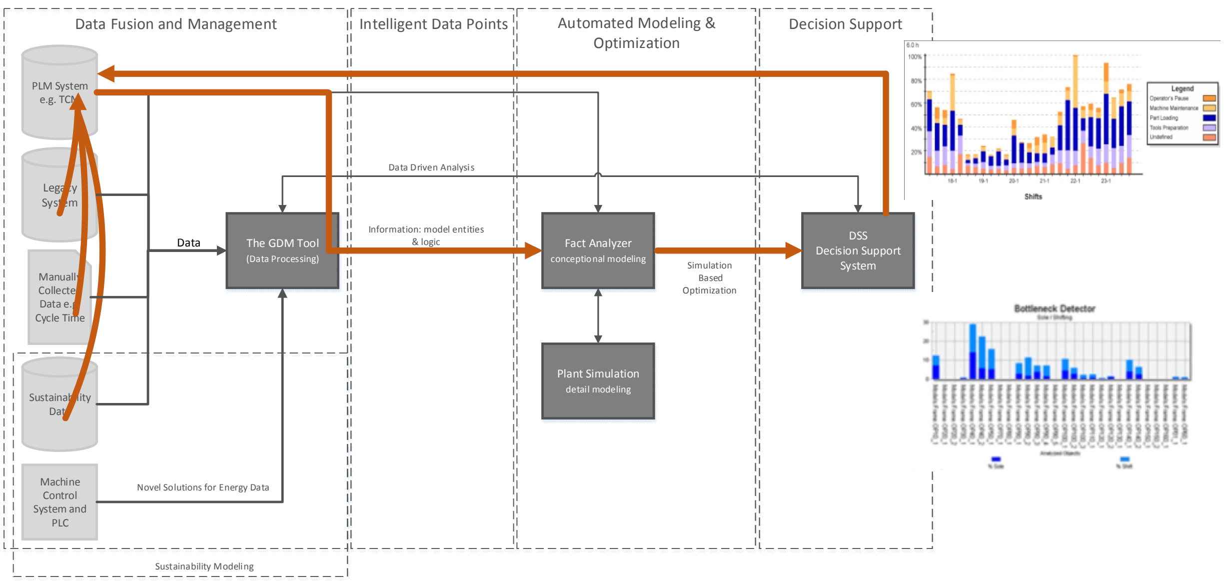

Automation of Input Data Management for Discrete Event Simulation

Master's Thesis in Production Engineering

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Master's Thesis - 2016

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Cover: Automation of Input Data Management for Discrete Event Simulation.

Printed by Reproservice, Chalmers
Gothenburg, Sweden 2016

Abstract

In manufacturing industry Discrete Event Simulation (DES) is a powerful tool in making decision support with the help of modelled production systems. DES is highly dependent on input data and the success of the project is depends on the quality of data that is obtained for simulation studies. One of the main weakness and most crucial step in DES is it is highly dependent on input data management and the time that it spent on collecting and mapping the data for simulation studies with in the enterprise. Another major challenge is to automate the input data management process with the use of data standards which will also help to structure the input data that would integrate simulation applications to manufacturing application software from a single data source.

The main purpose of this thesis is to enable fast and efficient method to exchange information between manufacturing and simulation application in this case study. Firstly, to evaluate the input data management method on how to reduce the time consumption for input data for DES and to propose a generic structure on how to structure relevant input parameters required for simulation models into a single data source for efficient and standardized exchange of information. This thesis is represented as objectives (1&2) which is performed with a case study in Volvo Group Trucks Operations, Gothenburg.

The result of this thesis from objective 1 is with the help of Generic Data Management (GDM) Tool there is an significant reduction in time consumption in input data management process, and from objective 2 with the help of manufacturing standards CMSD and ISA-95 a generic structure is proposed for the case study to structure the information of the production system and the applicability for DES modeling has thoroughly investigated.

Still there is lot of scope and improvements for input data management as it depends on the available data and data quality. Tool such the GDM Tool has great potential to support to reduce the time consumption in input data management process, a complete automation is possible in near future with some additional developments and to integrate a common data source to manufacturing application software for decision support from simulations.

Keywords: Input Data Management, Discrete Event Simulation, Core Manufacturing Simulation Data (CMSD), ISA-95, GDM-Tool, Generic Structure.

Acknowledgements

This report is the result of our Master Thesis performed at the Department of Product and Production Development at Chalmers University of Technology during the spring of 2016. The thesis has been performed in co-operation with Volvo Group Trucks Operations, Gothenburg, Sweden. We would like to thank our Chalmers Supervisor Jon Larborn of Chalmers University of technology for helping us with continuous guidelines throughout the Thesis and we thank him for his significant contribution towards the GDM Tool. We would like to express our gratitude to our Company Supervisor Atieh Hanna of Volvo Group Trucks Operations for dedicating her valuable time for the successful completion of this thesis. In addition, our special thanks to Volvo Group Personnel and Volvo Umeå plant members for their help and assistance in this thesis work.

We extend our gratitude to our Examiner Anders Skoogh of Chalmers University of Technology for his valuable support and guidance throughout the Thesis. Lastly, we thank our parents for their support.

Phanindra Kshatra Damarapurapu,

Sourabh Gargatte,

Gothenburg, June 2016.

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1

Introduction

In the today's global market, the competition between companies and; demand and development of new products has rapidly increased in recent past decades (Minguela-Rata & Arias-Aranda, 2009). Industrial companies are challenged to reconsider their production capacity when it comes to fulfil the increasing customer demands (Minguela-Rata & Arias-Aranda, 2009; Cordero, 1991). This means the companies would often try to optimize their production capacity, this includes various aspects of production system, such as resource planning i.e. raw material, management team, equipment etc. with short production run-up to increase the efficiency of the production system. Due to the high number of variables and aspects involved in characterization of production system, it is demonstrated that Discrete Event Simulation (DES) is very useful technique and considered to be powerful tool, in regards to optimize production capacity and to improve the overall efficiency of production system. The manufacturing process could be modeled in the simulation environment to imitate it's dynamics behavior, which could be analyzed to predict the existing production system's capacity and performance before actually implementing short production run-up (Schroer & Tseng, 1988; Chance, Robinson, & Fowler, 1996). Industrial companies have been using Discrete Event Simulation (DES) in system planning, resource planning, scheduling, production planning, to detect bottleneck, and to improve the overall efficiency of equipment (Ingemansson, Bolmsjö, & Harlin, 2002). However, despite of it's benefits and potential, discrete event simulation (DES) tool has not been completely adopted by most of the industrial companies.

One of the main reason is due to the extensive time consumption of dynamic simulation studies (McNally & Heavey, 2004; Fowler & Rose, 2004). The time spent on input data management process for simulation modeling constitutes more than 30% of entire simulation project (Skoogh & Johansson, 2009; Bloomfield, Mazhari, Hawkins, & Son, 2012) due to fact that more than 200 samples require to represent stochastic parameters in dynamic simulation modeling (Perrica, Fantuzzi, Grassi, Goldoni, & Raimondi, 2008). Some of the major challenges that constitutes to increase in time consumption, includes non-availability of raw data, high level of model details, problems in extracting data from data source and extensive manual workload to transform the data into relevant information (Fowler & Rose, 2004). The present trend that has been practice in manufacturing companies is a manual approach in regards with input data management process. Most of the companies rely on the manually entering information into the simulation models due to the lack of raw data especially the data describing the dynamics of production system in it's data sources. Some of the data resides in several local data sources in form of spreadsheets, which is processed using statistical tools, with a manual approach. Fortunately, there has been significant research work has been carried in regards with input data management, to automate the process in order to reduce time needed for data collection with the help of an IT software knowns as Generic Data Management (GDM) Tool (Skoogh, 2011; Boulonne, Johansson, Skoogh, & Aufenanger, 2010; Skoogh, Michaloski, & Bengtsson, 2010). The GDM Tool automates the entire process of input data management and delivers the final information in form of excel format or in XML format to simulation models.

Secondly, interoperability between business applications has been a trending issue in today's companies. Particularly, the area that is affected with the interoperability issue is manufacturing operation area, this is because to perform a detail analysis by representing the manufacturing operations in simulation application and due to the collecting the data manually, also from various other manufacturing application sources which consumes time, also lacks a detail data specification to perform a detail analysis. Further managing this complex task of deployment of information from different source is a difficult task to support the simulation studies (Lee, Riddick, & Johansson, 2011). Thus, enhancing interoperability between manufacturing and simulation application facilitates fast and efficient method to exchange the information with collaboration of interorganization department to share required information. One such manufacturing standard that addresses the interoperability issue which has been employed in previous related research work is Core Manufacturing Simulation Data (CMSD) developed by National Institute of Standards and Technology (NIST), (Lee, Riddick, & Johansson, 2011; Lee, 2015). Facilitates efficient exchange of information between simulation and other manufacturing application, provides detail data specification and industry standards make it easier and cheaper for companies to access and use certain technologies (Lee, Riddick, & Johansson, 2011; Bloomfield, Mazhari, Hawkins, & Son, 2012; Lee, 2015).

1.1 Input Data Management

Input Data Management in simulation is process of preparing a quality assured simulation adapted data and representation of relevant parameters for simulation models. In other words, it's the process to transform the raw data to a relevant information that is suitable to adapt for simulation models. The input data management process basically includes, identification of relevant input parameters, collection of relevant input parameters i.e. data collection, processing the raw data to a quality assured simulation adapted information according to the simulation user requirements (Skoogh & Johansson, 2009; Skoogh, Perera, & Johansson, 2012; Bokrantz, Skoogh, Andersson, Lämkull, & Ruda, 2015) and finally providing the final information in form of spreadsheets or in a standardized file that are easily readable in any DES software. Often the connection between the data collection and final representation of information in form of standardized file or spreadsheets is not realized, which constitutes the whole process of converting raw data to a quality assured data as an information to the simulation models around 30% of entire time of simulation project (Skoogh & Johansson, 2009). Thus, it is essential to automate the input data management activities to reduce the time consumption in simulation projects.

Figure 1, describes the entire process of input data management, the process consists several activities that are necessary to prepare quality assured data, some of them such as, removal of data points that are irrelevant, corrections, filtering, calculation etc., (Skoogh & Johansson, 2009).

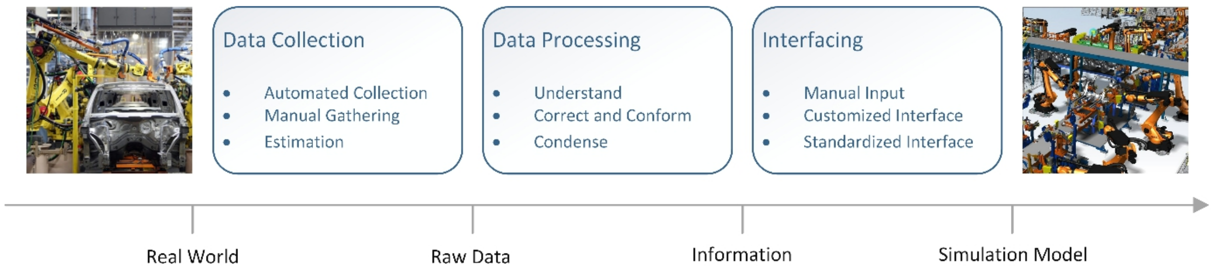


Figure 1. Different sections of input data management (Skoogh, 2011)

1.2 Purpose

The main purpose of this thesis is to enable fast and efficient method to exchange information between manufacturing and simulation application in this case study. Firstly, this thesis work would evaluate the method presented in various previous related research work in this new case study, on how to reduce the time required in input data management process, in which the input data management activities has been automated i.e. data extraction, data processing, data representation and publishing the final information in form of either spreadsheets or XML format that is readable in any DES software. At present the practice at Volvo Group is a manual approach of input data handling, this includes, manual data gathering from the data source or Corporate Business System (CBS) and human involvement in data processing with the help of statistical software or MS- Excel.

Secondly, to address the interoperability issue to enable standardized and efficient method of exchange of information, a detail investigation would be performed on few manufacturing standards such as Core Manufacturing Simulation data (CMSD) and ISA-95 standard to analyze it applicability for DES studies. In addition to this, based on the manufacturing standard, to propose a generic structure that would integrates different manufacturing applications, so that all the necessary data required for a detail modeling to mimic the dynamics of production system is available in a single source and not to rely solely on sources such as Entrepreneur Resource Planning (ERP) systems.

1.3 Objectives

The thesis work would evaluate a method that would reduce the time consumption in input data management process in simulation studies with a case study. Improvement of the input data management process i.e. converting raw data to a useful relevant information for simulation models is essential to reduce the time consumption and this would be realized with help of IT software known as Generic Data Management (GDM) Tool, this would automate the entire process of input data management. Further, suitability of few manufacturing standards for efficient exchange of information to the simulation models, would be investigated.

1. Evaluating the method of input data management process with help of an IT software GDM Tool, with a test case

The thesis work would evaluate the input data management method presented in various previous related work and will strive to reduce the time consumption in input data management process in this test case. In this process, the solution is realized with help of an IT software known as Generic Data Management (GDM) Tool, which would help to fulfil this objective and the proposed solution is demonstrated in one case study. Further, the thesis work would compare the result of proposed solution with the manual approach of data handling.

2. To investigate the applicability of International Standards for efficient exchange of information in Discrete Event Simulation (DES) modeling with a test case

To enable efficient exchange of information to simulation models, some of the standards and it's applicability would be investigated. Further, as mentioned in the purpose, to propose a generic structure on how to structure the information of a production system, including it's flow of material into a single data source, that could be a database, standardized file or in a spreadsheet. This would increase the frequent use of the discrete event simulation (DES) modeling for simulation users and as well for production engineers due to the efficient exchange of information to simulation models. International Standards such as Core Manufacturing Simulation Data (CMSD) standard and ISA-95 (International Society for Automation Standard) for Discrete Event Simulation (DES) modeling, would be investigated it's suitability for DES modeling with a test case.

1.4 Scope

The scope of the thesis work is within automotive manufacturing industry. The production data that is gathered belongs to the production line, work areas, which consists several equipment such as, welding, drilling, pressing jobs, assembly operations and runs automatically without any interference of human. Further, in this thesis work only one case study has been considered to investigate the production data that would be relevant for simulation studies. Also, only those input parameters that are relevant for the simulation of manufacturing operations and material flow in DES software are considered during the input data management processing. It is possible that the solution presented in this thesis through the case study, is likely to work on different type of industries that has similar data requirements but an additional work on different applications areas is required to testify the solutions presented through this case study.

1.5 Delimitation

The international standards that would be investigated for it's suitability in discrete event simulation (DES) modeling is mainly related to the manufacturing industrial standards, as the scope of the thesis is focused within automotive industry and to provide information regarding manufacturing operations and material flow of production system. Further, the production data quality has been addressed sufficient enough while providing information to simulation models but it is important to note that the data quality is not addressed in detail as it is required according to the industrial standards as this was not the main priority but it's matter of concern that has been kept in mind while processing the data. About the input data parameter, some of the input parameter information such as number of operators, conveyor speeds has not been considered during the case study as the information was not collectable but were available. The main focus of this thesis work has been as mentioned in previous sections, is to evaluate input data management methodology to reduce time consumption in input data handling process and propose generic structure based on manufacturing international standards for efficient exchange of information. In order to realize, reduce time consumption in input data handling process, a software known as GDM Tool, would be tested in this thesis based on previous related research work and recommended to use it, as this is an open source windows based application and no additional programming skills is required to use it's functionalities. However, because of limited time, only one case study at Volvo Groups, Gothenburg has been considered to perform the thesis work. And only two international standards i.e. Core Manufacturing Simulation Data (CMSD) standard and ISA-95 (International Society for Automation Standard) has been thoroughly investigated for two reasons, firstly there has been several related work with CMSD in DES modeling and ISA-95 was investigated based on the company's interest, secondly, the thesis had limited time to complete the project.

1.6 Report outline

Chapter 1 - Introduction: Here the Background, Purpose, Business and Project Objectives are presented.

Chapter 2 - Theory: The Literature study and the Theory part done in this thesis is presented here. The theory presented here is used in the industrial projects and specifically in automotive industry.

Chapter 3 - Method: Several Methods used in this project are presented here. The Chapter is divided into 4 parts the first part describing the theoretical framework. The second part describes the data collection. The third part describes the Tools and Software used in this thesis. The fourth part describes the use of Standards for DES.

Chapter 4 - Results: The results from the evaluation of Generic Data Management (GDM) tool, the standards Core Manufacturing Simulation Data (CMSD) and ISA 95 is discussed here. Evaluation of input data management method is presented. The Volvo Follow-up system's SWOT analysis is also described in this chapter.

Chapter 5 - Discussion: The results and the analysis of the Automated Input Data Management, Generic Data Management Tool and the Standards Core Manufacturing Simulation Data(CMSD) and ISA-95 are discussed and Legacy System SWOT analysis are also discussed and Final conclusions are drawn in this chapter. The methods used during this project are also discussed here.

Chapter 6 - Conclusion: The final conclusions of this project are presented in this chapter.

2
Theory

The Theory part is described in the following sections, that are various surveys and case studies and interviews that are applied in industrial systems of same type and are described here, namely Data collection, Analysis and Processing, Automated Input Data management, Core manufacturing Simulation Data (CMSD) and ISA-95. These theories are widely used in industries for simulation perspective.

2.1 The difference between Data and Information

This section is important as it serves a basic understanding difference between data in industry and information that is relevant for simulation studies. Understanding data, information and knowledge is required while in input data management process to transform raw data to relevant information for simulation studies.

According to Davenport and Prusak (1998), data is a set of discrete, objective facts about events. In an organizational context data is described as structured record of transactions. Data is very important for the daily activity in the organizations and most of the manufacturing industries are heavily dependent on it (Davenport & Prusak, 1998). Information is meant to change the way the receiver perceives something, to have an impact on his judgment and behavior and it is improvised form of data with relevance and purpose (Davenport & Prusak, 1997). Knowledge is broader, deeper, and richer than data or information. Figure 2, describes the difference between Data, Information and Knowledge.

Data	Information	Knowledge
Simple observations of states of the world ▪ Easily structured ▪ Easily captured on machines ▪ Often quantified ▪ Easily transferred	Data endowed with relevance and purpose ▪ Requires unit of analysis ▪ Need consensus on meaning ▪ Human mediation necessary	Valuable information from the human mind Includes reflection, synthesis, context ▪ Hard to structure ▪ Difficult to capture on machines ▪ Often tacit ▪ Hard to transfer

Figure 2: Difference between Data, Information and Knowledge (Davenport & Prusak, 1997).

In Input Data Management when describing and developing the input model is important to make a distinction between Data, Information and Knowledge, because data is transformed into information for simulation models (Skoogh, 2011). The important factor is that model receives the data and the input data activity is to interpret and process the data in order to have a meaning, purpose and relevance of the data to convert into Information from the output (Skoogh, 2011). Knowledge on the other hand is skill, proficiency know-how and experience of the people in building the model which is important to make change and improvise the models and needed after simulation modelling and not important part of input data management process.

2.2 Data requirements in Discrete Event Simulation (DES)

Simulation is used in companies to improve the production processes that are already present in the company and are being developed for future purpose for increasing efficiency of the system (Williams, 1994). Depending on the type of industry simulation models differ because of variations in production systems and model building procedure (Skoogh, 2011). In order to have a realistic simulation analysis setting of objectives is most important in simulation projects, these objectives will help to reflect the system that we actually need; objectives help to understand the system with which one can make decisions for the improved system with accuracy and efficiency (Hatami, 1990). In the initial phase of the simulation studies analyzing a system to evaluate as many number of alternatives as possible to verify the design parameters is common, so in this case approximations are common to test different simulation parameters (Hatami, 1990). The most argued parameters that is responsible to mimic the dynamics of the production system are Processing times (assembly time and machine time), and Breakdowns (MTTR and MTBF). Below is the list of some of the most common parameters that are used in DES models (Hatami, 1990).

- Storage Space Capacity or Buffer
- Machine/Operators Speed
- Processing time
- Set-up Times
- Breakdown Frequency (MTBF)
- Repair Times (MTTR)
- Work Schedules
- Material Handling Systems
- Layouts
- Product Flow Mix
- Quality related parameters (scrap rate, frequencies) Etc.

2.3 Data Collection

This section helps to understand different data collection methods that are significant in order to collect, to make it available to simulation models. This is later performed to collect data in this case study.

Data collection is the most significant and the central part of the Input Data Management. The first step is to identify the data, where it is located and how to collect the data. At first the data is identified and defined by relevant parameters according to the requirements. After all the relevant parameters are considered according to Discrete Event Simulations (DES), specific accuracy requirements are defined.

Then identification of data is very important and should gather the available and not available according to DES requirements. After all the data is gathered, statistical and empirical representations should be made according to the data and check where the representations suit them or not. After the final step the data is transferred to the processing with an IT support either using a statistical tool or Generic Data management (GDM) tool (Skoogh & Johansson, 2009).

The Data collection consist of 3 categories

1. Category A: Extraction
2. Category B: Gathering Methods
3. Category C: Estimation

1. Category A - Extraction: In this category the data is found in different places in the industry may be in spread system or in computers. This data can be collected by automated collection systems, computerized manual collection systems, ERP, MRP, MES or maintenance systems in the industry. This data is available from Production Engineer's own document measurements and documents from previous gatherings or old historical documents in the industry.

2. Category B - Gathering Methods: In this category the data is not readily available in the industry but can be gathered. The most common way of gathering this data is by doing time study using stop watch, time study using video analysis or SAM analysis, MTM studies using video analysis, frequency studies, follow-up studies for several days or weeks, shop floor data analysis and Interviews.

3. Category C - Estimation: In this category the data is not readily available in the industry and cannot gather. This type of Data is most available from interviews from industry. Focus expert groups, data that is historically present for similar processes, information from supplier, machine vendor information, use statistical distributions or combination of sources (Skoogh & Johansson, 2008).

2.4 Data Processing and use of Generic Data Management (GDM) Tool

This section is significant as it helps to understand the approach to process the data. Further, data representation theory allows to understand which statistical distribution could be preferred after data processing and why. GDM Tool helps to transform the data to relevant information, which is employed in this case study to process the data and prepare output representation.

The concept of automated input data management is done with the help of an IT solution for example, one such tool called as Generic Data Management (GDM) tool. GDM Tool is mainly used for 3 functions

1. Data Extraction: It is the key feature of the GDM tool where this feature has the ability to extract raw data or data from the legacy system with different formats. However, the GDM tool can extract data from most of the data formats that are available in the industry and has the potential to connect to different data sources or File formats.

2. Data Processing (Conversion): When the raw data is extracted from the legacy system, depending on the requirements of DES parameters, raw data is converted into relevant simulation input data using different plugins available in the GDM tool. The following are the activities that are required to transform the Data:
   a) Contextualization
   b) Categorization
   c) Correction
   d) Calculation
   e) Condensation

a) Contextualization: Contextualization is essential to understand the purpose of the data, to know what kind of information we can get from the data we collected and which part of the company or organization is responsible for this data.

b) Categorization: Categorization is understanding the characteristics of the data, it tells what are the data formats present and what are the units of analysis, it specifies the key components of the data, and it tells what simulation parameters can be extracted.

c) Correction: Correction is excluded or modification of incorrect or irrelevant data, it specifies what type of data that need to be excluded, what irrelevant data depending on the data that is collected.

d) Calculation: Calculation is to change or calculate the new parameters from the existing Data, it is used to obtain the relevant data for simulation, it also stands as a tradeoff between the available time and quality of results.

e) Condensation: Condensation gives the statistical or empirical representation of the Data that is available and condense the data for the simulation studies. Usually they are Exponential, Lognormal, Weibull, Gamma, Triangular etc. These are discussed more in section 2.4.2 (Skoogh, 2011).

3. Output: The legacy system is developed according to the user requirements of the company needs and are not according to the standards.

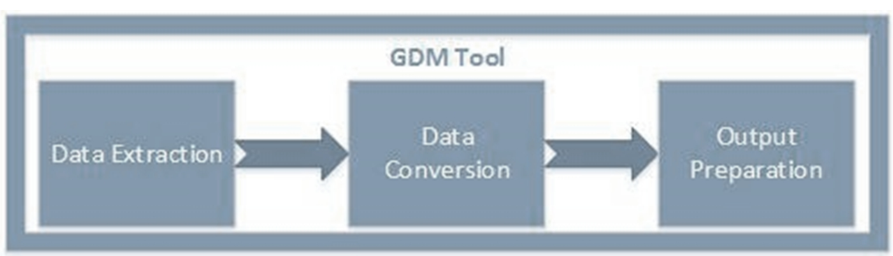


Figure 3: The concept of GDM tool (Skoogh, 2011).

2.4.1. Data Representations

It is one of the most important part of input Data because it supplies the Data to the Simulation models. There are different types of distributions

1. Traces
2. Empirical distributions
3. Statistical distributions
    a. Continuous distributions
    b. Discrete distributions
    c. Approximate distributions
4. Bootstrapping

1. Trace is the stream of data which describes the sequence of events that occur over a period of time. In general the automated data collection system contains data which is collected over a period of time.

2. Empirical distribution is normally obtained from the historic data, it generally shows the data values or ranges of data values represented by histogram or frequency charts, most simulation software can use direct empirical data distribution.

3. Statistical distribution is defined by some mathematical function or probability density function. This distribution condenses the data to a distribution family name preferably normal distribution and deal with two specific parameters mean and standard deviation which deals with Continuous, Approximate and Discrete distributions.

4. Bootstrapping is used when a small sample of data set is available, the available data is randomly used with replacement from the original trace. Of these Statistical or Empirical distributions are the most commonly used because they condense the data. For this thesis we have used the statistical distribution (Robinson, 2004; Skoogh, 2011)

2.4.2 Input Modeling for Simulations:

Input Modeling as described as the condensation of raw data to suitable representation, it is more mathematical calculations involved and several steps. This along with data correction and calculation is the most time consuming process in Input Data Management (Skoogh, 2011).

In general, there are 3 ways to input model data.

1. **Trace Drive Simulation**: This input modeling procedure allows the simulation engineer to use the data collected directly used in simulation.
2. **Empirical Input Modeling**: This input modeling procedure will produce random variables are generated from the collected Data for the simulation.
3. **Theoretical Input Modeling**: This input modeling procedure will estimate the parameters of the theoretical distribution function from the actual data and random variables are generated from the fitted distribution function (Choi & Kang, 2013).

Input modeling starts with data that is corrected and calculated. These data set requires a number of steps to get the statistical distribution form that can be used in simulations. Distribution fitting is a statistical estimation process and these steps were discussed by several authors, these steps consist of:

1. Evaluating the characteristics of the data and checking data independency
2. Selection of a distribution function
3. Estimation of parameters and selecting best fitting parameter value
4. Determining Goodness-of-fit test (Skoogh, 2011; Choi & Kang, 2013).

1. Evaluating the characteristics of the data and checking data independency

After having the data sets that are to determine the Input Modeling in Discrete Event Simulation, the first step is to assess and check whether the observations of the data set are independent. The obtained data must be in the order of collection to check and asses the data independency. There are many graphical and statistical methods that are used to assess the data independency. Among the graphical solutions scatter plot is most widely used. The data that is obtained are plotted in order of collection, and check if there is no tendency of data is identified as a function of time with number of observations made, for the data the time and the order of observations are plotted on the x, y coordinate system and if the plotted data points are randomly distributed one can conclude that data are independent (Leemis, 2004; Skoogh, 2011; Choi & Kang, 2013).

2. Selection of a distribution function

The second step is the analysis of the data set for further evaluation with a suitable distribution function, this can be done by plotting a histogram and calculating the values of some sample statistics or the distribution family is chosen on the nature of the sample data

1. Inter-arrival time Exponential or Erlang distributions are most commonly used
2. Service times Triangular, Beta, Normal or Lognormal distributions are used and
3. Interfailure time Weibull distribution is used. (Leemis, 2004; Skoogh, 2011).

3. Estimation of parameters and selecting best fitting parameter value

The third step is the input modeling procedure which estimates the parameters for the distributed families, the parameter estimation for distribution function is found by Rank Regression Method, Least Square. Method of Moments and Maximum Likely hood Estimator (MLE) of these three MLE is most preferred for parameter estimation

1. MEL is used for Exponential, Log Normal and Normal distributions
2. Method of Moments is used for Erlang and Beat distributions
3. Rank Regression Method is used for Weibull distribution (Leemis, 2004; Skoogh, 2011; Choi & Kang, 2013).

4. Determining Goodness-of-fit test

In the fourth step in order to assess the model accuracy for the distribution function with the estimated parameters, goodness-of-fit test is used (Skoogh, 2011; Choi & Kang, 2013).

Table 1: Distribution Fitting for Input Modelling (**Choi & Kang, 2013**)

Distributions	Input Variable Type	Parameter Estimation
Exponential	Inter-Arrival Time	Maximum likelihood method
Erlang	Inter-Arrival Time	Method of moment
Triangular	Service Time(Repair	———
Beta	Service Time(Repair	Maximum likelihood method
Normal	Service Time(Repair	Maximum likelihood
LogNormal	Service Time(Repair	Maximum likelihood
Weibull	Interfailure Time)	Rank regression method

2.5 Data Interfaces and Standards

Standard Data interface could help to reduce the cost that are associated with simulation model and data exchange between simulation software and other software applications, thus make simulation technology more affordable and accessible to a wide range of industrial users (McLean, Jones, Lee, & Riddick, 2002).

When a new project is started a simulation engineer builds models and imports data from scratch, so it is important to have a software architecture, a standard data interface that can be readily used by the simulation engineer with in less time frame work.

Unified Modeling Language (UML) is being used for the development of software architecture and the data interface specification are being developed using Extensible Markup Language (XML). Unified Modeling Language (UML) is used to develop model in the simulation, the UML model gives the manufacturing related entities in the shop/cell and the individual activities that are applied to those entities, it also provides the relation between the entities and the production activities which supports the manufacturing processes in a shop/cell. UML has several advantages where it is recognized standard for structured and object oriented modeling, it is a visual language based and simple to understand. Usually the model contains boxes and line drawings which supports the encoding of large amount of information in each diagrams. It is visually easy to locate the relationships between different activities (McLean, Jones, Lee, & Riddick, 2002). Extensible Makeup Language (XML) is a standard which is supported by World Wide Web (W3C) standard body, refer (W3C, 2016), this standard is used to define the exchange formats for UML for the information. XML is most widely used language in the machine shop data through industries. The major elements used in XML structure are

- Units of Measurement (e.g. length, weight, currency, speed etc.)
- Departmental structure
- Skill definition
- Operation definition
- Resources
- Probability Distribution
- Layouts
- Parts

- Bill Of materials
- Work
- Orders
- Process Plans
- References
- Etc. (McLean, Jones, Lee, & Riddick, 2002).

2.5.1 Core Manufacturing Simulation Data (CMSD)

The Core Manufacturing Simulation Data (CMSD) is an open standard information model developed with in the Simulation Interoperability Standards Organization (SISO). This standard provides a neutral and generic structure for efficient exchange of manufacturing data in simulation environment (SISO, 2010).

The purpose of CMSD is to:

- Enable data exchange between simulation applications and other software applications.
- Support the construction of manufacturing simulators.
- Support the testing and evaluation of manufacturing software and.
- Enable greater manufacturing software application interoperability.

CMSD standard is represented in two methods Unified Modeling Language (UML), and the XML schema definition language (XSD). Figure 4, shows the packages that make up the CMSD model.

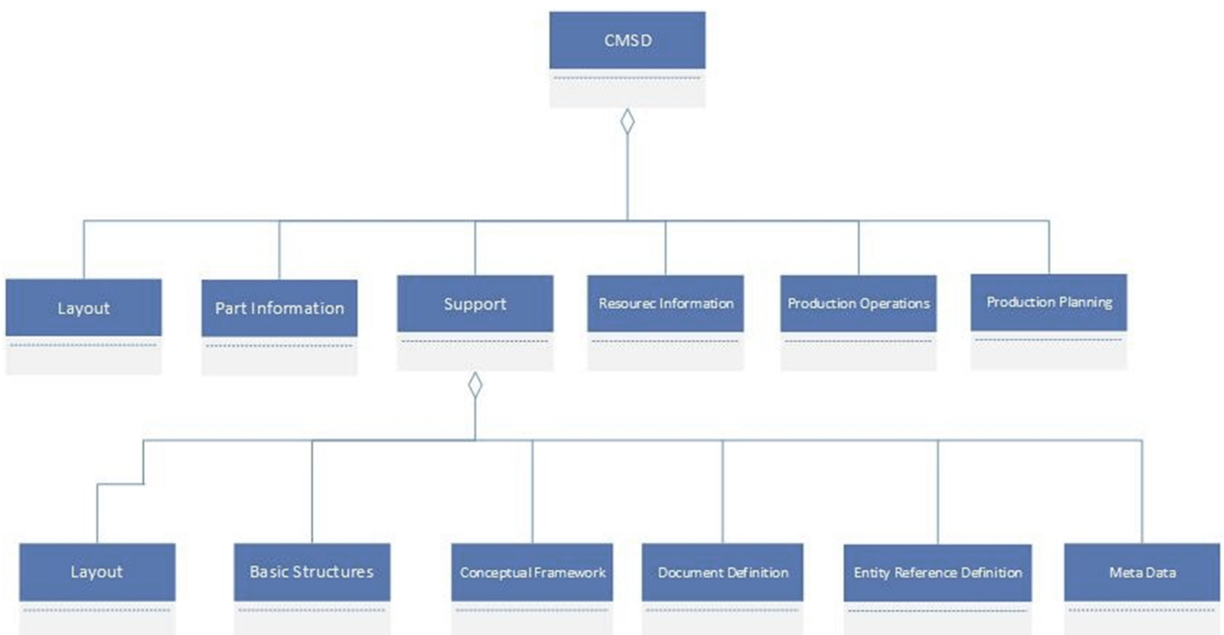


Figure 4: The Packages of CMSD Model (SISO, 2010).

The main advantage of using CMSD is that in discrete event simulation models it provides the specific information about stochastic characteristics of production processes using probability distributions. Another advantage is it also provides a neutral data formats for storing the manufacturing data needed to develop and run simulation models. Its structure defines and represents the relationship between attributes and entities that are specific to one another and the data connected to it (Lee, Riddick, & Johansson, 2011).

According to Tina Lee, 20 major data elements are identified. These data elements are Organizations, Calendars, Resources, Skill Definition, Setup Definition, Operation Definition, Maintenance Definition, Layouts, Parts, Bill-of-Materials, Inventory, Procurements, Process-Plans, Work or Job, Schedules, Revisions, Time sheets, Probability Distributions, References and Unit-of-Measurements. These data elements are related to one another in the data standards (Lee & McLean, 2006).

The CMSD information model provides neutral data structures for the efficient exchange of manufacturing data from machine shop to simulation models. This data structure is used to support the integration of data source to simulation applications (SISO, 2010). ISA-95 is the standard which describes the interface between manufacturing operations and enterprise control functions. This standard is defined and developed for computer integrated manufacturing of activity models. This standard also acts as activity models between the enterprise and actual physical process (Scholten, 2007).

CMSD data standard can be implemented in XML and UML schema and all the data elements described by Lee & McLean, 2006; were used for this standard and addition to these elements, it also contains Machine program, Meta Data, Property etc. These XML and UML schemas provides the relationship between these Data elements.

2.5.2 ISA-95 Standard

ISA-95 is the international standard that is developed for the integration of Business Enterprise and Control Systems. It is mostly used as a reference starting from Business objectives to different systems by organizing and allocating the information flow throughout the system (Scholten, 2007).

ISA-95 is an Enterprise-Control functional model, see Figure 5, this model represents the structure of different organizational functions in a company.

The Main purpose of the standard is to

- Emphasize the integration of Business Enterprise to Control Systems throughout its life cycle.
- Can be used to change and adapt the existing model and to integrate the manufacturing control systems to business functions.
- Continuous improvements can be made to the developed model and information exchange can be made fully automated (Scholten, 2007).

ISA-95 standard consist of five parts.

- **Part: 1** - Models and Terminology, ANSI/ISA-95.00.01 (IEC 62264-1 Mod).
- **Part: 2** - Object Model Attributes, ANSI/ISA-95.00.02 (IEC 62264-2 Mod).
- **Part: 3** - Activity Models of Manufacturing, ANSI/ISA-95.00.03 (IEC 62264-3 Mod).
- **Part: 4** - Objects and attributes for manufacturing operations management integration, ANSI/ISA-95.00.04.

- **Part: 5** - Business-to-Manufacturing Transactions, ANSI/ISA-95.00.05. (Scholten, 2007).

ISA-95 defines a Functional Hierarchy model, this Hierarchy model consist of 5 levels starting from 0 to 4 with each level provides specialized functions and has characteristics response types. Figure 6, shows the functional hierarchy model.

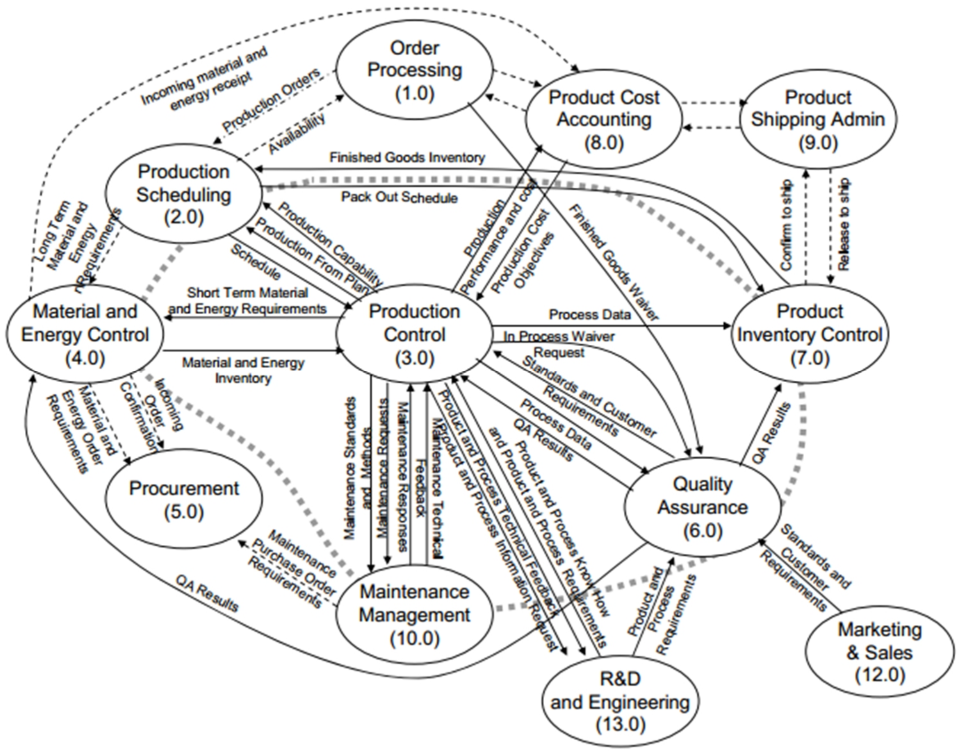


Figure 5: The Functional Enterprise-Control Model (Scholten, 2007).

Level 0: This level describes the actual physical process.
Level 1 and 2 are in combination and is called as **Control Domain**, but each has its own specific significance.
Level 1: This level describes the activities involve in sensing and manipulating physical processes. The time frame measurement at this level is done in Seconds.
Level 2: This level describes the activities of monitoring and controlling of actual physical processes. The time frame measurement at this level is done in Hours, Minutes, and Seconds.
Level 3 is called as **Manufacturing Execution System (MES)** layer
Level 3: This level defines the work flow activities of the desired output from the manufacturing process and ensure the end product to the customer. It includes the activities of actual processes, coordinating the flow of the process, maintenance records of the machine, logistics Etc. The time frame measurement at this level is done in days, shifts, Hours, Minutes, Seconds.
Level 4 is called as **Enterprise Resource Planning (ERP)** layer.
Level 4: This level describes the business related activities that need to manage the Manufacturing Organization.

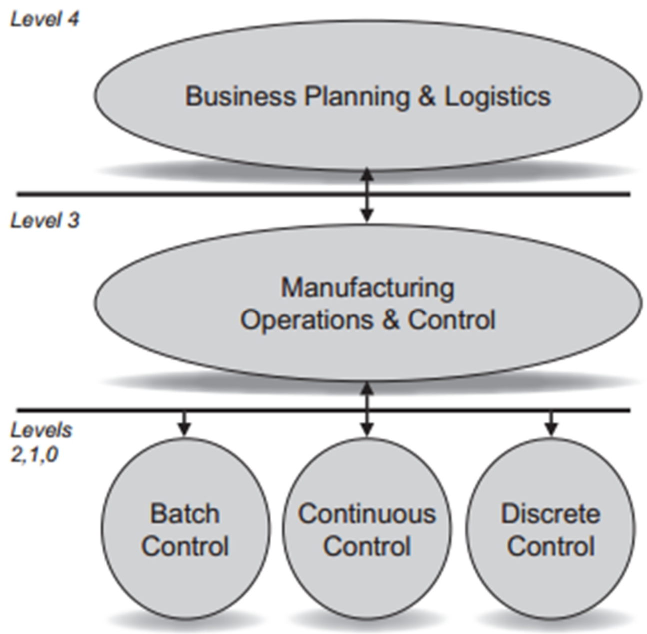


Figure 6: The Functional Hierarchy model (Scholten, 2007).

These Levels describe the Manufacturing organization of a company, but each mode has its own representation where it relates to the dynamic aspects of that particular system for which a model is built. These different models contains detailed level of information that a business analyst collects and analyze the potential outcomes for the organization and make improvements accordingly.

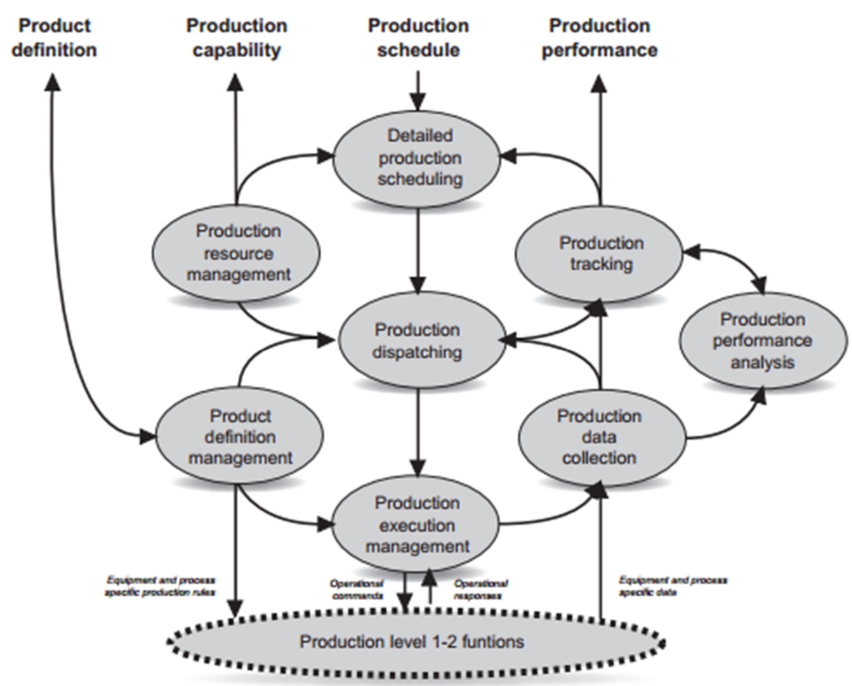


Figure 7: The activity model of Production Operations Management (Scholten, 2007).

In this thesis we are more focused on the Manufacturing Operations Management for our work, ISA-95 had developed the Level 3 activity models in Manufacturing Operations Management (MOM) that are described in generic way of Product Definition, Production Capability, Production Schedule and Production Performance. Figure 7, is the activity model of Production Operation Management (Scholten, 2007).

Once the activity model is defined depending upon the user specification and model, we use the B2MML (Business to Manufacturing Markup Language) schema, refer (MESA, 2016) in order to create the work flow order using Extensible Makeup Language(XML) and develop the generic structure according to the model and user requirement specifications.

ISA-95 data standard is represented in B2MML which is a XML implementation of ISA-95 standard. The XML schema of ISA-95 standard provides necessary information for the data exchange between scheduling component and manufacturing environment. As ISA-95 is a defined standard, the B2MML provides with a defined schema files with standard naming. These contain most of the data elements that are identified by Tina Lee, 2006. The ISA-95 elements are named as EquipmentInformation, Material-Information, PersonalInformation, ProcessSegmentInformation, ProductionDefinitionInformation, ProductionCapability, ProductionSchedule, ProductionResponse these contains the same information of data elements. These XML schema provides the relationship between these data elements.

2.5.3 Open Applications Group integration specification (OAGIS)

OAGIS is the standard that is developed by Open Applications Group Inc. (OAGi), it is a nonprofit standards development organization. This standard provides the industry business network language for information integration that works on cloud computing (OAGIS 10.2.1, 2016; Lee Y-T. T., 2015).

OAGIS divides the business information and business processes into scenarios and these scenarios provides the business messages in the form of Business Object Documents (BODs). These BODs are the business messages and information that are exchanged between software applications, between different companies that use OAGIS, provide information transaction across supply chains and between supply chains.

The scope of OAGIS includes Customer Relationship Management (CRM), E-Commerce, Enterprise Resource Planning (ERP), Manufacturing and Logistics (Open Applications Group, 2016). OAGIS is a web based service and is used with Electronic Business using XML (ebXML) standard. In OAGIS the interaction between the sender and receiver is a two way interaction so, an effective communication is needed for the transfer of communication status and error conditions for this reason the common business objectives are referred by "NOUNS" and the actions for these business objectives are referred as "VERBS". For the easy BOD representation, a merging of noun and verb information is defied to common business transaction (OAGIS 9.0, 2016). Different industries have different needs so a common architecture is needed OAGIS provides the information that is relevant to the industry specific needs, this is done by using a simple transport protocols such as HTTP and SMTP. But when a complex transport protocols information is needed it uses ebXML Transport and Routing or Enterprise application integration control system (Lee Y-T. T., 2015; OAGIS 9.0, 2016).

In OAGIS the systematic horizontal message architecture provides a common understanding of information between systems, companies and supply chains, for this the OAGIS uses the business scenarios identify the application that need to be integrated and BOD's are used for these business scenarios. The system can cover the Data exchange requirements for a manufacturing system and production supply chains. The current Version of OAGIS is 9.5 and it contains 68 68 Business Scenarios, 12 Verbs Defined, 80 Nouns (Common Objects) and 498 Messages (BODs), this model supports the exchange of information to define the manufacturing processes. Additionally, some nouns are defined form ISA-95 like ProductionPerformance and ProductionSchedule to form mixed-mode manufacturing for the standard. Thus both OAGIS and ISA-95 forms a manufacturing interoperability standards for process, discrete and Mixed-mode information exchange standards (Lee Y-T. T., 2015; OAGIS 9.0, 2016).

2.6 Previous related research work on CMSD and ISA-95 standard in DES

Several case studies had been performed on Core Manufacturing Simulation Data (CMSD) which provides the information model of the production system for efficient exchange of Data that is collected from one or more different manufacturing domains (Michaloski, Proctor, Arinez, & Berglund, 2013). CMSD is the suitable Data format for manufacturing system, The CMSD entities represent the relationship between different entities of the manufacturing system.

1. Resource: Resource describes the equipment i.e. personnel, machines, stations, conveyors fixtures etc. which performs the manufacturing activity
2. Part: Part provides the characteristic of the materials that the final product is made.
3. Process Plan: Process Plan provides the necessary steps to transform the material into subcomponents and to finished product. The process plan builds the process steps to create the raw material into final product.
4. Process: Process contains the information of the resources used to make the product and the sequence of steps to create a product.
5. Job: Job defines the normal manufacturing operation to create a work, job in general made into sub jobs and sub jobs contains part knowledge with in the actual job (Michaloski, Proctor, Arinez, & Berglund, 2013).

CMSD standard is represented in two methods Unified Modeling Language (UML), and the XML schema definition language (XSD). Below figure shows the packages that make up the CMSD model. XML language is used for the purpose of storage, retrieved, shared or process the data, In CMSD the XML language can be used for 2 transformation process, the first one is it can be used to construct a result tree and second is interpreting the result tree for formatted results (Bergmann, Stelzer, Wustemann, & Strassburger, 2012).

Most of the academicians and Researches used CMSD in Discrete Event Simulations (DES), one such case study was discussed in the automotive industry presented by Michaloski, Proctor, Arinez, & Berglund (2013). CMSD was used for the development of model formation and standardized representation of machine shop environment. This case study is applied for the high level overview of the precision casting. At first data is collected from the shop floor and used in DES analysis for optimization. Here CMSD is used for the collection and adaptation of KPI parameters for cycle times, process steps and equipment data. The CMSD was helpful in creating the complete process plan and steps and the resources and used in DES, the purpose is to model the complete casting process and to analyze for the optimization of the process so they used CMSD to structure the entire production model in this case study.

Two more case studies had been presented by Ryan Bloomfield. A Lean design software for camera production another is inter probability issue of manufacturing application in a simulation environment. In the lean design case study, the product has the Bill of materials, process plan, assembly time, resource information, quality data and ergonomic feasibility. The software estimates the cost product cost and help to breakdown the finished product to its lowest level order of assembly even though all the data is available, the data has to input manually every time and the product designer must work closely with manufacturing engineer. And assembly engineer in order to specify accurately how the modifications are made, this took lot of manual effort, with the introduction of CMSD with the help of XML schema the inter probability issue between design engineer, manufacturing engineer and assembly engineer is solved by providing the neutral structure of creating the production planning which includes the process plan changes that helps to solve the issue. Another case is to solve the inter probability issue to improve the manufacturing process, in this case three manufacturing systems are developed with different products different machines and are produced in a generic shop environment. The application contains all the information of the different products and CMSD XML is used for the exchange of information for different manufacturing applications, this was created by XML where the translation of information from one system to another system and connecting all the 3 applications by process plan, so the developed solution methodology demonstrates the inter probability between different manufacturing applications (Ryan Bloomfield, 2012).

One such research work in regard with ISA-95 standard for DES modeling has been found. In this work, generic structure based on CMSD has been proposed and comparison of both the CMSD and ISA-95 standards has been made. GDM Tool was employed to process the data and a datasource was created to store the information. Further, with same datasource i.e. RIM database was used to map the information to CMSD standard. The main purpose was to integrate the CMSD standard for efficient exchange of information to simulation model. Further, after a thorough investigation it has been found that ISA-95 has some inconsistence to provide all information needed for simulation studies (Lee, Riddick, & Johansson, 2011).

2.7 Automated Input Data Management

In model building process data collection is the most crucial process because Data influences the simulation results. But data collection is the most time consuming process and Automating this process is extremely advantageous (Robertson & Perera, 2002). According to Robertson and Perera (2002), there are four methods or approaches to input the required data to the model starting from entirely manual work procedure towards completely automated link between Data source to the model. Figure 8, shows four approaches to the input data to the models.

According to Robertson and Perera (2002), methodologies ‘a’ and ‘b’ are currently used extensively within the industry, whereas methodologies ‘c’ and ‘d’ are only just emerging and the companies prefers to go towards them because the integration offer great advancements with respect to data collection in the future. Below are the methodologies described individually:

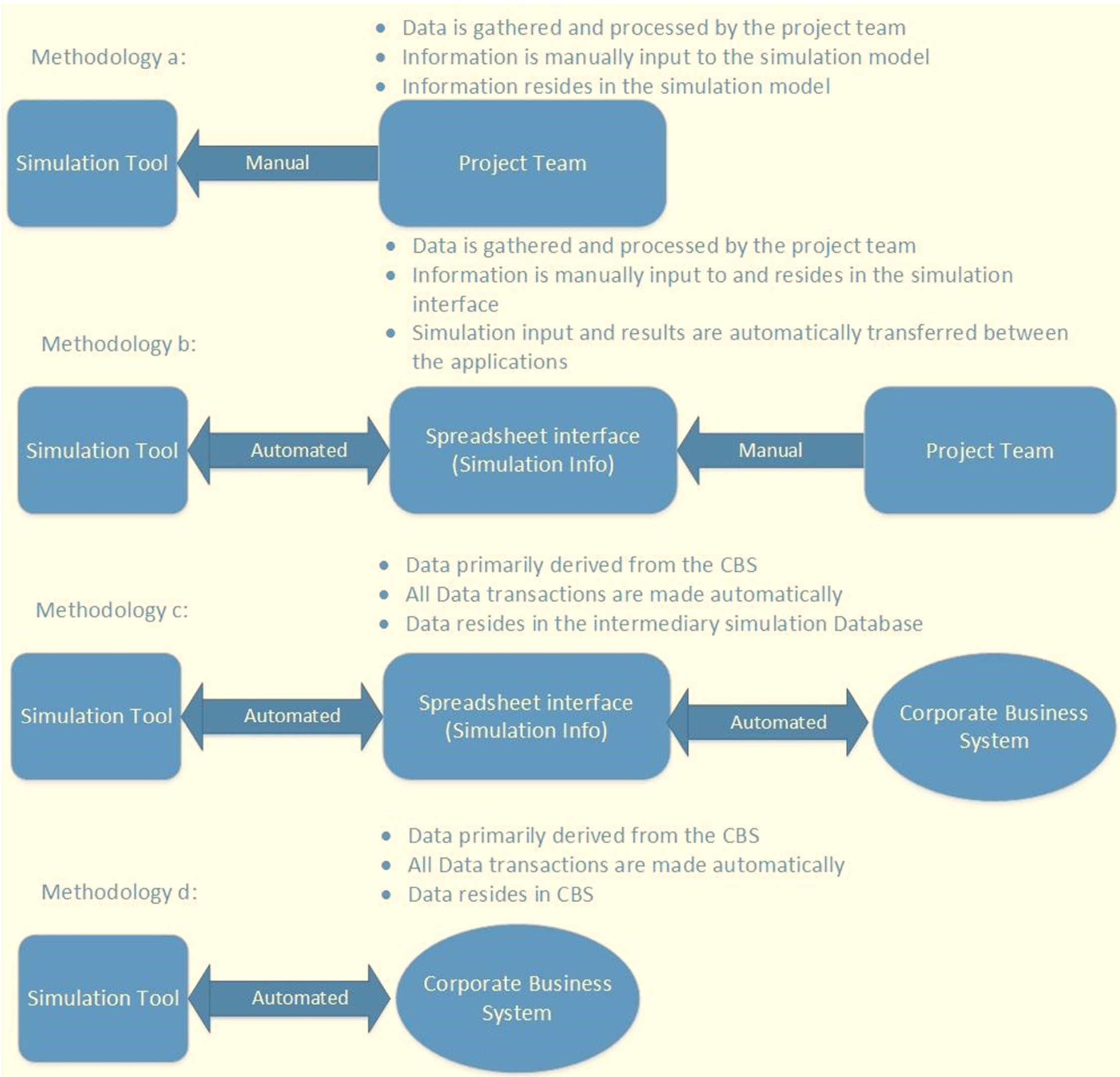


Figure 8: Four approaches to input data management using various levels of automation (Robertson & Perera, 2002).

Methodology A: In Methodology A, the model builder collects the data manually by using templates from the project team by using spread sheets or gathering in- formation by interviewing the individual experts. Analysis of the data is done by the model builder by manual methods, after the verification of the data and transformation to information, the results are manually typed into the model by coding. The main advantage of this method is, it's very simple method to follow for model builder. The main disadvantage is, it can have lot of errors due to manual work and most time consuming process (Robertson & Perera, 2002).

Methodology B: Methodology B is similar to that of Methodology A as the collection of data and transform raw data to information, but the difference is the information is supplied to the model builder in the form of spreadsheets which can be directly imported to the model. The main advantage of this model is importing and exporting and storage of data resides outside the model which is flexible. The disadvantage is, it takes time and effort to change the format of the data to use as it is, this methodology is more popular in the Industries (Robertson & Perera, 2002).

Methodology C: In methodology C the simulation model utilizes an off line intermediary simulation Data base which stores the data and is connected to Corporate Business System (CBS) where the data is automatically transferred from CBS to the data base and to the simulation model. The main advantage is that the model reads the required data from the integrated data base to run the simulation. Another advantage is there is, no error and time being wasted and can obtain the accurate results (Robertson & Perera, 2002).

Methodology D: In methodology D the data is automatically collected from the Corporate Business System (CBS) and transfer of simulation information to the model is fully automated. The data is stored in the CBS and is external to the model having flexibility to the model for changes. This automated system will reduce the major amount of time, reduce errors during simulation results and will also reduce the effort needed without the external intervention.

In most of the cases the data source can be of one legacy system or different legacy systems where the data is taken for the simulation purpose. In order to reduce the effort there can be the data collection is done where different tools are used throughout the entire product and production engineering processes. In this case there are two possible solutions.

1. Use of commercial software PLM packages like Siemens Teamcenter or Delmia (Dussault systems).
2. Use of engineering tools that can connect different sources within the CBS by using neutral formats.

In future Methodology C and D can be further developed and can completely use the automated input data methodology (Skoogh, 2011).

3
Methodology

This chapter describes the thesis work procedure that has been performed in order to fulfil overall project objectives. Following sections below are arranged in order of thesis work procedure.

3.1 Theoretical Framework

Significant theories that has provided common understanding of concepts/methods such as input data management, data collection methods, data processing methods and data interfacing methods. The theoretical frame work has been made available from the different journals, scientific data sources which has been accessed through Chalmers Data bases such as

1) Science direct (sciencedirect.com)
2) Pro-Quest (proquest.com)
3) Google scholars (scholar.google.com)
4) Books 24/7 (books24x7.com)

Following keywords has been used such as Input Data Management, Discrete Event Simulation, Core Manufacturing Simulation Data (CMSD), ISA-95, GDM-Tool, Generic Structure and interoperability to obtain the required literature from above database.

Among these literature's some of the methods and tools such as methodologies for automation of input data management, data requirements for simulation tool, functionality requirement for automation of input Data, use of Generic Data Management (GDM) tool and manufacturing standard such as CMSD and ISA-95 standard has been thoroughly studied for this thesis work. Further, these methods and tools had been critically reviewed and it's applicability has created a foundation to proceed with the thesis work to answer the overall project objectives.

3.2 Case Study

This section presents description of the one case study that was undertaken as part of thesis work, in order to realize the thesis objects.

Case study are performed to get insight of a particular problems that may not be possible to solve it by other approaches. Case study serves as well-structured tool with a systematic approach to explore the platform in detail, which could be significant in case of surveys i.e. qualitative or qualitative approaches and experimentation. This would help to collect the data that are evidence of reality (Rowley, 2002).

3.2.1 Volvo GTO – Cab Manufacturer

The needs of the cab manufacturing industries has been our starting point to begin with the thesis work. To perform simulation studies of entire cab plant, some of the significant issues related to simulation studies has been addressed in this case study as mentioned below,

1. Efficient exchange of information to simulation models. This, in order to specify detail requirements of DES modeling and neutral transfer of information to simulation applications
2. To reduce significant lead time in simulation projects i.e. mainly in input data management process.

Volvo GTO is a Swedish multinational company and world's leading manufacturer of trucks, buses, construction equipment, marine and industrial engines and headquarters located in Gothenburg. The company had three main divisions Truck sales, operations and technology and this thesis is the part of Group Trucks Operations (GTO). This thesis work focuses on a one cab plant of Volvo GTO that is located in Umeå. Evaluating of new design concept, analyzing the improvements in production and performing analysis to optimize the production capacity have become increasingly important with aid of virtual tools. It is the managers who needs to take early decision for the commencement of the program. In this regards, quick analysis on production plant is not possible due to time consumption in input data management process. In order to address this issue, goal of this study has been well formulated and addressed in this case study.

3.2.2 Description of Production System – Cab Manufacturer

A simple production flow diagram of the sub-assembly production unit has been illustrated in Figure 9. The sub-assembly production unit is responsible to produce all Engine Tunnel parts. The first M1 Station is responsible to pick the material/part from the source point which is a manual loading area and transfer to the next station. Further, M2 Station is accountable to spotweld the part and transfers it to the next work station. Further the part is again spot welded in M3 Station area and transfers the finished Engine Tunnel part to the next station. The final M4 Station in sequence according to the flow diagram now transfer the finished Engine Tunnel part to the buffer conveyor, which holds the part in buffer conveyor until the order is processed on MainLine Station. The entire process is complete automatic driven, meaning that other than source point no operator efforts are needed to accomplish the process. The resources that are automatically driven those are M1 Station, M2 Station, M3 Station, M4 Station, Buffer Conveyor and MainLine. Further, speaking of new orders, the MES system keeps track of all the parts with help of logistic application, it also directs the part to the destined production unit from buffer storages. If the part is not found or has not been made than MES system creates an internal order, after which the logistic person delivers to destined production unit with help of fork lift drive but whereas in BIW area i.e. most of the sub-assembly production units are automatically driven, even supply of sub-assembly parts to MainLine.

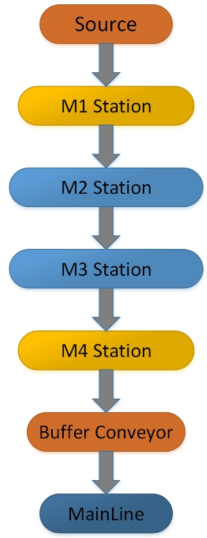


Figure 9: Engine Tunnel Production Flow for Variant 12 &11

The study has been involved to evaluate the input data management method and further to automate the raw data from Volvo follow-up/DataBase system for Engine Tunnel production area as our scope was limited to only Engine Tunnel Production area due to the limited time involved for the Thesis. Further to enable standardized process of input data management, the applicability of CMSD and ISA-95 standard has been investigated and has been used to represent the processed data associated with help of GDM tool. A user interface plugin was developed using Microsoft Visual Basic Scripts in GDM tool that would help to specify certain table or a row and then it generates an output in CMSD standard format. The information needed for simulation modeling is encoded in form of XML instance after generating output in CMSD standard format.

3.2.3 Parameter Specification Requirements

Important parameter specification are described as below,

1. Cycle Time
2. MTTR
3. Availability
4. Scrap Rate
5. MTBF

These are the parameter that has been found to be significant to mimic the dynamics of the real production system, which has been used by simulation experts of Umeå Plant to perform analysis on the production system. Further, speaking of accuracy requirement, the deviation limits for cycle time, it was also found that for all ideal cycle times, the deviation limits were 4-5 secs but in reality, the deviation of cycle time for same part variant was found to be varying more than 10 sec or some times more than 50 sec and in extreme case more than 200 sec. Once the rate of production was calculated from the raw data, it was found that the minimum rate of production was 240 sec, meaning that for every 240 sec a new cab will be produced out of BIW area theoretically. It doesn't mean that it takes 240 sec every time, it can take less than or minimum

240 sec. Statistical representation of data is also important part that will condense the data to convenient size. As of now, Triangular and Uniform statistical distribution representation is begin used for simulation studies for one of the production areas of Umeå plant. Apart from that, we have suggested other statistical distribution representation to include in the simulation models such as Weibull or Gamma distribution due to the data best fits. Either MTTR and Availability or MTBF has been included in the simulation model. Operator information has been excluded as the aim of the simulation studies for Umeå Plant is to optimize the manufacturing capacity and all the value adding work and support work (transfer of part) of all sub-assembly areas and MainLine area is automatically driven. The task involved was to deliver these parameter information in efficient manner to simulation models.

3.2.4 Volvo Legacy System (Follow-up System)

Volvo Legacy System is an IT system jointly developed by Volvo Powertrain Skövde and Volvo IT. The purpose of Volvo legacy system is to collect the Data from the equipment and use it for analysis. It is a system for operational monitoring and management that is developed to implement various activities and equipment. It also helps to monitor and analysis of Volvo production line.

Legacy system communicates and collects the Data in two ways.

1) Automatic Data collection- This is done by using equipment control systems or PLC’s. Signals are sent to legacy system and there is a feedback for each individual process back to legacy system (follow-up system). Manual sent signals (manual codes) by operator are also sent from equipment control system where they are typed manually in pc’s.

2) Manual Input- Losses such as Availability, Performance and Quality are manually input for each equipment. Volvo follow-up system has many functionalities and built in tools where it can give the operational follow up for equipment’s in the form of pre calculated reports. These reports contain bottle neck analysis, OEE analysis, cycle time analysis, MTTR/ MTBF analysis etc. in the form of statistical charts to see the variations, data can be collected in the form of spread sheets and stored as reports and can be downloaded from the option Advanced Export.

3.3 Input Data Management and GDM Tool Methodology

This section describes the methodology that has been adopted in order to reduce time consumption in input data management process. The methodology has been evaluated in this thesis work with a test case as mentioned in Introduction Chapter.

The input data management process (Skoogh & Johansson, 2009; Skoogh, 2011; Skoogh, Perera, & Johansson, 2012) followed in this thesis is described below,

1. Data Collection
    a. Manual data Collection
    b. Qualitative Data Collection
    c. Data obtained from Volvo Legacy System
2. GDM Tool for Data Processing (Conversion) and Data Representation

3.3.1 Data Collection

Thesis work was involved initially to identify the data and further to understand the structure of data and it's source if the data resides within Volvo legacy system. Three types of data collection has been performed those are: Manual Data Collection, Qualitative Data collection and Data collection from legacy system.

a) Manual Data Collection

In this thesis Manual data collection is done in order to gather the information by visiting one of the Volvo Trucks plant, where to identify the flow of product, material, inventories locations and operations information.

I) Survey

A survey was conducted at Volvo plant, in order to understand overall production flow and to get the process step by step to develop the logic for the objective 1 & 2 as stated in section 1.3. Manually the project team examined each equipment/station to capture the overall flow according to the product, which would help in order to propose a generic structure for the case study.

b) Qualitative Data Collection

The purpose of the qualitative data collection i.e. qualitative interviews has been performed in order to collection relevant information that is required for simulation studies. Weekly skype meetings with Umeå plant manager and simulation expert were conducted in order to understand the flow of material in detail of all sub-assembly areas, which was a difficult task to grasp from the raw data file, as the data present in Volvo follow-up system was not structured properly. Also to collect information about the specification requirements and data accuracy requirements, skype meetings has been conducted.

c) Data obtained from legacy system

Data such as Process Time, MTBF, MTTR, Availability Percentage, Scrap Rate etc. has been collected from the legacy system. Further, to proceed with the data collection present within the Volvo's follow-up system, a thorough investigation was involved in order to understand the structure of the follow-up system. The investigation is beneficial in order to enable extraction point to automate the input data management process with help of software known as GDM Tool.

3.3.2 Generic Data Management (GDM) Tool

Evidence from the previous related work as described in Theory Chapter, software such as GDM tool has been used to process the raw data extracted from the Volvo's Legacy System (follow-up system) and condense the data to next step for simulation. The main purpose of this tool, is to reduce the time consumption in input data management process eliminating traditional approach to do the same i.e. transforming raw data into relevant information for simulation studies with automated procedure. Following are the steps briefly described as below.

1) Data extraction
2) Calculation

3) Distribution Fitting

1) Data Extraction: From the data source of Volvo's follow-up system, raw data is manually extracted in the form of MS Excel file. These MS Excel files are exported into GDM tool to process the raw data in order to transform into relevant information

2) Calculation: With the help of few functionalities present in GDM Tool the raw data is converted into relevant information using different plugins based operations like addition, subtraction etc. in GDM tool. Statistical calculations such as Availability, MTTR, MTBF and Cycle Times/Process Time are done which are essential simulation parameters.

3) Distribution Fitting: Finally, the processed data, depending on the type of statistical representations were chosen for condensing the data for simulations using Distribution Fitting.

The GDM tool was modified and developed for this case and has the user interface functionality that maps and exports the information in the CMSD standard neutral format to simulation models.

3.3.3 Validation of Results and Data Quality

The procedure adopted to process the data in GDM Tool and which has been considered from the input data management steps, acts as self-validator in this case study (Perera & Liyanage, 2000; Skoogh, Johansson, & Stahre, 2012). To verify the quality of the results obtained through the use of GDM Tool, in order to reduce the time consumption in input data management process, a validation process was performed by comparing with the real world production system. One of the task involved was to deliver information of entire BIW area of plant processed with help of GDM Tool, to the two simulation based optimization project teams. One team working on detail modeling using Plant Simulation software and other team working on aggregated modeling using Facts Analyzer software. The processed information with which both the teams simulation model was run had less than 5% deviation in total compared with real world production system.

Further, the proposed generic structure based on CMSD and ISA-95 standard has been validated using XML schema software to check the integrity of the XML structure. Also, with help of the two interview the ISA-95 information model specifically the purpose of the individual classes/segments has been understood apart from the literature study and is defined in the proposed generic structure.

3.4 Applicability of CMSD and ISA-95 Standard for DES Modeling

Thorough study of these manufacturing standards has been conducted and documented, in regards with it's applicability for DES modeling. And a comparison of both the standards has been performed in brief. The documents that were required to study CMSD standard is freely available on the Simulation Interoperability Standards Organization website (SISOSTDS DigitalLibrary, 2016), from which the two documents, one with UML class diagrams and another with XML schema to encode and transfer the data. Apart from documents, some of the previous related examples are available, which has helped in this case study as well. Also, literature about CMSD standard research work that were made available through the various database has helped in thorough understanding of this standard. Further, in similar way, documents that were important to understand ISA-95 standard were made available from the Chalmers library, as the ISA-95 standard books were not available freely. All class diagram information model documents and XML schema of latest ISA-95 standard were downloaded from the Manufacturing Enterprise Solutions Association (MESA) website (MESA, 2016), which are freely available to use.

3.5 Interviews

Three semi-structure interviews were performed, to get the insight of the topic from the experts. Two interviews aimed on the topic implementation of ISA-95 standard in industries apart from the theoretical understanding, the questions that were asked in these two interviews are present in section A.1 of A Appendix. Among these two interviews, the first interview was carried with Wahlström Leif - Business Analyst expert in ISA-95 standard, who has vast experience. The second interview was carried with Sterud Björn - Sr. Project Manager and Andersson Mattias- Product Specialist WLO, who had designed the new Volvo follow-up system according to ISA-95 standard.

The third interview was aimed on the topic connection between PLM system (Teamcenter software) and Plant Simulation software. The questions that were used in interview are present in section A.2 of A Appendix. This interview was performed with Siemens Manager, Johan Nordling and Johan Olofsson, who are expert in Teamcenter and Plant Simulation software. Similarly, a demonstration was also performed by our Chalmers Supervisor in this regards.

4

Results

4.1 Applicability of CMSD and ISA-95 Standard for DES Modeling

The applicability of both the standards has been investigated by thorough study of these standard. Also from the previous related research work that has helped to understand these standard's applicability for DES modeling. This study is performed in regards with development of generic structure based on both the standards, finding out how best these information model fits the detail requirements of simulation modeling.

4.1.1 CMSD Standard

This section contains the description of those information model that has been used for this case study. Other type of information model such as Order, Skill Definition, Setup Definition, Maintance Plan information model, part of CMSD standard has not been described here, but found to be applicable. For detail description of those information model please refer (SISO, 2010).

Resource Class information model: This information model represents equipment and personal that would perform manufacturing activities. Resources Class information model in the CMSD are used to represent stations, machines, employees, tools and fixtures, transporters, conveyors, power and any other equipment. With help of Property entity and Distribution entity, that is present within Resource Class information model, it is possible to encode information such as MTTR, MTBF, Availability or even Process Time. This entity information is now permanent part of Resource Class information model, which was decided in one of the previous related research work (Lee, Riddick, & Johansson, 2011).

Part information model: Provides a means to specify the characteristics of the parts/materials and subcomponents. Also, it represents, the part/material or subcomponents that will be used in process execution or an end product that will be produced out of final production.

Bill of materials information model: This information model provides a means to define the part/material or subcomponent parts and the quantities of those, which would require to produce the desired final product.

Process Plan information model: A systematic process step could be provided, along with this, other relevant information such as resource required etc., all those activities needed to transform raw material into a final product can be specified. Further, with help of Property and

Distribution entity present within Process Plan information model, parameter information such as Process Time, Scrap Rate etc. can be specified.

Job Class information model: Originally this information model is used to provide specific details about a request originating from external or internal organization, to perform production related activities. Based on the previous related research work, this information model has been also used to create systematic process steps that is needed to transform raw material to a final product. It is also available to specify parameter information such as Process Time with help of ProcessingTime entity and Scrap Rate information with help of Property entity, present within this information model.

Calendar information model: Provides a mean to define, shift timings, holiday and time period information during which the production related activities will or will not take place.

Schedule Class information model: Defines a plan that consist job order to be processed in a day/week. Basically, the planned schedule information is used to specify using this information model, however even results obtained from actual job production order could be specified using this information model.

4.1.2 ISA-95 Standard

This section contains the description of those information model that has been found applicable for this case study. ISA-95 standard contains many models and terminology. For detail description of other type of information model please refer (ISA, 2010; ISA, 2013; Scholten, 2007).

Equipment information model: Provides a mean to define the characteristics of equipment. This information model represents equipment that would perform manufacturing activities. It defines equipment type such as stations, machines, tools and fixtures, transporters, conveyors and any other equipment. It is possible to encode information such as MTTR, MTBF, Availability or even Process Time using EquipmentProperty entity present within this information model. However, it doesn't hold statistical distribution representation.

Personnel information model: This information model provides a mean to specify characteristics of a person that will be part of manufacturing activities.

ProductDefinition information model: This information model allows to specify characteristics of part/material or subcomponent or desired end product. Further, all manufacturing activities that are required in order to produce the end product can be specified with the help of ProcessSegment attribute, by relating concerned process. Other information such as site or area location can be specified within this information model with the help of HierarchyScope attribute present within this information model.

MaterialDefinition information model: This information model is equivalent to the ProductDefinition information model. It provides a mean to define a part/material or subcomponent or desired end product.

ProcessSegment information model: It provides a means to specify a systematic process step, along with this, other relevant information such as equipment, personnel required etc., all those activities needed to transform raw material into a final product can be specified. Further, information about material that will be part of process execution or desired end product that will be produced can be specified within this information model. Further, information such as routing of process can be specified. Parameter information such as MTTR, MTBF, Availability or Process Time is can be defined with help of this information model. To note that, it cannot define statistical distribution representation of DES parameter.

ProductionSchedule information model: The true purpose of this information model, is to specify the entire planning of a production activities to produce desired end product based on production request. However, in this case study, the purpose has been to specify information about only job orders that would be processed in a day/week in sequence.

4.1.3 Specification comparison between CMSD and ISA-95 standard

Table 2: Specification comparison – Background

Standard Name	Organization	Application Supported	Standard Availability	Model Language	File Exchange Format
CMSD	SISO	Discrete event simulation (DES) application	Free to public	UML, XML schema	XML
ISA-95	ISA	ERP, MES, MRP, PLC	Require payment to obtain these standard information; Free to ISA members	UML, XML schema	B2MML, an XML implement

Table 3: Specification comparison - Properties

Standard Name	Scope	Information Model Support for DES modeling	Attribute Definition Support	Comments
CMSD	DES modeling of manufacturing operation, mainly focuses on job shop environment	Resource Package i.e. Resource, Setup Definition, Skill Definition; Part Package i.e. Bill of Material, Part, Inventory; 2D Layout Package; Production Operation i.e. Schedule, Order, Job; Production Planning i.e. Calendar, Process Plan, Shift Schedule, Maintance Plan	All attributes with which, most of the information required for DES can be defined	Ability to define characteristics of manufacturing entities such as stochastic processes, and allows the statistical distribution information
ISA-95	Business to Manufacturing integration framework, mainly focuses on continuous process manufacturing environment	Resource i.e. Equipment, Personnel; Product Definition; Material Definition; Production Schedule; Production Capability; Process Segment;	Attributes definition doesn't clearly support the requirement of DES modeling. Only certain attribute definition are applicable	Doesn't hold statistical distribution information. Information such as calendar, shift times, not possible to encode with present objects and attributes.

4.2 Generic Structure Based on Core Manufacturing Simulation Data (CMSD) Standard

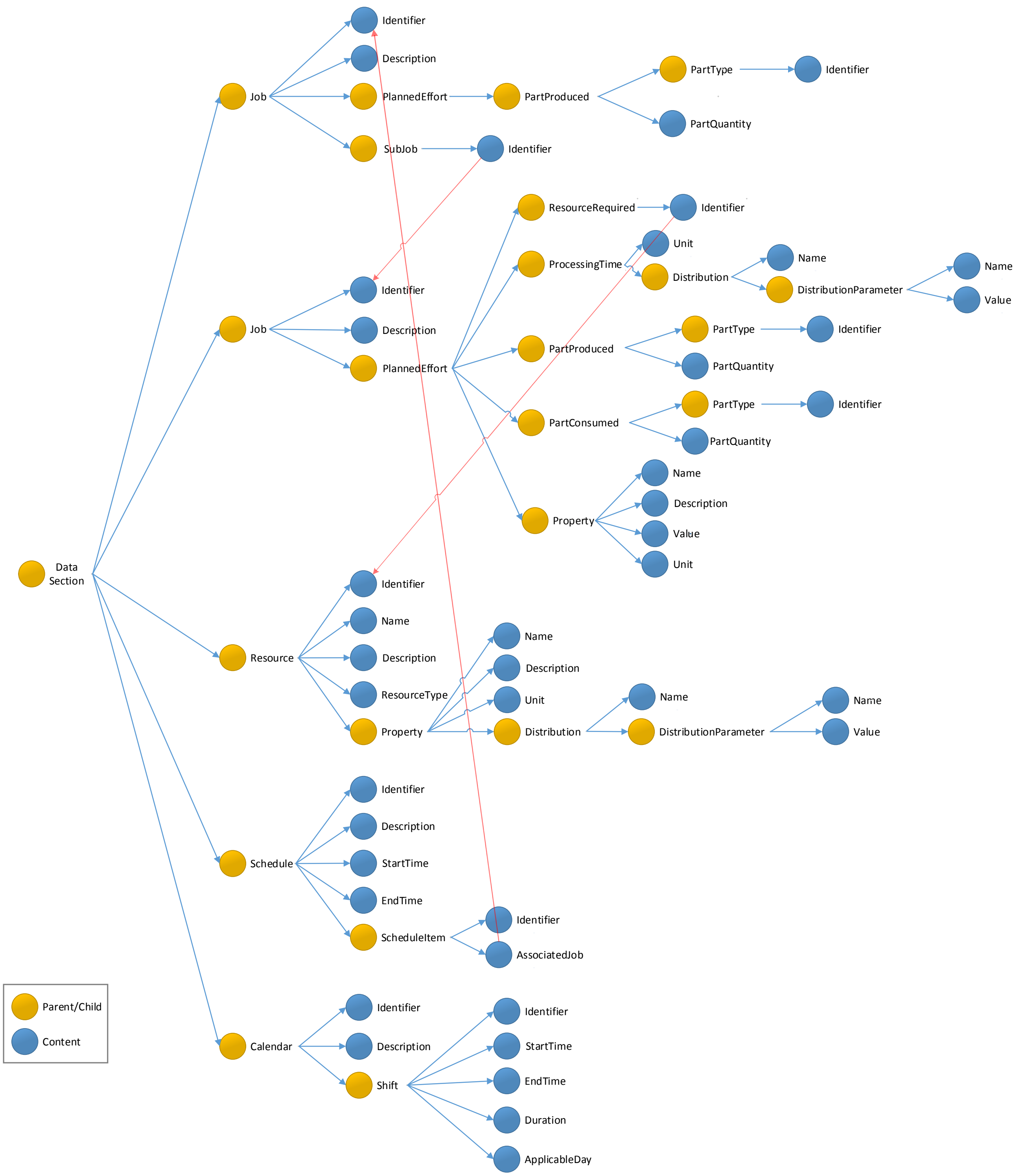


Figure 10: CMSD Generic Structure - Tree View

The Figure 10, depicts our proposed generic structure based on CMSD standard. It consists of various class definitions and relationships, a means to provide manufacturing related information to the simulation software.

Resource Class illustrated in Figure 10, provides a means to define information about an employee or a manufacturing equipment or a group of employee and/or manufacturing equipment that are used in order to accomplish the production activities.

In this case study, employee related information is not encoded in the model as scope of this thesis was only limited to provide information about operational characteristics of manufacturing equipment, which has been modelled in the study. Resources that are generalized under the category such as station, machine, conveyor, buffer, tool/fixture or employee, this information are encoded with help of ResourceType attribute on each Resource Class. Parameter information such as MTTR, MTBF that needed to specify information in form of statistical distribution to simulation models, that are associated to resource has been encoded using Property entity as shown in Figure 11, represented in XML format. In addition to this, parameter information such as Availability Percentage is encoded using the Property entity on each Resource Class as shown in Figure 11. Other kind of information that can be provided on Resource Class such as conveyor's speed and material handling equipment speed (Johansson, et al., 2007). In this case study the data of such resource i.e. conveyor equipment and material handling equipment speed was not collectable but were available due to this reason in the model, operational characteristics of conveyor equipment and material handling equipment speed has not been encoded. Example of Resource Class XML according to CMSD standard as shown in Figure 11.


```xml
<Resource>
  <Identifier>M1</Identifier>
  <Name>Handling Station</Name>
  <ResourceType>Station</ResourceType>
  <Description>Pick and transfer of material</Description>
  <Property>
    <Name>MTBF</Name>
    <Unit>second</Unit>
    <Distribution>
      <Name>Weibull</Name>
      <DistributionParameter>
        <Name>λ</Name>
        <Value>11304.3922817335</Value>
      </DistributionParameter>
      <DistributionParameter>
        <Name>k</Name>
        <Value>1.10633005428524</Value>
      </DistributionParameter>
    </Distribution>
  </Property>
  <Property>
  <Property>
</Resource>
```

```xml
<Resource>
  <Identifier>M1</Identifier>
  <Name>Handling Station</Name>
  <ResourceType>Station</ResourceType>
  <Description>Pick and transfer of material</Description>
  <Property>
  <Property>
    <Name>MTTR</Name>
    <Unit>second</Unit>
    <Distribution>
      <Name>Weibull</Name>
      <DistributionParameter>
        <Name>λ</Name>
        <Value>104.802631785608</Value>
      </DistributionParameter>
      <DistributionParameter>
        <Name>k</Name>
        <Value>1.10809528779619</Value>
      </DistributionParameter>
    </Distribution>
  </Property>
  <Property>
</Resource>
```

```xml
<Resource>
  <Identifier>M1</Identifier>
  <Name>Handling Station</Name>
  <ResourceType>Station</ResourceType>
  <Description>Pick and transfer of material</Description>
  <Property>
  <Property>
  <Property>
    <Name>Availability Percentage</Name>
    <Value>99.9809100907718</Value>
  </Property>
</Resource>
```


Figure 11: Resource Class XML- CMSD Standard

Job Class illustrated in Figure 10, defines information about manufacturing related activities that has been originated from a person's request or from the internal of the organization. Job Class element/entity would provide information such as product that will be manufactured, material that is required, resource required in order to manufacture the product, process time to perform the task and scarp rate.

A type of information to represent finished product/part or material that is required during the execution of Job/Process is specified using PartProduced and PartConsumed attribute on each Job Class. All products/parts that will be subsequent part of Job Class is defined separately and then to be associated with specific Job Class. Further, to represent the information about resource i.e. equipment in our case study, that is, to be utilize in order to produce the product/part, is specified/linked using ResourceRequired entity on each Job Class. The Resource Class are defined separately in same manner as PartType and then to be associated/linked to specific Job Class. This allows flexibility to reference the required resource to multiple Job Class, instead of defining same resource i.e. equipment, multiple time.

In this case study parameter information such as process time was decided to encode using ProcessTime element on each Job Class. This is because the process time differs for each variant and then to be associated with required resource that will perform the Job or task. Another kind of parameter information was needed to define in this study was scrap rate percentage, that is defined using property element/entity on each Job Class element as shown in Figure 12. Example of Job Class XML according to CMSD standard shown in Figure 12.

```xml
<Job>
  <Identifier>12</Identifier>
  <Description>Job to manufacture VariantID:12</Description>
  <SubJob>
    <JobIdentifier>1</JobIdentifier>
  </SubJob>
  <SubJob>
    <JobIdentifier>2</JobIdentifier>
  </SubJob>
  <SubJob>
    <JobIdentifier>3</JobIdentifier>
  </SubJob>
  <SubJob>
    <JobIdentifier>4</JobIdentifier>
  </SubJob>
  <PlannedEffort>
    <PartTypeProduced>
      <PartTypeIdentifier>12</PartTypeIdentifier>
    </PartTypeProduced>
  </PlannedEffort>
</Job>
```

```xml
<Job>
  <Identifier>1</Identifier>
  <Description>First SubJob to pick and transfer the material</Description>
  <PlannedEffort>
    <ProcessingTime>
      <Unit>second</Unit>
      <Distribution>
        <Name>Weibull</Name>
        <DistributionParameter>
          <Name>λ</Name>
          <Value>128.07449597743</Value>
        </DistributionParameter>
        <DistributionParameter>
          <Name>k</Name>
          <Value>10.9343264788744</Value>
        </DistributionParameter>
      </Distribution>
    </ProcessingTime>
    <Property>
      <Name>Scrap Rate Percentage</Name>
      <Value>0</Value>
    </Property>
    <ResourcesRequired>
      <Resource>
        <ResourceIdentifier>M1</ResourceIdentifier>
      </Resource>
    </ResourcesRequired>
  </PlannedEffort>
</Job>
```

Figure 12: Job Class XML- CMSD Standard

Once all required resources and jobs are defined with required parameter information encoded within, the next step is to provide information about the order in which the Job should be processed in a day/week to simulation user. This was realized with the help of Schedule Class element. Schedule Class entity depicted in Figure 10, describes information about planned production related activities that are to occur during specific stated time period. All the jobs that are needed to be processed in a day are sequenced by encoding using ScheduleItem entity on each Schedule Class element by relating the main defined Job Class. Example of Schedule Class according to the CMSD Standard as shown in Figure 13.


```xml
<Schedule>
  <Identifier>S1-121</Identifier>
  <Description>Job Sequence</Description>
  <StartTime>02-22-2016, 6.00</StartTime>
  <EndTime>02-22-2016, 23.59</EndTime>
  <ScheduleItem>
    <AssociatedJob>12</AssociatedJob>
  </ScheduleItem>
  <ScheduleItem>
    <AssociatedJob>10</AssociatedJob>
  </ScheduleItem>
  <ScheduleItem>
    <AssociatedJob>12</AssociatedJob>
  </ScheduleItem>
  <ScheduleItem>
    <AssociatedJob>11</AssociatedJob>
  </ScheduleItem>
  <ScheduleItem>
    <AssociatedJob>12</AssociatedJob>
  </ScheduleItem>
  <ScheduleItem>
    <AssociatedJob>10</AssociatedJob>
  </ScheduleItem>
</Schedule>
```


Figure 13: Schedule Class XML-CMSD Standard

Calendar Class entity illustrated in Figure 10, defines a manufacturing calendar for the plant facility. The Shift entity subsection of the Calendar Class provides a means to define the shift timings of a day throughout the week during which resources should be made available for production activities for a defined time period. The start and end of shift times were encoded using StartTime and EndTime attribute for an applicable day. ApplicableDay attribute provides information about a day type that can take a value between 1-7, meaning that first day of the week is taken as value one and in the same manner remaining days of the week takes respective values between 1-7. Example of Calendar Class XML based on CMSD standards is shown in Figure 14.


```xml
<Calendar>
  <Identifier>C1-2V3</Identifier>
  <Description>Shift Schedule 24/7</Description>
  <Shift> <Identifier>Monday1</Identifier> <StartTime>06:00 </StartTime><EndTime>15:00</EndTime><Duration>9</Duration><ApplicableDay>1</ApplicableDay></Shift>
  <Shift> <Identifier>Monday2</Identifier> <StartTime>15:00 </StartTime><EndTime>23:59</EndTime><Duration>9</Duration><ApplicableDay>1</ApplicableDay></Shift>
</Calendar>
```


Figure 14: Calendar Class XML-CMSD Standard.

4.3 Generic Structure Based on ISA-95 Standard

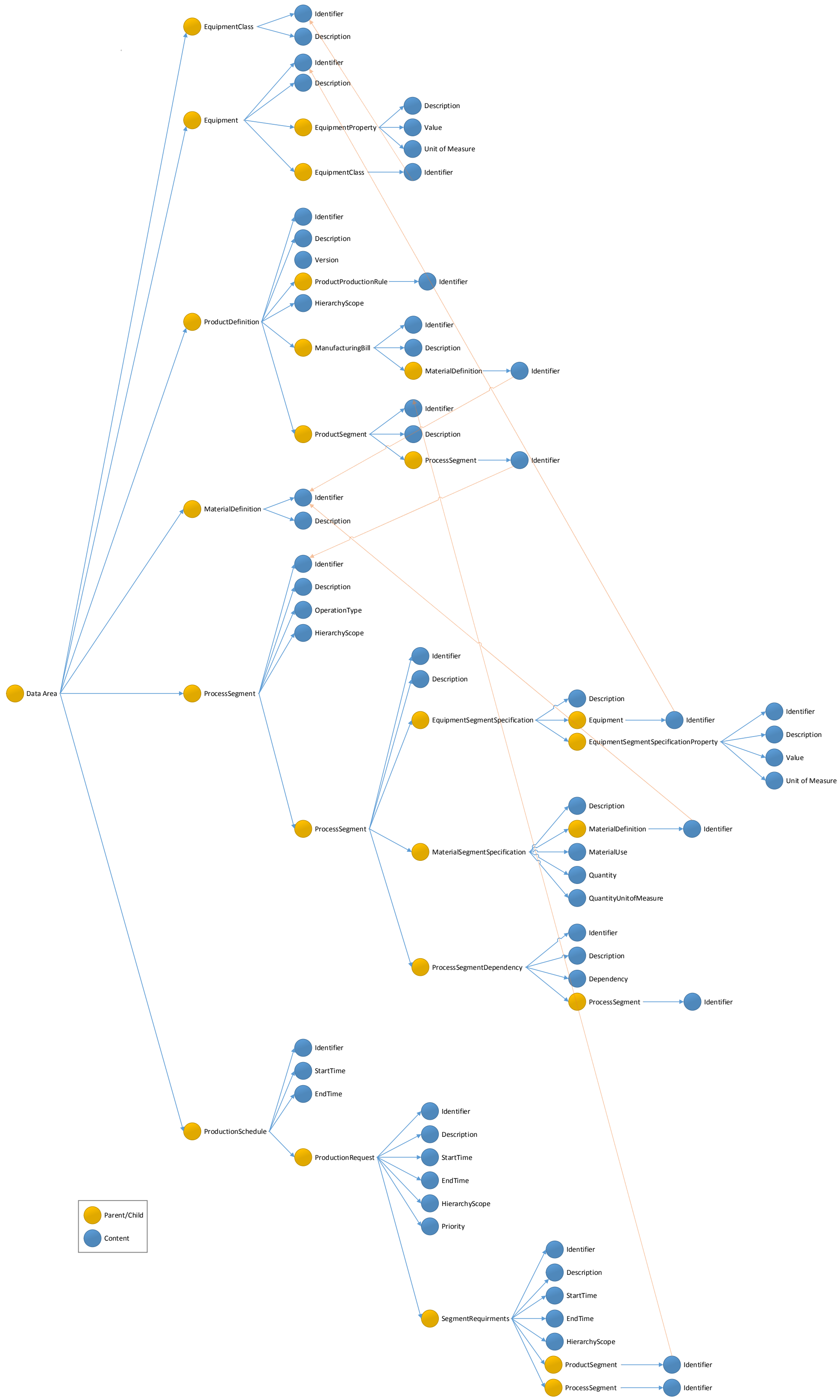


Figure 15: ISA-95 Generic Structure - Tree View

Figure 15 illustrate proposed generic structure according to the ISA-95 standard. The developed generic structure consists several class definition and its relationships, a means to provide manufacturing related information required for discrete event simulation (DES) modeling.

Equipment Class as described in the section 4.1.2 of Result Chapter, has been used in our case to provide information of grouping of all equipment having similar characteristics. Figure 16, represents EquipmentClass from our generic structure. The purpose of Identifier attribute is to distinguish from other EquipmentClass and Description attribute provides additional information of Equipment Class. The purpose of Identifier and Description attributes serves the same role throughout in the ISA-95 information model. Equipment Class information model can be treated as optional, as the purpose is to provide information as an overview of list of EquipmentClass categories to the simulation user. Example of Equipment Class represented in XML based on ISA-95 standard is shown in Figure 17.

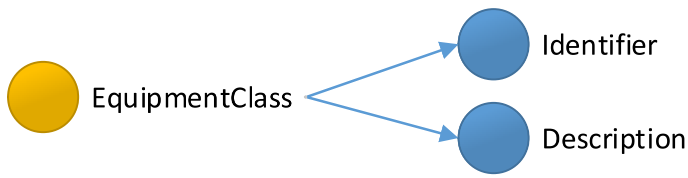


Figure 16: Equipment Class-Tree View

```
<EquipmentClass>
  <ID>VK1</ID>
  <Description>Class of Handling Station</Description>
</EquipmentClass>
<EquipmentClass>
  <ID>VK2</ID>
  <Description>Class of Spotwelding Robots</Description>
</EquipmentClass>
```

Figure 17: Equipment Class in XML format-ISA-95 Standard

Equipment entity is similar to the Resource Class defined in CMSD information model. Figure 18, represents Equipment entity from our generic structure. In this Equipment entity information model only equipment information could be provided. To provide information about personal i.e. employee, then a separate Personnel segment/entity information model is required to provide information, as this was not included in the proposed model due to the thesis scope. Equipment entity provides information about equipment type it could be production line, process cell, work cell, work center or units (Scholten, 2007; ISA, 2010). In this case study the equipment type is work center or units as shown in Figure 19 in XML based format.

The capacity information of equipment is encoded using EquipmentProperty entity on each Equipment entity, this is similar to Property entity defined in CMSD information model. Further, in order to group the equipment type to a specific related Class category from other Equipment Class, a reference of particular EquipmentClass is associated/linked on each equipment entity. As mentioned above, this part of information i.e. EquipmentClass attribute, is an optional as it just to pinpoint the equipment to which Equipment Class it belongs. Example of Equipment entity represented in XML format based on ISA-95 standard is shown in Figure 19.

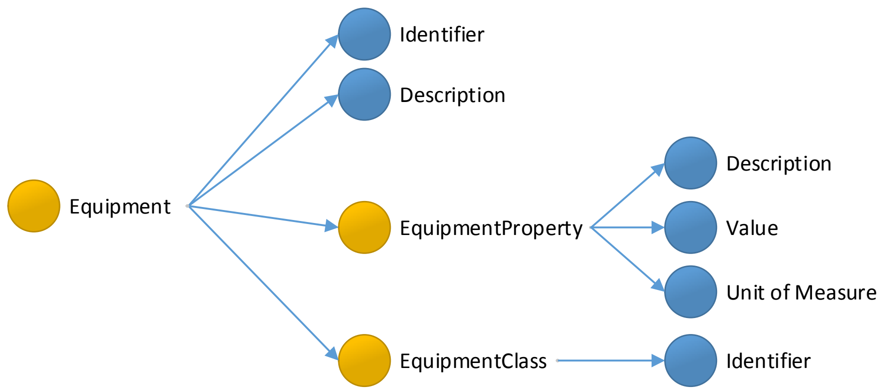


Figure 18: Equipment entity-Tree View

```xml
<Equipment>
  <ID>M1</ID>
  <Description>Handling Station</Description>
  <EquipmentProperty>
    <Description>Capacity</Description>
    <Value>1</Value>
    <UnitofMeasure>Units</UnitofMeasure>
  </EquipmentProperty>
  <EquipmentClassID>VK1</EquipmentClassID>
</Equipment>
```

Figure 19: Equipment entity in XML format-ISA-95 Standard

ProductDefinition Class is means to provide information about a type of product that could be a fully assembled product or a single part. Figure 20, represents the ProductDefinition Class from the proposed generic structure. Further, to pinpoint the manufacturing facility within site or area that is required to produce the product is encoded with the help of HierarchyScope attribute on ProductDefinition Class. This part of information serves as additional information to the simulation user. Further, all the materials needed for the product in order to manufacture the product is encoded with the help of ManufacturingBill entity, all the material needed are referenced/linked within the ManufacturingBill entity on ProductDefinition Class. Note that, only required material indicated within the ManufacturingBill entity are used in order to manufacture specific product and it doesn't mean that all material specified will be used, it is just a possibility that if required.

Next kind of information that needed to provide to simulation user about sub-parts (assembly parts) that are part of the main product and the process information that are responsible to produce the sub-parts are encoded with the help of ProductSegment Class. Both the information about sub-parts and process are encoded using ProductSegment Class and referencing/associating the required process plan to the ProcessSegment attribute provided within ProductSegment Class. Example of ProductDefinition Class represented in XML based on ISA-95 standard is shown in Figure 21.

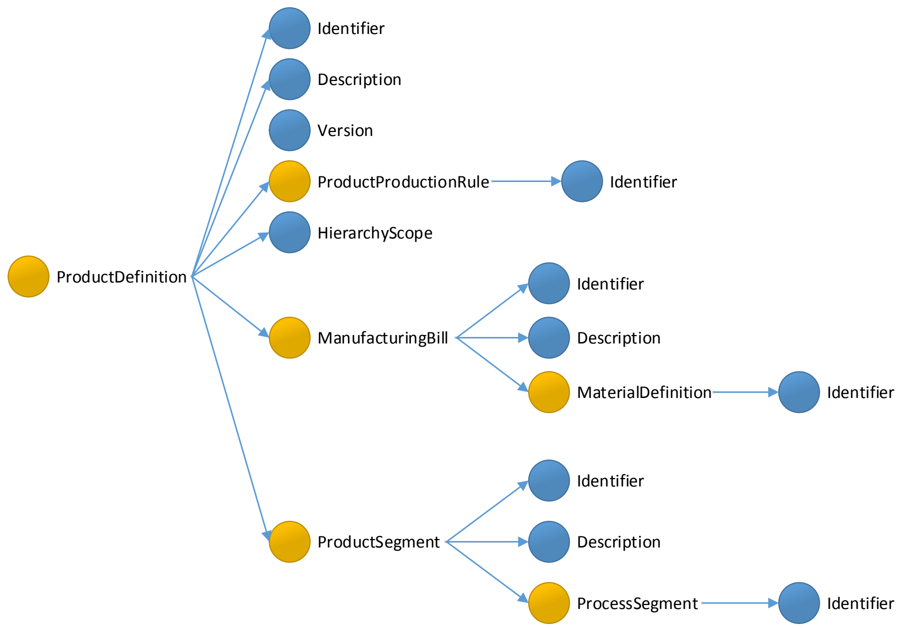


Figure 20: Product Definition Class - Tree View


```
<ProductDefinition>
  <ID>12</ID>
  <Version>1</Version>
  <Description>Engine Tunnel sub part</Description>
  <ProductProductionRule>
    <ID>PPR-11</ID>
  </ProductProductionRule>
  <HierarchyScope>V3: Production Area</HierarchyScope>
  <ManufacturingBill>
    <ID>MB1</ID>
    <Description>Material required during process execution</Description>
    <MaterialDefinitionID>ENT11</MaterialDefinitionID>
  </ManufacturingBill>
  <ProductSegment>
    <ID>12</ID>
    <Description>This segment represents sub-part (assembly) of main product and process execution</Description>
    <ProcessSegmentID>PR-ENT-11</ProcessSegmentID>
  </ProductSegment>
</ProductDefinition>
```


Figure 21: Product Definition in XML format - ISA-95 Standard

MaterialDefinition Class provides information about material that will be consumed during execution of a process or material that would be produced after executing the process. Figure 22, represents the MaterialDefinition Class information model from the proposed generic structure. Note that, the ProductDefinition Class is equivalent to the MaterialDefinition Class (ISA, 2010). Example of MaterialDefinition Class represented in XML based on ISA-95 standard is shown in Figure 23.

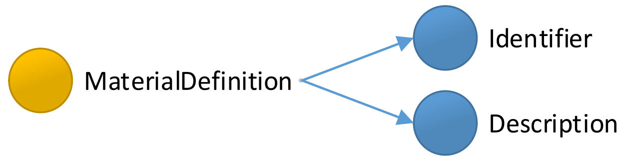


Figure 22: MaterialDefinition Class - Tree View

```xml
<MaterialDefinition>
  <ID>ENT11</ID>
  <Description>Material to be used during process</Description>
</MaterialDefinition>
<MaterialDefinition>
  <ID>12</ID>
  <Description>Material to be produced after executing the process</Description>
</MaterialDefinition>
```

Figure 23: MaterialDefinition in XML format - ISA-95 Standard

ProcessSegment Class information model in other words it is a systematic way of planning of execution of the process in order to produce the product. Figure 24, represents the ProcessSegment Class from the proposed generic structure. This information model consists information about, part/material that will be the subsequent part of the process execution and the final product that will be produced, type of equipment that is needed in sequence in order to transform semi-finished material/part to a finished product and sequence in which the execution of the process should commence. The information about required equipment is encoded using the EquipmentSegmentSpecification entity by relating/linking the required equipment. Further, parameter information such as MTTR, MTBF, Availability, Process Time and Scrap Rate are encoded using the EquipmentSegmentSpecificationProperty entity on each EquipmentSegmentSpecification entity. Parameter information about MTTR, MTBF and Availability could be encoded using EquipmentProperty entity on Equipment entity. The reason the parameter information was decided to encoded under ProcessSegment Class, as all the major parameter information are available under one section. Next, to provide information about material that will be part of the process execution and material/product that will be produced out of process execution is encoded using MaterialSegmentSpecification entity. The systematic planning of process execution or in other words, routing of process is encoded using ProcessSegmentDependency entity on ProcessSegment Class. Example of an EquipmentSegmentSpecificationProperty and MaterialSegmentSpecification entity represented in XML format is shown in Figure 25. Example of ProcessSegmentDependency entity represented in XML format based on ISA-95 standard is shown in Figure 26.

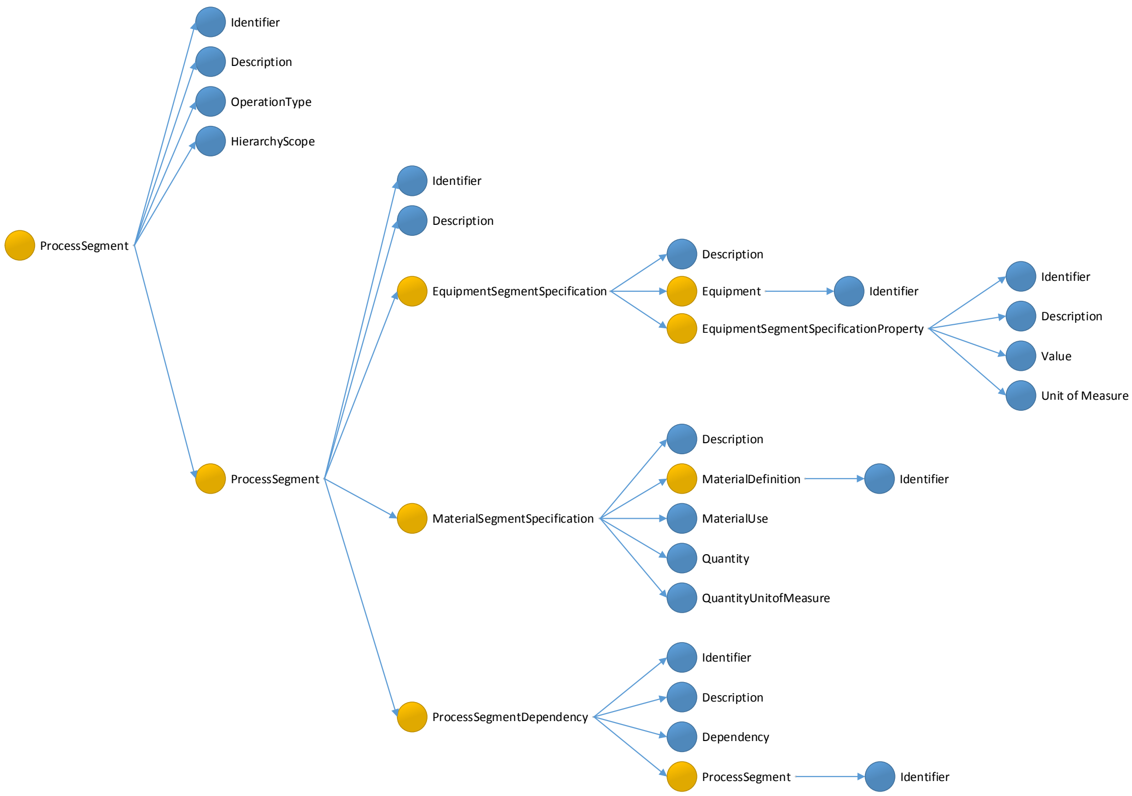
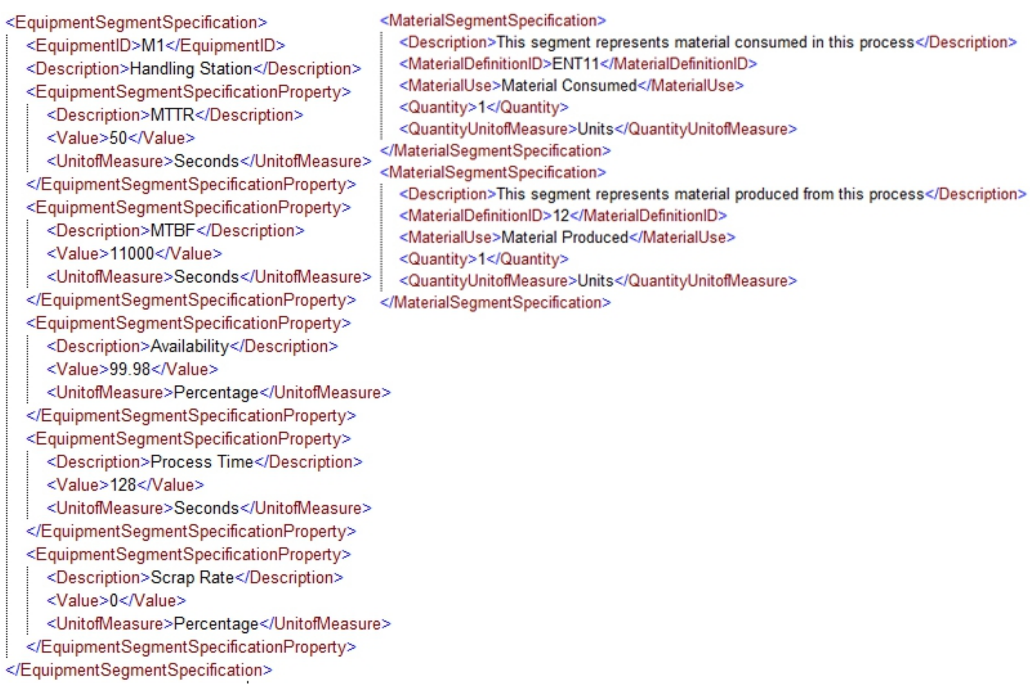


Figure 24: ProcessSegment Class - Tree View



```xml
<EquipmentSegmentSpecification>
  <EquipmentID>M1</EquipmentID>
  <Description>Handling Station</Description>
  <EquipmentSegmentSpecificationProperty>
    <Description>MTTR</Description>
    <Value>50</Value>
    <UnitofMeasure>Seconds</UnitofMeasure>
  </EquipmentSegmentSpecificationProperty>
  <EquipmentSegmentSpecificationProperty>
    <Description>MTBF</Description>
    <Value>11000</Value>
    <UnitofMeasure>Seconds</UnitofMeasure>
  </EquipmentSegmentSpecificationProperty>
  <EquipmentSegmentSpecificationProperty>
    <Description>Availability</Description>
    <Value>99.98</Value>
    <UnitofMeasure>Percentage</UnitofMeasure>
  </EquipmentSegmentSpecificationProperty>
  <EquipmentSegmentSpecificationProperty>
    <Description>Process Time</Description>
    <Value>128</Value>
    <UnitofMeasure>Seconds</UnitofMeasure>
  </EquipmentSegmentSpecificationProperty>
  <EquipmentSegmentSpecificationProperty>
    <Description>Scrap Rate</Description>
    <Value>0</Value>
    <UnitofMeasure>Percentage</UnitofMeasure>
  </EquipmentSegmentSpecificationProperty>
</EquipmentSegmentSpecification>

<MaterialSegmentSpecification>
  <Description>This segment represents material consumed in this process</Description>
  <MaterialDefinitionID>ENT11</MaterialDefinitionID>
  <MaterialUse>Material Consumed</MaterialUse>
  <Quantity>1</Quantity>
  <QuantityUnitofMeasure>Units</QuantityUnitofMeasure>
</MaterialSegmentSpecification>
<MaterialSegmentSpecification>
  <Description>This segment represents material produced from this process</Description>
  <MaterialDefinitionID>12</MaterialDefinitionID>
  <MaterialUse>Material Produced</MaterialUse>
  <Quantity>1</Quantity>
  <QuantityUnitofMeasure>Units</QuantityUnitofMeasure>
</MaterialSegmentSpecification>
```


Figure 25: EquipmentSegmentSpecificationProperty & MaterialSegmentSpecification XML- ISA-95 Standard

```xml
<ProcessSegment>
  <ID>PR1</ID>
  <Description>First process to execute</Description>
  <EquipmentSegmentSpecification>
  <MaterialSegmentSpecification>
  <MaterialSegmentSpecification>
</ProcessSegment>
<ProcessSegment>
  <ID>PR2</ID>
  <Description>Second process to execute</Description>
  <EquipmentSegmentSpecification>
  <MaterialSegmentSpecification>
  <MaterialSegmentSpecification>
  <ProcessSegmentDependency>
    <ID>PR-SD-1</ID>
    <Description>Defines ordering of process</Description>
    <Dependency>PR2 must follow PR1</Dependency>
  </ProcessSegmentDependency>
</ProcessSegment>
<ProcessSegment>
  <ID>PR3</ID>
  <Description>Third process to execute</Description>
  <EquipmentSegmentSpecification>
  <MaterialSegmentSpecification>
  <MaterialSegmentSpecification>
  <ProcessSegmentDependency>
    <ID>PR-SD-2</ID>
    <Description>Defines ordering of process</Description>
    <Dependency>PR3 must follow PR2</Dependency>
  </ProcessSegmentDependency>
</ProcessSegment>
<ProcessSegment>
  <ID>PR4</ID>
  <Description>Fourth process to execute</Description>
  <EquipmentSegmentSpecification>
  <MaterialSegmentSpecification>
  <MaterialSegmentSpecification>
  <ProcessSegmentDependency>
    <ID>PR-SD-3</ID>
    <Description>Defines ordering of process</Description>
    <Dependency>PR4 must follow PR3</Dependency>
  </ProcessSegmentDependency>
</ProcessSegment>
```


Figure 26: ProcessSegmentDependency XML- ISA-95 Standard

Next kind of information is about the orders that needed to be processed in a day/week and this type of information is encoded using the ProductionSchedule Class information model. Figure 27, represents the ProductionSchedule Class information model from the proposed generic structure. This is similar to the Schedule Class information model defined in CMSD generic structure. In this information model, Start and End time indicates the beginning and approximate end of the order either according to planned schedule or actual performed and this information is encoded using StartTime and EndTime attribute. Further, to provide information about product that needed to be produced according to the demand that has been place by the customer or internal organization is encoded using the ProductSegment attribute by relating the defined product within ProductDefinition Class. Also in similar manner, to provide information about specific process is encoded using ProcessSegment attribute, by relating the process that is responsible to manufacture the product. Example of ProductionSchedule Class represented in XML format, based on ISA-95 standard is shown in Figure 28.

Figure 27: ProductionSchedule Class-Tree View

```xml
<ProductionSchedule>
  <ID>PS-ENT</ID>
  <StartTime>02-22-2016, 6.00</StartTime>
  <EndTime>02-22-2016, 23.59</EndTime>
    <ProductionRequest>
      <ID>1</ID>
      <Description>First order of Engine Tunnel part</Description>
      <HierarchyScope>Production Area:V3 EngineTunnel</HierarchyScope>
      <StartTime>02-22-2016, 6.00</StartTime>
      <EndTime>02-22-2016, 6.10</EndTime>
      <Priority>1</Priority>
      <ProductProductionRuleID>PPR-11</ProductProductionRuleID>
        <SegmentRequirement>
          <ID>ENT</ID>
          <Description>Actual data from performed production</Description>
          <HierarchyScope>Production Area:V3 EngineTunnel</HierarchyScope>
          <StartTime>02-22-2016, 6.00</StartTime>
          <EndTime>02-22-2016, 6.10</EndTime>
          <ProcessSegmentID>PR-ENT-11</ProcessSegmentID>
          <ProductSegmentID>12</ProductSegmentID>
        </SegmentRequirement>
    </ProductionRequest>
</ProductionSchedule>
```

Figure 28: ProductionSchedule in XML format - ISA-95 Standard

4.4 Comparison of CMSD and ISA-95 according to the properties

For simulation studies the data that describes the production system and its state are needed, the data can be System Data, Organizational Data, or Technical Data which is important for input data. The manufacturing standards that can match the data specifications, especially in the area of manufacturing operations management are CMSD and ISA-95, and these standards can support the integration of simulation data.

The important simulation properties such as Resources, Job, Part and shift schedule and calendar are described below, the naming for these properties are different because the ISA-95 is standard that is in particular but the naming for CMSD is of user requirement.

Resources can be described as Equipment, Personnel, Material and conveyor, Data on Equipment property is important because it has properties like MTTR, Availability, MTBF is associated with it. Personnel describe as mobile resources and the properties describe their skills for the job is important and their state as well. Material Property describes the parameters like what material consumed what material it produced and the property for that particular material information is described. Both CMSD and ISA-95 can describe the Resources Properties that can be used for simulation data.

Job describes the property of type of job, process steps associated with it and the state of the job, the parameters described are process times, scrape rates. Job is central element in the simulation models because it describes the dynamic objects of the physical system. Job describes the current process steps and its status, it also contains the knowledge of Process Plan, each process plan contains the information about the process steps for which associated resources are related for parts produced and parts consumed. Both CMSD and ISA-95 can describe Job property that can be used for simulation data.

Part or Part type describes when the part is produced or consumed during a process example: in assembly process, this describes the parameter where the data on which station or machine the part resides and the information about the state of the part can be known. Both CMSD and ISA-95 can describe Part or Part Type property that can be used for simulation data.

Shift schedule and calendar describes the property of the scheduled jobs, it describes the schedule of ongoing jobs and the jobs that will be processed. The parameters that define them are process plan and actual or planned times/ dates for what jobs to be produced at particular schedule. Only CMSD is capable to describe Shift schedule and calendar that can be used for simulation data.

Most of the properties can be described in both CMSD and ISA-95 Standard but there is a significant difference between them,

1. In terms of Specification availability CMSD is free public source, whereas ISA-95 is a payment service.

2. The CMSD is designed to develop a standardized representation that has the ability to exchange information in a machine shop environment, ISA-95 is mainly designed for Enterprise-

control activities and interface between them and exchange of information in a continuous or flow manufacturing environment.

3. ISA-95 use the standard framework of terminology throughout the organization for integrating the manufacturing systems with other enterprise systems, whereas CMSD can be defined according to user requirement specification.

4. CMSD has the ability to define the characteristics of manufacturing entities such as stochastic processes, and allows the statistical distribution information that are associated with different manufacturing parameters whereas ISA-95 cannot provide this ability.

5. ISA-95 has the structured way of interpreting the activity models for the manufacturing industry, but it cannot provide the neutral form of data formats for storing the manufacturing data that are needed for simulation studies, whereas CMSD facilitates the exchange of manufacturing life cycle data in the simulation environment.

4.5 Input Data Management

The concept of automated input data management is illustrated in Figure 29, which has been previously implemented by Skoogh (2011) and Boulonne, Johansson, Skoogh, & Aufenanger (2010), in their work, which could be classified as solution in our case study as well. The input data management method has evaluated in this case study and documented. GDM Tool consist three major functions data extraction, data processing and output representation (Skoogh, 2011) and this has been performed in regards with our solution as well, as described below. The GDM tool doesn't resides the raw data into it's application, infact the GDM Tool processes the raw data imported from the original sources and finally the information is exported in CMSD standard format to enable efficient data sharing as described in section 2.5 of Theory Chapter. However, it is also possible to export the final results in different output format in excel or text file to create flexibility and avoid hindrance to the application use.

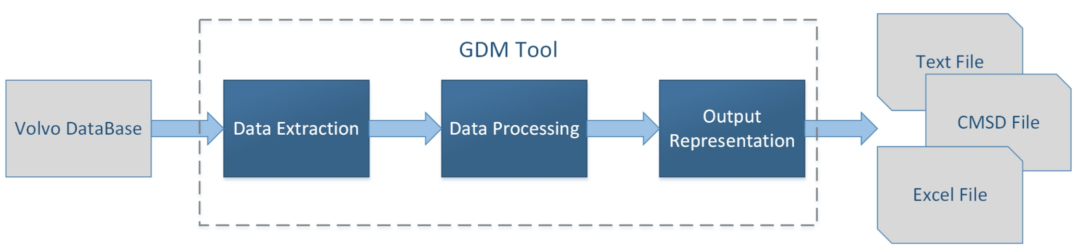


Figure 29: Outline of GDM Tool

4.5.1 Data Extraction

The available data has been identified and resides in Volvo Legacy System (Follow-up system). Due to administration rights, the direct server connection from Volvo Legacy System to GDM Tool was not realized. Because of this technicality issue arise during the case study, the identified data was downloaded manually from the Volvo Legacy System to transform the raw data to relevant information. Further, all identified raw data had to be imported manually in the GDM Tool. The case study performed belongs to the one of the Production Area coded as V3. The raw data imported are represented in form of tables as shown in Figure 30, using the Excel File plugin. The raw data imported consists, for instances cycle time, MTTR, MTBF, OEE parameter values. Further, to transform the imported raw data to a relevant information required for simulation models, the data processing step represented in GDM Tool were performed as described in detail in next step. Note that, the process of identification and understanding of raw data is only required to perform once.

Due to the Volvo data privacy, in our report, dummy data has been represented. However, in our actual case study the real raw data downloaded from the Volvo Legacy System has been used to perform the steps described in GDM Tool, where the data gets transformed to information.

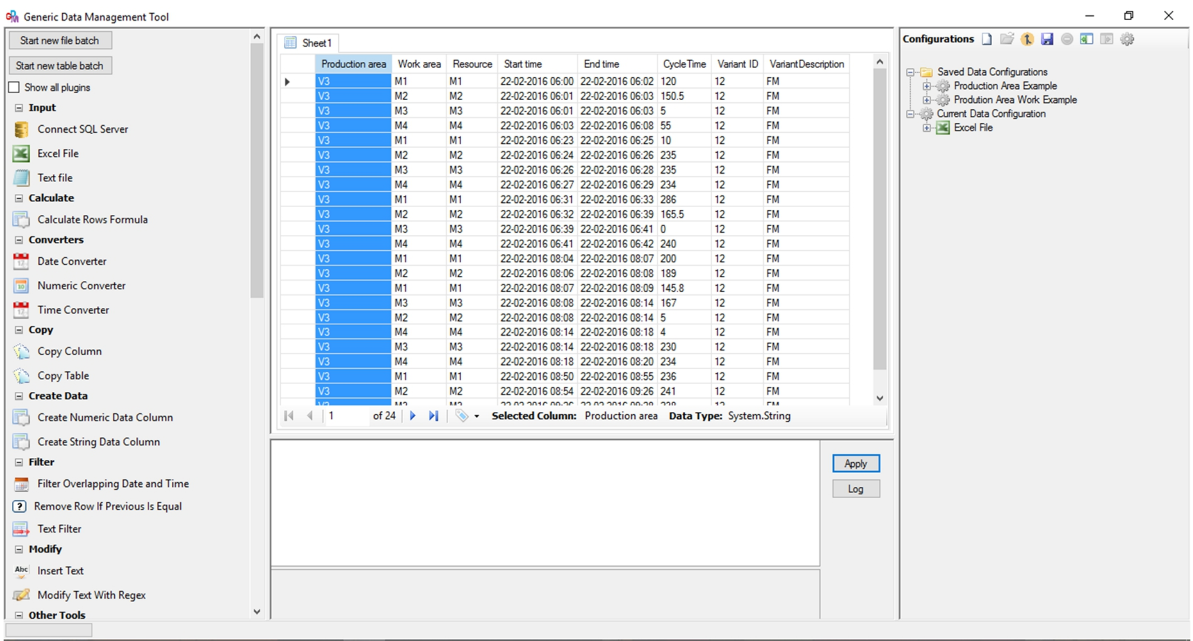


Figure 30: Imported raw data in GDM Tool with use of Excel File plugin

4.5.2 Data Conversion (Processing)

Data processing is performed by series of operations using plugin based functionalities to transform the raw data to a relevant information for simulation models. The purpose of raw data was well identified before importing the data sheets into the GDM Tool and the information that can be obtainable from the imported raw data is also analyzed by thorough look out for instance cycle time, MTTR, MTBF, Availability and Quality Percentage parameter information. This comes under Contextualization and Categorization of the Data as described under section 2.4 in Theory Chapter.

The data sheets contain more than 7200 rows of raw data for cycle time and around 1200 rows of raw data for breakdowns, this is in our case study. The other raw data that was handled during the case study consists around more than 52000 rows of raw data for cycle time and more than 10000 rows of raw data for breakdowns. Further, the all rows and columns consisting those data points that were irrelevant to the simulation input were excluded using Remove Plug-in operation in GDM Tool. Some correction was needed to exclude irrelevant raw data for instance all cycle time not falling between interval time 10 sec - 240 sec was filtered out with help of Filter plugin operation as shown in Figure 31, this was done in order to prepare quality assured data based on user specification requirement (Bokrantz, Skoogh, Andersson, Lämkull, & Ruda, 2015). Calculation of parameter for instance Availability Percentage were performed using planned production time and availability loss data present in the OEE raw data sheets. Similarly, Quality Percentage was calculated using planned production time and quality loss data present in same OEE raw data sheets. This was calculated using Create Numeric Data Column plugin operation.

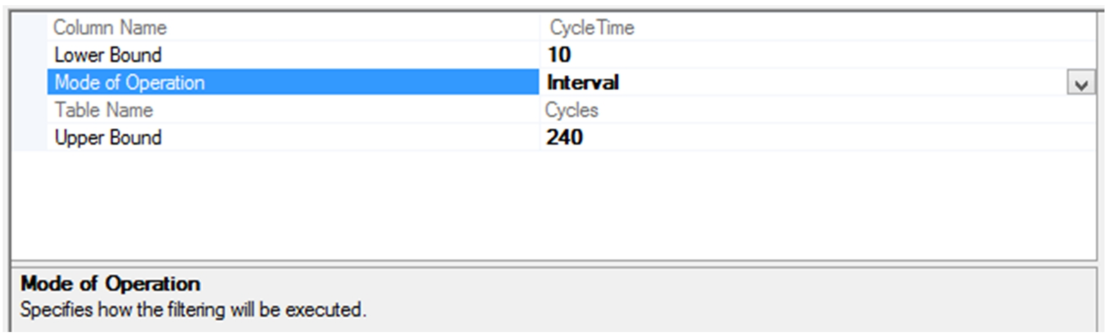


Figure 31: Filter Plug-in

4.5.3 Output Preparation

In this thesis, statistical distribution representation was preferred as it is possible to condense the processed data from the previous step to a convenient size. As described by the author (Robinson, 2004) statistical distribution has ability to include dynamic behavior of production system that has not been noticed during data collection (Robinson, 2004). Moreover, variation for example machine breakdowns have most effects on the system and that's why authors suggests that not to replace distributions with it's mean (Bokrantz, Skoogh, Andersson, Lämkull, & Ruda, 2015). The empirical distributions approach is not preferred in our this case study, as it consumes more space to convey the information to the simulation models (Robinson, 2004) and also this was not within our scope. Two approaches have been experimented in GDM Tool. Firstly, best fitting the statistical distribution according to the empirical processed data. Secondly, selecting statistical distribution based on the properties of process (Banks, Carson, Nelson, & Nicol, 2004; Leemis, 2004). Both of the approaches has basic initial steps to be performed before proceeding with both the approaches as described above. Evaluating the basic characteristics, this is performed by using the Generate Distribution plugin in GDM Tool. From the Figure 32, the scatter plots is widely used to visually observe data independency, other data independency method has been described by (Leemis, 2004). The functionality provided in statistical plugin in GDM Tool, allows to analyze data by importing the data sets, along with grouping column and starts analyzing the sample independency as shown in Figure 32. The graph indicates that the data are independent and no systematic data changes has been noticed during data collection (Leemis, 2004) this is in our case study. Note that, sufficient data sample more than 190 samples have been used to proceed with statistical representation (Perrica, Fantuzzi, Grassi, Goldoni, & Raimondi, 2008) to capture dynamic behavior of production system.

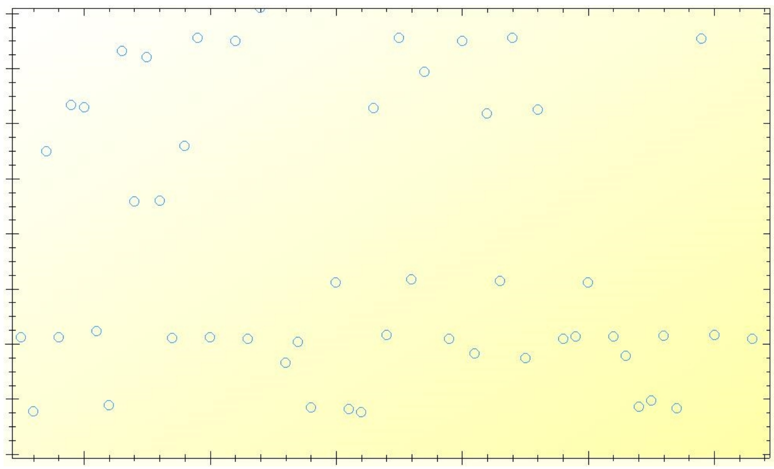


Figure 32: GDM Tool – Scatter Plot

Furthermore, in regards to the MLE as described in section 2.4.2 of Theory Chapter, the plugin identifies distribution parameters and further using the P-P plot, one can select best fitting statistical distribution according to the empirical processed data or select the desired statistical distribution according to the property of the process as shown in Figure 33, illustrates the goodness of fit evaluation using P-P plot as described in section 2.4.2 of Theory Chapter.

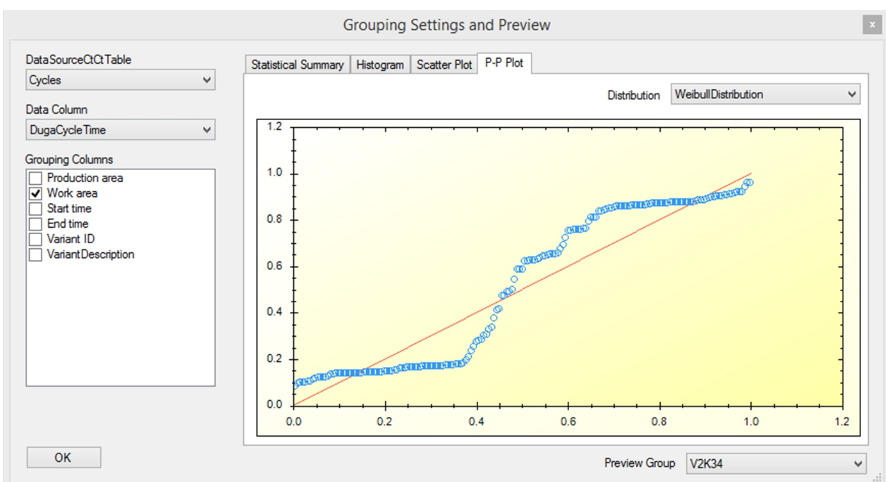


Figure 33: P-P Plot provided by statistics plugin

Example showing the statistical distribution not best fitting the data set are illustrated in Figure 34.

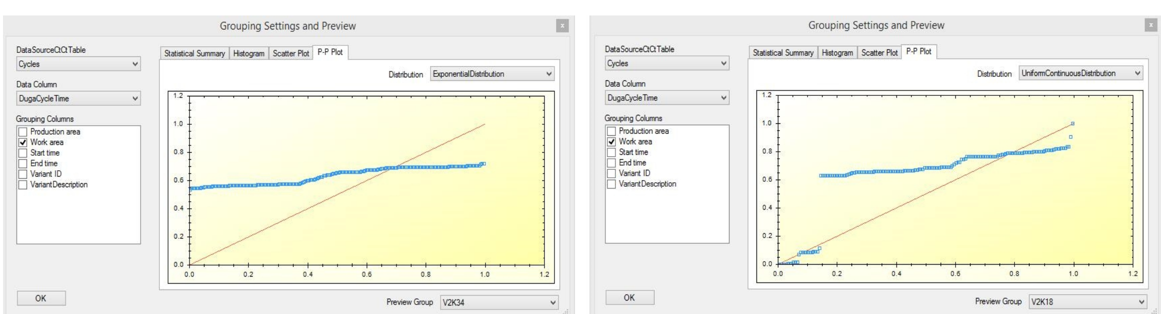


Figure 34: Example of statistical distribution not best fitting the data sets

In our case study, Weibull and Triangular statistical distribution for process time were preferred based on both the approaches as described above and in section 2.4.2 in Theory Chapter, as illustration in Table 4. Secondly to represent breakdowns, Weibull statistical distribution has been used to condense the information, depicted in Table 4. This is in our case study, the statistical representation was selected with help of P-P plot visual representation, this allowed to experiment different fittings based on process properties and as well the best fitting method to condense the information.

Table 4: Statistical distribution to condense Process Time and MTTR parameter information

Parameter	Statistical Distribution
Process Time	Weibull(= 128.07449597743, k = 10.9343264788744) s & Triangular(a = 71.32, b = 151.47, c = 141.884307692308) s
MTTR	Weibull(= 104.802631785608, k = 1.10809528779619) s

4.5.4 User Interface: CMSD Standard Format

To enable standardized and efficient input data sharing with simulation applications, a neutral format CMSD (Lee, Riddick, & Johansson, 2011; SISO, 2010) is preferred as primary output to provide the information processed from the above performed steps in our study to simulation models. Due to the fact that, CMSD standard is exclusively used and is suitable to provide information for simulation models (Lee, Riddick, & Johansson, 2011; SISO, 2010; Johansson, et al., 2007), and also evidence from previous related research work (Lee, Riddick, & Johansson, 2011; Johansson, et al., 2007). A user interface plugin *"Save to CMSD"* is integrated within the GDM Tool. With the help of this plugin *"Save to CMSD"*, allows the user to specify the Table/Sheet and rows associated with Table/Sheet that contains Job, SubJob, Resource associated to the Job and SubJob, and Schedule information. In similar way, parameter information such as CycleTime/ProcessTime, MTTR, MTBF, Availability Percentage is provided that are associated to the concerned Job and SubJob. Figure 35, illustrates the *"Save to CMSD"* plugin user interface according to our case study.

Furthermore, all the information mapped based on the CMSD standard format with the help of user interface plugin "Save to CMSD" in GDM Tool, the saved CMSD document is a CMSD-XML based document. This enables efficient input data sharing with any simulation application. Example of a CMSD-XML based document containing the mapped information imported in Plant Simulation based on proposed CMSD generic structure is illustrated in Figure 36.

A plugin based on ISA-95 information model was not preferred in this case study, as per our comparison results between CMSD and ISA-95 standard, some of the class/segments, objects and attributes that are required to encode the information were not present, due to which it has led to decide to use CMSD information model to map and save the information in neutral format.

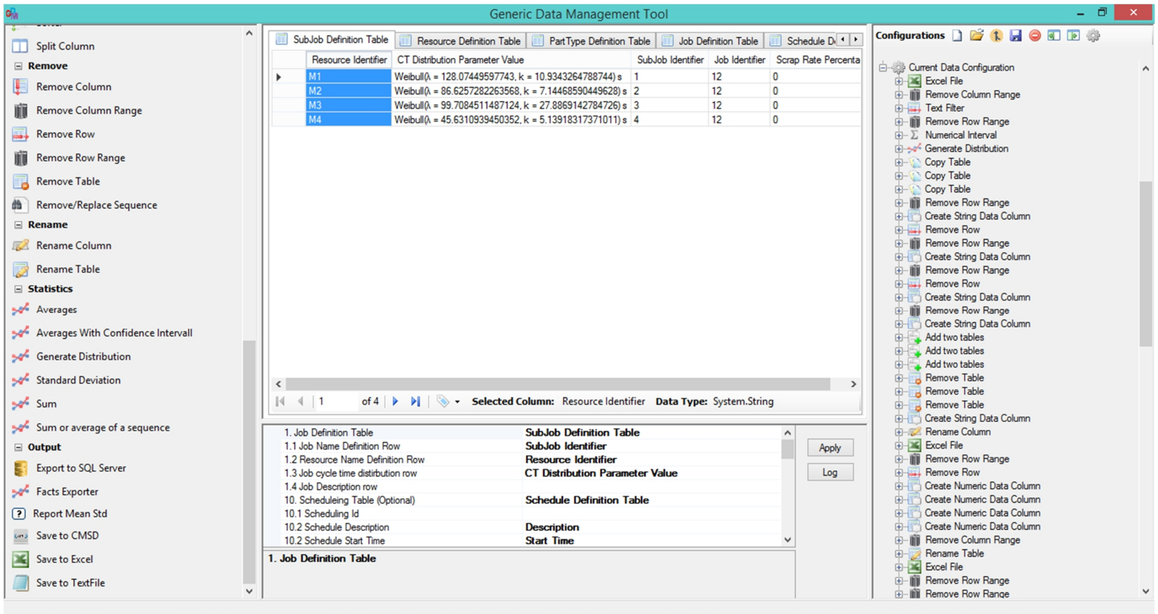


Figure 35: User interface "Save to CMSD" plugin functionality

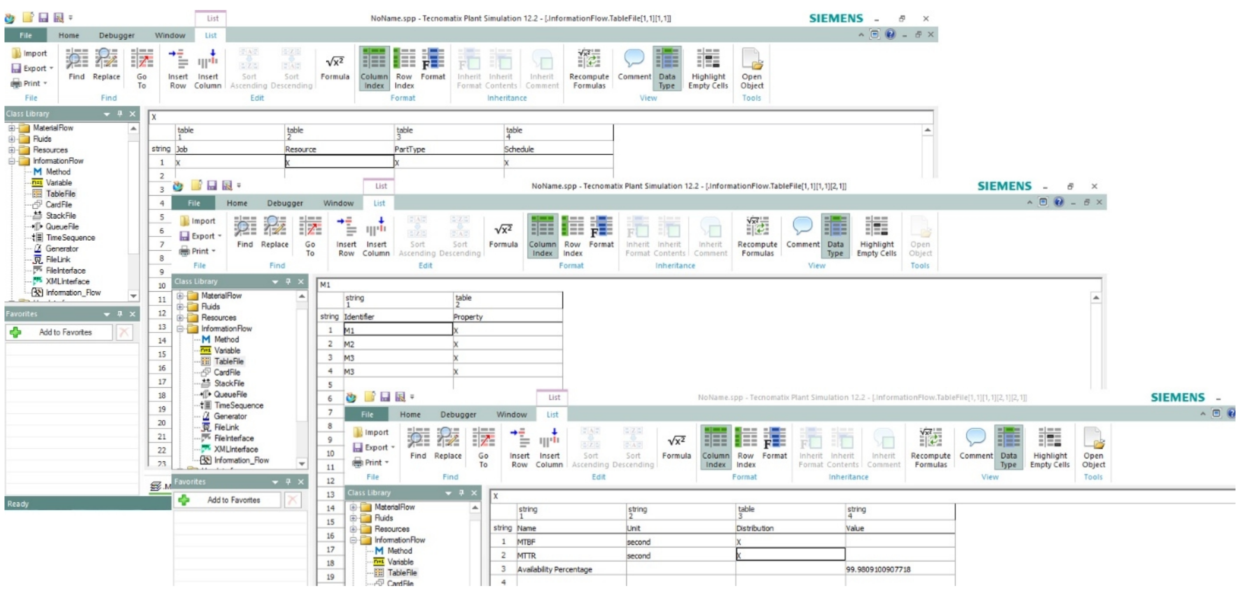


Figure 36: CMSD - XML based document imported in Plant Simulation software

4.5.5 Configuration and Automation Mode in GDM Tool:

The final step was to evaluate and compare traditional approach with automated approach in this case study. The GDM Tool operates in two modes, Configuration Mode and Automation Mode. The steps performed to transform the raw data to relevant information generates a configuration file. This configuration file consists all necessary plugin based activities from data extraction to the exporting of mapped information in CMSD-XML based format in sequence. Figure 37, illustrates few plugin based activities from the configuration file, performed in the case study. The Excel File activity imports data sheets, Remove Row Range, Remove Column Range, Remove

Column are used to delete unneeded columns and rows, Text Filter and Numerical Interval activity are used to remove unneeded data points or errors and Generate Distribution activity allows to condense the information to a convenient size by representing in form of statistical distribution.

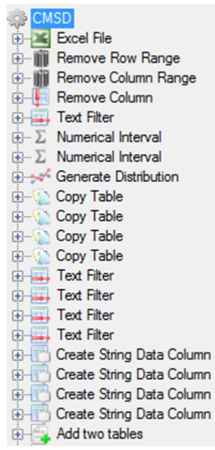


Figure 37: Plugin based activities from configuration file

The configuration file is one time requirement. Once the configuration file has been established, to process a new data sets automatically to the simulation models, same configuration file is applied and the output CMSD-XML based file would be updated with new production information. This makes the process of data extraction to the exporting of mapped information in CMSD-XML based format to simulation models completely automatic. This is known as automation mode. Figure 38, illustrates the concept of Automation Mode. Automation mode is the desired mode of operation to reduce input data handling time drastically. Note that, Automation mode is repeated without further changes as long the model is constant.

In our case study a week's data was considered and the results of the both the configuration mode and automation mode has been presented in Table 5. These results shows that the GDM tool is a important tool for the Input Data Management where a significant amount of time is reduced by using the Automation mode.

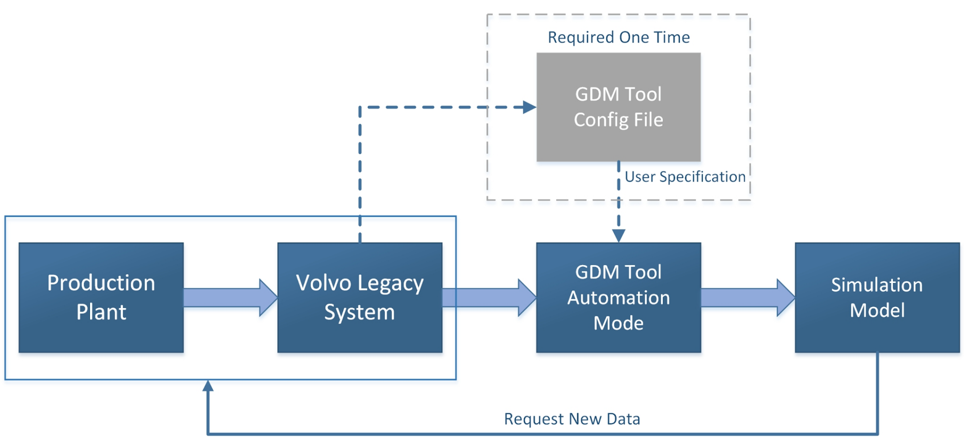


Figure 38: GDM Tool, Configuration and Automation Modes

Table 5: Comparison of Configuration and Automation Mode

Task	Tool	Mode	Time Consumption
Data Extraction, Data Processing, Condensation, Save in CMSD Format	GDM Tool	Configuration Mode	50 min
Data Extraction, Data Processing, Condensation, Save in CMSD Format	GDM Tool	Automation Mode	1 min

4.5.6 Validation of Results

The procedure adopted to process the data in GDM Tool and which has been considered from the input data management steps, acts as self-validator in this case study (Perera & Liyanage, 2000; Skoogh, Johansson, & Stahre, 2012). The quality of results obtained through the use of GDM Tool, in order to reduce the time consumption in input data management process, a validation process was performed by comparing with the real world production system. One of the task involved was to deliver information of entire BIW area of plant processed with help of GDM Tool, to the two simulation based optimization project teams. One team working on detail modeling using Plant Simulation software and other team working on aggregated modeling using Facts Analyzer software. The processed information with which both the teams simulation model was run had less than 5% deviation in total compared with real world production system. The Facts Analyzer team had 4.6% deviation compared to real world production system.

4.6 Volvo Legacy System (Follow-up System) SWOT Analysis

STRENGHTHS:

- It is a good Follow-up System
- Provides Production Data, such as Cycle Times, MTTR, MTBF, OEE etc.
- Bottleneck Detection-Powerful Tool
- Provides Cycle Time trends, deviations

WEEKNESS:

- Misleading information
- Requires lot of understanding of the flow according to variant-Not easy
- Parameter information such as Cycle Time missing in most places from the Excel document present in follow-up system

OPPORTUNITY:

- For better flow analysis, attribute such as priority for each Work Area/ Resource can be provided in Cycle Time Excel document.
- Tool features of such GDM Tool can be integrated in Volvo Legacy System – Helps to reduce time needed to deliver the input data to simulation user.

THREATS:

- Flow interpreted from the follow-up system CycleTime Excel document may not be true and could lead to wrong results from the simulation runs

5

Discussion

In this Chapter, a thorough discussion of results has been presented. Beginning with Core Manufacturing Simulation Data (CMSD) and ISA-95 (International Society of Automation) information model, it's applicability and feasibility for DES modeling that has been investigated and documented in this case study will be discussed here. Further, a brief discussion on comparison made between CMSD and ISA-95 information model has been presented. And finally, the Input Data Management method and GDM-Tool that has been evaluated in this case study and results would be discussed here.

5.1 CMSD Standard

The Core Manufacturing Simulation Data (CMSD) standard has been developed to address following purposes, to enable efficient exchange of manufacturing data to simulation models, to support the construction of manufacturing simulators, to support testing and evaluation of manufacturing software, and to support manufacturing software application interoperability between manufacturing and simulation application (Lee, Riddick, & Johansson, 2011; Johansson, et al., 2007; Lee, 2015). In our case study, the primary reason to implement manufacturing standards such as Core Manufacturing Simulation Data (CMSD) in simulation studies is to create standardized and efficient exchange of information to simulation models i.e. to address interoperability issues between manufacturing software and simulation system. The study has been involved to explore on how well these manufacturing standards could support the requirements of a detail simulation modeling. The proposed generic structure based on CMSD has been established specifically in order to enable fast and efficient exchange of information to simulation models and to provide detail information to simulation models. The CMSD standard information model integrates information from various applications such as Enterprise Resource Planning (ERP) system also known as Corporate Business System (CBS) in this thesis, Manufacturing Execution System (MES). Many of previous related research work pertaining to the interoperability issues between manufacturing and simulation application has been well supported in our thesis work in regards with CMSD generic structure in this case study.

Applicability of the CMSD standard has been thoroughly investigated and a generic CMSD information model has been proposed in this thesis work, which has been presented in Results Chapter. The CMSD standard consist several information model that are suitable for DES modeling. However, in this case study, only few information model and it's relationship pertaining to the specification requirements has been implement to create a generic structure. For example, resource information model in our case study, indicates the resource types i.e. operators, equipment, conveyors etc. and resource characteristics such as MTBF, MTTR, Cycle Time, and Availability Percentage. Further, to create a detailed process steps, either Job Class or Process Plan information model is applicable to create systematic planning of process execution based on information gathered from the planned scheduling or from actual performed operation. During the study of CMSD standard, we tried to develop generic structure based on both Job Class information model and Process Plan information model. After which, it was concluded for this case study, a simple Job Class information model is sufficient to create systematic planning of work execution based on information gathered through the Volvo follow-up system (DataBase) and also/or from the weekly Skype meetings with Volvo Group employees. Both the information model i.e. Job Class and Process Plan information model relates directly resource required and indirectly characteristics of resource i.e. parameter information such as MTBF, MTTR etc. Further, cycle times that is variant specific, it is important to provide either using Job Class or Process Plan information model as it's much suitable rather than specifying into the resource information model because the resource (i.e. equipment) are constant, that doesn't change their location, whereas part variant changes and so does the cycle time to process the part variant. In such case as it has been carried in our case study, defining the resource information independently and then relating to specific process that consist the variant cycle time information pertaining to the resource related to it. This doesn't create unnecessary duplication of resource definition. Speaking of Process Plan information model, it is recommended or in other words more suitable for a bigger production area, only if the routing of the parts is complex and has many parallel operations. Secondly, in the plant simulation software once the information encoded using process plan information model was imported in table format, it has been observed that it generated many unique tables in plant simulation software and this created a sort of little confusion to the plant simulation expert to pinpoint the fourth process or tenth process table in plant simulation software but just to note that this won't be a sort of problem if there is a need of process plan information model because in plant simulation one creates a method to read the parameter information from the table file. However, unlike before, the information provided without the help of a standardized method lack a good description of the data i.e. the purpose of the resource or process and detail information, all sort of information that is supposed to be helpful for simulation or production engineer, to understand the information, was missing. With help of the Job Class or Process Plan information model by systematically indicating the process steps and relating the resources to these process steps, this deficiency of proper explanation is eliminated and thus any production engineer or new simulation engineer who is unfamiliar to the manufacturing plant could easily understand the provided information with the help of CMSD information model and also could use as daily desktop to optimize the plant's throughput (McNally & Heavey, 2004; Lee, Riddick, & Johansson, 2011; Skoogh, Johansson, & Stahre, 2012).

Interesting aspect of the CMSD standard is that, it could integrate information from different manufacturing application. Another kind of information that was needed to provide was job order and weekly shift timings information. Basically, the information about job orders should be either retrieved from the Manufacturing Execution System (MES) or from the Enterprise Resource

Planning (ERP) system where the planned scheduling information about job order is present in these manufacturing application. And information about weekly shift timings should be retrieved from the Enterprise Resource Planning (ERP). In our case study a Schedule Class information model helped to encode the job order information but to note that, the information that was used is from actual performed operation. This is because the planned scheduling information was available but not collectable, so to proceed with the work, in order to develop a concept on how to structure the information from the different manufacturing application, information retrieved from actual performed operation about job orders was encoded using Schedule Class information model. Similarly, to develop a concept in order to provide the shift timings information was encoded using Calendar information model, this information was also not collectable but was available on the follow-up system.

Some of the parameter information such as number of operators, conveyor speed or energy consumption information was not included in this case study but with the help of CMSD information model it is possible to encode such parameter information. Evidence from previous related research work carried by author (Johansson, et al., 2007; Lee, Riddick, & Johansson, 2011; Boulonne, Johansson, Skoogh, & Aufenanger, 2010), in these projects, a concept was developed demonstrating a method to encode the energy consumption, conveyor speed information using the CMSD information model. And in the case of Johansson, et al., 2007; project work, a method was demonstrated on how to encode the operator information using CMSD information model. Further, speaking of data translation, all the encoded data is done in XML language, this makes possible to open the encoded file that consist manufacturing information in any manufacturing or simulation application. Once the XML file is opened in simulation application, all the information gets arranged in table format i.e. rows and columns, this is the unique attribute of XML language.

The proposed CMSD generic structure could be implemented irrespective of any kind of model, meaning that it is not model dependent and could be applied on various manufacturing industries that has similar parameter information requirements. This shows that the CMSD information model is a potential and has great benefit to implement in manufacturing industries. Also, it is applicable and more suitable to provide manufacturing related information to the simulation models.

5.2 ISA-95 Standard

ISA-95 standard is an international automation standard, it integrates business enterprise and manufacturing control system. The objective of ISA-95 is to reduce cost, risk and errors associated with implementing interface between business enterprise and control system. ISA-95 standard has been implemented in many manufacturing industries for efficient exchange of information between business enterprise and control system. Even Volvo Group uses ISA-95 standard for daily communication to exchange information between enterprise and control system, which has created an interest to proceed with thorough investigation of ISA-95 standard, in order to address it's applicability for DES modeling. `

The underlying objects/entities that builds layer 3 i.e. Level 3 of ISA-95 standard are responsible for efficient exchange of manufacturing information to lower levels and vice versa. All the actual performed operation data is collected in the production performance segment and this is where our interest grew to look into this section for information that is suitable for DES modeling. There are different section such as inventory, production and quality in level 3 and each has it's own responsibility to communicate information to lower level, within same level and to higher level. However, production performance segment is responsible to record all performed operation and mainly consists KPI's and not all information within this segment are relevant for DES modeling in our case study, so the challenge was again to use some of the objects and its relationship to arrange the processed parameter information because production performance segment would mislead the simulation users. And during the interview with the Volvo employees, who had designed their new follow-up system, it was confirmed that production performance segment records all actual performed operation and which is later used as feedback to create new schedule plans. In this case study, our investigation was limited to only Production section of level 3, as this is the section to communicate and exchange major manufacturing information to lower and higher levels. The proposed generic structure in depicted in Figure 15 in Results Chapter. Within the Production section of layer 3 i.e. Level 3 of ISA-95 standard, there are several segment that can be used to encode processed information. During our investigation and study of ISA-95 standard, segments such as Work Schedule or Job Order found to be potential to encode processed information but there were lack of attributes definition within these segment, which are significant to create a systematic process steps. And thus, it was concluded after thorough investigation of ISA-95 standard to encode the parameter information as per the specification requirement with the help of few segments in our case study for example, Equipment Segment information model indicates machine, conveyor or any other equipment information. Further, with help of Process Segment it was possible to create systematic process steps and using equipment specification links present in Process Segment, parameter information such as MTTR, MTBF, Availability Percentage, Cycle Time and Scrap Rate could be encoded, also relating equipment required. Other segments such as Work Schedule or Job Order are also potential information models to encode such parameter information but the problems is, there is no attribute definitions to encode sequence of process steps and whereas in Process Segment information model, process sequence using dependency object can be encoded.

One of the unique feature of this Process Segment information model is, it can also specify material consumed and material that will be produced after process execution. Interesting thing is that, Product Definition and Material Definition are treated equivalent in ISA-95 standard, so either Material Definition or Product Definition information model can be used to indicate what material to be consumed or produced. Moving further, regarding job order i.e. customers order to produce the Cabs in a day/week, this information encoded using Production Schedule information model. Originally, the Production Schedule information model is used to create a detailed planning, which includes equipment, personnel, material to be used, product definition and some ideal parameter information. One of the aspects that was discussed in interviews with Volvo employees, about process dependency i.e. sequencing of equipment flow, this has been encoded using parameter object within Production Schedule information model. But while providing information to simulation models or in other words, in simulation studies, parameter objects/entities consists parameter information such as process time etc. That's why there are many aspects within Production Schedule information model that would mislead simulation user, even though it is the right way practiced in manufacturing industries. Another challenge that was faced to encode shift timing i.e. calendar information. During the interview with the Volvo employees, this was encoded using Operation Capability information model in their newly developed follow-up system. Again the problem is that it will mislead for simulation user in regards with simulation studies, who are not familiar with ISA-95 standard. It's always a challenge for implementation team to design the ISA-95 as per their requirement and it has been always appreciated their efforts throughout the work but some of the naming of the information models and attributes will mislead the simulation user in regards with simulation studies. That is why, the part to encode calendar information was excluded because there was no other potential information model to encode this information.

Less work has been carried in regards with development of ISA-95 generic structure in previous related research work. Some of the parameter information such as operator, energy consumption, conveyor speed information was not included as per the scope of this thesis and limited time. Using Personnel Segment Information model, it is possible to encode operator information. ISA-95 information model of level 3 integrates information from different sources as well. Further, speaking of data translation, all the encoded information is done in XML language, this makes possible to open the encoded file that consist manufacturing information in any manufacturing or simulation application. Once the XML file is opened in simulation application, all the information gets arranged in table format i.e. rows and columns, this is the unique attribute of XML language. The proposed ISA-95 generic structure could be implemented irrespective of any kind of model, meaning that it is not model dependent and could be applied on various manufacturing industries that has similar parameter information requirements. ISA-95 standard has potential to encode simulation information but it lacks attribute definition that is significant to encode many other such information.

5.3 Brief Discussion on CMSD and ISA-95 Standard Properties

CMSD and ISA-95 standard are both potential standards to encode DES related information. The information models present in CMSD standard i.e. elements/objects and their relationships are designed specifically to encode DES related information. In our case study, the ISA-95 standard could not hold all information that was needed for simulation modeling, such as statistical distribution information and calendar information. Whereas CMSD standard was able to encode most of the information without any issues. In broader sense, the information that is required for detailed modeling in discrete event simulation studies can be encoded using CMSD information model, this is because of the objects and the attributes definition that are defined in CMSD information model. To note that, CMSD standard is not an enterprise standard, it can only communicate DES related information i.e. mainly shop floor information. Also many previous work related based on CMSD standard has proven that most of the DES modeling requirement can be encoded using CMSD information model. ISA-95 standard is specifically for whole enterprise and the main purpose is to integrate business enterprise and control system to create efficient exchange of information from higher level to lower level, ISA-95 focuses on flow shop or continuous process manufacturing (Scholten, 2007). From our investigation and in this case study, only some segments were found to be suitable to encode some of the information for simulation models, and this is because the incapability of objects and attribute definition in ISA-95 information model that was lacking to encode some of the information. Further, in the ISA-95 standard, Process Segment information model and it's attributes is much better information model than the Process Plan information of CMSD standard. Even though in industries some of the manufacturing information that has been communicated using defined objects and attributes of ISA-95 information model, but in simulation studies, sometimes same objects cannot be used to encode simulation related information, as it will mislead simulation users. Interesting thing about both the CMSD and ISA-95 standards is that, the information that is encoded using these standard are written in XML based language, which is easy to read in any manufacturing and simulation application and also it is editable.

5.4 Input Data Management and GDM Tool

Input data management process constitutes more than 30% of entire simulation project (Skoogh & Johansson, 2009; Trybula, 1994). The present practice in regards with input data handling in Volvo Groups is carried manually. The project is performed in the automotive industry, it has been identified that the level of automation for Input Data management as Methodology B, described in section 2.7 in Theory Chapter. More research had to be done in order to attain the desired Methodology C and D, as it takes more time and effort and also involve the management commitment to develop and implement such methodologies. Further efforts have been made in this thesis work, to increase efficiency in input data management process by automating the process with the help of a software knowns as Generic Data Management (GDM) Tool, which was developed by our Chalmers supervisors in one of the previous related projects. The software solution i.e. GDM-Tool enables automation of two most time consuming activities of input data management process i.e. raw data extraction and transformation of data into relevant information. All the activities described in input data management process i.e. data extraction, data processing and data representation with help software solution GDM-Tool, these activities are further automated. With help of a default user interface CMSD standard based on our proposed generic structure, the information can be exported to this user interface, that enables direct transfer of information to simulation applications such as Plant Simulation. Contribution of the CMSD user interface plugin, enables a neutral transfer of information, meaning that all the information in CMSD is written in XML language and thus CMSD file containing information will get opened in any simulation application, in this case study Plant Simulation was tested the import of CMSD file. The benefit of CMSD standard is that, logic i.e. production flow, in other words flow of material and combining data in structured format will always beneficial for detail modeling requirements.

Further, other export format are also available in GDM-Tool, so that the tool is not constrained to use of just one format but rather to be flexible to be decided by user. The results presented through the case study, depicted in Table 5, in Results Chapter, shows that, the time reduction is around more than 90 % when compared to configuration mode, which is mainly performed only once manually. The automation mode is the desired solution that will reduce time consumption in input data management process. The GDM Tool and CMSD standard is tested only in this case study, evidence from the previous related research work shows that with help of GDM Tool, significant time has been reduced in regards with input data handling. Interesting aspect of GDM Tool, is that it can extract data from different sources but not just CBS, also this automation with help GDM Tool has been possible due to data that resides in their follow-up system. However, this tool requires to have user experience to understand the interface and creation of macro files which will take some time to understand, for this case study a familiar user can understand the data in the system and can use IT tool for the automation of input data management studies. It is believed that, the GDM Tool would also result in positive for other types of data, which are neither structured properly nor even similar to this case study. This is because the GDM Tool has ability to extract the raw data in table format and once the data is transformed after processing, the information can be transferred in structured format to simulation applications with help of CMSD user interface plugin.

It is important to mention here that, only production models that is intended for longer use, then a automation configuration mode is useful, if not it takes around 45-60 min to generate a configuration file and later using it as Marcos takes less time. Further speaking of data quality while transforming the data into information, it was found that the processed data using GDM Tool which was delivered to other simulation project group had the deviation of 4.6% from the real world system. This indicates that, processing data with help of GDM Tool by performing all steps described in input data management process is satisfactory for any simulation projects.

5.5 Future Research

The proposed CMSD and ISA-95 standard based generic structure has been tested only in this case study. One can extend our work and test our proposed generic structure on different production system. As it was discussed in earlier sections, that CMSD standard suits better to fit the requirements of DES modeling and this is why a user interface in GDM Tool developed by our Chalmers supervisor, developed only for our proposed CMSD based generic structure. Further, only one production area data of BIW area has been automated using GDM-Tool due to time constrain, the task remains for other researchers to extend this work and test other production area's data, to process and automate using GDM Tool. In this thesis work, Methodology C as described in section 2.7 of Theory Chapter is the solution in this case study and all the facts has been mentioned to be Methodology C in this case study in previous sections. In addition to this, one can try to experiment Methodology D i.e. Total automation of input data management process by extending this thesis work. For this success of Methodology D, features of GDM Tool can be integrated in Corporate Business System (CBS), and from the simulation applications such as plant simulation software, DES information from CBS can be directly extracted automatically.

Another significant development in GDM Tool will be a relevant additional i.e. development of a plugin that could connect directly to PLM system such as Teamcenter and simulation application such as Plant Simulation software. As of now a plugin that could extract data directly connecting to any server is available, only thing left is development of the plugin that could connect directly to Teamcenter and Plant Simulation software.

During our thesis work, connection between PLM software i.e. Teamcenter and simulation application i.e. Plant Simulation was explored with help of two interviews. The two interviews, one with Siemens employees and another one was with our Chalmers supervisor. In both the interviews, connection between Teamcenter software and Plant Simulation software was demonstrated and how the data that is present in Teamcenter about product or process information, could be directly transferred to Plant Simulation software to a table file. In regards with this, one can further propose on how to structure the processed data from GDM Tool in PLM system.

6 Conclusion

The main purpose of this thesis has been to enable fast, efficient and standardized method to transfer the information between manufacturing and simulation application. The manufacturing standards such as CMSD and ISA-95 enables an efficient and standardized method to provide the information to simulation model and further a tool such as GDM Tool, enables to reduce time in the input data management process. Findings from this case study has been necessitate the requirement of standardized and efficient method to transfer the information to simulation models and use of GDM-Tool to reduce the time consumption in input data management process. Both manufacturing standards CMSD and ISA-95 has been thoroughly investigated and documented. And the use of GDM Tool to reduce the time consumption in input data management process has been thoroughly evaluated which has been previous implemented in various related research work.

Further, the conclusion has been drawn by answering the objectives as below:

1. Evaluating the method of input data management process with help of an IT software GDM Tool, with a test case

The method to reduce time consumption in input data management process has been evaluated and documented, in this thesis work. As mentioned before, in this case study, a manual approach has been practiced in the company that consumes time in input data management process. This has initiated to evaluate the input data management method that has been presented in various previous related research work. The GDM Tool enables the automation of two of the most time consuming input data management activities i.e., raw data extraction and transformation of raw data into relevant information. From the case study, it shows that, time consumption has reduced to around more than 90% when compared to configuration mode (traditional approach), which is mainly carried manually. Thus, a drastic reduce in time consumption in input data management process has been achieved with the help of GDM Tool. The generation of configuration file is thus required just once and after which, for continuous use of the same model, use of same configuration file would significantly reduce time and this is known as automation mode in GDM Tool, which is the desired solution to reduce lead time in simulation projects. It has been observed that the data quality when compared with the real world system, shows only 4.6 % difference between the processed data with help of GDM Tool and real world system. This shows that the data processed using GDM Tool is satisfactory for any simulation projects. Further, with the help of CMSD user interface developed by Chalmers supervisor, the information is mapped and transferred in a neutral data format to simulation application. The neutral data format is written in XML language; this makes it possible to import the file in any simulation applications.

2. To investigate the applicability of International Standards for efficient exchange of information in Discrete Event Simulation (DES) modeling with a test case

Both manufacturing standards CMSD and ISA-95 has been thoroughly investigated and documented. The proposed generic structure based on CMSD and ISA-95 information model enables efficient and standardized method to exchange information to simulation models. A comparison of both CMSD and ISA-95 standard based on their specification has been made and presented in section 4.1.3 of Result Chapter, and which shows that, CMSD information model is better applicable in regards with details requirements of DES modeling. However, ISA-95 information model is also having potential information model to create production flow logic and to structure data systematically, but ISA-95 standard is an enterprise model, and focuses mainly on continuous process manufacturing flow of production system (Scholten, 2007). Apparently, objects and attributes definition in ISA-95 information model are inconsistent to structure information required for DES modeling. The proposed CMSD based generic structure from this case study, shows that the CMSD information model has ability to represent characteristics of manufacturing operations and it is more suitable for DES projects, which can hold various information related to simulation studies. In addition to this, a CMSD user interface plugin developed by Chalmers supervisor for this case study in GDM Tool, demonstrates the transfer of information mapped according to CMSD and exported to simulation application in neutral format i.e. written XML language. Thus, this make possibility to integrate simulation and other manufacturing application with the CMSD information model effective, efficient and inexpensive.

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A

Appendix

This section cover interview questions that were used to discuss the topics

A.1 Interview Question Set A

The question below were asked to understand practical implementation of ISA-95 standard in industries, apart from theoretical studies.

Q1. What is the difference between Operation, Production and Work Schedule segment? And in what context these segments to be used?

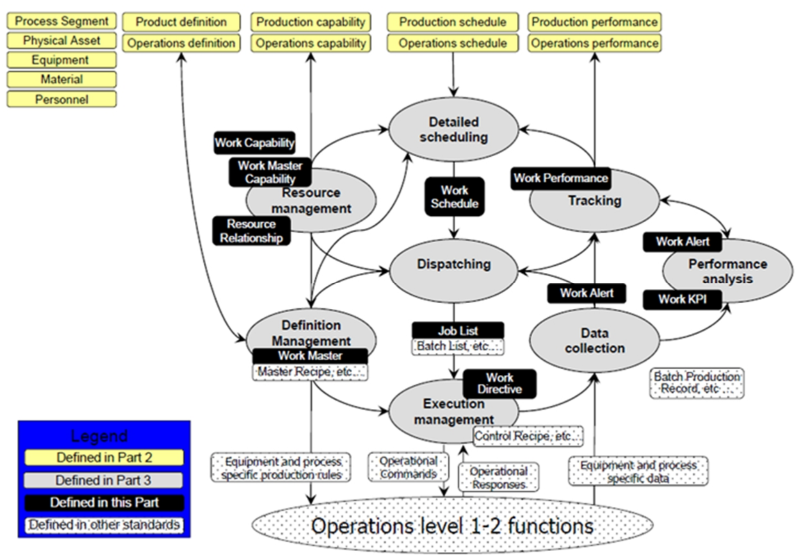

Figure 39: Activity model of ISA-95 Level 3 (ISA, 2013)

Q2. According to ISA-95 standard, the Operation/Production Schedule has production request and later is divided into detail plan i.e. Work Schedule, which has Job list and Job order. How to give a reference identifier of Work Schedule or Job Order to Production Schedule?

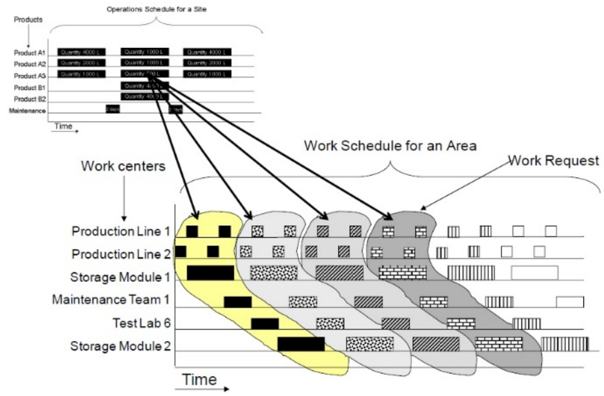

Figure 40: Work Schedule diagram of ISA-95 standard (ISA, 2013)

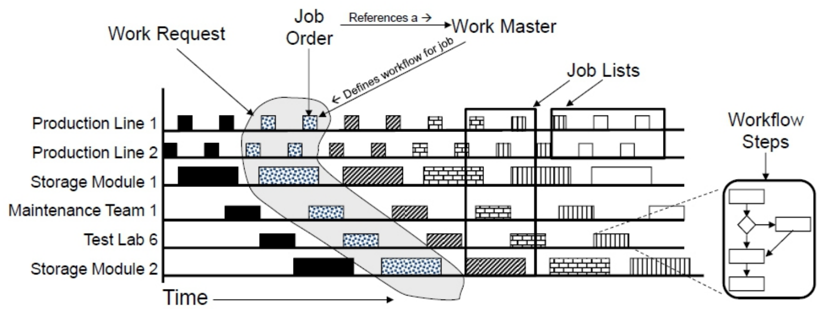

Figure 41: Work Request and Job Order diagram – ISA-95 (ISA, 2013)

Q3. While Defining Product Definition, there is a ProductProductionRule, BillofMaterial, BillofResource, what exactly these objects consist? And also there is no such detail XML schema information of these objects in ISA-95 B2MML.

Q4. We have come across the Operation Definition dependency, Product Definition dependency and Process Segment dependency but how to define dependency for Segment Requirement or Segment Response in Production Schedule?

Q5. In which segment we could define the shift schedule timing of entire day?

Q6. Is it required to define each segment separately i.e. material, equipment, and personal or can be included in a single segment i.e. in process or product segments.

Q7. We would like to have some feedback from you about our developed ISA-95 Generic Structure according to Discrete Event Simulation requirements. (Our developed Generic Structure is very small, consist of four processes and each process consist one equipment, material consumed, material produced details, along with defined DES parameters such as cycle times, MTTR, MTBF & Availability). We would explain our developed ISA-95 Generic Structure briefly during the meeting

A.2 Interview Question Set B

The questions below were asked in order to explore the connection between Teamcenter software and Plant Simulation software. Along with this, some other few question on how to structure the data.

Q1. Could you please show us a quick demonstration of how to create Product Family and Parts connected to same Product Family and then Resource Plan & Process Plan? Further, how to link same Resource Plan and Process Plan to Product Family?

a. How to create a Product Structure by variant in Manufacturing Process Planning and link Process Plan and Resources to same Product Family?

Q2. How to allocate the exported simulation data (Excel File that contains batch of information to manufacture a Product or Part) to Process Plan that is linked to Product Family and also Parts of same Product Family?

Q3. Could you please show us a demonstration on how to export the structured simulation data that has been previously allocated to Product Family, Part type of same Product Family, Process Plan to Plant Simulation Software?

Q4. If an Item has same variant ID but has different resources associated with that variant, then how can it be done in Item master form?

Q5. In engineering schema for manufacturing process planning, how to construct an Item model, data set model, Bill of material model, variant model and link them according to the process.

Q6. How to get back a deleted item? (General Question)