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Enterprise wide Data Model (EDM) as a Basis for Integrated Information Systems

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Abstract:
The focus of the development of integrated information systems is the application-independent structuring of the database.
This paper depicts how data structures are designed to meet the requirements of the horizontal and vertical data integration. This approach leads to an enterprise-wide data model (EDM), which forms an important first step to build-up an enterprise-wide information system. The data structure is graphically represented by the entity relationship model.

A. Integrated Information Systems

In the first phase of development of EDP-based information systems the attention was focused on functional requirements. With the design of integrated information systems it has shifted to structuring the database.
If business functions are emphasized, data only have the function of a "feeder line". As a consequence, considerable data-redundancy has been produced which led to inconsistencies, differences in topicality and increased expenditures on updating (Scheer 1987, pp. 41). However, if the design of information systems is concentrated on the data, the data structures are designed almost independently of specific applications. This implies that one has to start from a relatively high level of abstraction. Here, the findings of business administration, particularly of the theory of the enterprise, which deals with the fundamental issues of business management, may assist in a useful way.

Data structures of integrated information systems encourage two directions of integration (cf. figure 1): the further utilization of data within process chains (horizontal integration) and the further utilization of data between the levels of an information pyramid (vertical integration).
In the coordinated utilization of data within process chains, the data are recorded at the beginning of a process chain and merely completed or corrected at later levels of processing in order to avoid a repeated (redundant) input. This approach concentrates on the operative processes of an enterprise. Whereas initially, processes within the typical range of functions of companies

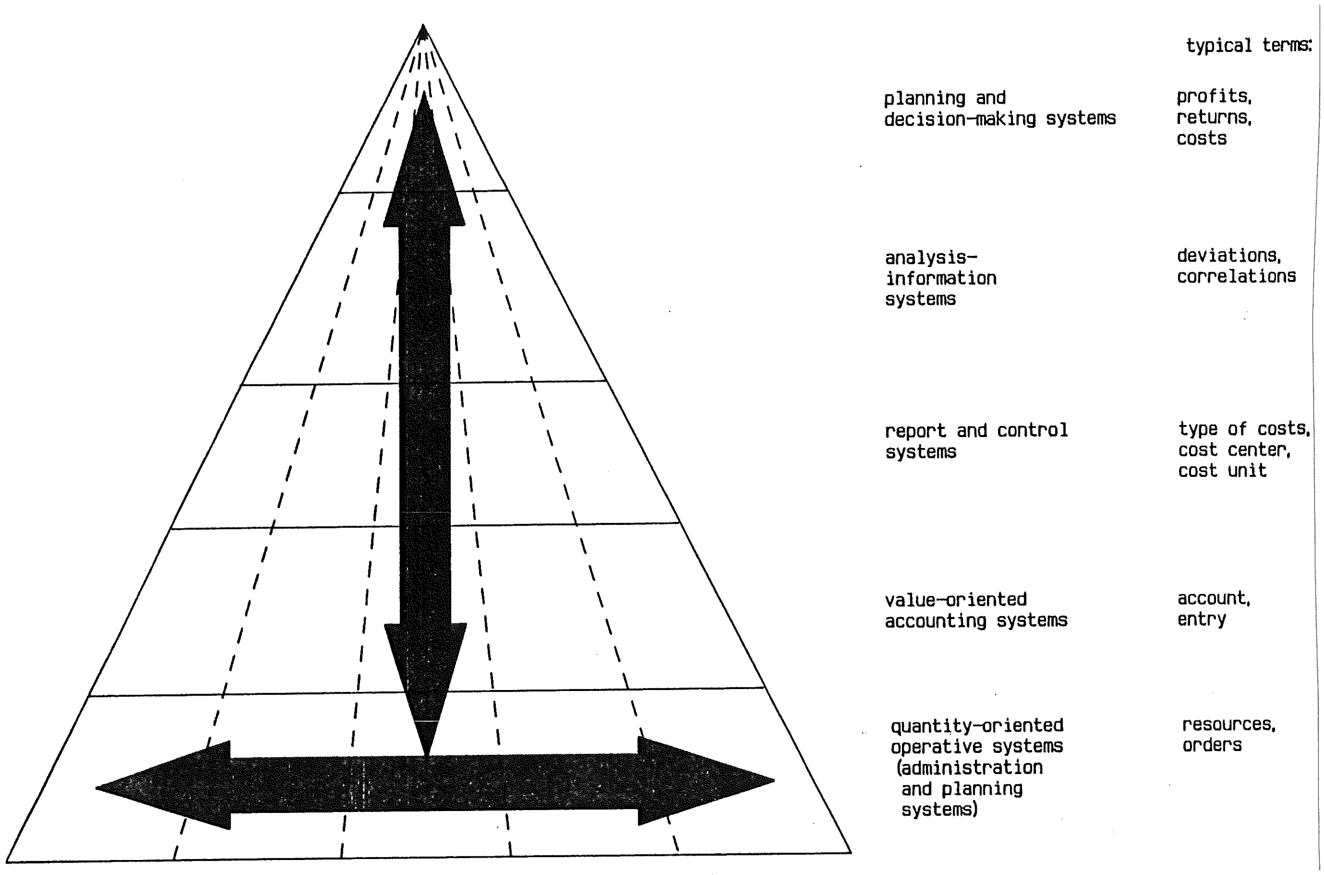

Figure 1: Integrated information systems: horizontal and vertical data integration

(purchase, production, sales) have been considered, now inter-company processes which also include technical and business operations are increasingly examined. In this context, the concept of CIM (Computer Integrated Manufacturing) for industrial companies serves as a striking example (Scheer 1988a; Schweitzer 1985; Vernadat 1984).

Apart from the design of integrated data structures on the operative level which requires an integration across the whole range of functions (see the horizontal arrow in figure 1) the subsequent application of data in information systems that are based upon operative systems is also important.

Value-oriented accounting systems based upon quantity-oriented systems should therefore have direct access to the data of the operative systems. Furthermore, the quantity-oriented systems should also record those data originating from operative processes. The same requirements hold for the concentration of data towards controlling systems up to planning and decision support on the company level (Mertens/Griese 1988). This integration approach is illustrated by the vertical arrow in figure 1.

In figure 2 the relation between horizontal and vertical data integration is represented by an example of the process chain for purchasing. The chain starts with the calculation of the demand and leads to the selection of a supplier and the placement of an order. With the delivery note enclosed, the received commodities are checked by the receipt inspection. After receiving an invoice, it is compared with the order and the goods received. After the checking of the invoice, the record is forwarded to the accounts payable department which generates the entries and arranges the settling of the invoice.

Such a sequence of proceedings may cover a longer period (often several months) and, as the right-hand part of figure 2 shows, is treated by several departments.

In spite of the necessary time, the participation of different organizational units and the inclusion of different documents (order form, delivery note, invoice, remittance slip), progressive EDP-systems handle the operations starting from an integrated database. The data of the preceding functions are made available to the employee in charge of handling a certain case on the screen. The increasing origination of data is represented graphically in figure 2. Each function has access to the data recorded before by other functions. If deviations are discovered, e.g. by comparing the goods received with the order, only the data which are to be corrected are entered. The check of the invoices is also limited to corrections. If there is a high correspondence between order, goods received, and invoice the checking of the invoices may be carried out largely automatically.

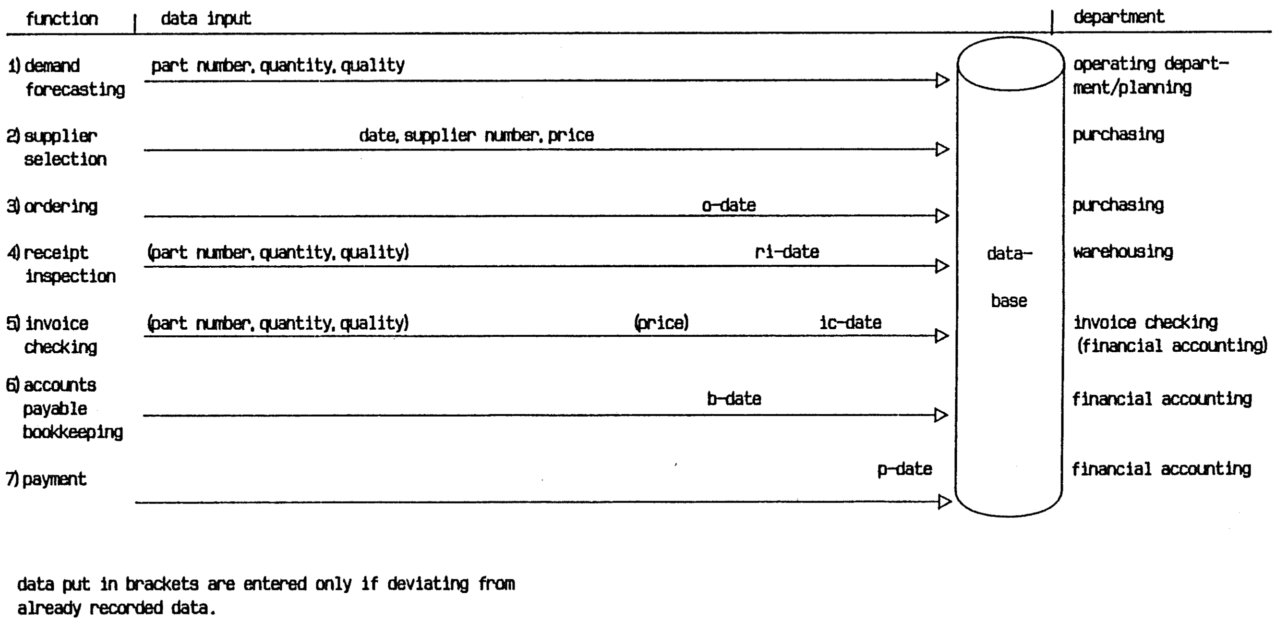

Figure 2: Process chain for purchasing

It is obvious that the subsequent functions in the sequence of proceedings just perform notices of corrections or confirmation. The sequence described first shows the horizontal data integration, as well as the vertical data integration. By selecting the supplier, the order price is already known. Thus, virtually all data for rendering the invoice and even for generating the accounts payable entries are available. Simultaneously to the setting up of the order, a pro forma invoice including a pro forma entry can be created. The accounts payable department can utilize these data structures, so that there is an integration of the operative settling of the order and the parallel value-oriented accounts payable bookkeeping.
In the following, it is shown how data structures must be designed in order to meet the requirements of the horizontal and vertical data integration. Here, the findings of business theory are linked to the methods of structuring data.
This approach leads to an enterprise wide data model (EDM) that includes the essential types of objects with their relations. It is the foundation of both, an integrated handling of operations and the MIS (Management Information System) conception.

B. Enterprise wide Models of Business Administration

Business theory examines business functions in detail; besides, it analyses problems concerning the company as a whole. Because of the variety of issues, different types of description for companies have been developed, among them:

- The Production Factor System developed by Gutenberg. It allows the description of procedures which are essential for industrial companies' outturn (Gutenberg 1983).

- Financial accounting created the terms "account" and "entry", and thereby found a level of abstraction which is highly commendable, as it describes all different processes within a company by a uniform and simple description language.

- By the terms "type of costs", "cost center", and "cost unit" the cost accounting has developed a simple description language to picture diverse business processes.

- Enterprise wide models which have been created by operations research (Rosenkranz 1981 with enumerated literature) describe in detail cross-functional decision problems.

The terms of business description models can be related to the levels of figure 1: The Gutenberg model refers to the operative level, financial accounting to the value-oriented accounting level, the cost accounting model relates to the controlling level, and the operations research model to the level of planning and decision-making systems.
The following consideration is based on the findings of these company models. Because of its closeness to processes the Gutenberg model is helpful to the derivation of data structures at the operative level. The financial accounting model is useful for completing the data structure on the value-oriented level. The terms of cost accounting and operations research can also be related to the developed data structure.

C. "Entity Relationship Model" (ERM) as a Method for Constructing an EDM

The Entity Relationship Model (ERM) was developed by Chen (Chen 1976). Because of its graphic notation (ERM-diagram) and its precise definition, it is a user-friendly communication interface between business knowledge and the formal requirements of computer-based information systems.
The ERM differentiates entities, attributes and relationships. Entities are concrete or abstract objects which are of interest to the company, e.g., suppliers, materials, orders. If entities are regarded as sets, they are denoted as entity types while the individual items are called entities. In the following, entity types are characterized by capitalization and represented by rectangles in the ERM-diagram (cf. figure 3).

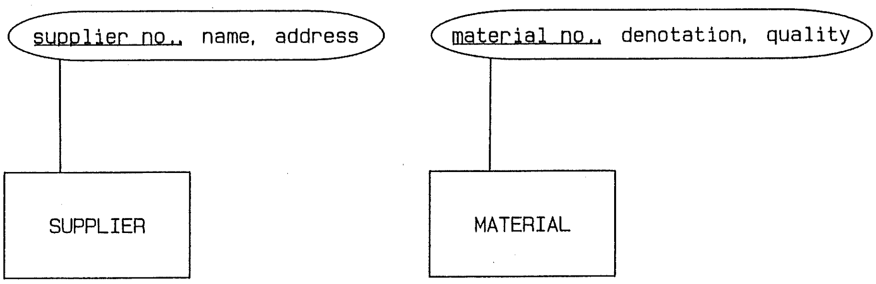

Figure 3: Representation of entity types and their attributes in the ERM

Attributes are properties of entities, e.g. number, name, and address of SUPPLIER. They are related to the entity types by bubbles. Attributes that definitely identify an entity of a certain type are called key attributes and are underlined. In figure 3 these are the <u>supplier number</u> for SUPPLIER, and <u>material number</u> for MATERIAL.

A relationship is a logical connection between two or more entity types. Whereas entities can exist autonomously, relationships can only exist in reference to the respective entity types. A relationship between SUPPLIER and MATERIAL is the delivery denomination "which materials are delivered by which suppliers". If relationships are seen as sets they are denoted as relationship types. Then the individual items (relationships) are the respective associations.

In the following, relationship types are written in capitals, too. They are represented graphically by diamonds and are connected with their respective entity types (cf. figure 4).

Attributes are also related to relationship types. The key attribute is a combination of the key attributes of the involved entity types, here of <u>supplier number</u> and <u>material number</u>.

When a relationship type is constructed, a new term (in the present case SUPPLY) is created by merging two existing terms (SUPPLIER and MATERIAL). This process is called aggregation (Smith/Smith 1977).

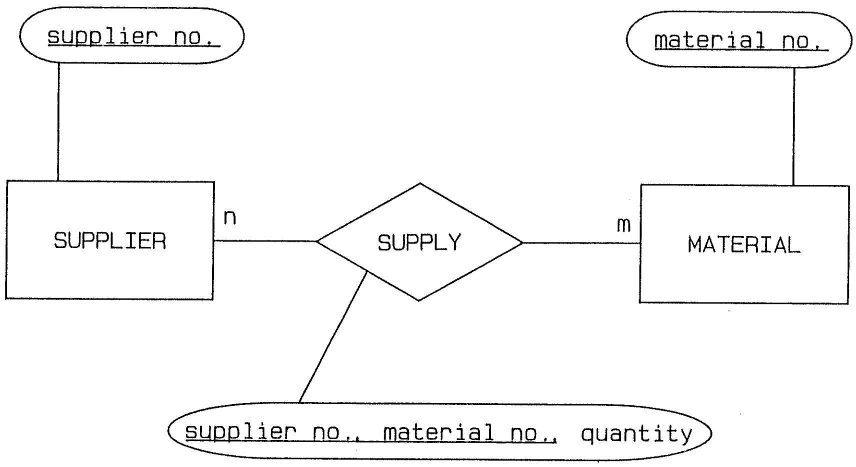

Figure 4: Representation of a relationship in the ERM

An instantiation of the relationship type SUPPLY relates to a certain supplier a certain material that he can deliver. All properties that concern this combination can be associated with this instantiation, e.g. the quantity of material that is purchased from the particular supplier during a period or the stipulated conditions that relate to SUPPLIER and MATERIAL. Generally, entity types are referred to by nouns and relationships by verbs. This can serve as an indication to distinguish between these two.

In the following, the design of entity types and relationship types is emphasized. Therefore, the mentioned attributes are mainly key attributes. Relationship types can be characterized according to the degree of their connection (cf. figure 5).

In an 1:1-relationship, each item of the first entity type is associated with exactly one element of the second entity type and vice versa. In an 1:n-relationship, each element of the first set is associated with n elements of the second set, whereas each element of the second set is associated with only one element of the first set. A n:1-relationship refers to the same situation but in reverse order. In a n:m-relationship, each element of the first set is attached to more than one element of the second set and vice versa.

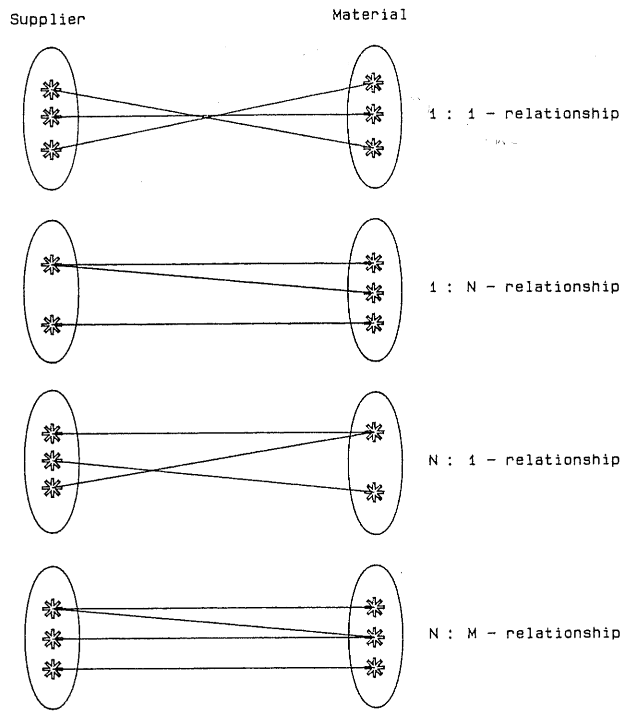

Figure 5: Kinds of relationship between sets

The complexity of the relationship type is indicated at the respective arc. Obviously, the relationship SUPPLY is generally of the type n:m.
A special type of the 1:n-relationship is the hierarchical dependence. In this relation each instantiation of the entity type the relationship emanates from (superior entity type) must be attached to at least one element of the other

entity type (subordinated entity type) and vice versa, to each subordinated entity there must be associated a superior one. These facts are characterized by a double arrow (figure 6 shows this type of relationship connecting an order to the respective order items).

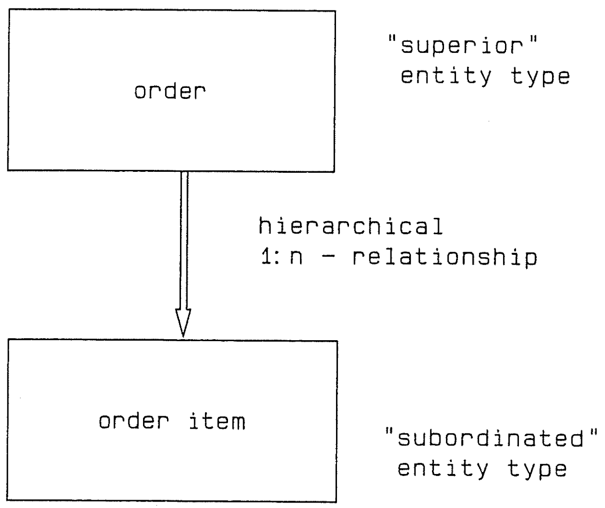

Figure 6: Hierarchical 1:n-relationship

Within the process of constructive design, relationship types can be the origin of new relationship types. Therefore, they are regarded as entity types and rimmed by a rectangle (cf. figure 7). The new relationship type and the border of the rectangle are connected by an arc in order to show the origination of the relationship type. Figure 7 shows SUPPLY (CONDITIONS) as a combination of SUPPLIER and MATERIAL. A stipulated condition (or several ones) can be attached to an order item, and several order items can be related to a certain stipulated condition in the course of time.
The entity-relationship model, published by Chen in 1976, has been refined and improved at several conferences and in numerous publications (Chen 1981; Davis/Jajodia/Ng/Yeh 1983; Batini 1988).

In the following, we will mainly refer to the principal elements introduced so far.

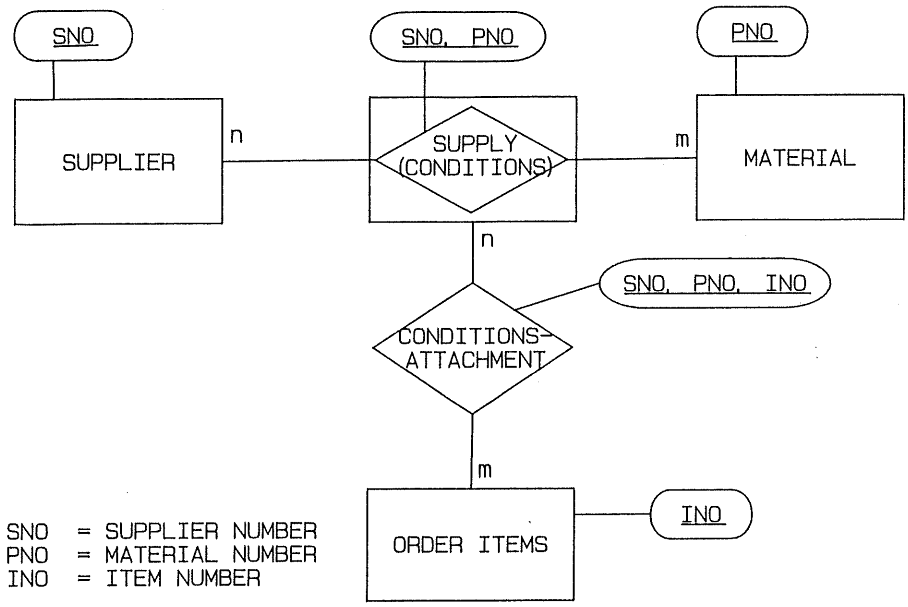

Figure 7: Reinterpretation of a relationship type

D. Constructive Design of the operative EDM

Describing the production process of a company as the combination of resources is a conception derived from the theory of the enterprise. So is the consideration according to which a company maintains business connections with market partners. These conceptions are the starting point for the examination of entity types and relationship types. Figure 8 represents these facts using the entity types MARKET PARTNER, PRODUCTS and RESOURCES. The term MARKET PARTNER means partners of both, the markets for purchasing and selling. The term PRODUCTS includes the output produced by the company, as well as the output that has been purchased externaly. The terms will be specified later. Business relations form a n:m-relationship type between PRODUCTS and the outside world of the company, represented by the entity type MARKET PARTNER. A very good example for this relationship are the stipulated conditions for a customer concerning a specific article. The manufacturing process is described by the relationship type MANUFACTURING INSTRUCTION. It describes how to produce an outturn by employment of resources, equipment, employees, and materials. Since a certain product can often be produced according to different manufacturing instructions and since the resources can go into different products, this relationship type is a n:m-one.

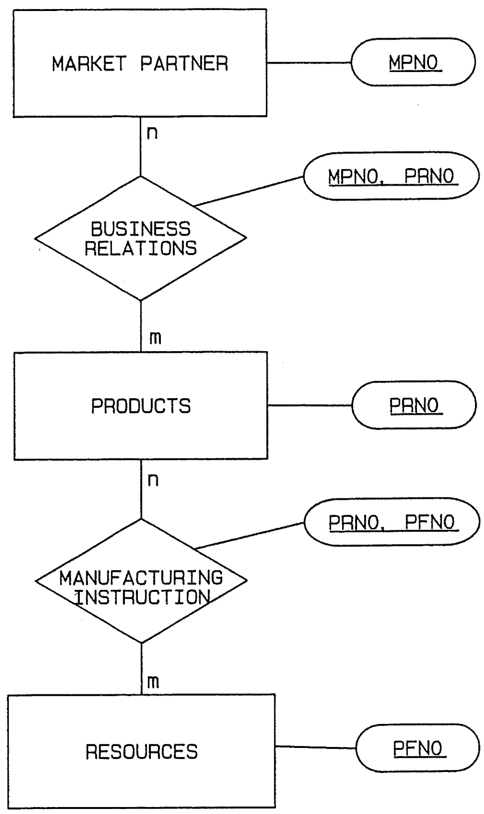

Figure 8: Elementary entity types and their relationships independent of time

The described structure is a static one, i.e. the data structure does not consider time. In EDP-terms, these data are called primary data. This static structure is then completed by proceedings covering distinct periods of time. Typical examples are orders from (or to) external partners or for in-house products addressed to the own manufacturing. By specifying the time relatedness (date), (repeat) orders of the same kind may be identified. Furthermore, this specification serves to describe that - in contrast to static data - these proceedings are only important for the maintenance of data as long as they are not yet processed. In order to represent them, the principal entity type TIME is introduced (cf. figure 9). EXTERNAL ORDERS constitute a relationship between MARKET PARTNER, PRODUCTS and TIME. Similarly, INTERNAL ORDERS have to be interpreted as a combination of TIME and PRODUCTS.

So far, the term PRODUCTS has been interpreted as an output for selling or purchasing from or to MARKET PARTNERS and as in-house products in the context of RESOURCES.

Usually, a marketable output is produced by the invested resources over several levels of manufacturing. This leads to the production of intermediate goods which may be stored and processed into different final-products. These

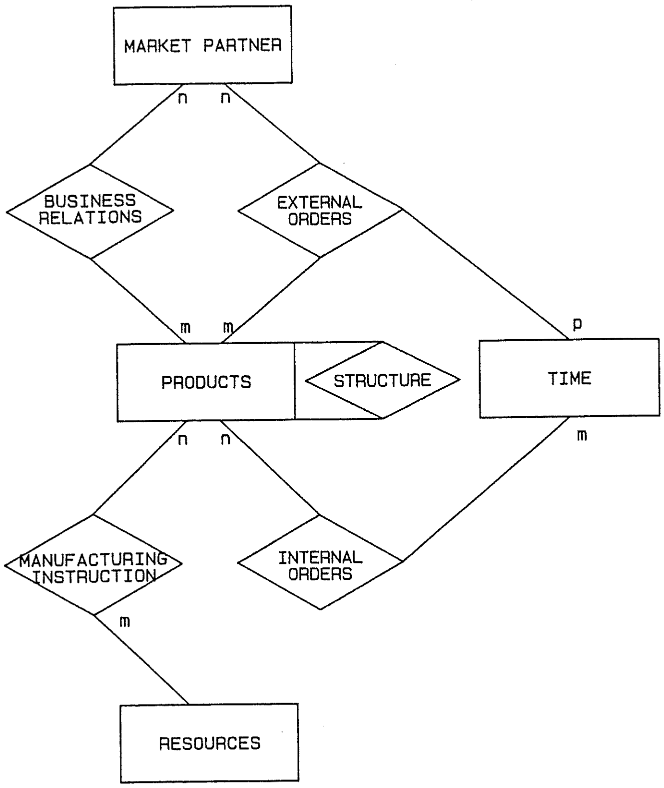

Figure 9: Elementary entity types and their relationships dependent of time

interrelations are illustrated by a diagram (cf. figure 10). The pre-product (intermediate product) B is processed into the final-products P1 and P2 and is itself assembled by the bought-in products (materials) E1 and E2.

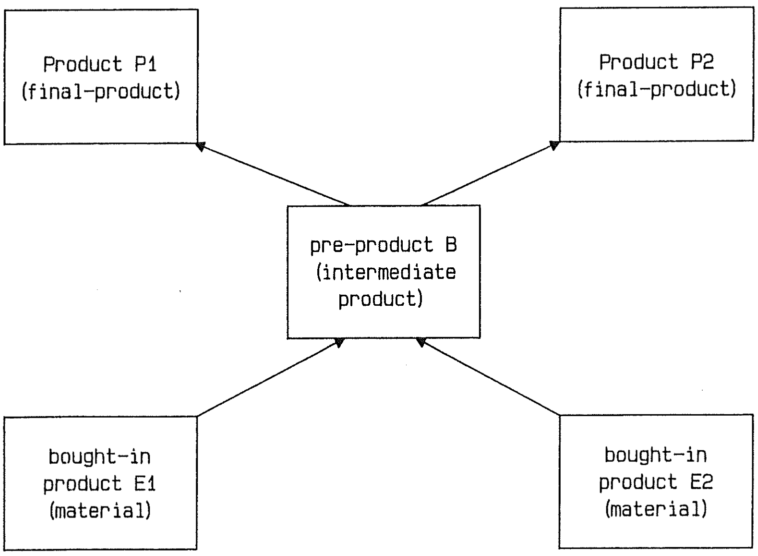

Figure 10: Specification of the entity type PRODUCTS

Applying this broad formulation of the term "products", the flow of material is represented by a n:m-relationship within the entity type PRODUCTS. According to the direction of the flow of material, each product may be regarded as assuming a "superior role" or a "subordinated role" (cf. figure 11). In the present example, only the intermediate product B can assume both roles.

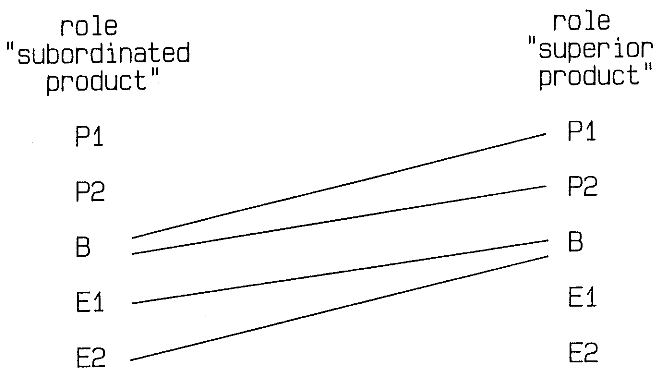

Figure 11: Relationship between superior and subordinated products

In the ERM-diagram (cf. figure 12), these facts are described by the STRUCTURE-relationship. With its help, each connection is identified by a superior (SPPRNO) and a subordinated product number (SOPRNO).

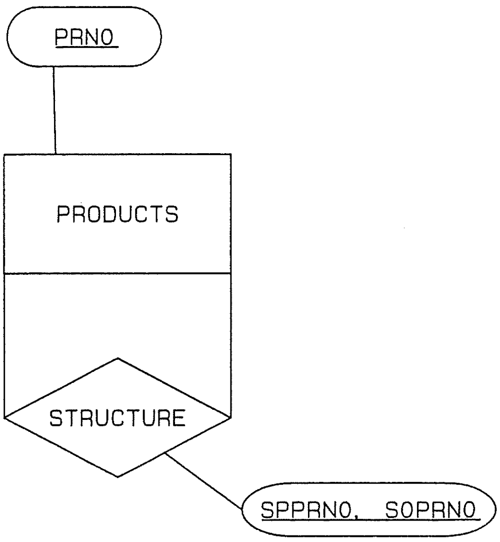

Figure 12: n:m-relationship within the entitiy type PRODUCTS

Since the term PRODUCTS also includes the bought-in products (material, bought-in assembly), the term MARKET PARTNER relates to customers as well as to suppliers. For the same reason EXTERNAL ORDERS relate to both customer-orders and purchase-orders.
Figure 9 already includes the interlocking of production and therefore gives a very general view of the data structure of an enterprise.

In the following steps of our discussion, the data structure will be improved by splitting the introduced terms into more distinct ones. This process will be called specialization.

To achieve this, the entity type MARKET PARTNER is split into the terms CUSTOMER and SUPPLIER. RESOURCES are likewise split into MATERIAL, EQUIPMENT, and EMPLOYEES. In order to describe this step in a diagram, a so-called "is-a"-relationship marking the specialization of a general term into partial terms is introduced in figure 13. At the same time, PRODUCTS are split into MARKETABLE PRODUCTS, BOUGHT-IN PRODUCTS, and IN-HOUSE PRODUCTS. In terms of PRODUCTS, BOUGHT-IN PRODUCTS are a specialization because they cover only materials and assemblies. On the other hand they are a generalization as far as the resources MATERIALS and EQUIPMENT are concerned since EQUIPMENT is not recorded in the bill of material, but nevertheless represents a bought-in product and is for example subject to purchase-orders.
Figure 13 ignores the indication of attributes for reasons of clearness.

This specialization of entity types implies distinctions in relationship types. EXTERNAL ORDERS, which included purchase orders and sales orders in figure 9, are now introduced as independent relationships. Accordingly, BUSINESS RELATIONS between SUPPLIER and BOUGHT-IN PRODUCTS relate to conditions granted by suppliers, whereas BUSINESS RELATIONS between CUSTOMER and MARKETABLE PRODUCTS include data with reference to customers.
The process of specialization is of great importance for the design of information systems. By splitting MARKET PARTNER in SUPPLIER and CUSTOMER the two seperated fields "purchase" and "sales" arise from a previously uniform range of applications, namely the processing of external orders with yet unspecified partners.
Nevertheless, the close relation between both fields is stressed by the symmetric data structures.
Specializing terms at a too early stage leads to a split-up of information systems. With regard to figure 9, it was possible to carry out the processing of external orders by one application software system only; in view of figure 13,

obiously two separated application systems for purchase and sales need to be developed now.

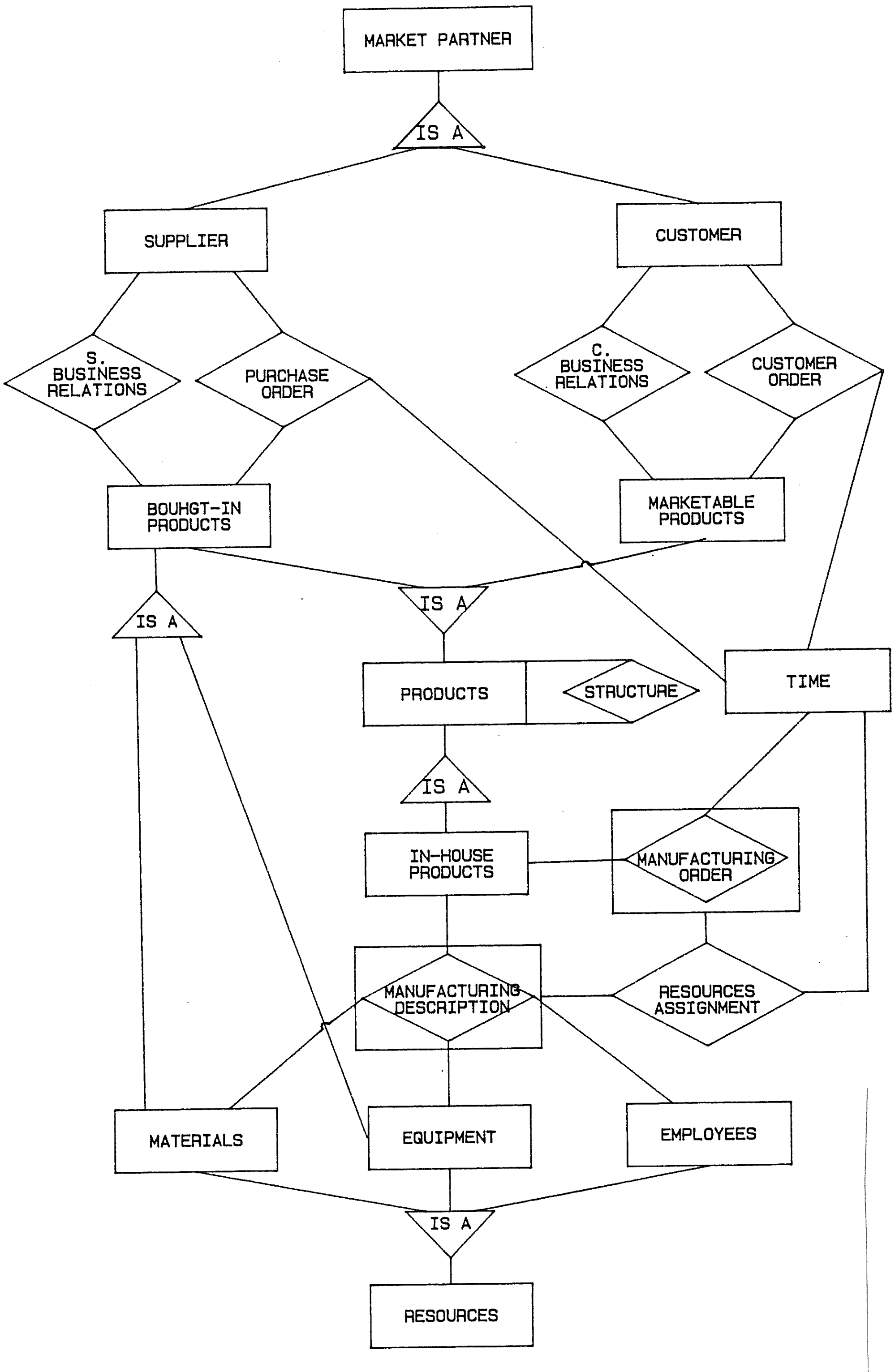

Figure 13: Application of the operation "specialization" to the data structure shown in figure 9

The lower part of figure 13 depicts the manufacturing process. The MANUFACTURING DESCRIPTION contains the information how in-house products are manufactured by the use of MATERIALS, EQUIPMENT and EMPLOYEES. Manufacturing orders are transaction data and are therefore related to the entity type TIME. A manufacturing order is comprised of the kind of output to be produced (expressed for example by a part number), the date of completion, and the quantity to be produced. The planning of the order based on the resources leads to a relationship between MANUFACTURING ORDER and the assigned MANUFACTURING DESCRIPTION. This relationship is called RESOURCES ASSIGNMENT. In order to carry out this process, the manufacturing order has to be re-interpreted as an entity type previously. Though it has been constructed as a relationship type, it has now the character of an entity type in view of the relation RESOURCES ASSIGNMENT. This distinction is also visible in the diagram: when introducing MANUFACTURING ORDER, the arcs lead immediately to the diamond, whereas when introducing RESOURCES ASSIGNMENT, they start from the borders of the rectangle.

The enterprise wide data model of figure 13 is still on a high level of abstraction. For application in the real world, it has to be refined by constant specializations. This task was accomplished by Scheer (Scheer 1988b) for an industrial company. This specific enterprise wide data model includes about 300 entity types and relationship types of the operative fields of production, purchasing, sales, personnel, and technology. Figure 14, representing a section of the purchasing field, gives a rough idea of the sophistication of the model. It is a further specialization of the network of the entity types and relationship types SUPPLIER, S.BUSINESS RELATIONS, PURCHASE ORDER, and BOUGHT-IN PRODUCTS, which have already been shown in figure 13.
The figure describes the primary data management of suppliers, supplier conditions, bought-in products, and order types. Furthermore, it shows the purchase order processing, starting from the collecting of offers to the placing of an order and the arrival of the goods. The delivery plans and inspection plans are stated as specializations of conditions.

E. Linkage between the operative EDM and value-oriented Information Systems

As already explained while dealing with figure 1, quantity-oriented administration and disposition systems are followed by value-oriented accounting systems. In many cases, a quantity-oriented process passes directly into a value-oriented process as shown in the description of the process chain involved

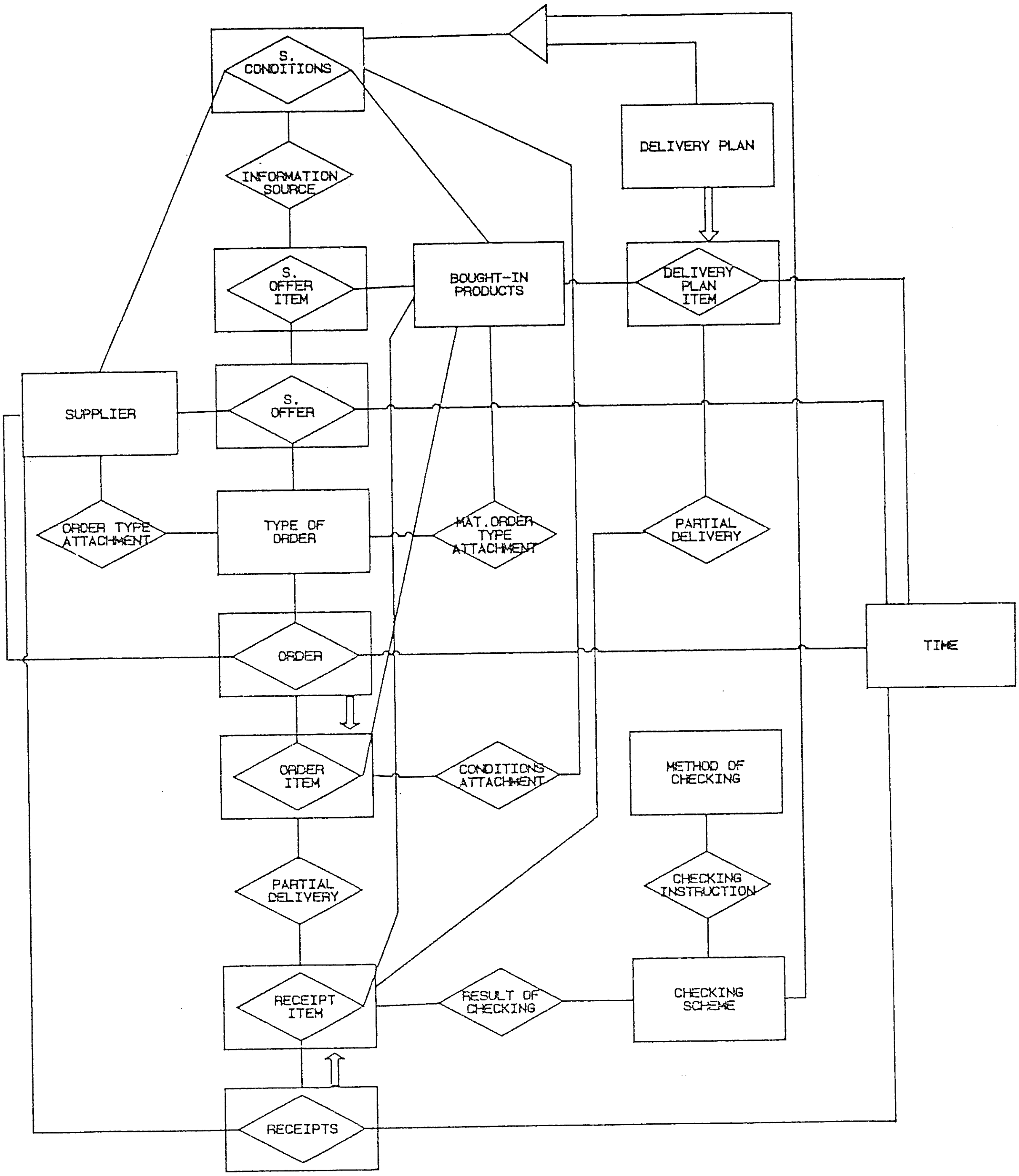

Figure 14: ERM: Receiving

in the processing of an order in figure 2. This connection is also established in an enterprise wide data model by passing data from the operative level directly to the level of value-oriented information systems. Figure 15 shows

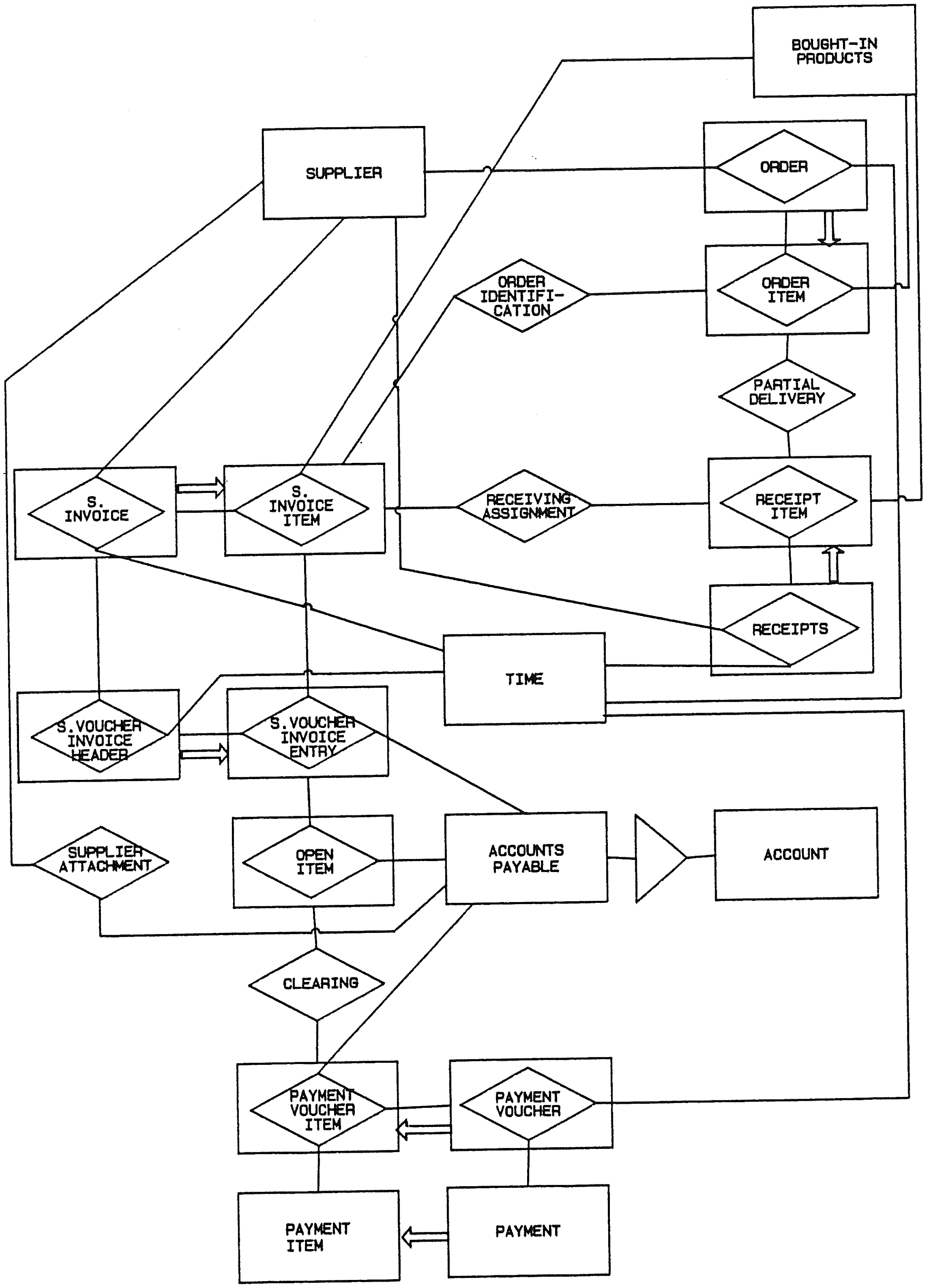

Figure 15: ERM: Accounts payable bookkeeping

this connection for the continued processing of the order introduced in figure 14. It starts with the receipt of the invoice. The supplier's invoice (S.INVOICE) is a relation between the entity types SUPPLIER and TIME. The respective items of the supplier's invoice which are initially designed as a relation between S.INVOICE and BOUGHT-IN PRODUCTS, are attached hierarchically to S.INVOICE. By associating S.INVOICE ITEM with the already existing ORDER ITEM, a direct access to the data of the order is possible. The same holds for the relation between the already set-up RECEIPT ITEM and S.INVOICE ITEM. Though there are still different terms for order item, receipt item, and invoice item, the data are mainly the same. By selecting a superior term, it would have even been possible to standardize the three terms, denoting their different character by a respective specification of their status.

The transition from the invoice to the sphere of accounts payable bookkeeping is illustrated by the term "voucher". Each invoice has a voucher associated with it. Recording new data is not necessary, instead a connection to the data of the operative level is established. The accounts payable bookkeeping connects the posting operations which are related to the respective accounts with the voucher. This involves that several concrete entries which affect different accounts may result from one bookkeeping voucher. The entry "receipts/liabilities", for example, affects the accounts of the creditor, of the concerned material and the value-added tax account. The entity type ACCOUNTS PAYABLE is connected with the entity type SUPPLIER by an association. A supplier may have several creditor accounts; vice versa, several suppliers (who for example belong to the same company, the creditor account has been opened for) may be affected using one creditor account.
After the auditing and the accounts payable bookkeeping, the payment is arranged. Several payment items may be assigned to one payment. Again, each payment leads to a voucher within the scope of the financial accounting. The payment voucher items are connected with the open items by a clearing.

The example of figure 15 shows the connection between the operative process of an order and its handling by accounting. In the following, this relation is generalized by characterizing the connection between operative systems and the financial accounting by data structures.

The financial accounting (the term also covers all so-called auxiliary-bookkeepings) lists the valuation of all transactions of an enterprise. For this reason, it uses the entity type ACCOUNT with the related entries as data structure. By introducing the term ACCOUNT a high abstraction of the different kinds of transactions is achieved. Figure 16 shows this process using operations of generalization.

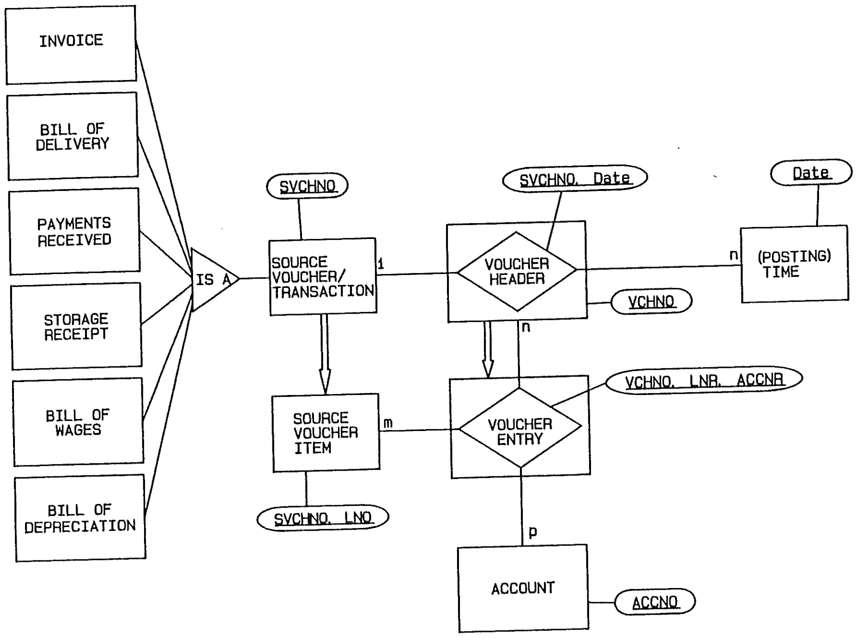

Figure 16: Data structure of a voucher

The entity types cited on the left-hand side represent data elements of the operative systems, which characterize transactions. Each transaction is charaterized by a SOURCE VOUCHER that contains a so-called head-information. Individual SOURCE VOUCHER ITEMS, in which the data referring to the transaction are entered, are connected with the SOURCE VOUCHER. Here, an invoice, which originally consists of an invoice header and the individual invoice items, may serve as an example. The double-arrow between SOURCE VOUCHER and SOURCE VOUCHER ITEM expresses again the hierarchical 1:n-relationship which implies that the head-information requires at least one line position and vice versa. By the first step of generalization, the multiple transactions are reduced to a uniform "format".

The next step includes the transition into the sphere of the financial accounting, where the introduced term ACCOUNT is related to the transactions. Each transaction is represented by a standard voucher. The VOUCHER HEADER is a relation between the specific TRANSACTION and the (POSTING) TIME. Individual voucher items which characterize an entry are attached to VOUCHER HEADER. Analogously, the respective VOUCHER ENTRY is connected with the ACCOUNT and with the SOURCE VOUCHER ITEM that causes the entry. In this process a source voucher item (e.g. an invoice item) may involve several entry items, for example if an invoice item leads to entries in the account payable bookkeeping and to balance entries within the real accounts of the material management. Analogously to the hierarchical source voucher item, a hierarchical relation is also set up between VOUCHER HEADER and VOUCHER ENTRY.

If the transactions designated as source vouchers are already recorded in the enterprise wide data model, the vouchers may either be produced largely automatically, or they just have a virtual function, which consists in the direct access from the superior layer of the information pyramid to the subordinated data level.

This context is shown in figure 17 according to which a section of the operative data structure is displayed on the lowest level, a section of the financial accounting on the next level and, superior to these levels, a section of the data structure of the cost accounting, or the controlling. It is shown that for example the cost accounting term COST UNIT is a generalization of the terms SUPPLIER, CUSTOMER, PART, and ORDER which have been introduced at the operative level. The connection between SOURCE VOUCHER or SOURCE VOUCHER ITEM and the terms of the operative level is also indicated by an "is-a"-relationship.

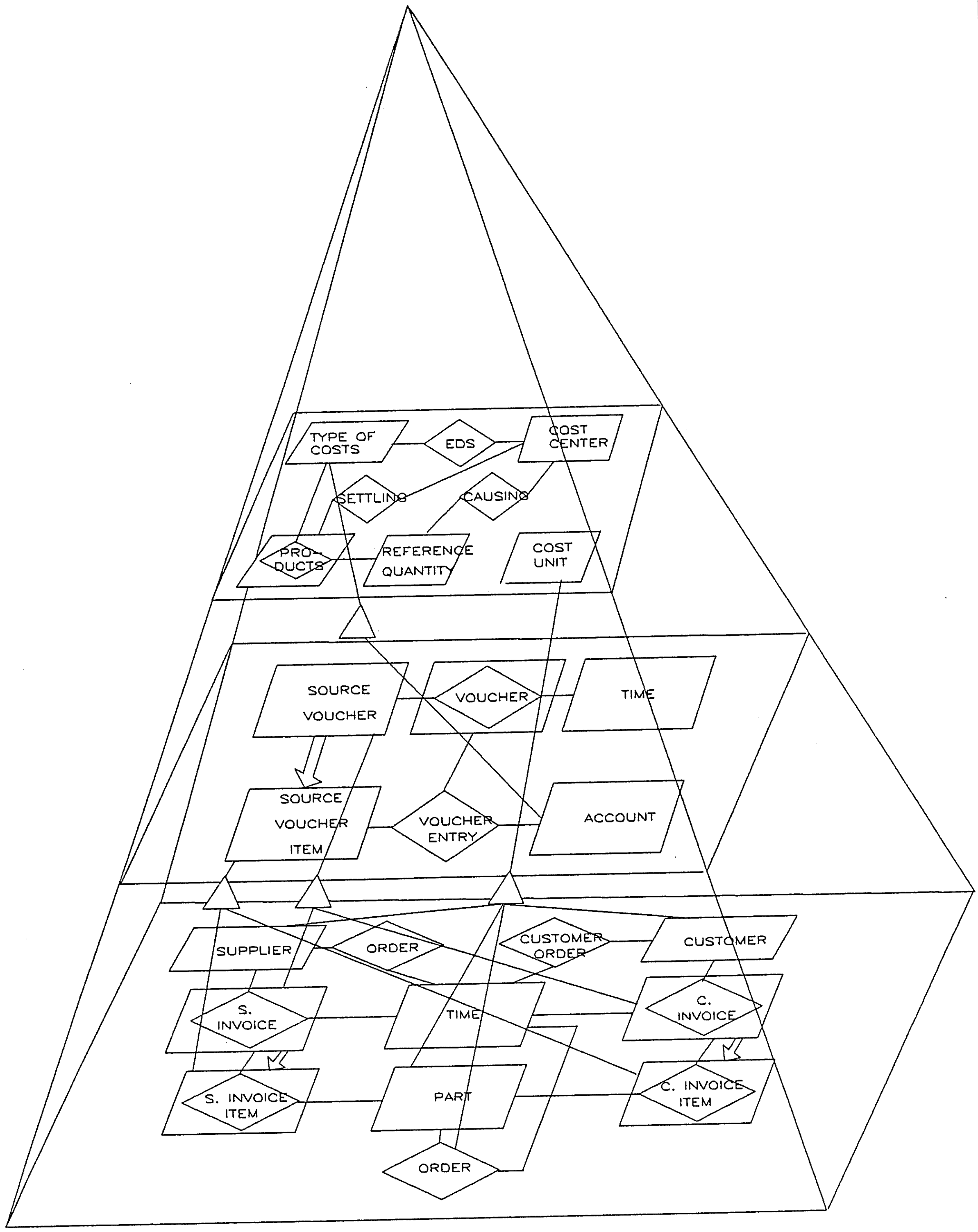

Figure 17: Example representing the further use of data structures

F. Embedding of the EDM in the Design Process of an Information System

The design of an enterprise wide data model is a relatively extensive process (Filteau/Kassicieh/Tripp 1988). First of all, the extent of particularization of the model needs to be determined. One should take into account that the extent of particularization has to be maintained uniformely over all levels of application. The design requires cross-functional knowledge and knowledge concerning the vertically continued utilization of data up to the strategic planning (cf. figure 18).

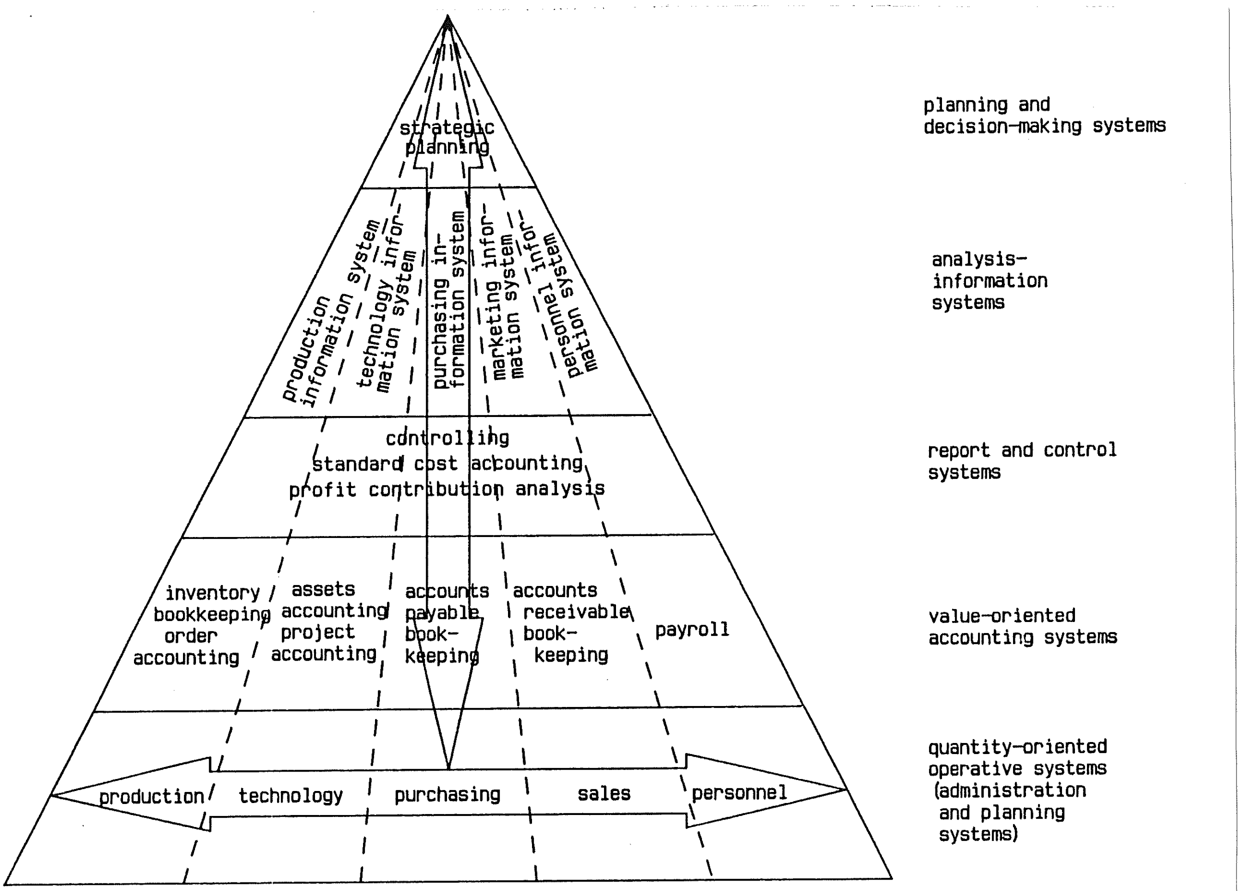

Figure 18: Integrated information systems

An existing pattern of an enterprise wide data model (Scheer 1988b) may therefore serve as a basis for a specific design which will be adjusted to branch and company particularities.

The EDM is an important first step to establish an enterprise wide information system.

The design of the logical data structure forms the interface between technical knowledge and a formalization which is necessary for the processing by information technology.

The transition from the logical data structures to the formal requirements of a data model (cf. figure 19 in Wedekind 1981) represents the second step. Data models are formalized aids to describe data structures, emphasizing certain views. The network model for example exhibits a close connection between the physical implementation and the logical description of the data structure, whereas the relational model permits a mathematical projection of data structures which is independent of the implementation (Wedekind 1981; Scheer 1988b).

Specific database management systems are based on data models. With the help of the so-called Data Description Language, database management systems provide the possibility of describing data structures, which enables the database system to employ these descriptions in the process of data management (Tsichritzis/Lochovsky 1982; Ullman 1980).

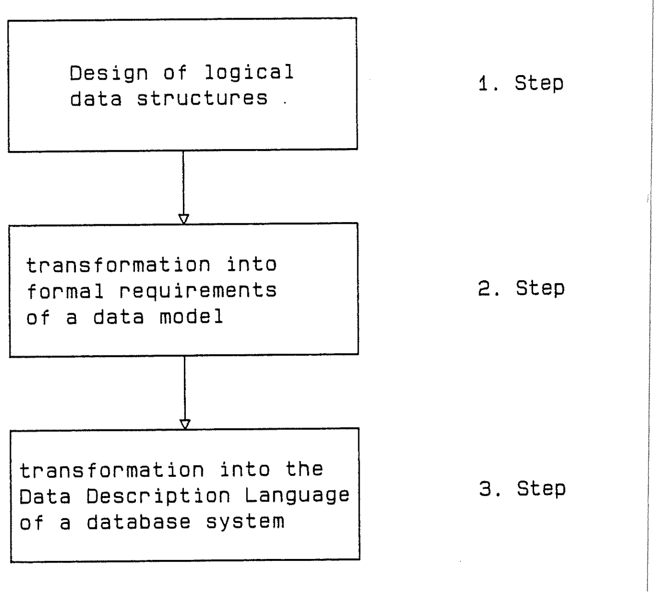

Figure 19: Formalization of an existing problem

It is generally known that the first step of the design of information systems, i.e. the interfaces between application knowledge and the first approach to formalization, is most important for the success of an information system. Mistakes made on this level have disproportionately negative effects compared with mistakes made in an advanced, more detailed phase of design. This also applies to the design of data structures.

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