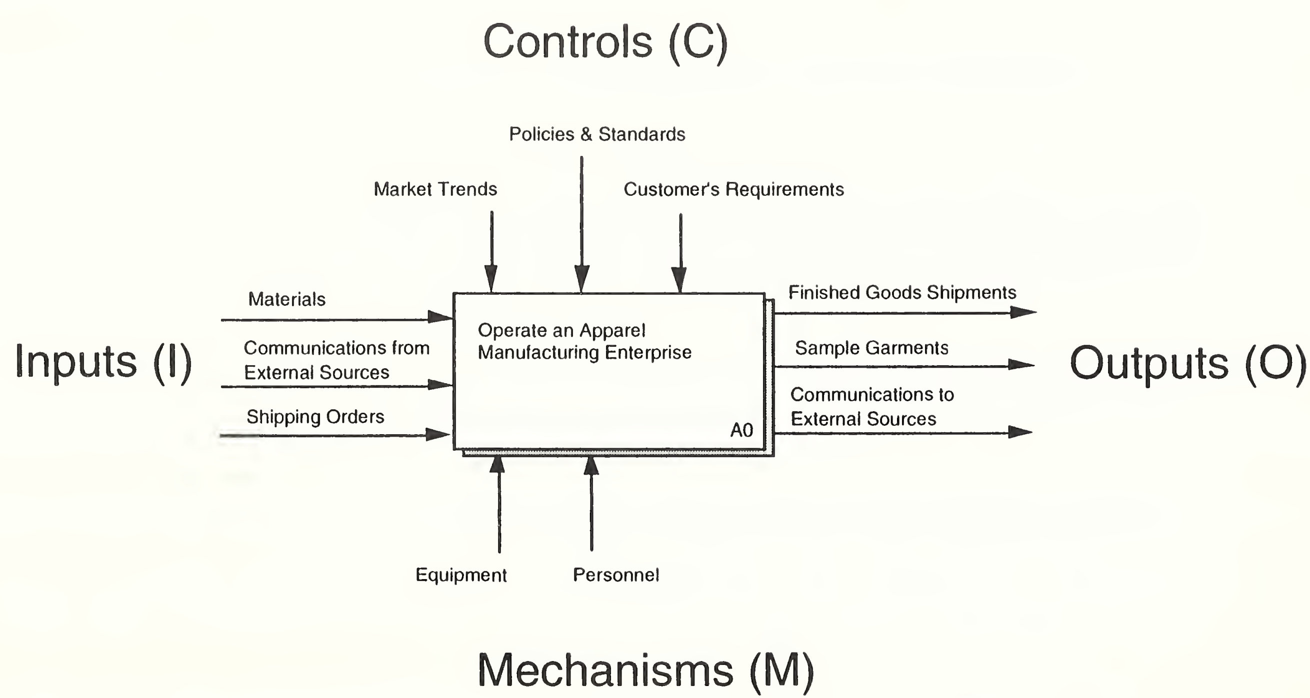
- Determine information interfaces appropriate to standardize.

A SUCCESSFUL EXAMPLE—
the Apparel Manufacturing Architecture (AMA):

- Developed by Georgia Tech, sponsored by the Defense Logistics Agency (DLA)
- Comprised of functional model (activities), information model, and dynamics model to represent the operation of an apparel manufacturing enterprise
- Defined in the IDEF language (a graphical language developed by the Air Force for modeling an enterprise)
- Has been instituted as the underlying road map used to plan DLA's entire apparel research program—the Apparel Research Network (ARN) [URL: http://mtiac.hq.iitri.com/arn/]
- Used to help determine where standards are needed, what priority they should be assigned, and what they should contain

IDEF0 is the component of IDEF that is used to model activities. A description of the IDEF0 methodology, using the Apparel Manufacturing Architecture as an example, is presented on the next two pages.

APPAREL MANUFACTURING ARCHITECTURE (AMA)



NODE A-0 Title: Operate an Apparel Manufacturing Enterprise (Context)
(developed by the Georgia Institute of Technology)

The top-level node in IDEF0 methodology is referred to as node A-0. Node A-0 specifies the main context for the activity model. The context is comprised of the overall activity, which, for the figure on the preceding page, is "Operate an Apparel Manufacturing Enterprise," and includes the information flows: "Inputs (I)," "Controls (C)," "Outputs (O)," and "Mechanisms (M)" as shown in the figure. In IDEF0 terminology, the information flows are referred to collectively as *ICOM*, for the first letter of each type of information flow.

Inputs are information entities that enter the activity and are processed by it to produce outputs. The controls act as constraints that restrict how the activity processes the inputs, and the mechanisms are the means which the activity utilizes in its processing. Note that the arrows represent information flows; they are not representative of physical artifacts. For example, the mechanisms in the preceding figure specify equipment and personnel. The mechanisms should be interpreted in the diagram as the information that specifies the equipment and personnel to the extent needed for the activity to process its information to produce the appropriate outputs.

The activity in the A-0 context diagram is represented by "A0." The shadow box that is seen below box A0 signifies that the activity A0 is further decomposed into lower level IDEF0 diagrams. In the AMA, A0 decomposes into six activities, labeled A1 through A6 according to IDEF0 methodology. Subsequent decomposition of activities adds a digit to the label for each level of decomposition. For example, if the A3 activity is decomposed into four activities, they would be labeled A31 to A34. Getting back to AMA, AO decomposes into the following six activities:

A1 Develop and Market Product Line;

A2 Provide Enterprise Support Services;

A3 Plan and Prepare for Manufacture;

A4 Monitor and Control Production Activities;

A5 Manufacture Garments; and

A6 Distribute Garments.

These activities are further decomposed in AMA, until ultimately, there is considered no more benefit to further decompose the figures. Note that the degree of decomposition, as well as the manner of decomposition itself is subjective and is dependent on the context and perspective that the representation is intended to serve.

A final point to understand is that an activity model is time independent. In other words, an activity model does not imply the order that any activity is done in relationship to any other. The activities could be done sequentially; at the other extreme, they could be done concurrently. The time relationships cannot be represented by the activity model.

The lesson learned from the apparel industry is that a business context based on the manufacturing life cycle is a useful first step to create a comprehensive and collaborative research program, to specify a context for standard interfaces, and to prioritize the interfaces according to their importance in the context of the research program. Furthermore, IDEF0 is a useful representation to specify the enterprise activity model, though that should not preclude other representation languages for enterprise modeling.

PROPOSED BUSINESS CONTEXT FOR CTF MANUFACTURING

- The business context is based on an analysis of the CTF manufacturing life cycle.

- It includes an activity model and an information model.

- The activity model is focused on the requirements determination and design specification phases of the life cycle, and the product information model is derived from those phases.

4 THE CTF MANUFACTURING LIFE CYCLE

The CTF manufacturing life cycle can be separated into sequential phases that are similar to those of other industries:

- Requirements Determination—the product's requirements must be determined based on the customer's needs;
- Design Specification—a product is specified which meets the requirements;
- Manufacturing Engineering—a production plan is created to make the product to best meet the company's production capability;
- Production—the product is produced;
- Distribution—the product is packaged and shipped to the customer;
- Service—customer service closes the loop to ensure that the product meets the customer's expectations, and should reflect the initial requirements. (If they do not, new requirements are necessary.)

The specific steps and processes used in each manufacturing phase are what distinguish the particular industry and the particular product being manufactured. The processes used in the CTF industry are described in [Moncarz2].

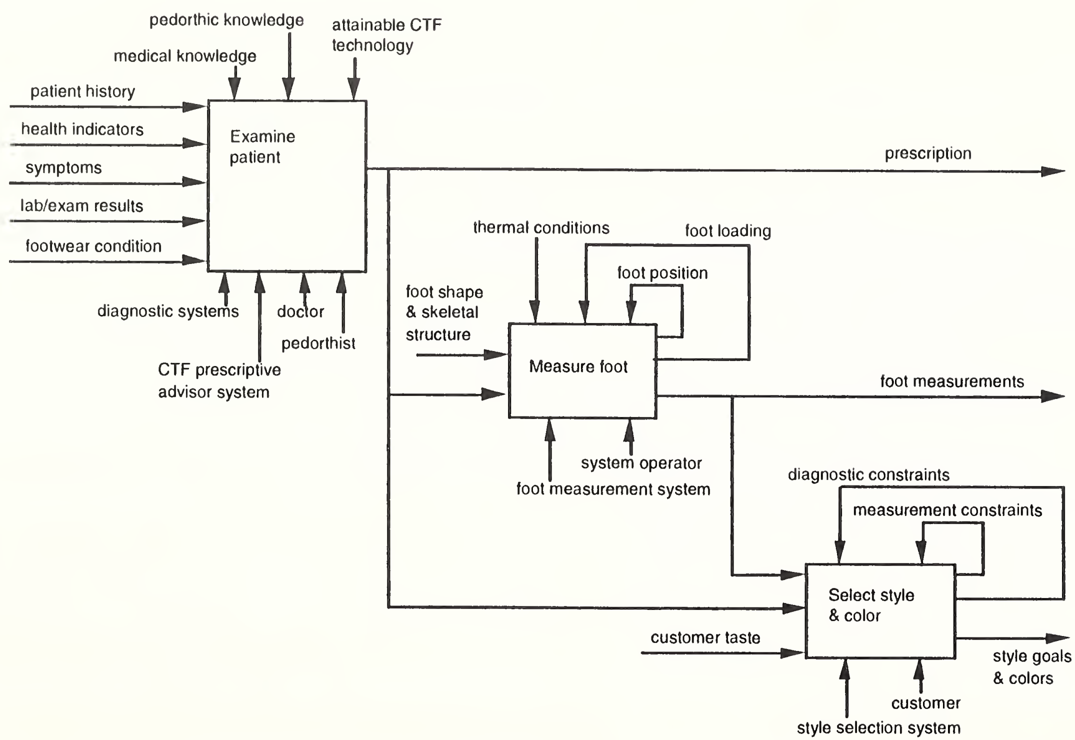
The differences between manufacturing custom footwear (CF) and custom therapeutic footwear show up mainly in the first two manufacturing phases—Requirements Determination and Design Specification. In the virtual enterprise envisioned, the customer who requires CTF will visit the appropriate professionals who will determine the footwear requirements. The requirements include a diagnosis and prescription as well as a comprehensive set of foot measurements. In addition, the customer will select the footwear style desired, within the restrictions set by the corrective constraints. The entire set of requirements—style goals, foot measurements, and prescription—is communicated to design systems that will automatically or semi-automatically create the design specifications for the footwear.

This report focuses on the activity models of these first two manufacturing phases and their corresponding information requirements. The activity model for Requirements Determination would be at the same level of decomposition as the activity model for Design Specification in the larger context of CTF manufacturing. The larger context is not specified within this report; thus the activity models in the following pages are not labeled according to their level of decomposition in accordance with standard IDEF0 methodology.

Requirements Determination Phase

The general processes required for CTF manufacturing apply whether the processes are done manually or whether they are automated. In this report, the processes for making CTF are described in a general way without referencing particular methods or technologies.

ACTIVITY MODEL FOR CTF REQUIREMENTS DETERMINATION



Three types of information are necessary to fully specify a CTF-customer's requirements: the accommodative and/or therapeutic corrections that must be applied to the footwear (referred to as the prescription), the dimensional measurements of the foot, and the consumer style preferences that can be accommodated within the limitations of the foot measurements and corrections required. The activity model shows that a separate activity is used to determine each of the three types of information requirements. Those activities are: "Examine patient," "Measure foot," and "Select style and color."

In the activity, "Examine patient," it is possible for an entire team of doctors, including a number of specialties, as well as a pedorthist to be involved. In a common example, a patient might first visit a podiatrist who would make a diagnosis and issue a prescription that could be further refined after a pedorthic examination.[7] The prescription in the proposed model does not specify particular footwear or devices. Instead, the prescription is intended as input to a CTF design system that is used to specify the exact CTF. Still, the "attainable CTF technology" will limit what type of information that the prescription should contain.

The main input to "Measure foot" is the actual "foot shape & skeletal structure" of the foot presented. The goal is to determine and represent, as accurately as possible, that input. The input is affected by the conditions that the foot is subjected to during the measurement. Those conditions include the "foot position"; the "foot loading" (i.e., the weight on the foot), both static and dynamic; and the "thermal conditions," for example, the temperature and humidity.

An operator makes the measurements required with manual or automated measuring devices. The type of operator could range from a low-skilled technician to a high-skilled pedorthist.

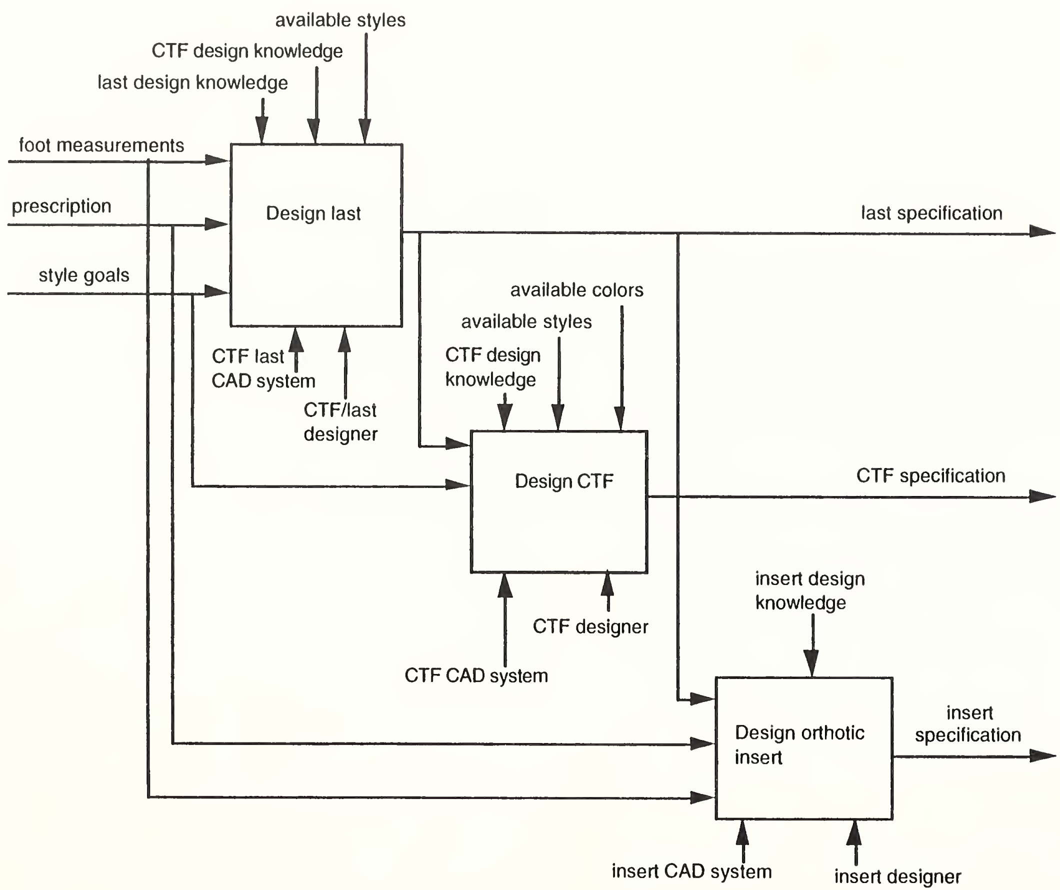
The measuring system used could range from a tape or other manual measurement device to an automated foot scanner. The conditions, in particular the foot loading and foot position, are often set by the operator and are influenced by the foot problem that is diagnosed. That information is accounted for in the prescription, which is an additional input to "Measure foot."

The main goal of the final activity, "Select style and color," is to give the customer as much choice as possible in selecting footwear. Therefore the main input to this activity is "customer taste." The other inputs necessary are the customer's "foot measurements" and the "prescription." The "measurement constraints" will limit the styles that the customer can select because of the particular foot measurements, and the "diagnostic constraints" will further limit the styles that can be selected because of medical considerations. (Of course both these constraints will be highly interactive along with the inputs presented to this activity in limiting the styles that are suitable.)

The customer will make the actual selection, perhaps assisted by a device that could present types of styles that would be appropriate for the particular consumer. The output of this activity is not necessarily a particular style, but instead, a set of style goals and colors that a design system could use to generate an acceptable specific style.

[7] Only a doctor is qualified to make a medical diagnosis, but the additional knowledge of a pedorthist can be very useful in specifying the consequent footwear requirements.

ACTIVITY MODEL FOR CTF DESIGN SPECIFICATION



Design Specification Phase

The information requirements generated in the *Requirements Determination Phase* are inputs to the *Design Specification Phase*.

"The last comes first." [Davis] The last is a 3D shoe form of wood, plastic, or other material used in the shoe manufacture. The last captures the style of the shoe desired for a specific sized and shaped foot. Once the last has been designed, the footwear itself (including all of the footwear pieces) and a removable orthotic insert, if necessary, can be designed. The orthotic insert will fit in the bottom of the shoe, matches the foot bottom, and adds accommodative/therapeutic corrections as required for maximum comfort and benefit. Both the footwear and the orthotic insert design processes use the last specification as input of the shoe form that is required.

Separate CAD systems (or at least separate modules of one packaged CAD system) will be used by the pedorthist and/or CTF designer to design the CTF last, insert, and footwear. The design systems will take into account the specific foot shapes, prescriptive requirements, and style selections. The last design system has the challenge to take the foot shape and the last shape desired (the style shape) and suitably integrate the two shapes to give the look of the style and accommodate the particular foot. The specific styles that are available from the manufacturer are constraints in the design process.

The insert must be designed to fit into the shoe as represented by the last for the bottom of the insert and by the foot contours, suitably corrected for therapeutic corrections, for the top of the insert. (Usually, the insert is not designed for a particular last, though that consideration could be beneficial.)

The footwear design system would be used to design the pattern pieces for the uppers, the heels and soles, the construction details, etc. Again, the specific styles, as well as colors, that are available from the manufacturer are constraints.

On output, the CAD systems will generate the appropriate design specifications that are sent to the particular last, insert, and footwear manufacturer required.

5 INFORMATION REQUIREMENTS

The product information requirements for custom therapeutic footwear can be divided into two main groups:

- Requirements Determination: the information that specifies a specific customer's footwear requirements and
- Design Specification: the information that specifies the footwear design that will satisfy those requirements.

An information taxonomy for custom therapeutic footwear is presented in a graphical representation[8] with accompanying text in the following pages. The "KEY" in the slide on the next page applies to all of the information-taxonomy slides.

(The tables in Appendix A define the information entities that are shown in this section.)

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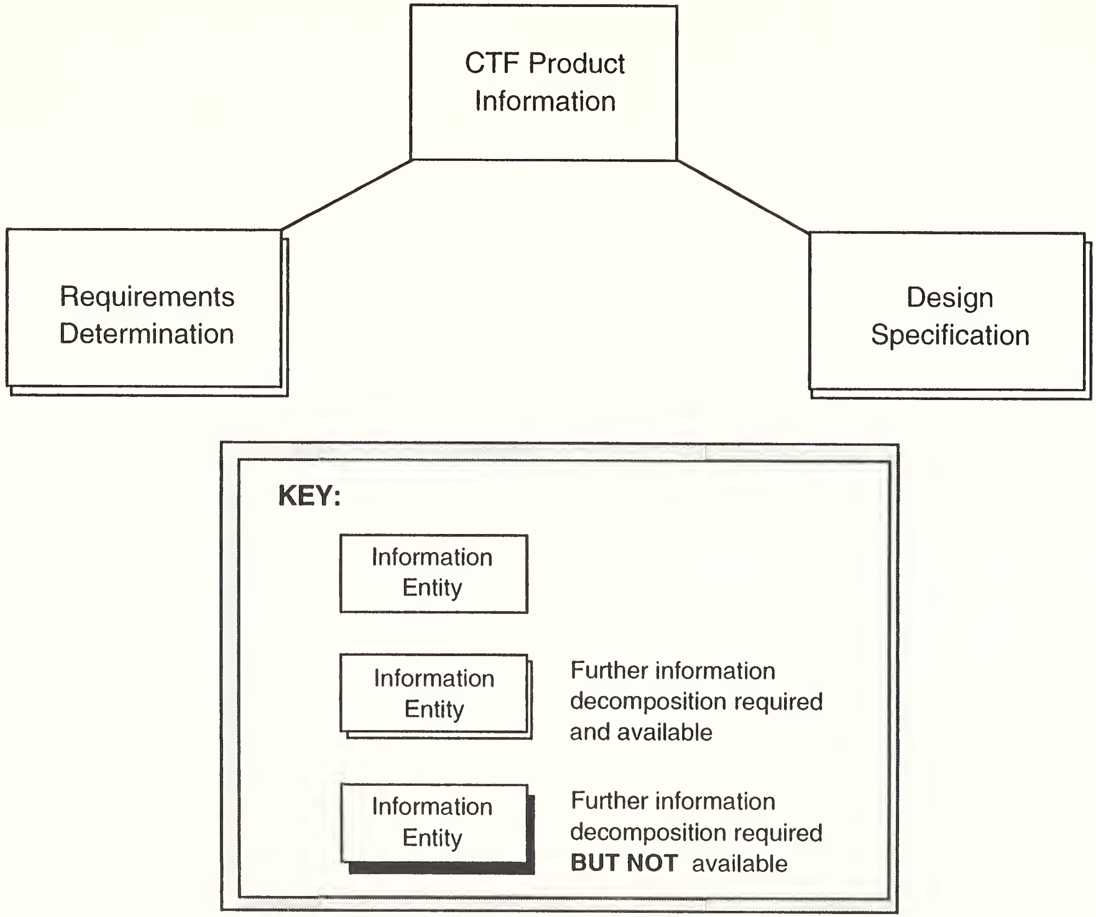
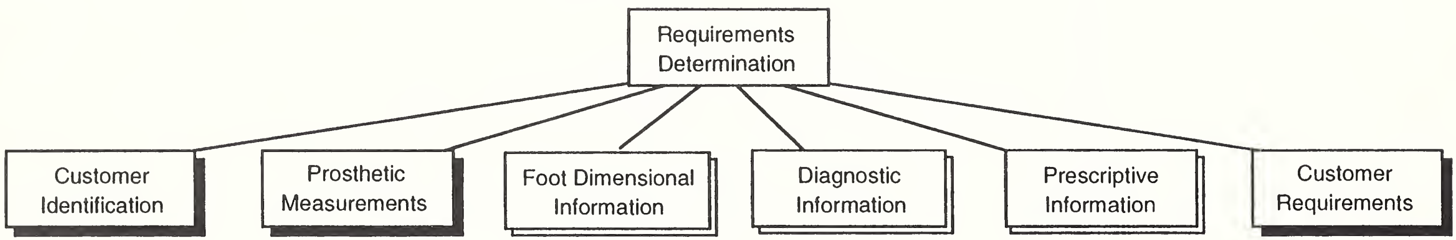
[8] Note that the graphical representation used in this report to specify the information requirements is not a formal information modeling representation. The purpose of the representation used in this report is to give the reader a general idea of how the information requirements are related to each other in a more general context.

INFORMATION TAXONOMY FOR CUSTOM THERAPEUTIC FOOTWEAR



THE REQUIREMENTS DETERMINATION PHASE



The information that specifies a customer's footwear requirements are divided into six general categories:

- Customer Identification: identifies the particular customer in order to match the set of information generated to that customer, and to provide the link to the corresponding business information, such as invoicing.

- Prosthetic Measurements: specifies the dimensions of any prosthetic devices that the customer wears that the footwear must accommodate.

- Foot Dimensional Information: specifies the exact foot shape and size as well as the specific conditions, for example, the position of the foot while it was measured.

- Diagnostic Information: specifies the information that characterizes a foot problem in sufficient terms to enable a footwear prescription to be generated.

- Prescriptive Information: specifies footwear therapeutic and/or accommodative requirements that are derived from the diagnostic information.

- Customer Requirements: captures the customer's preference for a particular footwear purchase that should be accommodated to the maximum extent possible within the constraints of the requirements specified above.

All of these requirement sets must be decomposed further to be meaningful. In the figures shown, foot measurements, diagnostic information, and prescriptive information are further decomposed; customer identification, prosthetic measurements, and customer requirements[9] are not.

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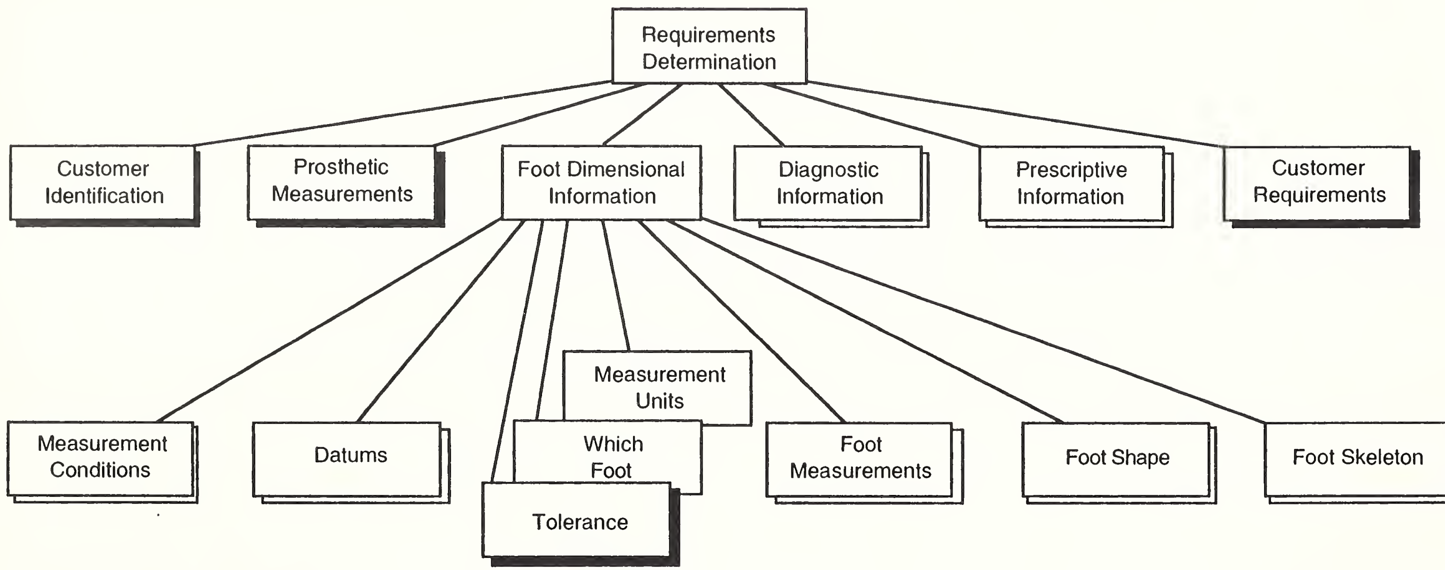
[9]Customer requirements are further decomposed in Table 1.4 in Appendix A, but are not further decomposed in the figures.

FOOT DIMENSIONAL INFORMATION



Foot dimensions are the primary requirements that determine what footwear size and shape are required. (Other requirements mainly affect necessary variations from the footwear made to fit a particular-sized foot.) The figures on the preceding page and the next several pages show the decomposition for the information entity, "Foot Dimensional Information."

In reference to the preceding figure, the "Measurement Conditions" under which the "Foot Dimensional Information" was determined are necessary to determine the proper interpretation of those measurements. For custom therapeutic footwear, the correct interpretation is essential; the necessity is progressively less for less customized footwear. "Measurement Units," whether metric or English, must either be built into the standard, or included as one of the information entities. Of course, the designation of "Which Foot" (left or right) must be specified for a custom fit of the particular foot. The information entity, "Tolerance," is included to indicate that a certain level of error is acceptable, or conversely, not acceptable, in the measurements made. Currently, this information is not used by the industry and perhaps is not necessary. The industry may determine to delete that information from the information necessary to consider.

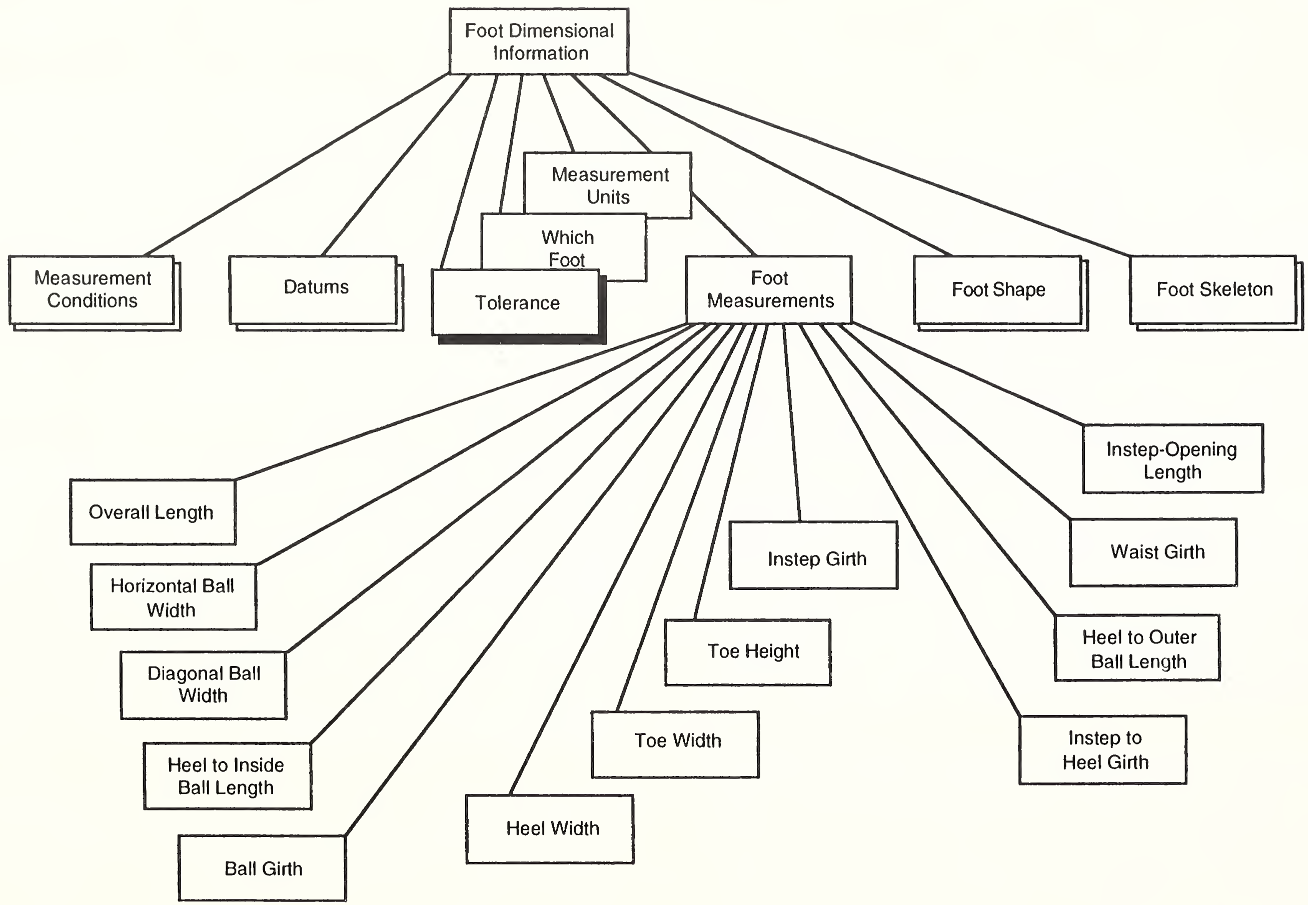
The "Foot Measurements" entity is the set of foot measurements, consisting of lengths and girths, that are important for specifying custom and custom therapeutic footwear. The other entities shown are "Datums," which specify reference points, lines, and surfaces, to base foot measurements upon; "Foot Shape," which designates the actual 3D representation of the foot; and "Foot Skeleton," which specifies the underlying bone structure that affects the fit.

As mentioned above, the footwear industry established the Foot Measurement Committee (FMC) in the first quarter of 1996. The committee defined its mission "to identify and implement three dimensional foot measurement standards that are required to develop, manufacture, and fit optimally functioning and fitting footwear, including custom and therapeutic footwear." In the initial efforts of the committee, a foot measurement standard was discussed. The information entities consisted of specific foot lengths and circumferences (or girths, the term commonly used in the footwear industry). Also, references, or datums, were discussed to specify the foot measurements unambiguously, based on the datums. As the committee work has progressed, further information types have been considered.

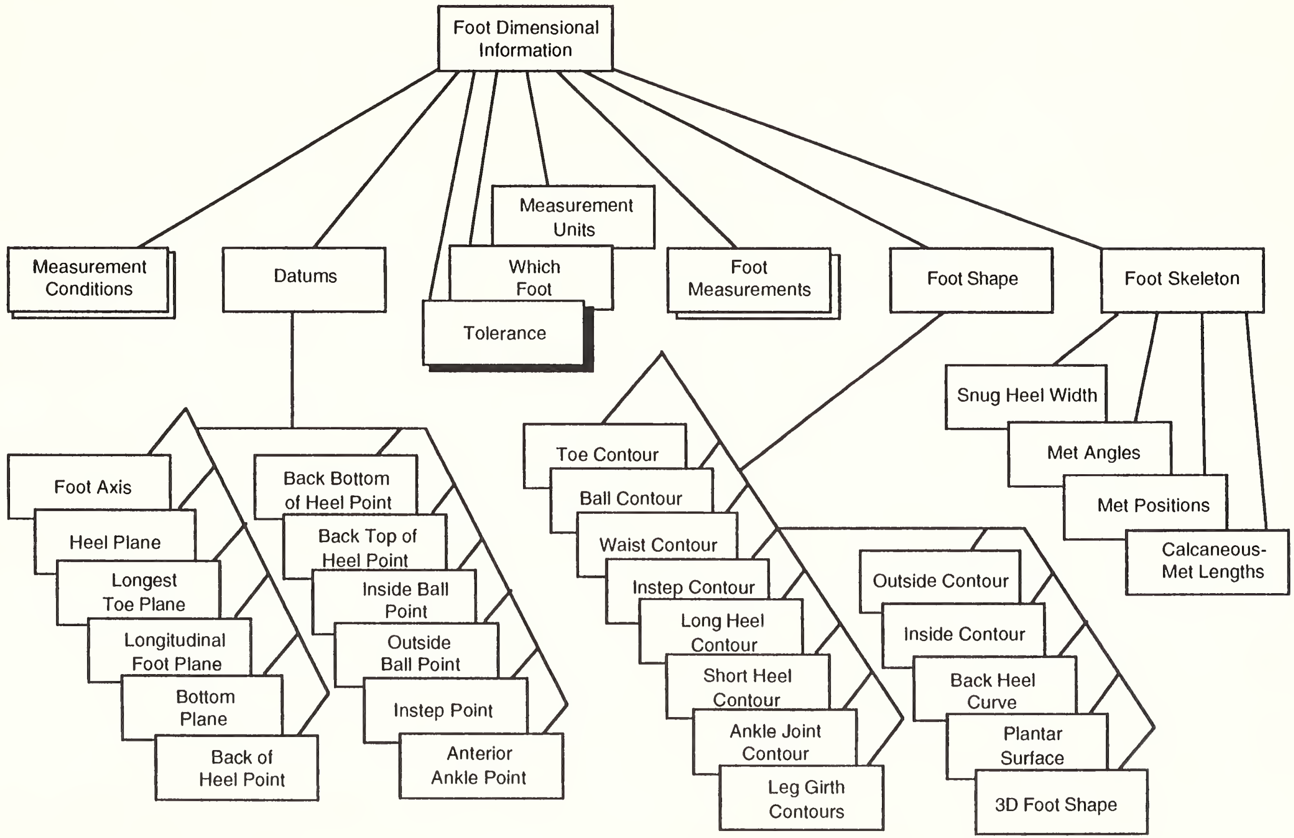
The specific lengths and girths that are being considered in the initial FMC foot-measurement standard are shown on the following page. Descriptions for these entities, as well as all the entities in these figures, are shown in the tables in Appendix A. (Note that the figure represents the FMC's thinking as of their last meeting in September 1996, and specifics are likely to change as the entities proposed are further discussed.)

The page following "Foot Dimensional Measurements" shows specific entities defined for "Datums," "Foot Shape," and "Foot Skeleton." The FMC is proposing to use a set of datums (likely with some slight modifications to them) that have originated from the Shoe and Allied Trades Research Association (SATRA), an international footwear organization. The datums specified in the figures in this report are similar, but are purposely defined in a general way in Appendix A to reduce conflict with the ultimate FMC standard. (The exact wordings, and meanings as well, are still being developed by the FMC. The main purpose of this report is to propose a larger information context that is consistent with current industry efforts.)

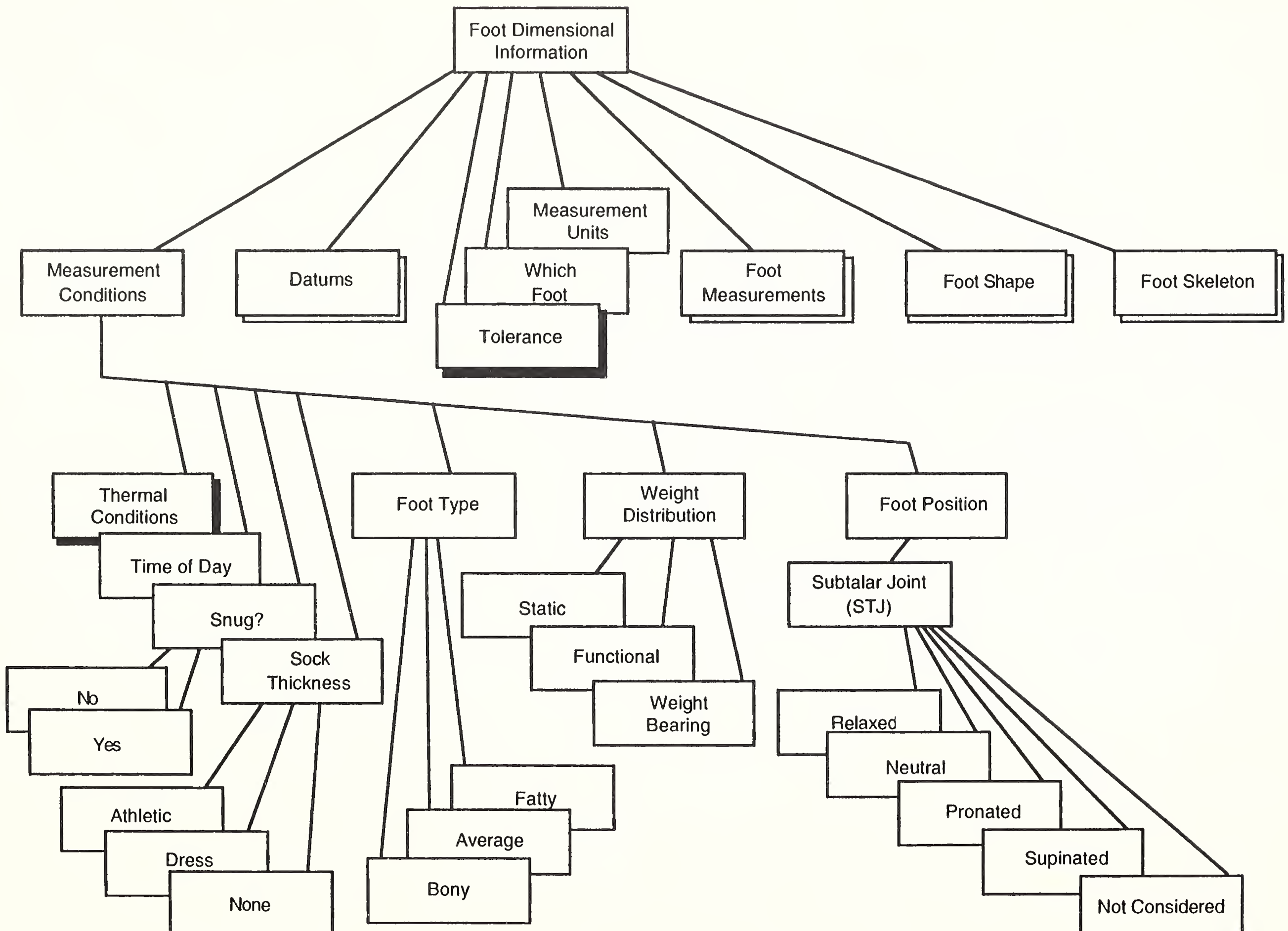
FOOT DIMENSIONAL MEASUREMENTS (LENGTHS AND GIRTHS)



FOOT DATUMS, SHAPE, AND SKELETON



CONDITIONS DURING FOOT MEASUREMENTS



The "Measurement Conditions" are important to correctly interpret the "Foot Measurements" specified. In the standard foot-measurement system used in the U.S., only one sixth of an inch difference means the difference of a half shoe size (for example, from a men's size 10 1/2 to an 11). In fact, a whole range of factors can have a large affect on the size and shape of the foot relevant to the footwear required. These factors include:

• Thermal Conditions: for example, temperature, pressure, humidity;

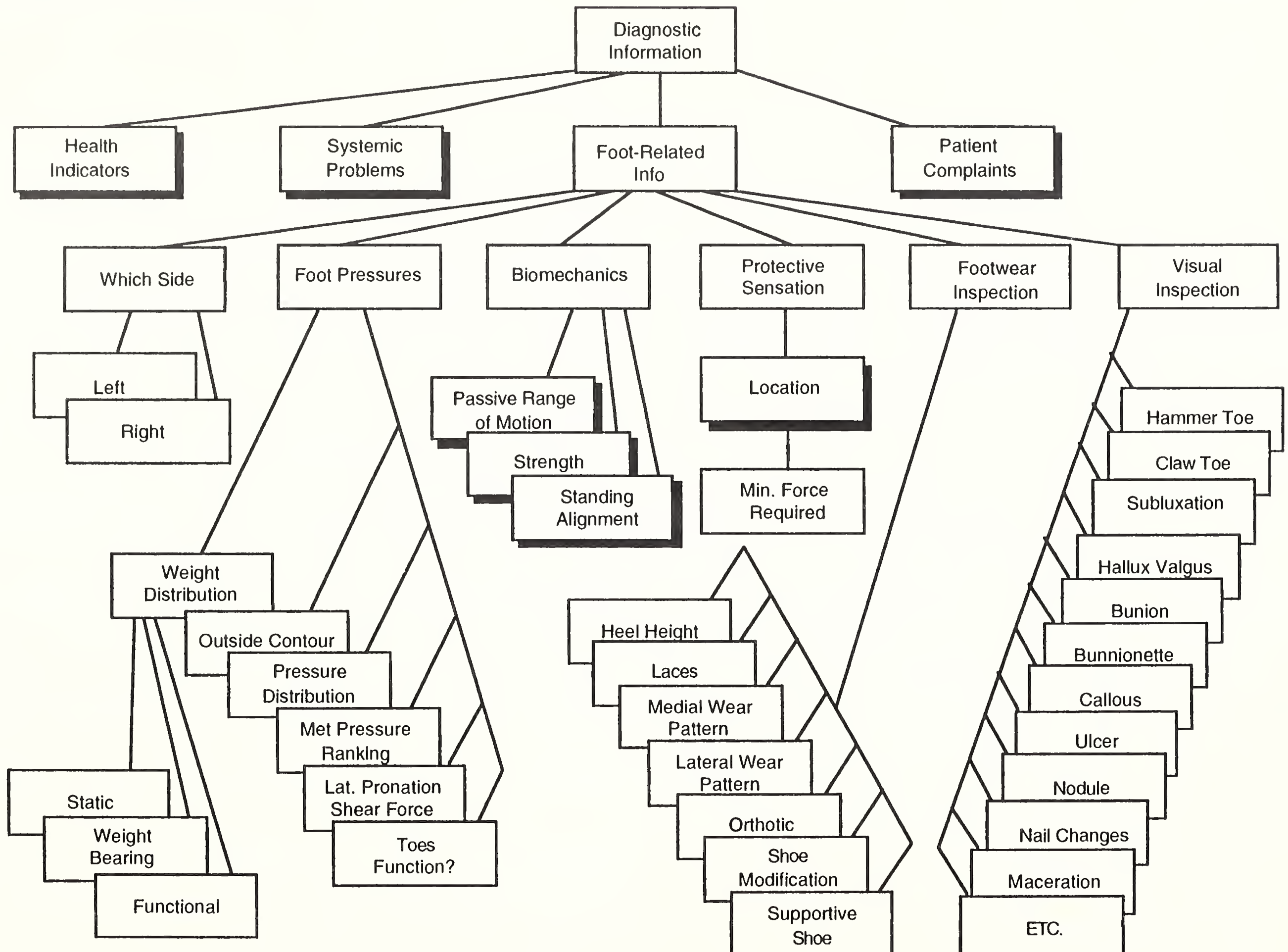
• Weight Distribution: for example, sitting, standing, walking, running;

• Sock Thickness: whether a sock is worn or not during measurement, and is it a thin dress sock or a thick athletic sock;

Furthermore, the "Foot Type" (whether fatty or bony) affects how the foot dimensions should be interpreted when mapping to a particular set of footwear. At certain points on the footwear, good fit requires a snug fit (to the bone); in other points good fit is needed to the outside foot dimension without compression.

One other factor is very important for fitting custom therapeutic footwear. That factor is the position of the sub-talor joint (STJ) during the measurement. (STJ is the joint below the ankle.) A professional should position that joint properly, usually in the "Neutral" position (but not always), during the measurement. Depending on the foot problem and the correction and/or accommodation required by the footwear, the professional will determine the STJ position during the foot measurement.

DIAGNOSTIC INFORMATION



The proposed model divides diagnostic information that is used to prescribe therapeutic footwear into four categories. Those categories are "Health Indicators," that specify the general health of the individual; "Systemic Problems," such as diabetes, arthritis, etc., that can have a large effect on the foot's health; "Patient Complaints," specifically related to foot problems; and finally, "Foot-Related Info," specific information that is determined by direct examination of the foot.

The model divides the latter information into five categories (in addition to specifying which foot, or side of the body, that is measured)—"Foot Pressures," "Biomechanics," "Protective Sensation," "Visual Inspection," and "Footwear Inspection." Each of these categories of diagnostic information is discussed in the following paragraphs.

• Foot Pressures: Pressures on the bottom of the foot while sitting (static—non-weight bearing or semi-weight bearing), standing (full weight bearing), or dynamic (functional—will vary for different types of activities) are very important information to prescribe custom therapeutic footwear and/or orthotic devices. As indicated by the model shown, the pressures might have a number of different representations and may be measured in different ways or for different portions of the foot. Each is suitable for different applications, that is, to fit a particular patient for a particular footwear device and/or footwear.

• Biomechanics: A patient's biomechanics can be vital to fitting therapeutic footwear correctly. In the model, biomechanics is divided into three categories: passive range of motion, strength, and standing alignment.

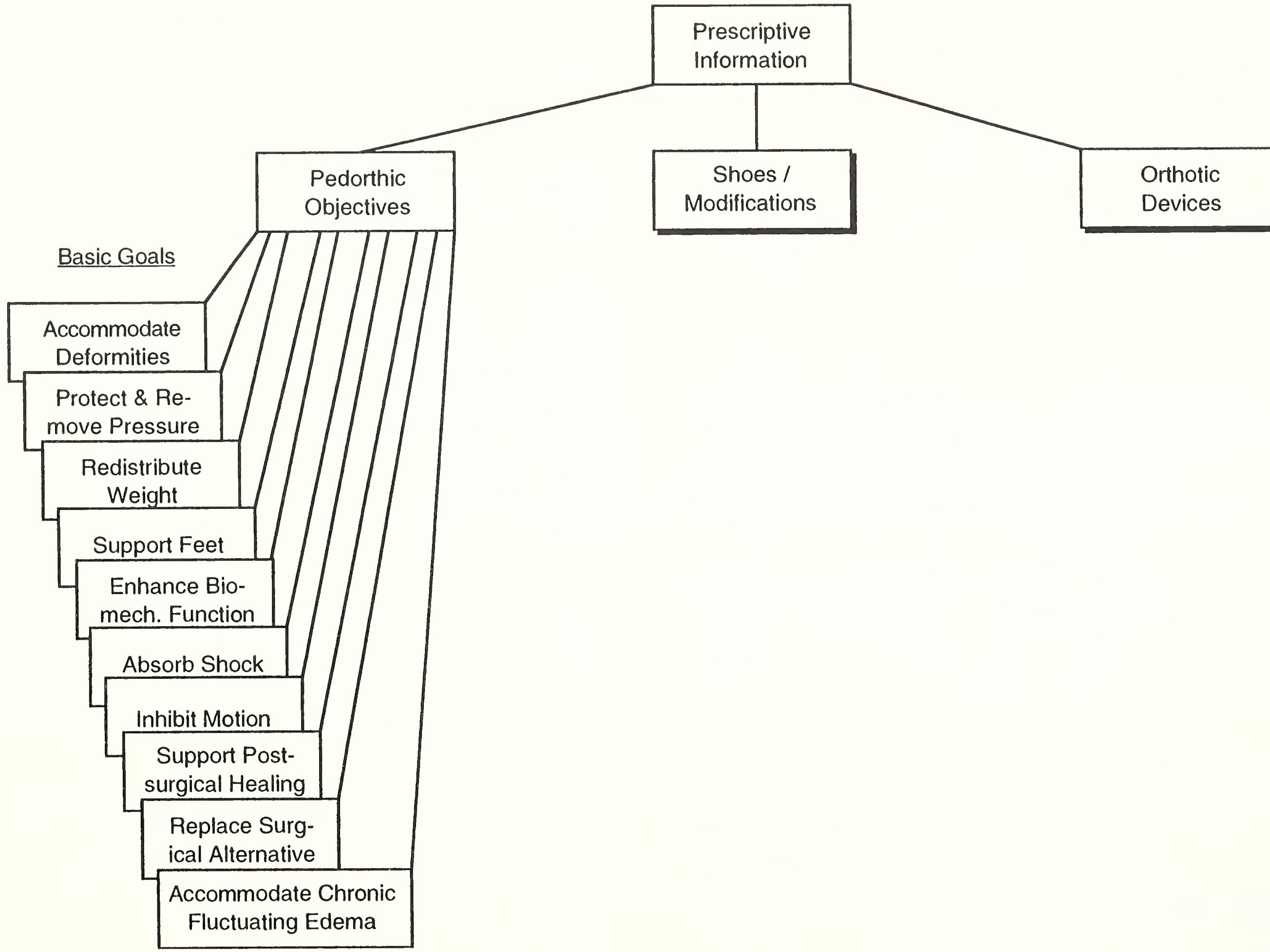
• Protective Sensation: Protective sensation is a measurement of what minimal force applied to a point location on the bottom of the foot can be detected by the patient. Certain diseases, such as diabetes, can diminish the body's important function of feeling a sensation. Without that capability, a person could have a continuous point pressure applied to the bottom of the foot, such as a stone that slipped into the footwear, without knowing it. That happenstance is a primary cause for a diabetic to develop a foot ulcer, a serious medical problem that could ultimately necessitate a foot amputation.

• Footwear Inspection: A quick analysis of the patient's current footwear can provide very useful information to the trained observer to help in making a diagnosis, as well as to help suggest a prescription.

• Visual Inspection: A simple visual inspection can detect many foot abnormalities and problems. Often, special footwear and/or devices can accommodate those types of problems. (The entities shown on the figure under "Visual Inspection" are examples, given by their medical term, and are not meant to be a complete list of conditions.)

In summary, a typical examination of the foot will provide the medical and/or pedorthic professional with a number of these items of information. The type of professional doing the examination and the extent of the examination done will determine how comprehensive is the information that is recorded.

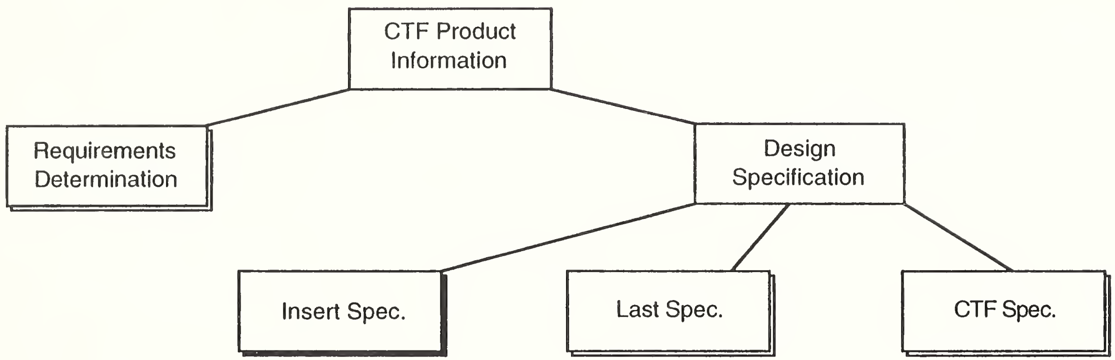
PRESCRIPTIVE INFORMATION



A footwear prescription contains three types of information: the pedorthic objective, a specification of the type of shoes and/or shoe modifications that are required, and a specification of special orthotic devices that are required.

The pedorthic objective is important information, because it conveys the basic goal that the footwear should accomplish as a result of the diagnosis made. The specifications for the actual footwear and/or orthotics could be general or more specific. The more general the prescription, the more latitude that the CTF manufacturer has to create the footwear. The latter is specially trained in making special footwear and should have the most knowledge of new materials, construction techniques, etc. Given that the basic pedorthic goal for the footwear is clearly specified, the CTF manufacturer may be able to execute the best design with minimal other prescriptive information necessary.

THE DESIGN SPECIFICATION PHASE

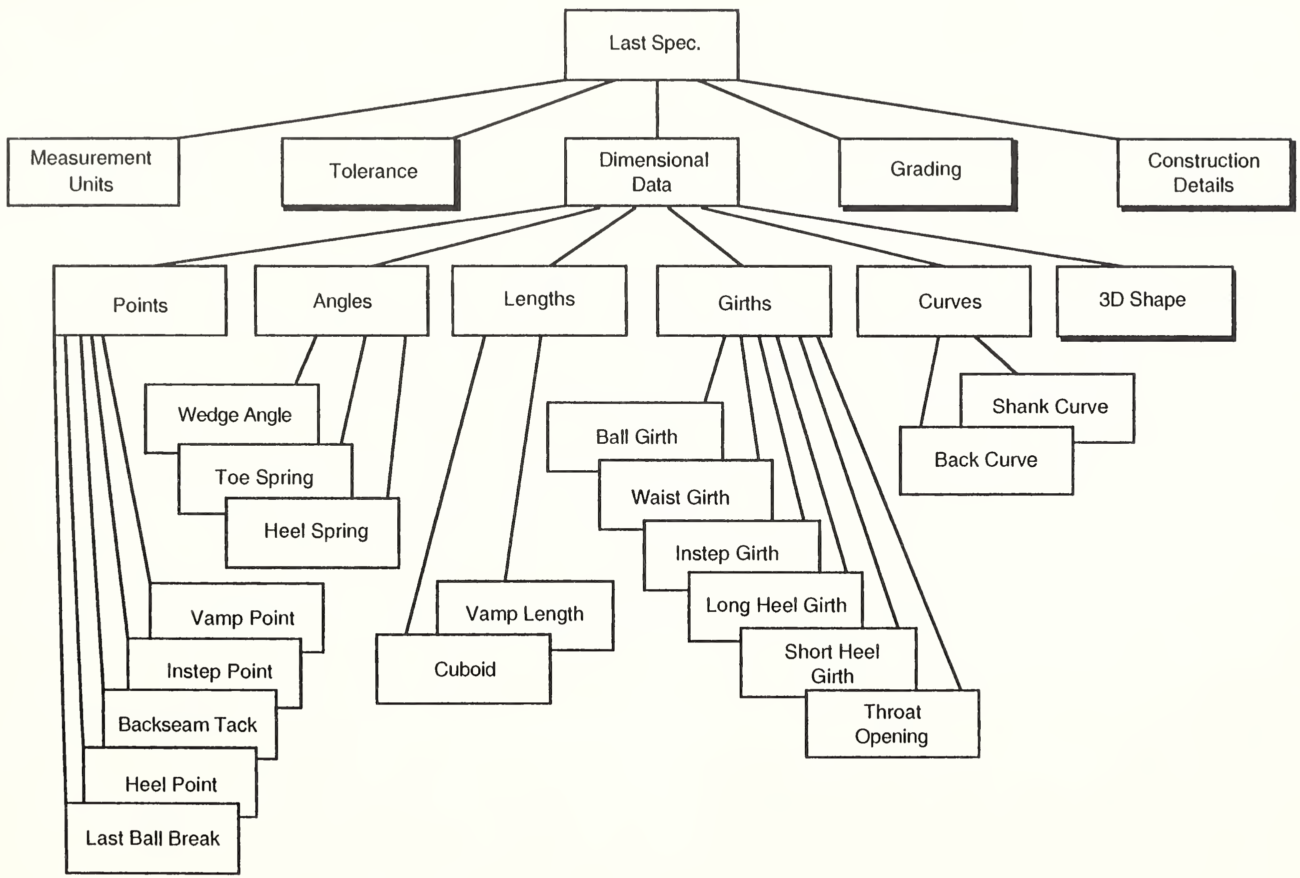


Once the footwear requirements are available, a footwear design can be specified to satisfy them. The less ambiguous, more comprehensive, and more accurate that the requirements are specified, the greater the opportunity that the design can specify the best footwear that will meet the customer's needs. In the same respect, the greater the quality of the design specification, the greater the opportunity that the footwear produced will reflect the specifications and, in turn, satisfy the customer. In short, the more effective the communication is throughout the CTF virtual enterprise, the more effective the enterprise can be in satisfying the customer.

A complete design specification will specify the last, the footwear, and the orthotic if it is required (nearly always the case for therapeutic footwear).

The following information contains terminology that is well known in the footwear industry. A good source of information that defines the terminology used here is the Glossary included in [Rossi].

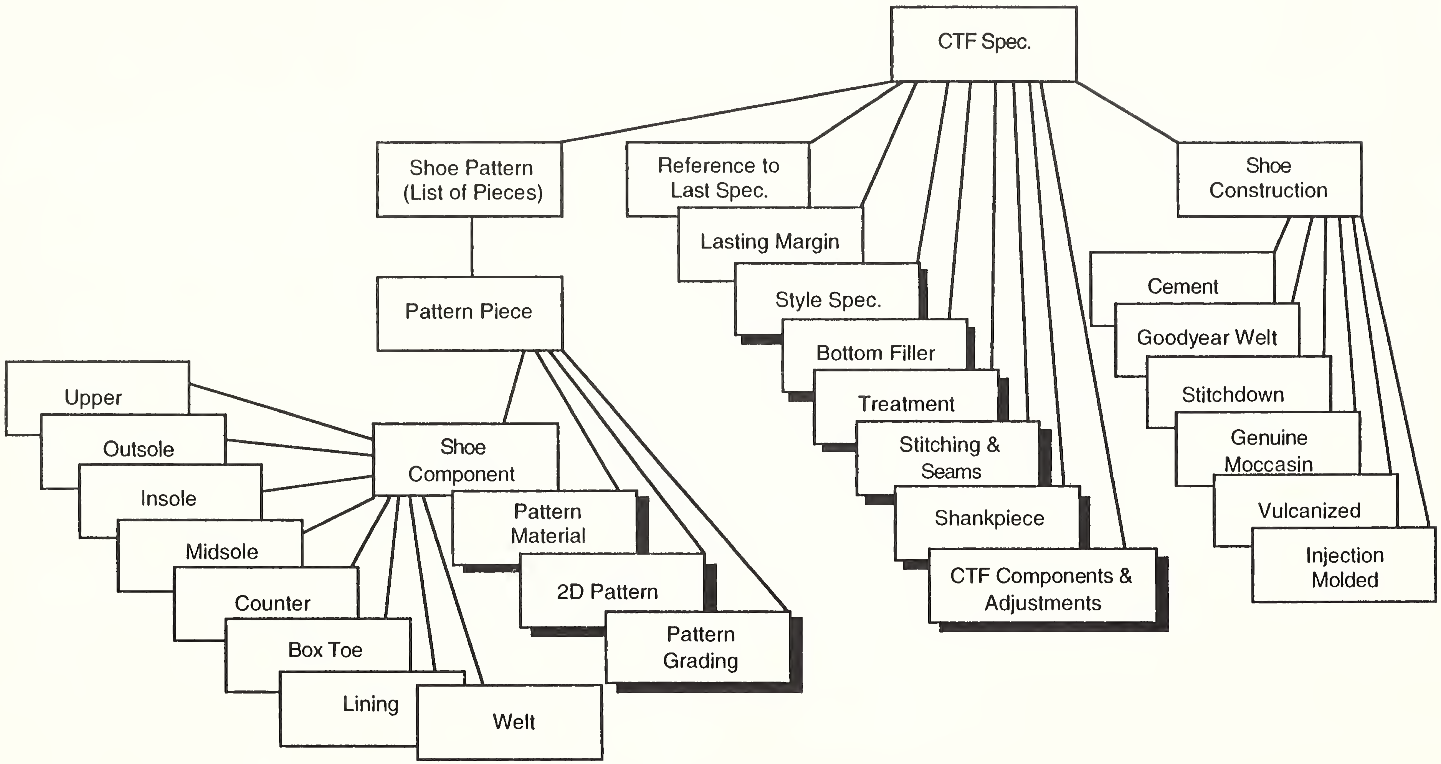
LAST SPECIFICATIONS



The figure on the preceding page shows that the last specification is divided into four categories of information, plus a specification of the measurement units used—either metric or English. The four categories of information are "Tolerance," "Dimensional Data," "Grading," and "Construction Details." The dimensional data is further decomposed into "Points," "Angles," "Length," "Girths," "Curves," and "3D Shape." Notice that the entire shape could be represented as a "3D Shape." However, usually, a number of key dimensions are used to specify the last. The points specified can be considered datums, used to define and measure the other information entities shown. The other information entities include several key angles; two key lengths; a number of girths (or circumferences), including the throat opening that is often specified as a length rather than as a girth; and two key curves.

The Dimensional Data information entities could be organized very differently. The purpose of the figure is to present the types of information entities that should be considered in developing an interoperability standard to represent a last.

CUSTOM THERAPEUTIC FOOTWEAR SPECIFICATIONS



The figure on the preceding page shows the decomposition of the information entity, "CTF Spec." A number of items and information categories are specified. First of all, the particular last used is referenced. Next, there are a number of basic types of shoe construction that determine how the sole is attached to the upper. In addition, there are a number of information elements and more complex items that specify other CTF components, i.e., the "Lasting Margin," "Style Specification," "Bottom Filler," "Treatment," "Stitching and Seams," and other "CTF Components and Adjustments." Finally, patterns for many of the shoe components (including the "Upper," "Outsole," "Insole," "Midsole," "Counter," "Box Toe," "Lining," and "Welt") are specified. The material used for each pattern piece is specified; the contour of each is specified; and the grading of each pattern piece for different sizes (if appropriate) is also specified.

6 RECOMMENDATIONS

(Refer to the slide on the following page.)

GENERAL RECOMMENDATIONS:

(for footwear standardization efforts)

- Develop standards committee affiliated with FIA and PFA.
  DONE

- Obtain accreditation from ANSI (as AAMA has done); then adopt ANSI procedures to develop standards for footwear industry.

- Form liaison with ASTM Textile Committee D13.55 committee which is involved in apparel sizing.

- Consider any interoperability-standards effort in context of broader industry focus.

- Maintain vigil of other industry interoperability standardization efforts.

- Commit to developing enterprise model for footwear industry
  - to use for R & D road map and
  - to help develop the interoperability standards needed.

The Foot Measurement Committee (FMC) was established in the first quarter of 1996 by the Footwear Industries of America and the Pedorthic Footwear Association.

As mentioned in the preceding text, obtaining recognition from the American National Standards Institute (ANSI) lends respect and credibility to the standards developed. That recognition can translate to wider support of the standards developed.

The mission of the American Society of Testing and Materials (ASTM) is to establish standards for materials, products, systems, and services. ASTM Textile Committee D13.55 is working to develop sizing standards for apparel products. The committee is interested in creating projects to acquire comprehensive body measurements that are representative of Americans for apparel-sizing purposes. There is potential that the American footwear industry could combine forces and expand the range of measurements taken to include foot measurements.

The *system approach* should be used to identify and develop the interoperability standards that will benefit the footwear industry, rather than use the *bottleneck approach* (subjectively determining point-to-point bottlenecks and developing short-term, quick-fix solutions).

Other industries have gone the same route now traveled by the footwear industry. There are opportunities to leverage previous efforts of other industries and save substantial time, energy, and money.

An enterprise model that achieves industry consensus and that adequately represents the manufacturing life cycle of the footwear industry is a valuable first step. The model can be a tremendous help to plan and structure a research program, both for the development of interoperability standards as well as for the development of new technologies.

SPECIFIC RECOMMENDATIONS:

(to standardize the output from a foot-measurement system)

- **Establish terminology for all entities that will be specified in standard.**
- **Consider additional entity classes beyond lengths and girths.**
- **Consider "soft" information entities, for example, measurement conditions, for inclusion in standard.**
- **Establish multiple conformance classes[1] carefully.**
- **Ensure standard is independent of any particular technology.**
- **Include additional CTF requirements within same CF standard.**
- **Allow the standard that a customer will use to specify fit to be separate from the foot-measurement interoperability standard.**

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[1] **A conformance class is a subset of the standard that is supported by an application.**

A clear, unambiguous terminology is essential to create clear, unambiguous standards. A separate standard that defines all terminology could be referenced by all of the interoperability standards developed. (This approached is used by ASTM in developing apparel sizing standards.)

As mentioned in the text, foot dimensions cannot be fully interpreted without understanding the context in which they were taken, i.e., the measurement conditions. In fact, as the title of this report declares, there is an entire context of information to consider in developing interoperability standards for the footwear industry.

However, due consideration needs to be taken so that new conformance classes are not created lightly. Each conformance class imposes a burden on the software applications that will implement it, and too many conformance classes will be harder to maintain across the industry.

The standards developed should be independent of any technology. The lifetime of the standard will thus be lengthened. Otherwise, new and better technologies may render the standard obsolete, or else, if the standard is widely accepted, it could be an obstacle to new technologies.

Interoperability standards for custom footwear and non-custom footwear can be derived as subsets from the same standards developed for custom therapeutic footwear. This will reduce the overall burden of development and maintenance of the standards for everyone. Also, it will enable the relatively small CTF sector to piggy-back on the effort of the much larger, mainstream footwear industry and provide the ability to afford the effort in the first place.

Finally, standards used by the consumer to specify footwear sizes don't have to be the same as those developed as interoperability standards. The goals for the two types of standards are not the same, and the effectiveness of interoperability standards should not be compromised to ensure that a human can fully understand how the information representing a foot is translated to a simple sizing standard to select shoes off the rack. That is not to say that a new sizing standard that includes shape as well as size (and perhaps other important information) would not be valuable to the customer, as well as the footwear industry.

7 SUMMARY/CONCLUSIONS

An initial business context has been suggested for the Requirements Determination and the Design Specification Phases of the CTF manufacturing life cycle.

Within that context, product information requirements necessary for sufficient information exchange among the applications required have been listed, and a structure for that information has been suggested.

The models contained in this report are intended as a resource to help set a context for interoperability standards for the footwear industry.

Finally, the NIST CTF project was completed in 1996 as NIST worked to transfer the effort to the private sector. The outcome was the creation of the industry's Foot Measurement Committee which the industry initiated in the first quarter of 1996.

ACKNOWLEDGMENTS

This work was supported by the government initiative on High Performance Computing and Communications (HPCC) through the Systems Integration for Manufacturing Applications (SIMA) program. The work was done by the Manufacturing Systems Integration Division of the Manufacturing Engineering Laboratory of the National Institute of Standards and Technology.

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[Moncarz2] Moncarz, H. T., *Information Technologies Make Business Sense for the Custom Therapeutic Footwear Industry*, NISTIR 5673, National Institute of Standards and Technology, Gaithersburg, MD, June 1995.

[NIH1] "Medical Record" form for "Lower Extremity Examination" developed by National Institutes of Health

[NIH2] "Foot Clinic Database" form developed by National Institutes of Health

[PFA] Pedorthic Footwear Association (PFA), *Pedorthic Management of Common Foot Disorders*, Conference Proceedings, PFA's 37th Annual Meeting and Symposium, Boston, MA, November 16-19, 1995.

[Rossi] Rossi, William A. and Tennant, Ross, *Professional Shoe Fitting*, National Shoe Retailers Association, Columbia, MD, 1993.

[USAir1] U.S. Air Force Wright Aeronautical Laboratories, Function Modeling Manual (IDEF0), Integrated Computer-Aided Manufacturing (ICAM) Architecture Part II, Volume IV, Materials Laboratory, U.S. Air Force Wright Aeronautical Laboratories, June, 1981.

[USAir2] U.S. Air Force Wright Aeronautical Laboratories, Information Modeling Manual IDEF1-Extended (IDEF1x), Report AFWAL-TR-86-4006, Volume 5, Part 4, Manufacturing Technology Directorate, U.S. Air Force Wright Aeronautical Laboratories, 1986.

[10] All reports from the National Institute of Standards and Technology are available from the National Technical Information Service, Springfield, VA 22161.

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APPENDIX Information Requirements for Custom Therapeutic Footwear (CTF)

This appendix lists a proposed set of information requirements for custom therapeutic footwear. The requirements are given in terms of *entities* of information and directly map to the information model presented (as a series of figures) in the main text of this report. The requirements are listed in the form of tables of information entities. A proposed structure for the information is indicated by a set of conventions that are described below.

- Table Organization: Each table is assigned a number that represents its position in the information hierarchy. For example, Table 1, "CTF Requirements Determination Specification," is the top-level table for the information model. Table 1 is further decomposed into Table 1.1, "Foot Dimensional Information," Table 1.2, "Diagnostic Information," etc.

- Title: Each table has a title that appears after its identifying number (as described above). The title is the name of the information entity that the entire table represents.

- Description: Next, in the top block of the table (and spanning across it) is a description of the information entity represented by the table.

- Entity Name: After the table's description, each table has two columns. The first column names the information entities that comprise the information entity represented by the table.

- Entity Description: The second column contains the corresponding description of each of those entities.

- Reference to: An information entity from one table that is further decomposed in another table is indicated by the convention, "<Reference to *number and name of other table*>."

- Valid Values: Some information entities have a finite number of values. Those values are indicated by the convention, "<Valid Values: Value1, Value2, etc.>."

- LIST OF: Some information entities may be repeated. For example, a "LIST OF" girths (circumferences) may be needed to specify the circumference of the lower leg at various increments up the leg for exact measurements for boots.

- References: Finally, the information contained in these tables originated from conversations, emails, and bibliographic references. In some cases the same entity was defined differently in different references. The source for the information entities is indicated by a reference enclosed in brackets (e.g., [ref]) and refers to the complete reference given in the REFERENCES section of this report. In some instances, multiple definitions are included. Entities and/or definitions without references declared have been suggested and/or defined by the author.

The information contained in this report proposes a general context for an information model that specifies custom therapeutic footwear. The model is not a final specification, but rather a source of information that can be used as a resource by a standards committee to help determine an exact specification. In that vein, some of the thinking that went into the development of the model and/or the inclusion of certain entities is included in the tables.

Table 1: CTF Requirements Determination Specification

Requirements needed to specify a particular customer's needs for custom therapeutic footwear.	
Entity Name	Entity Description
Customer Identification	Identifies the customer for linking to general business information and includes a general classification of footwear needs. For example, does the customer need custom or custom therapeutic footwear? Does the customer use a prosthetic foot? Etc.
Prosthetic Measurements	Measurements that characterize the size and shape of one or more foot prosthetics that will reside in the footwear along with the foot.
Foot Dimensional Information	Foot dimensions that characterize the external size and shape and the underlying skeletal structure that are relevant to making footwear for a particular customer. Also includes information needed to fully interpret the measurements (e.g., how the measurements were taken). LIST OF <Reference to 1.1: Foot Dimensional Information> (NOTE: This is a list because separate tables are required for left and right feet. Also, there might be several Foot Measurements tables associated with the same foot if Table 1.1.1: Measurement Conditions Information is different for different types of measurements taken.)
Diagnostic Information	Information that characterizes the customer's state of health (relevant to the feet), biomechanics, symptoms, etc. <Reference to 1.2: Diagnostic Information>
Prescriptive Information	Accommodative and therapeutic corrections to relieve symptoms and correct problems; does not reference specific CTF or device specifications. <Reference to 1.3: Prescriptive Information>
Customer Requirements	What customer wants and/or needs, independent of medical and foot measurement requirements. <Reference to 1.4: Customer Requirements>

Table 1.1: Foot Dimensional Information

Foot dimensions that characterize the external size and shape and the underlying skeletal structure that are relevant to making footwear for a particular customer. Also includes information needed to fully interpret the measurements (e.g., how the measurements were taken).

The Foot Measurement Committee (FMC) is planning to propose a standard in which datums will be based on a SATRA standard (with slight modifications), and foot measurements will be based on those datums. Since the FMC standard is in early development, this report will not reflect the latest developments of that work. The Foot Measurements described here will be similar to those that are being developed for the FMC standard. (They reflect the early thinking of the committee, before considering the SATRA standard.) The main difference will be the Datums; SATRA uses a methodology to define its Datums so they are completely unambiguous. In particular, instead of defining a Foot Axis that runs roughly along the center of the foot, SATRA defines a main axis that is tangent to the foot at the inside of the heel and goes through a point that is "close" to the inside ball of the foot.

Entity Name	Entity Description
Which Foot	Identification of whether left or right foot measured. <Valid Values: Left, Right>
Measurement Units	Unit of measure used; assumed that the same units are used throughout all foot measurements. <Valid Values: IN, CM>
Tolerance	Characterization of the accuracy of the measurements taken.
Measurement Conditions	Conditions that can affect the foot measurements and/or how the measurements should be interpreted. <Reference to 1.1.1: Measurement Conditions>
Datums	Datums (points, axes, planes) that are used as references to determine dimensions of the foot. <Reference to 1.1.2: Datums>

Foot Measurements	Set of foot measurements, consisting of lengths and girths, that are important for specifying custom and custom therapeutic footwear. <Reference to 1.1.3: Foot Measurements>
Foot Shape	Representation of the foot shape. <Reference to 1.1.4: Foot Shape>
Foot Skeleton	Measurements that characterize the underlying skeletal structure of the foot that are useful for designing appropriate footwear and related devices. <Reference to 1.1.5: Foot Skeleton>

Table 1.1.1: Measurement Conditions

Conditions that can affect the foot measurements and/or how the measurements should be interpreted.

Entity Name	Entity Description
Thermal Conditions	Quantification of heat, humidity, and moisture in the foot. The thermal condition of the foot affects the foot's size and shape.
Time of Day	Time of day will affect foot measurement and shape, since foot normally, or abnormally, swells during the day. Need to capture this condition because of the large effect possible, even under normal circumstances. Maybe need to take complete set of measurements during Times of Day when minimal and maximal swelling. (NOTE: this effect is interrelated with effect from Thermal Conditions.)
Snug?	Whether measurements are made "snug"—i.e., to obtain estimate of the underlying skeletal structure, e.g., using a tape measure pulled tight; or whether measurements are made "loose"—i.e., to obtain the shape of the outer skin, undeformed, as will result from a non-contact scanner. <Valid Values: Yes, No>

Sock Thickness	Identification of whether foot is measured with no sock, dress sock, or thicker athletic sock. <Valid Values: None, Dress, Athletic>
Foot Type	Consideration of amount of fat in foot, which will affect how to make and interpret certain measurements. <Valid Values: Average, Bony, Fatty>
Weight Distribution	How weight is distributed during the measurement. Static: foot is at rest—customer seated; Weight Bearing: customer is standing; Functional: customer is in activity—walking, running, jumping, etc. The foot's size, shape, and proportions will vary for each. <Valid Values: Static, Weight Bearing, Functional> (NOTE: for greater accuracy, could substitute the specific activity for the value, "Functional.")
Foot Position	How the foot is positioned during the measurement. <Reference to 1.1.1.1: Foot Position>

Table 1.1.1.1: Foot Position

How the foot is positioned during the measurement.

Entity Name	Entity Description
Subtalar Joint (STJ) Position	Position of the Subtalar Joint. <Valid Values: Relaxed, Neutral, Pronated, Supinated, Not Considered>
others?	This entry is a place holder for other foot positions that might be required.

Table 1.1.2: Datums

Datums (points, axes, planes, curves) that are used as references to determine dimensions of the foot related to fitting footwear.

Entity Name	Entity Description
Foot Axis	Longitudinal axis in the Bottom Plane (under the foot bottom) and intersecting the vertical projection of the Back of Heel Point to the ground, which point is considered the origin of the Foot Axis. The orientation of the Foot Axis is established by the requirement that it bisects the distance between the Inside and Outside Ball Points. ISSUES: - Back of Heel Point may not be directly above Bottom Back of Heel - What about foot that is curved in Bottom Plane, so that better representation of Foot Axis is a curve rather than a straight line? The SATRA standard avoids these issues in the way it defines the main foot axis as described at the top of Table 1.1: Foot Dimensional Information.
Heel Plane	Vertical plane perpendicular to the Foot Axis and intersecting the Back of Heel Point.
Longest Toe Plane	Vertical plane perpendicular to the Foot Axis and just enclosing all of the toes. The foot will just fit between the Heel Plane and the Longest Toe Plane.
Longitudinal Foot Plane	Vertical plane that is coincident with the Foot Axis
Bottom Plane	Horizontal (flat) plane under the foot
Back of Heel Point	Point on the Back Heel Curve at the most rear point of the foot.
Back Bottom of Heel Point	Point where the Back Heel Curve (see Table 1.1.4: Foot Shape) touches the ground at the foot axis.

Back Top of Heel Point	Point on the Back Heel Curve above the Back of Heel Point, where the Back Heel Curve reverses slope. Alternatively, Point on the Back Heel Curve where a horizontal plane intersects the Anterior Ankle Point (assuming that is a point that can be specified).
Inside Ball Point	Point on the inner surface (the medial side of the foot) of the great toe joint that is furthest from the Longitudinal Foot Plane.
Outside Ball Point	Point on the outer surface of the little toe joint (fifth metatarsal head) that is furthest from the Longitudinal Foot Plane.
Instep Point (top of the instep)	Point at soft area proximal to cuneoforms. [Davis] The point determined by locating the bone structure at the top of the instep, as determined by the circumference of the cross section of the foot with a plane passing through the instep point as described above, and a line across the narrowest point of the foot between the heel and the inside ball point. If this area is not well defined, it is the line with one half the distance from the heel to the inside ball point. If the instep bone structure is not well defined, the top of the instep is the point with distance from the heel equal to 76.3% of the distance from the heel to the inside ball point. [Hurd95]
Anterior Ankle Point	Point on the front of the ankle just above the top of the foot, where the ankle begins. Point in the Longitudinal Foot Plane (assuming this plane bisects the foot at the ankle) at the front of the ankle.

Table 1.1.3: Foot Measurements

Set of foot measurements, consisting of lengths and girths, that are important for specifying custom and custom therapeutic footwear. The entities in this table are the same as identified in [FMC96] and are listed in declining order of importance, as prioritized by [FMC96]. However, the definitions given in this table are referenced to the Datums in Table 1.1.2 and not the Datums that are being developed in the evolving FMC standard. The result is that the definitions given here are similar to those being developed in the FMC standard, but provide the reader with a perspective more common to current U.S. practice.

Entity Name	Entity Description
Overall Length	Distance between the Heel Plane and the Longest Toe Plane, measured along the Foot Axis.
Horizontal Ball Width	Distance between two vertical planes each parallel to the Longitudinal Foot Plane, one plane containing the Inside Ball Point and other plane containing the Outside Ball Point.
Diagonal Ball Width	Distance between the Inside Ball Point and Outside Ball Point.
Heel to Inside Ball Length	Distance between two vertical planes that are each perpendicular to the Foot Axis, one plane containing the Back of Heel Point and the other plane containing the Inside Ball Point.
Ball Girth	Circumference about the cross-section of the foot that is taken by a vertical plane that includes the Inside and Outside Ball Points.
Heel Width	The widest measurement across the heel of the foot. If the heel is not well defined, i.e., there is no maximum, then it is the width of the heel one quarter of the distance from the heel to the inside ball point. [Hurd95] NOTE: this definition doesn't account for the fact that the best fit footwear is determined by a "snug measurement" of the heel width. If the foot is "fatty" the measurement taken could be too large for the best fit. (See Snug Heel Width in Table 1.1.5:Foot Skeleton.)

Toe Width	Distance between the point on the medial side of the toes half way between the Inside Ball Point and the end of the big toe and the point on the lateral side of the toes where the medial point is projected to the lateral point perpendicular to the Foot Axis.
Toe Height	The maximum distance from the floor to the top of the toes (any toe), specifically the highest point of the toes. (Takes into account hammer or claw toes.) [FMC96]
Instep Girth	Circumference measured at soft area proximal to cuneoforms. [Davis] The girth of the foot at the instep point as determined by locating the bone structure at the top of the instep, as determined by the circumference of the cross section of the foot with a plane passing through the instep point as described above, and a line across the narrowest point of the foot between the heel and the inside ball point. If this area is not well defined, it is the line with 1/2 the distance from the heel to the inside ball point. If the instep bone structure is not well defined, the top of the instep is the point with distance from the heel equal to 76.3% of the distance from the heel to the inside ball point. [Hurd95] NOTE: numbers such as 1/2, and particularly, 76.3%, are arbitrary. Is it possible to specify point on bone structure that can be included in this definition unambiguously, even though a scanner that sees the outside skin only may not be able to detect it?
Instep to Heel Girth	Circumference of the foot in the plane that includes the Back Bottom of Heel Point and the Instep Point.
Heel To Outer Ball Length	Distance between two vertical planes that are each perpendicular to the Foot Axis, one plane containing the Back of Heel Point and the other plane containing the Outside Ball Point.

Waist Girth	Circumference measured proximal to metatarsal heads (narrow part of foot). [Davis] This is the circumference of the foot at its narrowest point between the ball girth and the instep girth. If this area is not well defined, it is determined as half way between the ball girth and instep girth measurements. [Hurd95]
Instep-Opening Length	Distance from the Instep Point to the Back of Heel Point along the Foot Axis.

Table 1.1.4: Foot Shape

Representation of the foot shape.	
Entity Name	Entity Description
Outside Contour	2D curve that represents the outside contour of the foot, i.e., the contour taken by a stylus held vertically and tracing around the contour of the foot. Generally taken while the customer is standing. [Davis]
Inside Contour	2D curve that represents the inside contour of the foot, i.e. the contour taken by a stylus held at an angle tilted under the foot so that a trace around the foot's contour will record the under surface of the foot that contacts the ground. Generally taken while the customer is standing. [Davis]
Back Heel Curve	3D curve along the back of the heel from the Back Bottom of Heel Point to the Back Top of Heel Point.
Plantar Surface	3D surface that represents the bottom of the foot.
3D Foot Shape	3D representation of the entire foot.
Toe Contour	Note: this and the following contours are the actual curves, rather than the girth measurements that are presented in Table 1.1.3: Foot Measurements. 3D contour about first met (i.e., metatarsal head) and including fifth digit. [Davis]

Ball Contour	3D contour in vertical plane that includes Inside and Outside Ball Points.
Waist Contour	3D contour in plane at waist of foot (narrow part of foot).
Instep Contour	3D contour in plane that includes Instep Point.
Long Heel Contour	3D contour in plane that includes Instep Point and Back Bottom of Heel Point. [Davis]
Short Heel Contour	3D contour in plane that includes Anterior Ankle Point and Back Bottom of Heel Point. [Davis]
Ankle Joint Contour	3D contour at Anterior Ankle Point in plane parallel to ground.
Leg Girth Contours	3D contours above the ankle, up the leg, that is used for designing boots. LIST OF <Reference to 1.1.4.1: Leg Contours Record>

Table 1.1.4.1: Leg Contours Record

3D contours above the ankle, up the leg, that is used for designing boots [Davis].

Entity Name	Entity Description
Increment	The distance along the ankle and up the leg between each circumference taken
Number of Contours	The number of contours taken
Leg Contours	LIST OF Contours

Table 1.1.5: Foot Skeleton

Measurements that characterize the underlying skeletal structure of the foot that may be useful for designing appropriate footwear and related devices.	
Entity Name	Entity Description
Snug Heel Width	Heel width that is taken "snug to the foot," so that the fatty tissue at the heel can be ignored. The footwear fit at the heel should be snug to the skin and bones.
Metatarsal Angles	LIST OF 5 (from first to fifth metatarsal head; relative to the orientation of the Foot Axis). [Davis]
Metatarsal Positions	LIST OF 5 (from first to fifth metatarsal head; relationship and distances between metatarsal heads—possibly give x-y positions of each). [Davis]
Calcaneous-Metatarsal Distances	LIST OF 5 (between center of calcaneous and center of each metatarsal head). [Davis]

Table 1.2: Diagnostic Information

Information representing the customer's health that is relevant to the need for CTF and/or related devices.	
Entity Name	Entity Description
Health Indicators	Status of patient's general health.
Systemic Problems	Specification of systemic problem/s (e.g., diabetes) that requires special footwear.
Foot-Related Info	General specification of foot health. <Reference to 1.2.1: Foot-Related Info>
Patient Complaints	Specification of foot symptoms/problems reported by the patient.

Table 1.2.1: Foot-Related Info

General specification of foot health.	
Entity Name	Entity Description
Which Side	Which foot (left or right) or, for more general biomechanics information that affects the foot, which side of the body. <Valid Values: Left, Right>
Foot Pressures	Distribution of pressure under the foot under load. <Reference to 1.2.1.1: Foot Pressures>
Biomechanics	Information related to foot and body biomechanics. <Reference to 1.2.1.2: Biomechanics>
Protective Sensation	Ability of the foot to detect a force applied to an area of it. Specified as the minimum force that patient can detect at various locations on the foot. Alternatively, specified simply as whether the foot behaves normal or not at various locations.
Footwear Inspection	Information that describes the person's current footwear and its condition; can be helpful in prescription of footwear as well as imply information concerning the foot's functioning. Information concerning heel height, laces, medial wear pattern, lateral wear pattern, orthotic, shoe modification, supportive shoe.
Visual Inspection	Identification of specific foot conditions that can be determined from a visual inspection, plus a corresponding specification of the location of the condition. Examples are: Hammer Toe, Bunion, Ulcer, etc.

Table 1.2.1.1: Foot Pressures

Distribution of pressure under the foot under load. [Davis]	
Entity Name	Entity Description
Weight Distribution	NOTE: refer to "Weight Distribution" in Table 1.1.1: Measurement Conditions. <Valid Values: Static, Weight Bearing, Functional>
Outside Contour	2D curve that represents the outside contour of the foot.

Pressure Distribution	Distribution of forces that can be measured underneath the foot throughout the footprint. There are a number of techniques and devices used to determine pressure distribution, so a number of alternatives to represent pressure distribution should be considered:
	
	- Point forces and positions throughout footprint.
	- Alternatively, specify contours that define pressure areas. There are three possibilities:
	    - 2D curve (one curve for rear and mid-foot combined, excluding metatarsal heads)
	    - 2D curve for rear-foot and 2D curve for mid-foot (if curves are distinct)
	    - same as above, but include metatarsal heads in mid-foot curve
	- Finally, specify pressure distribution as contour maps—representing contours of equal force distribution throughout the footprint.

Rank Order Of Metatarsal Pressure	LIST OF 5 (to determine which metatarsal heads bear the most weight).
Lateral Shearing Force Of Pronation	Force generated away from the body due to pronation (outer bending of the foot). Can be estimated by professional from under-foot pressure distribution.
Toes Function?	Do toes function for propulsion? (Professional can determine from the under-foot pressure distribution.) <Valid Values: Yes, No>

Table 1.2.1.2: Biomechanics

Indication of the structural health and integrity of the foot as well as the effect of the rest of the body on the foot. Measurements made on joints and joint alignments from foot all the way up the hip. [NIH1, NIH2]

Entity Name	Entity Description
Passive Range of Motion	Range of motion of an unloaded joint. For each joint considered: <Valid Values: Limited, Normal, Excessive>
Strength	Strength of a joint under load. For each joint considered: <Valid Values: Functional, Nonfunctional>
Standing Alignment	Alignment of joints while standing. For each body-alignment measure: <Valid Values: Left, Right, Even>

Table 1.3: Prescriptive Information

Accommodative and therapeutic corrections to relieve symptoms and correct problems; does not reference specific CTF or device specifications.

Entity Name	Entity Description
Pedorthic Objectives	The basic goal that CTF should address; can include more than one. LIST OF Objectives <Valid Values: Accommodate Deformities, Protect and Remove Pressure, Redistribute Weight, Support Feet, Enhance Biomechanical Function, Absorb Shock, Inhibit Motion, Accommodate Chronic Fluctuating Edema, Support Postsurgical Healing, Replace Surgical Alternative>
Shoes/Modifications	Specification of the general type/class of footwear needed to treat/accommodate the patient, as well as modifications needed
Orthotics	Identification of type/class of orthotic and/or objectives for the orthotic to serve

Table 1.4: Customer Requirements

What customer wants and/or needs, independent of medical and foot measurement requirements. [Rossi93]

Entity Name	Entity Description
Style Goals	Chief requirement of the customer (assuming the fit is acceptable). <Reference to 1.4.1: Style Goals> The other requirements listed below are often less important to the customer. However, the footwear that is selected or custom designed will represent a tradeoff of the Customer Requirements.
Protection	Specification of the type and degree of protection desired from cold and heat, abrasion and injury, soil and grime, hard or rough surfaces.
Wear	Specification of wear requirements in terms of service life under variety of environmental conditions.
Comfort	Specification of comfort desired. (Fit is the most important factor that determines comfort, but other factors (such as material softness) also contribute.
Functional Performance	Specification of how well the footwear should meet functional requirements of types of activities under the range of conditions that would be anticipated from them.
Foot Health	Specification of importance to customer that footwear help maintain foot health via design, construction, and fit.

Table 1.4.1: Style Goals

Specification of a customer's desires that can be translated to specific footwear that will meet the customer's expectations.

Entity Name	Entity Description
Style Specification	Information that identifies a particular shoe style (i.e., a particular shoe) from a customer's point of view. Often the customer has more general Style Goals that can be represented by other requirements such as those listed below. (The following represents examples of requirements that a customer could select to help specify a style.)
Basic Style	Footwear is derived from a finite set of basic styles. <Valid Values: Moccasin, Sandal, Mule, Clog, Boot, Pump, Oxford>
Treatment	Particular details such as a tassel, type of shoe finish, etc.
Toe Shape	Type of toe shape desired; an important style goal is the type of look at the toe of the footwear. <Valid Values: Crescent, Oval, Circle, Square, Round, Oblique, Bump>

Table 2: CTF Design Specification

Specifications for custom therapeutic footwear one foot. (Custom therapeutic footwear, as well as custom footwear, is specified on a one-foot basis, and designed one shoe at a time.)	
Entity Name	Entity Description
Last Specification	Shoe form that captures a shoe's style for a particular foot's size and shape and is used in the manufacturing process to make the shoe. <Reference to 2.1: Last Specification>
CTF Specification	Specification that completely defines a particular piece of footwear, excluding the specification of the insert. <Reference to 2.2: CTF Specification>
Insert Specification	Specification of the insert to fit into a particular shoe and treat/accommodate a particular customer's needs.

Table 2.1: Last Specification

Shoe form that captures a shoe's style for a particular foot's size and shape and is used in the manufacturing process to make the shoe.	
Entity Name	Entity Description
Measurement Units	Unit of measure used; assumed that the same units are used throughout. <Valid Values: IN, CM>
Tolerance	Accuracy required for the Dimensional Measurements specified. Tolerance could be a simple linear accuracy to apply to all dimensions; or it could be a more complex data structure that applies difference tolerance requirements to different types of feature measurements of the last.
Dimensional Data	Compilation of the actual, dimensional measurements that specifies the last. The entities presented in this report (page 52) are separated according to the type of geometric entities they are. A different organization might be more appropriate. Dimensions that are commonly used in the specification of a last are included. No judgments have been made on the particular subset to use for standardization purposes.
Grading	Applied transformation to convert one size to another (each category of footwear—men's women's, children's, infant's—has its own grading system).
Construction Details	Specification of construction details that determines, for example, how the last shape is divided into two (or more) pieces and how they are hinged together.

Table 2.2: CTF Specification

Specification that completely defines a particular piece of footwear, excluding the specification of the insert.	
Entity Name	Entity Description
Shoe Pattern	Pattern pieces that comprise the shoe's upper when assembled together. This definition is expanded to include all of the shoe's patterns (e.g., insole, midsole, outsole, heel). LIST OF <Reference to 2.2.1: Pattern Piece>
Last Specification	References the particular last that was used to design this shoe. <Reference to 2.1: Last Specification>
Lasting Margin	Amount of material from the upper (measured as a length) that is folded under the last and tacked or cemented down over the insole.
Style Specification	Specification from a customer's viewpoint that identifies a particular style. (Refer to 1.4.1: Style Goals.)
Bottom Filler	In certain constructions a bottom filler is used to fill in the cavity between the insole and outsole.
Treatment	Specification of final touches that are applied to the shoe such as ornamentation (for example, tassels), type of shoe finish, etc. It could also include ornamental stitching
Stitching and Seams	Specification that defines how pattern pieces are assembled together. (Also, could include the specification of decorative stitching that appears on uppers, if not included in Treatment.)
Shankpiece	Bridge between the ball line of the sole and the front of the heel to provide strength and stability to the shoe's construction.
CTF Components & Adjustments	Footwear components and adjustments that are used for specific treatment and/or accommodative requirements. Examples of these components include the following: Rocker Bottom, Wedge, Flare, Metatarsal Bar, Lift, Velcro Straps, Solid Ankle Cushion Heel, Pinch Pad, Arch Support, etc.

Shoe Construction	Refers to the manner in which the sole is attached to the upper. <Valid Values: Cement, Goodyear Welt, Stitchdown, Genuine Moccasin, Vulcanized, Injection Molded>

Table 2.2.1: Pattern Piece

Specification of a flat, bounded piece of material that is used in a shoe's manufacture.

Entity Name	Entity Description
Shoe Component	Shoe component that this pattern piece is used for. <Valid Values: Upper, Outsole, Insole, Midsole, Counter, Box Toe, Lining, Welt>
Pattern Material	Specification of the material used, including special processing requirements. For example, if leather is the material, there are many different types of leather that are used for the various shoe components; in addition, the tanning method could be identified; the leather finish could be specified; the Grain and Texture could be selected; and finally, the Grade, that reflects the quality of the leather could be selected.
2D Pattern	Complete specification of the pattern piece geometry and related information, including the contour of the pattern piece, restrictions on its orientation relative to the grain of the material, notches, seamlines, drill holes, etc.
Pattern Grading	Applied transformation to convert one size to another (each category of footwear—men's women's, children's, infant's—has its own grading system).