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Integrated Data Structures and Business Objects in ERP: Tool Development and Evaluation in SAP ERP System

Premaratne Samaranayake, Ashini Wesumperuma and Athula Ginige

Abstract— **Enterprise-wide data is central for timely and effective planning of materials, activities, operations and resources; and execution of those plans across many functional areas. Today, widespread use of Enterprise Resource Planning (ERP) systems has exacerbated a need for integrated data and visualisation of such data over many functional applications. In this research, integrated data structures are implemented in an ERP system, through a set of business transactions with visual business objects. Visualisation of integrated data structures is illustrated using a make-to-stock business scenario. It is shown that existing data of ERP systems can be integrated using additional relationships to form a foundation for simultaneous and forward planning of many components. Various business objects of integrated data structure are visually represented using Scalable Vector Graphics (SVG), an XML based technology. SVG forms a software component within the selected ERP system with the capability to display business objects and their linkages. It is shown that the concept of data integration and visualisation enables data maintainability, flexibility and transparency for better planning of manufacturing processes. The paper concludes by describing key features of integrated data structures and visual business objects implemented in the selected ERP system.**

Index Terms— **Bills of materials, Data structures, Planning and execution, Operations routings**

I. Introduction

In recent times, the significance of data and its characteristics such as data integrity, transparency and real-time access have attracted much attention among many researchers and industry practitioners [1]. This has been further emphasised by the widespread use of ERP systems, which provide enterprise-wide data, data integrity and real-time data access for various functional areas. ERP systems bring together a number of functional modules for planning, control and execution of enterprise-wide resources. These functional modules include Production Planning (PP) module with a comprehensive set of tools for manufacturing planning and control (MPC) [2] . In this regard, MPC covers a broad range of manufacturing industries from mass production to project-based manufacturing [3]. Application of MPC across many industries embodies various aspects ranging from long-term planning of materials/resources to short-term execution/follow-up of various plans involving materials, resources (machines, labour, etc), suppliers and customers. In today's business environment it is necessary to have current information available to remain competitive.

ERP systems such as SAP, Oracle Applications, PeopleSoft, The Sage Group [4], Microsoft Dynamics and SSA Global Technologies provide revolutionising ways to integrate MPC within ERP systems [5]. However, these technologies do have drawbacks. One such drawback is the complexities involved in the implementation and configuration of those systems to suit individual requirements. Further, organisations are finding it difficult to access big picture data and related processes that they may require due to the existence of functional silos, lack of data integration and interfacing among these silos [6]. Furthermore, there has been some research [7-9] on specific aspects of data and application integration. Themistocleous et al. [9] examined enterprise application integration (EAI) as the way forward in addressing data integration in supply chain management (SCM). Ma et al. [10] proposed meta-structures and systematic development of data modelling and integration. Further, Agt et al. [7] presented a methodology for software and data integration based on meta-models. They looked at software and data integration scenarios and generated multi level modelling environments and developed a set of domain specific languages for several platforms including ERP. Moody [11] proposed a multi-level architecture to represent enterprise data models. His approach was to add an extension to entity relationship models to represent multiple levels of abstraction. However these research activities do not describe in detail the hierarchical and sequential data integration in broader ERP systems, in particular within MPC.

There has been some reported research on data modelling and their applications in standalone or integrated systems [8, 12-15]. Work based on traditional entity relationship (ER), Zhou et al. [15] provides a generic and adaptable data model for manufacturing execution systems (MES). Similarly, Ma [8] provides selective bibliography of engineering information relevant for developing engineering information systems. Both data model [15] and bibliography of engineering information [8] are limited to either data modelling and/or to very specific manufacturing execution areas. However, there is a range of data and information relevant to functional applications which form the basis of ERP system, much more than just a specific manufacturing area considered by Ma [8]. Much attention has been directed at conceptual data modelling of engineering

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information [13, 16]. Further, Liang and Ginige [12] proposes smart business object for web applications. However, their approach confines to only data models but has no bearing on processes and integrated data structures as being used in ERP systems with cross-functional applications based on best business practices. Although these research activities attempted to improve data in ERP, almost of all of the activities mainly focus on data modelling or systems with limited functional applications with ERP context.

Recently, Samaranayake [17] proposed enhanced data models for master and transaction data in ERP systems, using unitary structuring technique [18]. The unitary structuring technique combines hierarchical bills of materials (BOM) with sequential operations routings and activity project networks. These enhanced data models eliminate manual interfacing and non-value added steps involved in existing business transactions of functional modules of ERP systems. For example, production order cycle as part of broader manufacturing planning and control, involves a number of manual steps such as capacity levelling and component availability checking. These lead to longer manufacturing lead-times. Samaranayake [19] examined traditional MPC approach with existing data against a holistic approach with integrated data structures and confirmed that the lead-times are significantly improved in the latter. Even though data integration is addressed from a theoretical perspective, the lack of integrated data structures with visual presentation in a system environment is a prominent problem and a drawback from a usability perspective. For example, infinite loading of resources using current data models requires manual capacity levelling during execution of operations. Although many ERP systems provide a graphical framework for individual data structures (hierarchical BOMs, sequential operations routings and project networks) and manual functions (graphical view for capacity levelling), they do not provide a visual representation of integrated data structures. This suggests that there is a need for integration of data structures and visual presentation in an ERP system for better planning of many types of components (materials, activities, operations and resources) and execution of those plans, in particular enhanced production planning as part of MPC.

Thus, the main purpose of this research is to build a framework that visualizes the integrated data structures in MPC within an ERP system. Further, integrated data structures when implemented in an ERP system with capabilities of visual representation can be used to represent additional relationships between data elements. This then will improve planning/execution methods over many functional applications and resulting in better decision making. Since data is identified as one of the most coveted assets in an enterprise, integrated data structures form a fundamental resource in business intelligence (BI) aimed at better business decision making [20]. In this research, integrated data structures are derived from exiting data models and this would allow intelligent information to be extracted from enterprise-wide data. Further, this information would then be presented in a graphical format aiding competitive business intelligence as an additional benefit.

The paper first outlines the research methodology, followed by an overview of existing data models and limitations of current functional applications. Next, integration of data structures, using unitary structures is discussed. Thereafter, an overview of implementation of integrated data structures is presented. In this regard, SAP ERP system (market leader in ERP solutions) is selected as the platform for implementation, for its ability to support software components required for visual representation of integrated data structures and business objects. Graphical representation of integrated data structures is illustrated using a selected business scenario and corresponding master data maintained in the SAP ERP system. Finally, the paper concludes with the findings of this research and future directions.

II. RESEARCH METHODOLOGY

The research methodology adopted in this study involves experimental testing of integrated data structures [17] in an ERP system, using implementation of visual representation of integrated data structures and associated planning methods. Experimental testing is based on a selected test case, illustrated with practical aspects of integrated data structures and visualisation in SAP ERP system. The following steps are planned for the implementation of integrated data structures and their visualisation.

Step 1. Identification of current data models and limitations in current functional applications

Relational data tables of existing data structures (BOMs, operations routings) in SAP ERP system are identified first. Additional data tables required for the integrated data structures are defined using attributes and relationships. Based on attributes, relationships and other technical aspects of defined tables for integrated data structures, the integrated data structures are mapped into a structure that can be seen as data objects within the system.

Step 2. Integrated data structures using unitary structuring technique

Integrated data structure, based on unitary structure is configured using a simple business scenario selected within production planning module of SAP ERP. In this case, the selected data definitions/tables are taken into consideration, when creating a single data table for the integrated data structure. The data table of integrated data structure is a combination of data fields, based on the knowledge (attributes, relationships and technical aspects) of hierarchical BOMs, operations sequence, component allocations and other relationships.

Step 3. Identification of technical requirements for implementation of integrated data structures

Technical capabilities in particular graphical aspects of SAP ERP system for developing integrated data structures and visual business objects are analysed. This analysis includes identification of technical constraints of SAP ERP system, in supporting implementation of integrated data structures and their graphical visualisation. Thus, technical requirements within SAP ERP system are identified, for developing integrated data structures and their visualisation with required links/relationships with existing data models.

Step 4. Visual representation of integrated data structures

The integrated data structure, identified and maintained with a single data table outlined earlier, is displayed in a graphical format. This involves significant amount of coding within SAP ERP system that generates SVG data from the underlying integrated data structure. As part of this process, the integrated data structure is expanded into one that does not have overlapping components within the same BOM level, using nesting procedures [21]. Application of nesting procedures, as part of this step, would have meant that the graphical components would not overlap each other and make it easier to visualise. The SVG data was then passed into an HTML control with an embedded SVG viewer to display the graphical representation and business objects. Business objects represent details of each data element (material, operation, activity, resource) using data attributes of each data element stored in the database of SAP ERP system.

Step 5. Numerical evaluation and model validation

Planning/execution methods developed earlier [2] for simultaneous planning of materials, resources, activities and operations of integrated data structure, with forward planning capabilities are implemented in SAP ERP system. This involves implementing of scheduling paths [22] and planning algorithm [23], using a set of business transactions. Planning of integrated data structure of various data elements (materials, activities, operations and resources) is based on a given set of demands (main input) for the finished product of the integrated data structure and schedules all data elements involved, using holistic approach to planning of many data elements. The planning results are stored in the SAP ERP system and are supported by existing manufacturing planning and control (MPC) functionalities.

III. Overview of Existing Data Models and Limitations in Current Functional Applications

Manufacturing planning and control (MPC) systems have evolved around materials requirements planning (MRP) and forms the core of the Production Planning (PP) module of ERP systems. MPC system performance directly influences organization performance, in particular on-time delivery, customer service level, quality and productivity. MPC system performance is influenced by many aspects such as functionality of each module; and integration of data and applications as well as system parameters such as MRP control data including manufacturing lead-time. In the recent past, the need for improving MPC systems, in particular planning of various data elements (components) with improved lead-time intensified with the increasing process approach for flexibility in planning, automation of workflows and optimisation of resource utilisation [19].

Currently, MPC systems in ERP system environment use mainly hierarchical BOMs and sequential operations routings for planning of many components at different levels. Planning of components and execution of those plans, using current data structures in ERP system involve at least two levels: planning of materials and resources independently, followed by capacity levelling for finite loading of resources at the time of execution of those plans. This leads to longer manufacturing lead-times, due to independent planning of materials and resources; and slack times built-in for manual capacity levelling of resources and other activities. Further, planning of materials is based on lot-size independent lead-times while execution of material plans is carried using operation times. Although operation times are incorporated into material plans for better reflection of lead-times, capacity evaluation for finite loading of resources is carried out manually during execution of material plans, leading to possible changes to scheduled start and finish dates/times. On the other hand, integrated data structures form the basis for lead-time improvements in manufacturing planning, control and execution. Transaction data including planned and production orders based on integrated data structures and execution activities eliminate various manual interfacing associated with the overall manufacturing planning, control and execution cycles. Thus, the integration of various data elements/structures enables reducing the lead-time by eliminating slack times within planned and production orders. The associated planning/execution methodology provides forward planning, simultaneous planning of materials, resources, operations and project activities and finite loading of resources. The results show that in general, manufacturing lead-time, based on integrated data elements/structures is shorter than that of original lead-time set as a parameter in an MPC system. Further, it is shown that the implementation of integrated data structures and associated methodology in ERP can be carried out using additional functions and associated business transactions. Once implemented, the data and information are visible and transactions associated with them are more flexible and transparent.

Overall, holistic approach for planning and execution incorporates capacity planning with finite loading of resources, simultaneous planning of all components involved and forward planning capabilities, based on integrated data structures [19], using unitary structuring technique [18]. The complete planning and execution process using integrated data structures is described by three levels:

(i) Integrating master data using unitary structuring technique [18]

(ii) Scheduling paths of components for forward and backward planning of all involved [22]

(iii) Planning of materials, operations and resources with capacity requirements and finite loading of resources [23]

In this case, a manufacturing business scenario of make-to-stock situation is considered. The finished product is an assembly of a semi-finished product with a number of raw materials. Planning of components is subject to various planning and execution methods within ERP system for meeting customer demands on time. In order to implement integrated data structure associated with this business scenario in an ERP system, the product and process details are maintained with a set of master data in current form. Master data include material masters for the finish product, sub-assemblies and raw materials; operations routings for the finished product and sub-assemblies representing all the steps/activities involved; resources and bills of materials representing product structures. Apart from the above mentioned master data, a number of other master data including cost centres are adopted from the ERP system for planning and execution of all involved. Once the required master data for the business scenario are maintained in the ERP system, integrated data structure of hierarchical BOMs and sequential operations routings is maintained, using developed business transactions within SAP ERP system environment. Planning of components of the integrated data structure can be carried out using planning methods developed as part of implementation of the integrated data structures and holistic approach for planning and execution.

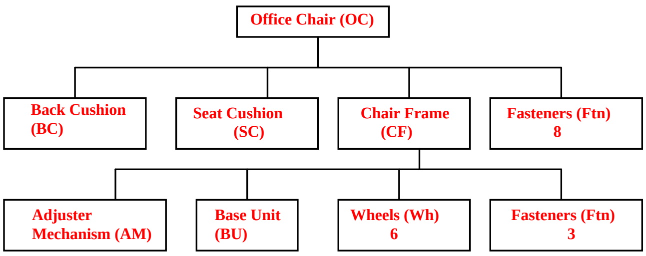

Figure 1: Product structure of the office chair

As briefly outlined, the above business scenario requires at least five key master data types maintained in SAP ERP system. These master data types include materials, BOMs, operations routings, work centres and cost centres for planning, control and execution of all involved. Individual master data of different types are derived from the product structure (Figure 1) and are maintained in the SAP ERP system, including a complete set of operations of the office chair (OC-200). The product structure with the finished product (OC-200), sub-assembly of chair frame (CF-303) and a number of raw materials (BC, SC, Ftn, BU, Wh and AM) are maintained as individual material masters. Two bills of materials are then maintained: one each for the office chair and chair frame. Since the complete product structure consists of two single-level BOMs, as an ERP system usually maintains, there are two operations routings: one for each single-level BOM of the product structure. The resulting operations routings are shown in Tables 1 and 2.

Table 1. Operations Routing of Chair Frame (CF-303)

Operation ID	Description	Work Centre	Set-up (min)	Machine (min/unit)	Labour (min/unit)
10	Cutting (CU)	T-M99	30	2	2
20	Bending (BE)	T-M99	30	2	2
30	Welding (WE)	T-M99	15	5	5
40	Painting (PBU)	1906	30	2	2
50	Assembly/ Adjustment of AM (AAM)	1904	30	10	5
60	Painting AM (PAM)	1906	30	2	2
70	Assembly of Chair Frame (ACF)	1904	15	10	10
80	Inspection (ICF)	1720	0	0	5

Table 2. Operations Routing of Office Chair (OC-200)

Operation ID	Description	Work Centre	Set-up (min)	Machine (min/unit)	Labour (min/unit)
10	Fabric Cut for Back Cushion (FBC)	2050	15	2	2
20	Back Cushion Assembly (ABC)	1904	15	5	5
30	Fabric Cut for Seat Cushion (FSC)	2050	15	2	2
40	Seat Cushion Assembly (ASC)	1904	30	5	5
50	Final Assembly and Inspection (FAI)	1720	15	5	10

In order to allow for components' availability at the scheduled start of relevant operation(s), components of the BOM for the office chair can be assigned to appropriate operation(s) using component allocation functionality. In this case, as depicted in Table 1, component base unit (BU) is assigned to operation 10 by default. Further, adjuster mechanism is assigned to operation 50 while wheels (Wh) are assigned to operation 70. Similarly, back cushion is assigned to operation 10, seat cushion is assigned to operation 30 and fasteners are assigned to operation 50.

It is evident from operations routings and component allocations that all of the key data can be maintained using various levels, for further processing during appropriate planning, control and execution methods. Materials, work centres and cost centres have no implications during planning/execution runs since they are simply values against other data within transaction data. However, BOMs have some implications when combined at the time of production order creation. Apart from those two data structures, additional functions come into the picture when a production order is created using such data elements and structures. Additional functions include component allocations, goods issues, good receipts and order settlement. However, the production order as a transaction data at this level does not have the capability of adding those functions into structured transaction data, rather the information is copied into the production order. Thus, the aspect of data being copied rather than directly linked to the database, and the need for separate functions during the order creation and beyond, limits the capabilities of smooth processing of production orders and/or other transaction data created with these data elements. However, these issues can be handled using unitary structure-based transaction data.

Master data described above are candidates for integrated data structures so that planning, control and execution can be streamlined and enhanced using additional functionality. For example, integrated operations routing with BOMs can eliminate component allocations in production order cycle. Further, longer lead times associated with sequential operations can be reduced when operations are integrated into BOMs, using operations routing of both sequential and parallel operations. Thus, integrated data structures form the basis for simultaneous and forward planning as well as finite loading of resources. An example of such integrated data structure, based on the business scenario outlined earlier, is presented next.

IV. Integrated Data Structures Using Unitary Structuring Technique

Since the unitary structure-based integrated data involves both hierarchical BOMs and sequential operations with additional relationships between components, the planning of such structures requires identifying (i) a sequence of explosions of the data structure and (ii) planning of components with finite loading of resources. In this regard, the sequence of explosions is based on scheduling paths [24]. The sequence of explosions of the integrated data structure replaces the traditional explosion of hierarchical BOM using low-level codes as part of the MRP process. In this case, the scheduling paths for the integrated data structure are identified by two sequences: “following sequence” and “preceding sequence”, for backward and forward planning of components respectively. Backward planning can be used to plan all the components including finite loading of resources, using “following component sequence” for a given set of demands for the finished product (office chair). The planning of the integrated data structure results in a combination of materials requirements, capacity requirements and capacity levelling of resources.

In order to arrive at scheduling paths (both preceding and following sequences), each component is numbered starting from the finished product level (the office chair) with a multiplication of 10, until the data structure is complete. Although each activity is attached with a resource, only activities are numbered since each activity is attached with only one resource for simplicity. Thus, scheduling sequence is simplified by one sequence number for each activity and corresponding resource. However, each activity can be expanded with different resource categories (labour, machine, energy, etc) at the time of scheduling of components.

Given each component is numbered as shown in Figure 2, scheduling paths for both backward and forward planning of components are identified. Scheduling paths depend on the type of component (material, activity, resource, operation, etc) and the component relationships (parent-component, component-component and activity precedence). In this case, the preceding component(s) and following component(s) are identified for each component starting from the first item, until the last item of the integrated data structure is reached. The resulting scheduling paths (preceding and following sequence of component(s)) for the entire unitary structure are shown in Table 3. Based on the scheduling paths and the integrated data structure, materials requirements are determined; activities and corresponding resources are scheduled with start/finish dates, using BOM explosion and operations scheduling. Planning of the integrated structure requires bill level of each component, which is based on the original BOM level. Bill levels of each component and other important fields required for the planning of the integrated structure are shown in Table 3.

In this case, the hierarchical BOM shown in Figure 1 is integrated with sequential operations routing (Tables 1 and 2) to make a unitary structure-based integrated data structure (Table 3). The resulting graphical representation of the data structure is shown in Figure 2.

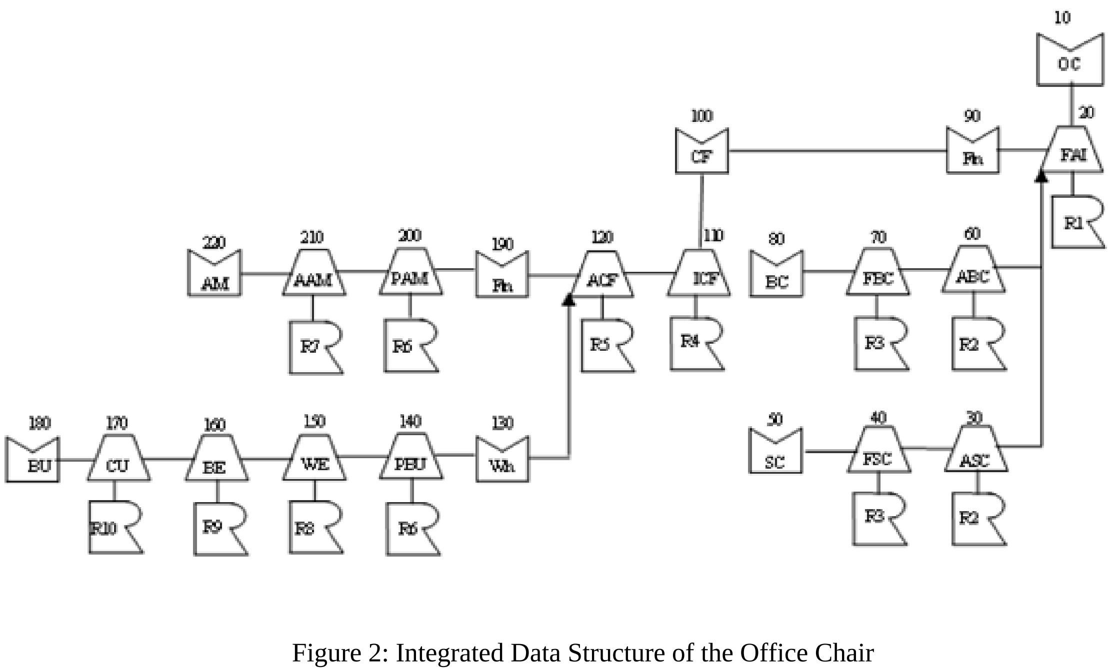

Figure 2: Integrated Data Structure of the Office Chair

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It can be noted from Table 3 and Figure 2 that the original routings and BOMs are combined into a single integrated data structure. Further, it also allows for three types of relationships (parent-component, component-component and activity precedence) and provides built-in component allocation as part of the structure rather than a separate activity in operations routing. In addition to integrated data structures, transaction data generated from this data can also be represented by unitary structure for effective execution of such transaction data [25]. In many situations, transaction data are combined with various other events and associated functions outside the functional application the original process belongs to. Further, there are many activities and resources in such functions and events, which require synchronous planning of all involved. For example, production order creation process and associated cycles involve goods movement at two levels: goods issued to production and goods receipts from production. These functions/tasks are required to be carried out at the correct time for timely completion of the production order. Using unitary structuring technique, these functions/tasks can be incorporated and planned for a better outcome of the overall process rather than the manual intervention required by current systems.

Table 3. Component sequence number, preceding and following components and bill level

Seq. No.	Comp. Type & ID	Comp Name	Preceding Seq. No.	Following Seq. No.	Bill Level	Component	Relationship
10	M (OC-100)	Office Chair	-	20	0	-	0
20	A (Op50)	FAI	10	30, 60, 90	1	P-C	0
30	A (Op40)	ASC	20	40	1	C-C	1
40	A (Op30)	FCS	30	50	1	C-C	2
50	M (SC)	Seat Cushion	40	-	1	C-C	3
60	A (Op20)	ABC	20	70	1	C-C	1
70	A (Op10)	FBC	60	80	1	C-C	2
80	M (BC)	Back Cushion	70	-	1	C-C	3
90	M (Ftn)	Fastener	20	100	1	C-C	1
100	M (CF)	Chair Frame	90	110	1	C-C	2
110	A (Op80)	ICF	100	120	2	P-C	2
120	A (Op70)	AAM	110	130, 190	2	C-C	3
130	M (Wh)	Wheel	120	140	2	C-C	4
140	A (Op60)	Painting BU (PBU)	130	150	2	C-C	5
150	A (Op50)	Welding (We)	140	160	2	C-C	6
160	A (Op40)	Bending (Be)	150	170	2	C-C	7
170	A (Op30)	Cutting (Cu)	160	180	2	C-C	8
180	M (BU)	Base Unit	170	-	2	C-C	9
190	M (Ftn)	Fastener	120	200	2	C-C	3
200	A (Op20)	Painting AM (PAM)	190	210	2	C-C	4
210	A (Op10)	AAM	200	220	2	C-C	5
220	M (AM)	Adj. Mechanism	210	-	2	C-C	6

V. Implementation of Integrated Data Structures in an ERP System

In order to implement integrated data structures and associated approach for planning and execution methods, SAP ERP system (market leader in ERP solutions) is selected. SAP ERP solutions dominate the world's business application software space and have the most used business software across the globe for the past decade. By streamlining processes and giving organisation more visibility and control into its business processes, SAP transforms and enables businesses to meet new demands [26]. Although SAP ERP has largest market share and is built upon the concepts of integration [4], it still has limitations in functional areas, in particular planning of components and execution of those plans in MPC as part of PP functional application, as discussed above. In this research, some of those limitations are addressed, by implementing integrated data structures and holistic planning/execution methods.

Implementation of integrated data structures is based on the existing data available within SAP ERP system and is carried out with appropriate data models and coding within the development area of SAP ERP system. The implementation is illustrated with the business scenario outlined earlier. The scenario involves planning, control and execution using standard data. Thus, the relevant data (BOMs, Operations Routings, Work Centres and Cost Centres) of the business scenario are maintained and made readily available for use throughout development and testing phases.

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In this case, business transactions required for maintaining integrated data structures are developed within PP module of SAP ERP, using Advanced Business Application Programming (ABAP) Workbench. ABAP Graphical Screen Painter is adopted as a Workbench Tool for creating dialog program screens. Dialog program screens are created to capture user inputs. For the visualisation module, the screen layout was designed in such a way that the business user is able to create the unitary structure by simply selecting the component from existing data (BOMs and operations routings of individual assemblies). Moreover user can select sub assemblies and build the complete integrated data structure to detail for a finished product (office chair). Flow logic behind the screen is controlled by "Process Before Output (PBO)" and "Process After Input (PAI)" ABAP modules.

In order to display BOMs, operations routings and the resulting integrated data structure using tables, existing tables for BOMs, operations routings and other master data (MAST (Material to BOM Link), STKO (BOM Header) and STPO (Routing Header)) are used In addition, a special transparent table was created as ZUNITORY (Unitary structure - BOM and Routing Integration) for maintaining integrated data structure. This special table is used to store variable/parameter values of the populated integrated data structure. Based on the details of special table (ZUNITORY), Graphical Screen Painter is used to design a screen for graphically displaying the integrated data structure. The designed screen labelled "Unitary Data Structure Maintenance" is shown in Figure 3. The program flow logic was included inside the screen design but the actual program processing was maintained as separate program modules.

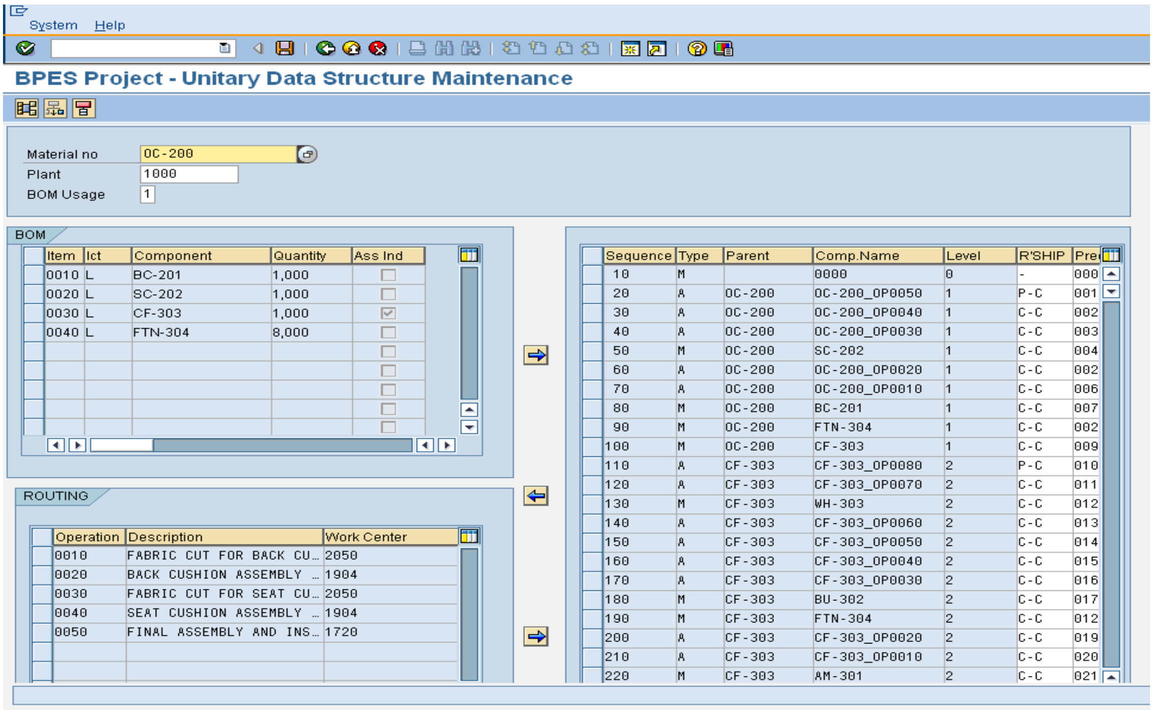

Figure 3: Integrated Data Structure Maintenance – Office Chair (OC-200)

VI. VISUAL REPRESENTATION OF INTEGRATED DATA STRUCTURES

As outlined earlier, graphical representation of the integrated data structures is important aspect of overall enhancement to data in ERP, in particular with additional components and relationships involved. Further, visual representation forms the basis for improving planning and execution methods, using concepts of business objects. After careful analysis of existing graphics in SAP ERP and capabilities of Scalable Vector Graphics (SVG), on the basis of business object visualisation, SVG is adopted for graphical representation of integrated data structures. SVG is an XML (eXtensible Markup Language) based mark-up language that can be used to declaratively draw two dimensional vector graphics. Further, SVG is compatible with SAP's interfaces that are capable of displaying embedded SVG graphics. XML is a very flexible text format and a simple general-purpose specification for creating custom mark-up languages and is derived from Standard Generalized Mark-up Language (SGML) [27]. Moreover, entire SAP Business Framework supports XML data format in data interchange and is considered as XML compliant [28]. SVG can be used to describe three types of graphic objects. These include vector graphic shapes, images and text. All these types of graphic objects are used in the implementation of visualisation of integrated data structures. By dynamically generating SVG mark-up, the graphics produced can also be made interactive so that users can drill down or get additional information relevant to the objects being displayed [27].

Even though the integration of SVG and ABAP (SAP's development platform) workbench is not complete from technical perspective, the required level of graphical functionality for the purpose of graphical display of integrated data structure can be obtained using SVG together with ABAP Workbench. In order for graphical display using the tool developed, Adobe SVG Viewer, a free plug-in is installed in the browser prior to executing relevant transactions for displaying integrated data structures. In order to display SVG in an ABAP Dialog program, a custom control container which can embed an ABAP HTML

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Control as a wrapper to display SVG content is required [29]. Details of coding including technical aspects associated with this development are not discussed here, as it is beyond the scope of the paper.

Once integrated data structure of the finished product (office chair) is maintained, based on BOMs and operations routings, as detailed in section V, two major procedures with a series of steps required to generate the graphical representation are planned and carried out. The first procedure is to read a number of fields from the unitary structure table (transparent table in SAP ERP system) created in section V above. Those fields include MAST (Material to BOM Link), STKO (BOM Header), STPO (Routing Header), PLPO (Task list - operation/activity), MAPL (Assignment of Task Lists to Materials), CRHD (Work Centre Header) transparent tables and the custom made ZUNITORY table. The next procedure is to organise each component and relationship into a graphical representation, without any overlapping and crossings. This procedure is based on nesting procedures [21] for generating XML and include following steps:

- Evaluate the parent row so that the Parent Tree Code of the current node can be determined,
- Find Head Component [21] for each component,
- Next the "Tree structure" of the components and their relationships are generated and overlapping positions are indentified. In this step, a procedure is used to push rows to display all components without any overlapping,
- According to the screen co-ordinates and the position of components within the "Tree structure", the SVG relevant to the components were created and written to the HTML control,
- By traversing the "Tree structure" again, the SVG relevant to the arrowed links between components are created to reflect relational dependencies among resources and activities. These relationships and associated characteristics are written into the HTML control,
- Finally, any additional component level details are created as SVG popup window and passed onto the HTML control.

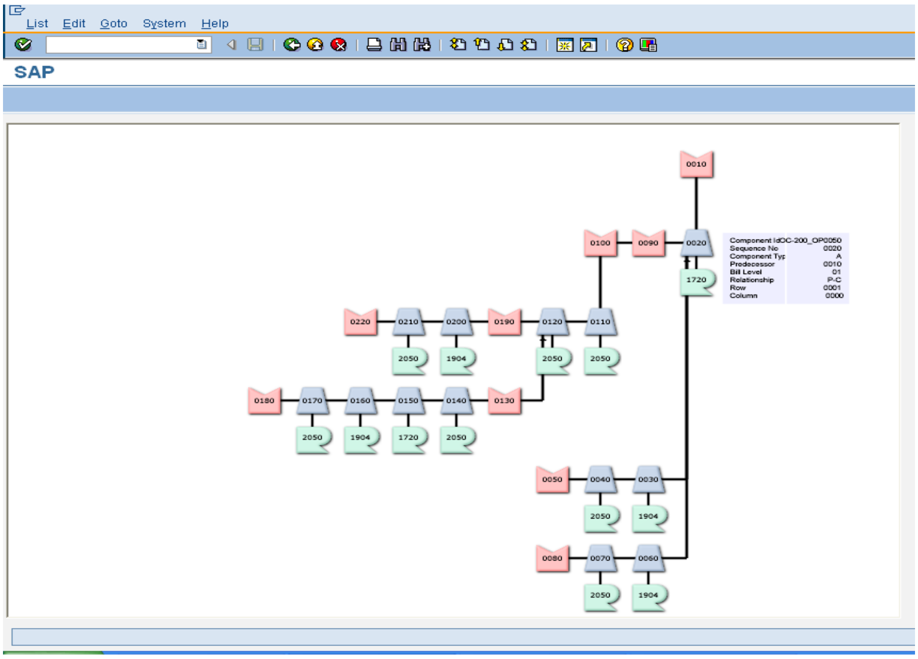

Figure 4: Visual Representation of the Integrated Data Structure (Office Chair) with Business Objects in SVG

The above procedure, implemented in SAP ERP system linking with SVG is resulted in associated business transactions of SAP ERP system. The resulting visual representation of the integrated data structure of the office chair is shown in Figure 4.

It can be noted from Figure 4 that integrated data structure represents a combination of individual data structures (BOMs and operations routings) and business objects of each component with details. Thus, visualisation of integrated data structures and associated business objects form the basis for simultaneous planning of many components with finite loading of resources. Further, this can be used for transparency of data across traditional functional silos of organisation.

VII. Visual Representation of Integrated Data Structures

Once the integrated data structure is maintained for a product/material in SAP ERP system, planning of all components involved in the structure can be carried out using planning/execution methods developed earlier [2]. However, planning/execution methods developed earlier need to be implemented in SAP ERP system. The procedure, when implemented in SAP ERP system resulted in a number of transactions. First, demands identified by planned independent requirements in demand management are captured for a material with other organisational elements, as shown in Figure 5.

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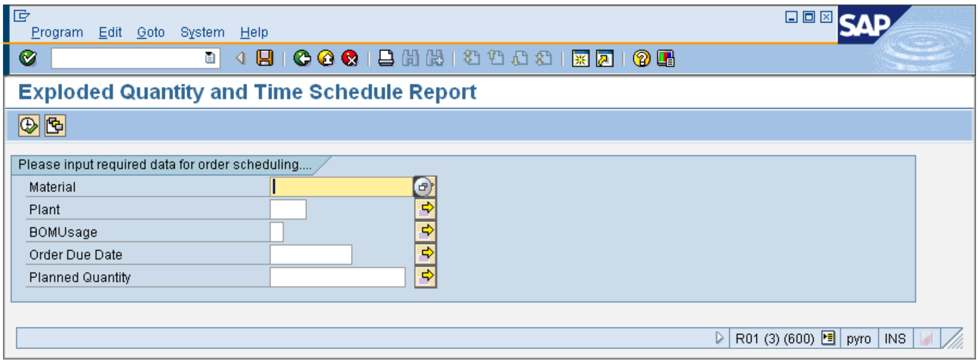

Figure 5: Graphical interface of capturing demand for exploded quantity and time scheduling report

Once initial demands (quantity and times) are captured, planning of all components involved in the integrated data structure is carried out using holistic planning/execution methods implemented as part of overall development. In this case, data structure is maintained in the SAP ERP system as a single data object, compared to many BOMs and operations routings in the traditional approach. Also, the methodology is based on a combination of MRP's BOM explosion and operations scheduling with finite loading of resources. Thus, overall planning and execution is carried out in two stages:

(i) Scheduling paths as identified by sequence number (Table 3) for planning and execution of material and resource plans over a selected planning horizon,

(ii) Planning and scheduling of components with finite loading of resources using scheduling paths, until completion of the entire data structure.

In the case of selected business scenario, the scheduling of components starts from the office chair (seq. no. 10) for a requirement of 60 units. The scheduling of components results in exploded quantities for both materials and activities. The exploded material quantity is based on BOM explosion while exploded activity duration is a combination of setup, labour and machine times. Since there is only one resource unit per activity, total resource requirements are same as those for activity duration. The exploded activity duration can be calculated by:

$$Total\ \ Activity\ Duration = \left\{ \begin{array}{l} Setup + \left(\dfrac{Assembly\ Qty}{Base\ Qty} \right) * \\ Max\{(Machine\ Time/Unit)\ or\ (Labour\ Time/Unit)\} \end{array} \right\}$$

As part of overall development, ABAP List Viewer (ALV) function modules are used to obtain an output of exploded quantity and time schedule report. ALV adds its own capabilities in addition to the visualisation provided by the SVG tool in section V. Readability is enhanced using colour coding whilst the dynamic sorting significantly helps to filter down the data. In addition, ALV provides users with the ability to update the data stored in the database. This makes it easier for users to perform what if scenarios and to determine the input required to gain the most optimised outcomes for a given scenario.

Samaranayake [25] proves that the lead times calculated using the integrated data structures is less than the times calculated by the traditional approach of MRP and PAC for planning and execution at two levels. Based on the developed technique using proposed planning/execution methods, materials, operations, activities and resources can be planned simultaneously. Planning results are not presented here since it is beyond the scope of this paper.

Apart from planning of those components, users can use the ALV representation and the SVG visual tool to easily track the critical activities. If any scheduling problem is encountered, the user would know which activity(ies) along the critical path is/are responsible for the delay. This analysis of the critical path can be performed before, during and after an operation. As a result, the users can be efficient in carrying out planning/execution of operations and activities in production planning. Moreover, the interdependencies are easily identifiable and the whole manufacturing lead-time is also available. The estimation and allocation of resources becomes more transparent to the whole organisation and the system can be used to test and analyse alternatives. The dynamic graphics and visualisations offered by the system would make it easier to identify and understand the constraints in a given scenario as the information is clearly visible for all to carry out business transactions and make timely decisions.

In order to support the enterprise gaining this competitive advantage, the implementation of integrated data structures and associated planning/execution methods not only streamlines the planning and execution functions but also provides a visual representation with added business objects perspectives to help users comprehend manufacturing planning and execution process. The integrated data structure, graphical tool and the planned schedule report provides information at each step of the process. They also help bring the holistic picture together. Users of this tool can easily perceive what is visually represented and improve their overall understanding of the process. By eliminating the human intervention in some parts of the planning and execution process, an increase in speed is gained and human errors are minimised.

VIII. CONCLUSION

The paper identified the need for integrated data structures and visualisation of such data across many functional applications of ERP systems. Implementation of integrated data structures in SAP ERP system is presented with capabilities of graphical display for effective and efficient planning of various components involved in such structures.

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It is shown that implementation of integrated data structures and graphical display form the foundation for enhanced data in ERP system environment. Further, existing data of ERP system can be integrated using additional relationships, making the basis for simultaneous and forward planning of many types of components involved. Various business objects contained within the integrated data structure are visually represented using Scalable Vector Graphics (SVG) and an XML based technology. SVG forms a software component within SAP ERP system, capable of representing integrated data structures using visual business objects. This also provides capabilities of business intelligence through SVG interface, enhancing capabilities of current ERP systems. It is expected that integrated data structures and visualisation of such data structures in SAP ERP system can be extended to many functional applications of SAP ERP system. It can be concluded that the concept of data integration and visualisation enable data maintainability, flexibility and transparency for effective and efficient planning and execution of manufacturing processes, as future research.

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