Test of Core Manufacturing Simulation Data Specification in Automotive Assembly

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ABSTRACT: *This paper describes the construction of an automotive assembly line simulation where manufacturing data is defined using the Core Manufacturing Simulation Data (CMSD) information model. This work is part of the Simulation-based Manufacturing Interoperability Standards and Testing (SBIT) project underway at the National Institute of Standards and Technology (NIST). The production line simulated can produce multiple car configurations that are defined according to the door type, roof type and color. Although CMSD can handle large variety of data, the data defined in the demonstration model are resource, process, and graphics display data only. In addition to being data driven, the simulation model can also exchange product and inventory data with other simulation systems. The results of the prototype demonstration prove that, with appropriate extensions, CMSD can handle most production line type manufacturing systems data*.

1. Introduction

Modeling and simulation are carried out to provide decision support to improve the performance of manufacturing systems. Simulation projects are carried out during the design, modification, and evaluation of the effect of different operational and control policies in manufacturing systems. Often, such simulation models have been custom-tailored to the solution of the current specific problem and neither the simulation nor the data could be of any use in other projects. Such a level of effort required in problem conceptualization, data collection, abstraction, and construction of simulation models for each project has limited the application of simulation technology, especially in the smaller companies. Moreover, the manufacturing environment has been evolving over the years and assembly plants have to now rely on many part suppliers, some of them located offshore. Hence, data must be communicated and shared among many partners in the supply chain throughout the product's lifecycle. Supply chain partners such as assembly plant, part suppliers, transporters, and customers often use disparate product and process data formats that are not interoperable. This lack of interoperability of manufacturing systems among different companies comprising the supply chain leads to excessive data reformatting costs in the automotive, aerospace, and electronics industries. Neutral, reusable data formats and interfaces are required to enable exchange of data across different manufacturing applications, simulation systems, and platforms.

In order to facilitate future interoperability and testing of manufacturing software, the SBIT project underway at NIST has developed integrated manufacturing simulations. These simulations have been constructed at four different levels; the supply chain level, the automotive assembly plant level, the engineering systems level, and the shop floor level. One of the objectives of the SBIT project is to test interoperability standards that can facilitate data exchange between simulations and other manufacturing software such as that used to design products, engineer production systems, and manage production operations. As part of the interoperability effort the Core Manufacturing Simulation Data (CMSD) information model has been developed in cooperation with the Simulation Interoperability Standards Organization (SISO) [1]. The development of a reusable, neutral, and standardized interface could help reduce the costs associated with simulation model construction, data exchange, and integration between simulations and other manufacturing applications.

The idea of the CMSD effort is to facilitate data exchange and sharing by using neutral data structures for managing actual production operations and for simulating the performance of the manufacturing shops. The rationale is that if a data structure used for a real manufacturing plant operation can serve the same purpose for a simulation model of the plant then the need for translation and abstraction of the real data would be minimized during construction of simulation models. This project developed a prototype demonstration of a data-driven simulation model of an automotive manufacturing plant .The data was defined using the CMSD neutral data format. We used the Delmia QUEST simulation application. If the simulation model were to be developed using another application, the same data would be used without reformatting. In addition, it would be possible to modify operating parameters of the simulation model by only altering information in the database.

Previous publications on the SBIT project center on simulation integration efforts for the automotive manufacturing supply chain and the exchange of data using fields consistent with the OAGIS/AIAG business object documents (BODs) for Inventory Visibility and Interoperability (IVI). See references [2] and [3]. They describe simulation models constructed at different levels of the supply chain to facilitate testing of standards for the exchange of data along the supply chain. This current paper describes the application and testing of CMSD for modeling automotive manufacturing assembly data. The data includes resources, process plans, and inventory data. CMSD is being developed into a standard for information modeling for manufacturing simulation. The rest of the paper is organized as follows. Section 2 describes the background to the SBIT project. Section 3 describes an overview and goals of the CMSD information model. Section 4 briefs on the automotive plant and the approach to encoding the model data using CMSD while section 5 describes the results of modeling. Section 6 discusses the results and concludes the paper.

2. The Simulation-Based Manufacturing Interoperability Standards and Testing (SBIT) Project

The Simulation-based Manufacturing Interoperability Standards and Testing (SBIT) project was initiated to illustrate the integration issues facing manufacturing industry today and to demonstrate architectures and interface standards solutions to the integration problems [4]. The goals were to establish a simulation-based manufacturing environment with visualizations to enable dynamic interoperability testing for manufacturing software applications, candidate interface specifications/protocols, and standards. In addition, it was intended to provide interoperability testing support to software developers, manufacturers, research institutions, consortia, and standards organizations for selected manufacturing product domains, facilities, systems, operations, and processes.

Based on an automobile manufacturing environment, the project identified the relevant supply chain members associated. These include the final assembly plant for which the systems and processes are essentially the body shop assembly operations, the paint shop processes, the chassis assembly, and the trim and final assembly processes. Simulation models of these operations and processes were constructed to integrate and test neutral interfaces that enable data transactions between simulations within the automotive supply chain domain. The supply chain network model was developed in Arena while the automotive assembly production was constructed in Delmia QUEST [5]. For shop floor operations, the project used the paint shop operations and the model was constructed using Enterprise Dynamics [6]. These simulation models exchanged interactive XML messages.

3. Core Manufacturing Simulation Data Overview

The CMSD effort was organized to address interoperability issues between simulation systems and other manufacturing applications. The CMSD information model (CMSDIM) defines a data specification for the efficient exchange of manufacturing data in a simulation environment. The specification provides a neutral data format for integrating manufacturing software applications with simulation systems.

CMSD, when completed, will satisfy the following goals: (1) to enable data exchange between simulation systems, other software applications, and databases, (2) to support the construction of manufacturing simulators, (3) to support testing and evaluation of manufacturing software, and (4) to support manufacturing software application interoperability. The CMSD information model specification is presented in two different documents: (1) the information model defined using the Unified Modeling language (UML); and (2) the information model defined using the eXtensible Markup language (XML).

The CMSDIM's UML representation has been organized using packages. UML packages, depicted as file folders, are UML constructs that can be used to organize model elements into groups. The CMSDIM consists of the following major UML packages: Support package, Resource Information package, Production Planning package, Production Operations package, and Part and Inventory Information package.

The major data categories of manufacturing information included in the CMSDIM include organization, calendar, resource, skill definition, setup definition, operation definition, maintenance definition, part, bill-of-materials, inventory, process plan, work, schedule, revision, distribution definition, reference, and unit defaults.

4. Manufacturing Process and Modeling Approach

4.1 Automotive assembly and products configuration

Automotive manufacturing is complex and includes coordination of design and manufacturing activities of many companies. The process involves thousands of operations that require assembling together thousands of fabricated and purchased components, subassemblies, and systems. The systems and processes used in developing and modeling an automotive assembly prototype demonstration were based on visits and studies of the Volvo assembly plant in Gothenburg, Sweden and the General Motors plant for Buick and Cadillac in Detroit, Michigan. This automotive assembly model includes processes typical in a body shop assembly, paint shop operations, chassis, and trim and final assembly operations involved in any automotive assembly plant. But it is not intended to represent either of the plants mentioned above. Other sections are the power train assembly that consists of the engine, gearbox, clutch and transmission, and the stamping press shop if sheet metal and body parts are stamped at the plant and supplied to the automotive assembly plant just-in-time. Final operations are the water leaks test and the stationery road test workstations. The schematic representation of the automotive assembly is shown in Figure 1.

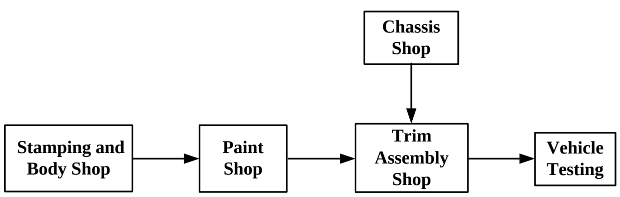

Figure 1: Basic shops in automotive assembly

In the body shop, different sheet metal parts and panels that make up the car body are stamped and assembled together and welded using robots. The body is then cleaned of oil and grease using a phosphate solution before being routed to the priming and painting operations in the paint shop. The final trim assembly processes then proceed. On a separate line, the chassis and axles are assembled and later married with the automotive body while in the trim assembly shop. In the trim assembly shop, various components and electronic subsystems are assembled into the car. Examples of these components are the body moldings, headlights, tail-lights, instrument panels with various options, steering wheel, center console, carpets, front and rear seats, headliners, sun roofs, windshields, backlit, and bumpers. After a car is fully assembled, it is tested for water tightness and functionality before being sent to the storage yard prior to shipment to the car dealer by truck or rail car. There are a large number of assembly stations and hence, many component parts, units in storage racks, and inventory waiting by the sides of the production line.

Plant characteristics of the simulated environment

- twelve configurations of a car based on 2-door or 4-door type, sun-roof or regular-roof type, and 3 body colors (blue, grey, and tan).
- body-in-white traveling on roller conveyor in the body shop and paint shops.
- power and free conveyors in the trim assembly.
- a car assembly production line could have more than a thousand workstations but the simulation model has about one hundred key processes and stations from each shop, to provide a pilot demonstration.
- there are storage spaces (queues) between successive shops and some processes.

Operations characteristics of the simulated environment:

- customer order information from the car dealer specifying the car configuration and quantity required is transmitted from the supply chain simulation via the High Level Architecture [4].
- a notification message about finished products is sent from the plant to the customer in a supply chain simulation informing the customer that the order has been completed.
- the system monitors the components' inventory levels and sends out reorder messages when the component level reaches a predetermined quantity level so that a replenishment can be received before the stock is depleted.
- there is a lead time between sending a message and receipt of parts replenishment.
- the cycle time and transfer time between stations is approximately 1 minute to comply with the usual design throughput of such plants for sixty cars per hour.
- cars are pre-determined whether they are to be two-door or four-door at the first station on the line and subsequent information which links a particular car in progress to the car dealer order is updated at the door and roof assembly stations and at the paint shop.
- sequencing of cars selected from a pool for painting a specific color to the customer order is carried out at the entry to the paint shop.

4.2 Workstation model logic

When a car reaches a workstation the process logic checks the readiness of the station to receive work, i.e., if it is not blocked. If it is not blocked, it accepts the car for processing. The logic then looks in the database to determine the component parts and quantities of each type required for assembly. This depends on the car configuration. Next, it scans the database to determine the status of parts availability in the quantities required. If any of the parts are not available the workstation is 'blocked'. The parts availability status is updated every minute of the model time for any deliveries of parts responding to previously sent messages. If the parts are available, the logic decreases the inventory by the corresponding number of parts assembled. This is followed by a delay to reflect the process time to assemble the parts. The delay is determined by lookup in a table of probability distribution functions and associated parameter values. The simulation of the workstation processes is then complete. We use "Seconds" as the unit of time.

After the parts have been assembled and a delay has been processed, the logic then looks in the entity display table in the database for the index associated with the appropriate model that is to be displayed after processing at the station. This display reflects the merging of the car and the parts assembled or the color that has been painted. The car subassembly is then moved out of the station to the next using the material handling system. The model also displays the graphics and the number of parts waiting for assembly at a workstation. To increase model run efficiency in QUEST, we represented the inventory of component parts at the various stations using variables. We used QUEST Simulation Control Language (SCL) to write the workstation process and inventory data update logic.

4.3 Manufacturing resource data in CMSD structure

The process and inventory data was originally structured and expressed in Excel spreadsheets. There was a file for process resource data, directory and file name of the car subassembly graphics display in various stages, and an inventory file. The inventory file contains for each item, the part name, initial inventory volume, reorder point, reorder quantity, supplier part identification, and supplier identification. For process resource data, a translator was written to generate CMSD XML instance documents from the Excel spreadsheets. The CMSD XML instance documents were then translated into a comma separated value file readable by QUEST simulation. The model data in comma separated values (CSV) represents:

- Process identification
- Station name
- Car configuration type
- Quantity of component parts to assemble into the car at the workstation
- Component part names
- Probability distribution function of the process time of the assembly tasks
- Distribution function parameters
- Graphics display index for the car after processes associated with the workstation (not part of CMSD)

Figure 2 is the schematic representation of the data input flow between various software modules while Figure 3 shows a sample manufacturing data in a CSV file used by the QUEST model.

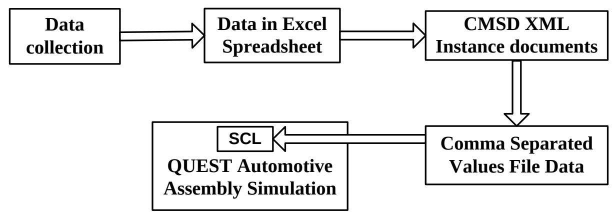

Figure 2: Process data input flow diagram

4.3.1 CMSD XML instance document

CMSD was originally formulated for modeling job shop operations where generally each job or part has a unique routing through the production facilities. Therefore, the instance document first lists all resources, i.e., workstations and then process plans for every car configuration. Since the assembly line is essentially a production flow line, the process plan lists all workstations in assembly order with the process requirements of each car configuration for each workstation. Lastly, the document lists display indexes of the file name and graphics display names of the QUEST files, and the directory and subdirectories where the files are located.

The XML section of code below shows the definition of the resource. It shows the resource identifier, name and resource type. In CMSD resource types include machine, station, employee, conveyor, fixture, and tool. The resource information package contains classes for creating definitions of the characteristics and capabilities of the equipment and employees. This includes information such as setup time for machines and skills for employees. The instance document generated reflects only the level of details provided.

```
- <Resource identifier="ST01">
    <Name>Floor_Pan_MS_Assembly</Name>
    <ResourceType>station</ResourceType>
  </Resource>
```

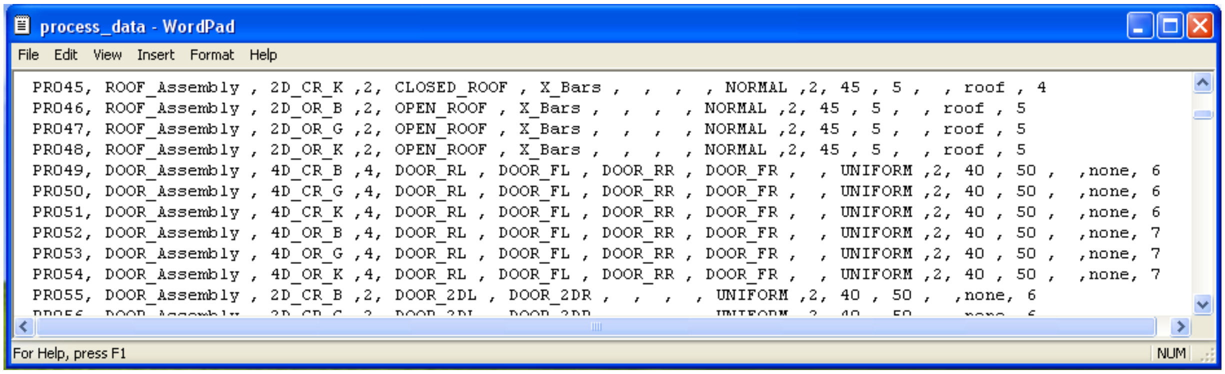

Figure 3: A section of the process data

A section of the process plan for the car model "2D_OR_K" process step number 46 is shown in CMSD format below. The production planning package contains classes and relationships to create plans for timing of usage of resources and describing the sequence of steps to manufacture products using the available resources. It defines information such as orders, resources, and operation time description.


```xml
- <PlanStep identifier="Car:2D_OR_K:46">
    <Description>Step '46' for the production of
    part 'Car:2D_OR_K'</Description>
    <Reference
    referenceIdentifier="Graphic:DisplayIndex:2D:1
    23" />
  - <Parameter>
      <Name>SequenceFlag</Name>
      <Value>none</Value>
    </Parameter>
- <UnitOperationTime unit="second">
  - <Distribution>
      <Name>NORMAL</Name>
    - <DistributionParameter>
        <Name>Parm1</Name>
        <Value>45</Value>
      </DistributionParameter>
    - <DistributionParameter>
        <Name>Parm2</Name>
        <Value>3</Value>
      </DistributionParameter>
    </Distribution>
  </UnitOperationTime>
- <ResourcesRequired>
    <ResourceType>station</ResourceType>
    <MaximumNumber>1</MaximumNumber>
    <MinimumNumber>1</MinimumNumber>
    <Resource resourceIdentifier="ST46" />
  </ResourcesRequired>
```


The graphics display index 1 for a subassembly for a four-door car is as provided below. The file name, directory, and subdirectories are also presented next.


```xml
- <Reference
    identifier="Graphic:DisplayIndex:4D:1">
   <Description>Graphic for a 4D car with display
    index 1</Description>
   <FileName>VME_SCDEMO/PARTS/4D CAR
    DISPLAY/FPMS</FileName>
  </Reference>
```


5. Results of the Prototype Testing

Traditionally simulation practice involves encoding all manufacturing resource data including workstations, processes, and inventory data within the simulation model. The associated data definitions would be an intrinsic part of the selected simulation software in a particular format and such data would be unavailable for use by other simulations and other manufacturing software systems. This CMSD approach of defining manufacturing data in a neutral format would save model development time, facilitate data input to simulations, and facilitate data exchange between and amongst simulations and other manufacturing applications. This neutral format approach also made it easier to modify model information such as process times or number of components needed at the station change. In this case a simulation analyst only needs to modify the data in the Excel spreadsheets. The translator will automatically translate the updated information into a new XML instance document for use by the simulation.

6. Discussion and Conclusion

This paper has described one of the applications of the CMSD information model for representing manufacturing resource data in a neutral format for use by simulation. Abstraction is part of the manufacturing simulation modeling process. In the development of a simulation model, an analyst develops a representation of the manufacturing system or process and consumes considerable time and effort. To speed up the modeling process the data should be represented in a neutral format for easy data sharing, exchange, and re-use in other simulation systems and manufacturing application domains. In the current CMSD draft document version each car configuration or product option is represented by a unique row in the process data. Yet much of the data for each workstation does not change for the different car configurations. As such, resource data in the XML instance document is very large. If a new configuration option is introduced, say different gear boxes, the process database size would grow substantially and double in size. The next stage is how we can handle a real life situation with hundreds of car configurations and options processed on an assembly line with more than a thousand workstations. In that case, we have to devise a simplified way of representing the data in CMSD. If not, it would be very time consuming because all this data will have to be parsed into the model at simulation initialization time. However, the most recent version of CMSD specification has seen improvement and generalization where the processes of flow line production data can be modeled by creating resource groups.

The future task for improvement of the prototype model is to extend the demonstrations to include labor, routing information, material handling systems, and layout. A CMSD draft data specification in the UML format has been developed by NIST. The CMSD draft is currently going through the balloting process guided by the SISO Standards Activity Committee (SAC).

7. Acknowledgments

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8. Disclaimer

A number of software products are identified in context in this paper. This does not imply a recommendation or endorsement of the software products by the authors or NIST, nor does it imply that such software products are necessarily the best available for the purpose.

9. References

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