Integrated Modeling and Application of Standardized Data Schema

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ABSTRACT

Application of discrete event simulation has been widely accepted in the manufacturing industry for shop floor capacity and flow analysis. Often the models are made to analyse a limited aspects of the system behaviour that abstract only few factors for the sake of simplicity in the expense of model accuracy. One of the prohibitive reasons for a detailed and multi objective model is the collection and management of the input output simulation data.

In this work an integrated and detailed simulation model of a machining line has been built for the purpose of a multi objective analysis and optimization with application of the standard simulation data schema for data management. The model incorporates detailed capacity and flow related factors as well as sustainability factors (energy usage in machine tools), The abstraction level of the model is sufficiently low to capture the effect of operators' movements in the shop floor and setup procedures. To support modeling of such a detailed model enhance model reusability, the Core Manufacturing Simulation Data standard XML schema was used. This neutral format of data will also help to build model with less effort, reuse the information, and communicate with different application tools. A case study is carried out to illustrate the methods and run a multi objective optimization. The results of the optimization work are reported in another paper.

Keywords: discrete event simulation, core manufacturing simulation data, energy usage.

1. INTRODUCTION

Discrete Event Simulation (DES) model has been extensively used and is an established way of problem solving and finding the best possible alternatives under a given set in the areas of manufacturing, transportation, service sectors etc.[1, 2]. However development of valid model for a multi objective analysis and optimization is not common in manufacturing simulation [3].

A multi aspect and detailed simulation model has been built for a multi objective analysis which includes capacity analysis (including batch size, planning schemes, buffer sizes, etc), energy usage/sustainability depending on the operational mode of the production equipment, sequential order of setup operations, operators' movement in the shop floor to prioritize and execute their tasks.

Furthermore in order to systematize the model building process and for model interoperability, the input output data is structured according to industry standard, Core Manufacturing Simulation Data (CMSD) schema. proposed by. This neutral format simplifies the model building process, reuse the information, interoperability

A relational database according to CMSD schema is built and embedded to the model to serve as the model data source and simulation output repository. This enhances model reusability since the simulation model is decoupled from the model parameter values which reside in the database, i.e., the model consists only of the partial models of the resources in the system and flow logics.

A case study that was carried out in one discrete part manufacturing line to illustrate the modeling and analysis concept and demonstrate the usefulness of the integrated modeling performed. The level of abstraction of the model is sufficiently detailed in order to obtain accurate results and clearly see the interdependence of the performance parameters.

This paper is divided into 5 sections. Section 2 discusses and outlines the data management and integration with simulation tool. Section 3 presents the detailed machining line model building. Simulation result and discussion are presented in section 4 and finally, conclusion from the analysis is given in section 5.

2. DATA MANAGEMENT FOR SIMULATION INTEROPERABILITY

One of the concerns in simulation studies is related to the model building time. This issue has been related with the difficulties in handling the simulation data, gathering the data, more specifically with the data collection and the simulation data structuring as well as interoperability and reusability of models.

Various attempts have been made by different sectors, academy, industry, institutes, etc., [4, 5, 8, 9] to solve some of these problems of simulation. One of the major efforts has been done by The National Institute of Standards and Technology - NIST addressed to standardize the use of the Core Manufacturing Simulation Data Information Model - CMSDIM.

The CMSDIM has been developed to facilitate the exchange of information, the use of manufacturing simulation and the integration of DES with other manufacturing applications. It describes neutral definitions of manufacturing entities and its relationship to create manufacturing simulation [6].

There are some studies about how the CMSDIM could be implemented using different software like: Arena, Lekin, Enterprise Dynamics, etc. Some examples of these studies have been done in the automotive industry, related with modeling approaches and data structure [7], other study has been done in the aerospace industry [8]. There are also some examples related with interoperability [9], development of methodologies related with input data management [10], and data architecture [11].

This research work has addressed only on production planning package with focus on the Process Plan and related classes (Fig. 1).

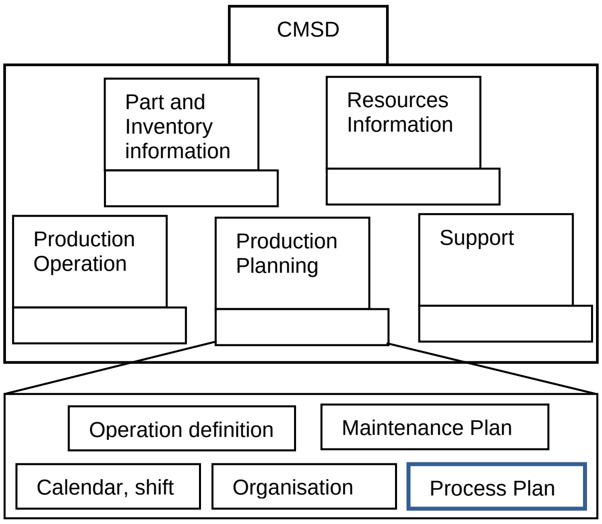


Fig.1: CMSD UML package diagram and Production Planning package

The CMSDIM is defined in two types: 1) Unified Model Language (UML) and 2) eXtensible Markup Language - XML schema. The UML representation is a graphical representation while the XML is a textual representation.

However, one of the objectives of this paper is to develop a method to import structured information based on the CMSDIM into the Simulation Software ExtendSim V8 and to apply this method in a case study in a discrete event simulation model developed for a production system.

Development of the method:

Some important issues were considered for the development of the method:

a) When the data is not structured and is difficult to import into simulation.

b) Apart from literal data, probability distributions need to be imported into the model.

The method consists of some stages presented in (Fig.2). An XML Schema was created based on the CMSDIM UML representation of the production planning package with focus on the Process Plan and related classes. Following an XML instance document was created and validated against the schema.

In addition a separate XML schema and XML instance document were created with the heading information that is required to import the database file into ExtedSim V8.

The Heading XML instance document was put together with the Process Plan XML instance document, but the schemas remained separated. Here a validation process was also carried out.

The heading information is composed of 22 lines. It consists of a description of the information containing each table of the database file to be imported in the software. Without this information the database file cannot be imported into ExtendSim V8.

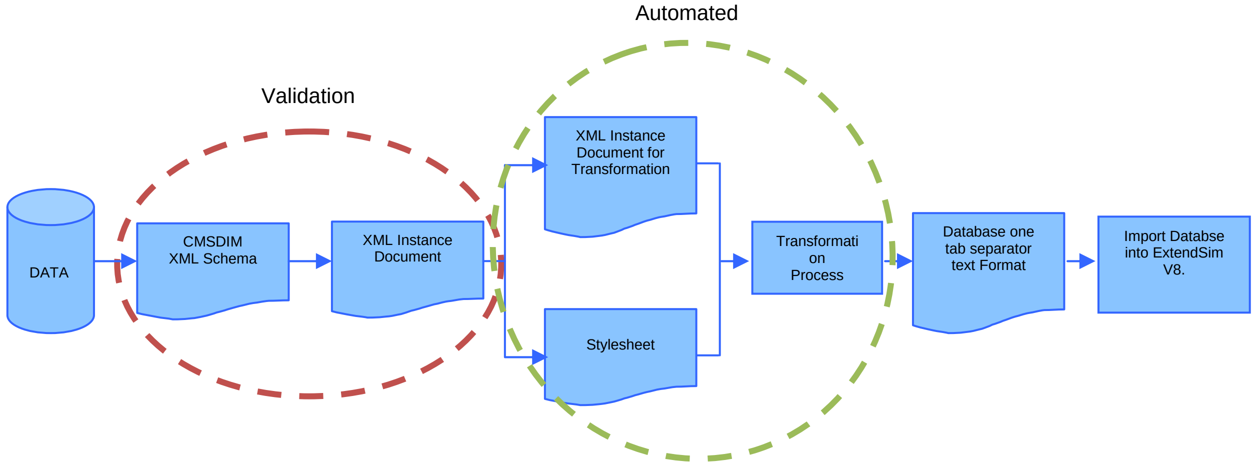


Fig. 2: Description of the stages in the method

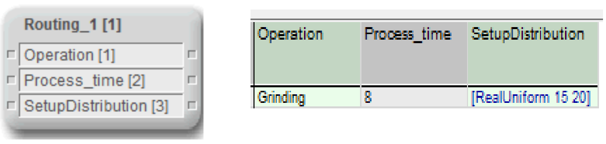
There are information that is not mandatory in the heading; however special attention should be given to the number of rows and columns, number of tabs, and the field format. Depending on the data, the field "decimal" should be also taken into account. Regarding the field format, ExtendSim V8 has an identification number for the field type.

For the transformation process Extensible Stylesheet Language Transformations (XSLT) was used. This will allow the transformation of the XML document into one tab separator text format. After that some Xpath expressions were used to extract the desired information to be included in the database and complete the information needed into the heading. In that way the output is ready to be imported (Fig. 3). That is the reason why it is called automated.

File_Name:	Data for Simulation			
Table Name	Routing_1			
Table Index	1			
Rows	1			
Cols	3			
Table Format	0			
Table Note				
Number of Tabs	2			
Tab Indexes				
Field Locations				
Field Notes				
Field Format	4000	2000	2000	
Field Decimal	0	0	0	
Field Comma	0	0	0	
Field Unique	0	0	0	
Field Access	0	0	0	
Record ID	0	0	0	
Field Initializer				
Do Initialization	0	0	0	
Init First Run Only	0	0	0	
Field Names	Operation		Process_time	SetupDistribution
1	Grinding		8	[RealUniform;15;20;]
EndOfFile				

Fig. 3: Snapshot of tab separated text file

The probability distributions as mentioned before are important in production and simulation. They should be written according to the ExtendSim V8 requirements to be readable. It is possible to get that format with the approach used to develop the method (Fig. 4).



(a) **(b)**

Fig. 4: Imported table into ExtendSim V8 a) structure mode b) Viewer mode.

3. Integrated Modeling and the case study description.

This literature takes a gear manufacturing line (Fig. 5) as a study case. This unit consists of machines, conveyors, robots and measurement points. The unit produces five different types of parts where cycle times are different.

Tool changes, setup and measurements are done by the operators. Items entry into the model is based on given production plans. Each workstation requires setup and tool change; tool change is performed after a certain number of operations whereas the setup is performed only when the new parts arrive into the system. Measurement is taken after some number of parts and when a new part is introduced. Simulation model of gear manufacturing line is built by using ExtendSim Version 8.

Information required to build the model is structured and transformed into a neutral and compatible format for the modeling environment ExtendSim V8. This transformation process is described in previous section.

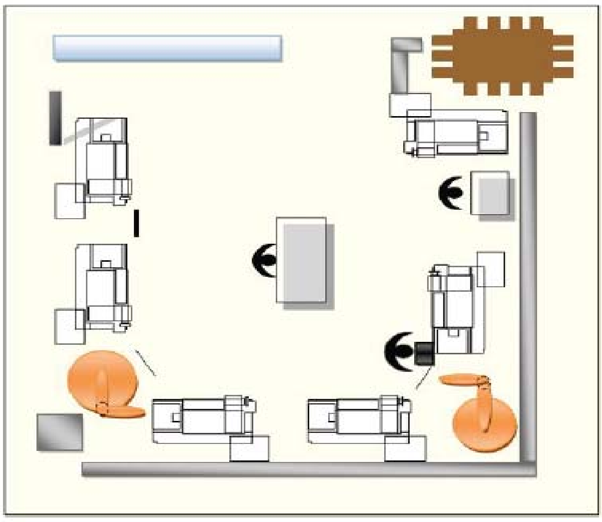


Fig. 5: Layout of the production line.

Information are collected and structured according to the method and as a result a database file has been created which contains information in terms of:

- Process Time
- Setup Time (Including probability distributions)
- Measurement operations (time and frequency)
- Parts
- Routes (Organized in the desired order)
- Batch Sizes
- Operations

The method helped to easily recognize the data for the model. It is convenient to change the data in the XML instance document and have a new database with new data. The use of databases is a good approach in ExtendSim V8 because the same model can be re-used with other set of data from databases [12]. Also, if a change in the configuration of the production line occurs it is also possible to include it in the XML instance document and subsequently develop a new database.

After successfully organizing the data into database a simulation model of the unit has been prepared by using ExtendSim Version 8 which is compatible for modeling discrete or continuous events as well as hybrid simulation [13].

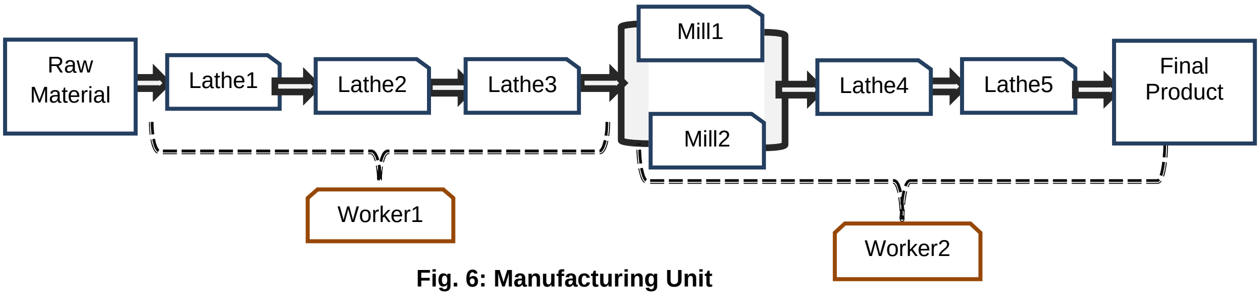


Fig. 6: Manufacturing Unit

In the simulation model, different work stations are placed based on their operation sequences from the raw material to the final product (Fig.6).

This simulation model provides the opportunity to incorporate multi-aspects modeling of manufacturing facility such as:

a) Different production schemes (scheduling and set of process parameters scenarios):

b) Modeling of setups and tool changes sequences and frequencies:

c) Modeling of material handling equipment capacity and speed:

d) Modeling of operators movement and task priority:

e) Modeling of energy: energy usage of the workstations in relation to operation mode of the stations were modeled.

Energy usage = Operational Time * (Energy consumption during operation) + Down Time * (Energy consumption during setup and tool change) + Standby Time * (Energy consumption when the machine is ready but not in used).

Measurement of energy usage was recorded a priori from which the relation between usage and operation mode is made.

Input needed to initialize the model and output results of the simulation are cloned in Input and Output hierarchical blocks which made user friendly and visible for analysis purpose. Some of the inputs can vary extensively and some have specific limits due to space and resource availability. Some trial runs and validation are performed by means of different parameters setting and in reference to real production line. The key purpose of the model is to optimize the key performance indicators which are shown below:

- Maximize the products i.e. Number of pallets and number of items
- Maximize the machine and worker utilization
- Minimize the number of work in process
- Minimize the energy consumption
- Optimum parameters selection

4. SIMULATION AND OPTIMIZATION RESULTS

A multi-objective optimization (MOO) run was made with the three conflicting objectives: {Maximize (Production), Minimize (WIP), Minimize (EnergyUsage)} with the following 9 decision variables in the case study:

- Conveyor (buffer) length before Lathe 1,2,3 and 5;
- Production scheme;
- Lathe 5 setting;
- Milling m/c setting;
- Number of operators in work position 1,2 (worker1 , worker2) in Fig. 6.

5000 evaluations were run with NSGA-II [14] by connecting an implementation of the algorithm to the developed Extend model. Fig. 7 and 8 visualize the optimization results (all 5000 evaluations) using 4D plots (3D plus color).

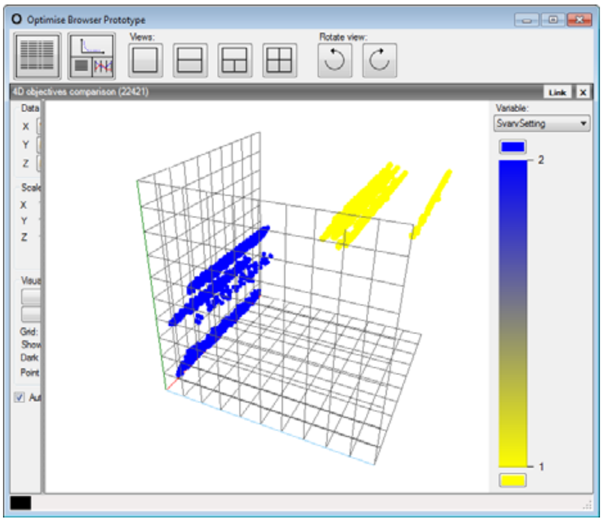


Fig. 7: 4D plot visualizing how Lathe5 Setting divides the solutions into two cluster groups.

Using the interactive user interface developed in the FFI-HSO project, the decision maker can browse the color change in the 4D plot by varying each decision variable. With the color change during the browsing, relationship between the selected decision variable to the objectives in the 3D plot can be visualized and interpreted.

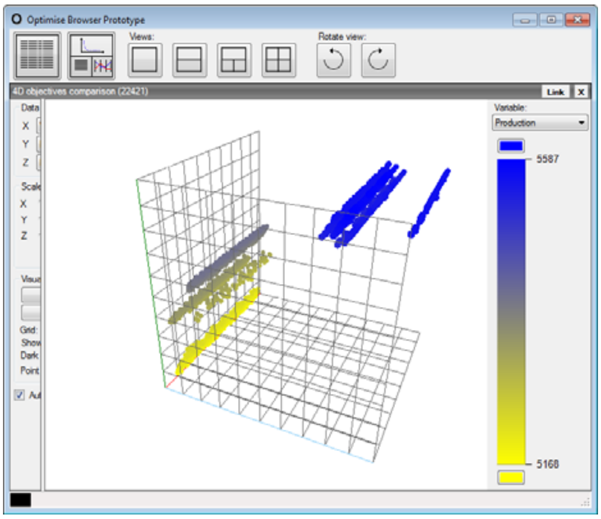


Fig. 8: 4D plot visualizing how Production Scheme divides the solutions into 8 clusters.

Applying this procedure to the data set generated from the MOO has discovered the following insight from the model: the two 4D plots clearly illustrate that there are mainly two decision variables which determine which objective cluster a solution will fall into: High production can be achieved only when *Lathe 5 setting* set to be 1 and the "Production Scheme" is the parameter which further divide the solutions into 8 clusters in the entire 3D objective space. The variables controlling the conveyor lengths, which indirectly controlling the buffer sizes between workstations, contribute to control the final average WIP of the whole cell, which is logical. In the 4D plots, it can be observed by the color change with respect to the WIP axis. Fig. 9 gives an example when the 4th axis (color) represents the variable *"Conveyor length before Lathe 5".*

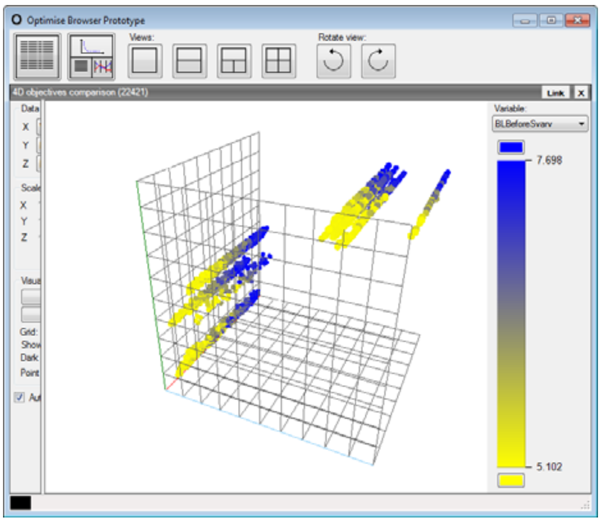


Fig. 9: 4D plot showing the buffer length before Lathe5 determines the WIP level.

Apart from the visualization of the solutions generated from the MOO, we used a distance-based data mining process [15] to extract knowledge, in terms of decision rules, from the entire MOO data set. Such a post-optimality data analysis process is an extension of the simulation-based innovization (SBI) approach proposed in [16]. It was assumed that the decision maker would be interested to solutions with relatively low WIP and low energy usage but can achieve the highest possible total production, which is a quite typical decision strategy of production managers. Therefore, the reference point chosen was [WIP=35, EnergyUsage=570000 (kW), Production=5600].

Fig. 10 shows the reference point and the Euclidean distances between every solution to this point calculated with the extended SBI approach.

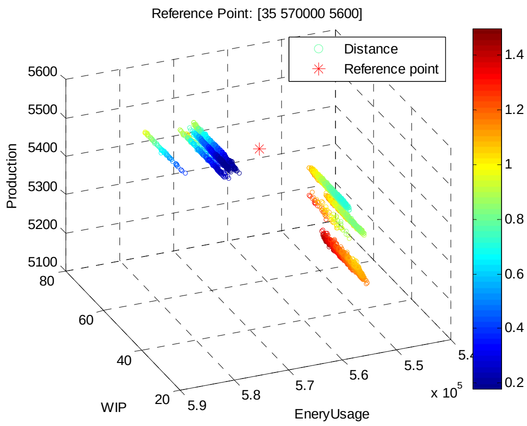


Fig. 10: Color-coded Euclidean distances between every solution to the chosen reference point.

The generated data mining result (see Tab. 1) is actually very crisp, in the sense it can be easily interpreted. For the system to reach the performance expressed by the reference point, i.e. highest production with the lowest possible WIP and Energy Usage, *Lathe 5 Setting* needs to be 1 (slow process), Production Scheme should be 2. Lathe 5 Setting should set to be low to increase total production is counter-intuitive but can be explained by the less setup when changing product variants. The buffer size before Lathe 5, Lathe 1 and Lathe 3 should be limited below 5.4, 4 and 1 respectively with an effect to limit the total average WIP. As shown in the generated rule, the other decision variables are not significantly influencing the objectives, with respect to the chosen reference point. To a certain extent, this rule extracted can be validated by the visualization in 4D plots shown in Fig. 7-9. It might require deeper analysis to locate the final solution for implementation, if the case study results had been used for real changes in the machining cell, but our SBI results have been sufficient enough to capture the essential characteristics of the good/optimal solutions for making that decision.

Tab.1: Rule set generated using data mining.

Decision Variables	Rule Set
Conv. Lathe 5	< 5.4
Conv. Lathe 1	< 4
Conv. Lathe 2	-
Conv. Lathe 3	<1
Lathe 5 Setting	= 1
Production Scheme	= 2
Mill m/c setting	-
Worker1	-
Worker2	-

5. CONCLUSIONS

This paper revealed a multi objective simulation model that captured the classical capacity analysis, flow related properties, the energy usage and shop floor operator activities which facilitated the model wider application of discrete manufacturing activities.

The developed method of data interoperability can contribute to the use of the CMSDIM as a base to structure the information. This structured neutral format data will help to build model with less effort, reuse the information, and communicate with different application tools.

6. ACKNOWLEDGEMENTS

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