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THE SIMULATION LIFE-CYCLE: SUPPORTING THE DATA COLLECTION AND REPRESENTATION PHASE

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ABSTRACT

The life-cycle of a DES study goes through a number of phases, from initially goal setting to validation of experiments. Of these, the phases to support DES data collection and representation have been underrepresented in the literature to date. This paper sets out to describe a process of data collection and representation for DES within the context of the DES life-cycle. It is recognized that for large companies the data collection and representation phase differs when compared to SMEs. Due to the high complexity in performing a DES study in an SME data might not be in a DES ready format in existence whatsoever. This complexity can cost without budgets to meet it. This paper describes an expanded process in relation to the data collection and representation phase specifically for SMEs. Finally, a preliminary high level overview of a prototype is presented which supports this phase at an SME level.

1 INTRODUCTION

Discrete event simulation (DES) allows for the capturing of the complexity of real systems through the development of representative models. DES is a powerful problem solving method and decision support tool available to organizations ranging from small to large. It is widely used in a vast array of industrial sectors worldwide, and allows for experimentation with a simulated system that might not be cost-effective or feasible in reality. Within organizations, DES studies and associated models typically follow a life-cycle whether knowingly in a structured supportive fashion, or unknowingly in a self-guided effort. In the past efforts have been made to develop flowcharts and process models in order to capture and represent the steps and interactions in the DES life-cycle, examples of which can be found in literature presented by Balci (1994), Law and Kelton (1991) and Pidd (1989).

Figure 1 gives the typical steps in a DES process, adapted from Law and Kelton (1991). At a high level, the DES life-cycle goes through a number of phases. According to Law and Kelton (1991), the process starts with formulating and planning the DES study. After this has been completed, the data must be collected and the model defined. A validation step takes place whereby if the model and data are proven not to be valid, the modeller returns to the problem formulation and study planning step. Once it has been validated, the modeller constructs a computer program and again defines the model. Following a further validation step, experiments are defined, production runs are made and the output data analysed. The final step is to document, present and implement the results of the DES study.

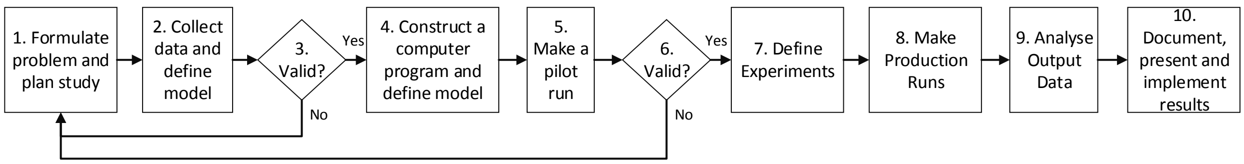

Figure 1: The DES process, adapted from Law & Kelton (1991).

This paper specifically focuses on the second "collect data" step. It has been noted in literature that this phase is a significant phase in most DES studies and can take up to 40% of the project time (Trybula 1994). The time it takes can be attributed to such issues as data being stored in a variety of formats, difficulties identifying what data is required to solve a specific problem scenario and data not always being available or stored. Given its significance in terms of project time, it is worthwhile understanding the steps of this phase in the form of a sub-process within the overall life-cycle of a DES study, as it is through a further understanding of the data collection sub-process that efficiencies can be gained and entities can be developed in order to support it.

The data collection step can be further defined as *data collection and representation*, as data not only has to be collected (requiring a number of sub-steps) but also requires an additional representational step in order for data to be presented in the correct form to be used by a DES model. Therefore the term *data collection and representation* is used to describe this step in this paper. Given the importance of this step in the context of the overall DES study life-cycle, in this work the data collection and representation sub-process is presented and discussed in Section 3. This is presented with reference to the overall life-cycle of a DES study.

One aspect of interest in the data collection and representation phase is the difference in difficulty in executing this phase between large organizations and small to medium enterprises (SMEs). In terms of SMEs, the European Union definition of an SME is used in this paper whereby micro companies have less than 10 employees and a turnover of equal to or less than €2m, small companies have less than 50 employees with a turnover equal to or less than €10m and medium sized companies have less than 250 employees with a turnover equal to or less than €50 million, (European Commission 2014). Within large organizations, data population of DES models (although complex and iterative) is generally completed through automatic connectivity links between organizational databases and/or manual upload/input to embedded model data tables. Data feeds to DES models originate from a wide variety of sources as dictated by the particular scenario under review. Examples of data sources range from manufacturing execution systems (MES), enterprise resource planning (ERP) systems, human resource (HR) employee databases, customer relationship management (CRM) tools, supplier relationship management (SRM) tools right through to localized spread sheets. Large companies generally have larger budgets available to support DES studies, and the required data is typically stored in a more structured way, and is typically more readily available. However, at an SME level, budgets are not always readily available, and in order to perform a DES study time can be taken up in the complexity involved with data identification in relation to the specific problem to be solved, data gathering from a variety of sources and (where data is not available) data generation. This complexity is a barrier to DES adoption by SMEs due to higher costs in relation to time. A summary of typical differences between large organizations and SMEs for data collection and representation is given in Table 1.

Due to the barriers that typically exist in the data collection and representation phase for SMEs to be able to utilize DES for their benefit, Section 4 presents the sub-process for the data collection and representation. This is in relation to steps required for a DES study in an SME if there were supporting tools to aid in overcoming these barriers. Referring to Figure 3, the actors and supporting tools required are defined in a cross-functional flowchart, as well as phases within the sub-process.

Table 1: Typical differences between large organizations and SMEs for data collection and representation of data for DES studies.

Large Organizations	Small and Medium Enterprises
Available budgets for DES studies	Restricted budgets available to support SME studies
Understanding and awareness of DES as a problem solving tool	Lack of awareness and understanding DES to support problem solving
In house expertise to recognize the need for DES and identify both problems that DES can potentially aid in solving and data required to solve them	Expertise not readily available to identify problems in which DES can be used to support in solving and to identify data required to solve them
In house resources available to commit to support external DES studies	Lack of in-house resources to commit to support external DES studies
Data in structured format stored in files, business information systems or in centralized repositories, available to use in a format suitable to support a DES study	Data not always readily available and where available can be stored in formats not suitable for DES studies (paper based, tacit, etc.)

Previous work has been presented in relation to defining the requirements and design for a tool in this space that would aid SMEs to overcome the barriers at the data collection and representation stage (see Byrne et al. 2013) and a Cloud-based prototype implementation based on this work supporting this phase is described at a high level in Section 5. Finally, Section 6 gives a discussion, conclusions and future work in this area of research.

2 RELATED RESEARCH

The DES life-cycle in the past has been represented in a number of related ways with a similar set of steps to those presented in Figure 1, which has been adapted from Law and Kelton (1991). Sargent et al. (2006) distinguish between the "DES project life-cycle" (which has a definite beginning and ending and typically produces a product that has its own life-cycle), the "DES product life-cycle" which is the life-cycle of a DES product. Mayer and Spieckermann (2010) introduce a third concept which is centered around the DES to support each phase of the life-cycle of a production and logistics system. The work presented in our paper focuses on the data collection and representation phase of the "DES project life-cycle" (which we shorten to "DES life-cycle"), represented as procedure models which are required to define the activities for each step in the life-cycle.

There are a number of modeling and DES life-cycles or related procedure models reported in the literature to date. Nance and Arthur (2006) present an overview of these and report on the Balci-Nance modeling and simulation (M&S) life-cycle model (Balci and Nance, 1987), the Kreutzer model for life-cycle of a DES project (Kreutzer, 1986), and the Sargent model (Sargent, 2001) which is not developed as a DES life-cycle model but can be used as such. Another model presented relating to the DES life-cycle includes one introduced by Rabe, Spieckermann, and Wenzel (2008), who give a procedure model of DES including verification and validation. Bengtsson et al. (2009) define a similar methodology to one defined by Banks (1999) whereby they increased the number of starting and ending phases in the process flow. In summary, these life-cycle procedure models follow a similar set of steps and have a similar granularity to the one presented by Law and Kelton (1991) in Figure 1.

In terms of the data collection and representation phase within the DES life-cycle, most procedure models represent this in some form at a high level. The model presented by Rabe, Spieckermann, and Wenzel (2008) focuses on a number of standard tasks with data collection and preparation running in parallel to the rest of the tasks. This is interesting from the point of view of the data collection and representation phase, in that they represent two steps – data collection in which raw data is verified and validated, and data preparation which follows from data collection in which prepared data is verified and validated. They separate the paths for model and data, the two data steps running in parallel with the modeling steps from task definition right through to experimentation and analysis. They do this intentionally as they state that the data phases can be handled in parallel with respect to content, time and involved persons.

Sargent (2001) places "data validity" at the center of their simplified version of the modeling process. When comparing real world relationships with verification and validation, they show system data and results for experimenting with the real world and DES model data/results as an output of the experimentation process with the DES model. Operational (results) validation takes place between the DES model data/results and system data/results.

The Kreutzer life-cycle model of a DES project defines "data collection and parameter estimation" as one step in an iterative waterfall-like process, with iterations from this phase with model design before it and program design after (Kreutzer 1986, Nance and Arthur 2006). The Balci-Nance life-cycle model of a DES project places data verification and validation at the centre of the model feeding the steps of system and objectives definition, conceptual model, communicative model(s), programmed model and experimental model (Balci and Nance 1987, Balci 1994).

In their work, Skoogh and Johansson (2008) focus on what they describe as *input data management* (IDM). They propose a methodology for increased precision and rapidity in input data management. Their stages include identifying and defining relevant parameters, specifying accuracy requirements, identifying available data and choosing methods for gathering of not available data in sequence. If all specified data will be found, the next step is to create a data sheet, however if it is predicted that it will not be found then the relevant parameters will need to be identified and defined again. The compiling of available and not available data occur in parallel and both feed into the preparation of a statistical or empirical representation of the data. Once a sufficient representation of the data exists, the next step is to validate the data representations and finish final documentation. If a sufficient data representation does not exist, then the compiling of available data and the gathering of not available data begins again. This is also the case if the data representations are not validated. In a related work, Bengtsson et al. (2009) define a methodology whereby the data collection stage occurs after the data knowledge collection phase, runs in parallel to the conceptual model development phase, and feeds into base DES model development. They describe a methodology for IDM in which data is identified, located and collected. Different data sources are connected through a tool called "Generic Data Management (GDM)-Tool" which then writes the data to the National Institute for Standards and Technology (NIST) Core Manufacturing Simulation Data (CMSD) format. This allows for the possibility for reuse of the same data within a company for different DES projects as connections may already be in place to the correct databases.

In this section, a review of related work in the areas of models representing the life-cycle of DES have been presented, and their inclusion of the data collection and representation phase discussed. It can be concluded that while all life-cycle models include data in some form, outside of the work presented by Skoogh and Johansson (2008) there has been little effort identified in literature to expand beyond the DES life-cycle procedure models to expand on the data collection and representation phase in detail. Complementary to work done by Skoogh and Johansson (2008), the next section takes a representative life-cycle model (from Bengtsson et al. 2009) and provides a detailed description of the data collection and representation phase as part of the overall life-cycle.

3 THE DES DATA COLLECTION AND REPRESENTATION PHASE

As noted in Section 2, the DES study life-cycle goes through a number of phases from formulating the problem right through to documenting, presenting and implementing the results. Referring to Figure 2, the left hand side gives an overview framework for a DES project (adapted from the overview framework for a DES project presented by Bengtsson et al. 2009), which is representative of the phases of the DES life-cycle in general. The right hand side of this diagram gives the steps involved in the DES data capture and representation sub-process developed in this paper.

Referring to Figure 2, the DES data collection and representation sub-process begins after formulating the problem, describing the goal, making a project plan and forming the project group. The goal for this sub-process is to complete a representation or *model* of the data that will be used in developing the base DES model. The first step in this sub-process is to define the data modelling components. These components are used to build a representation of the data. An example of a data model component from the manufacturing domain would be a *machine*, whereby the modeller might want to collect data relating to the set-up time for a specific *machine*. Whether this *machine* data modelling component is captured in a tool, on paper or in the mind of the data model developer, the process is still the same – at this stage, one or more data modelling components will be defined. The modeller goes through a validation step with the modelling components to validate that the correct components are being used to collect the relevant DES data.

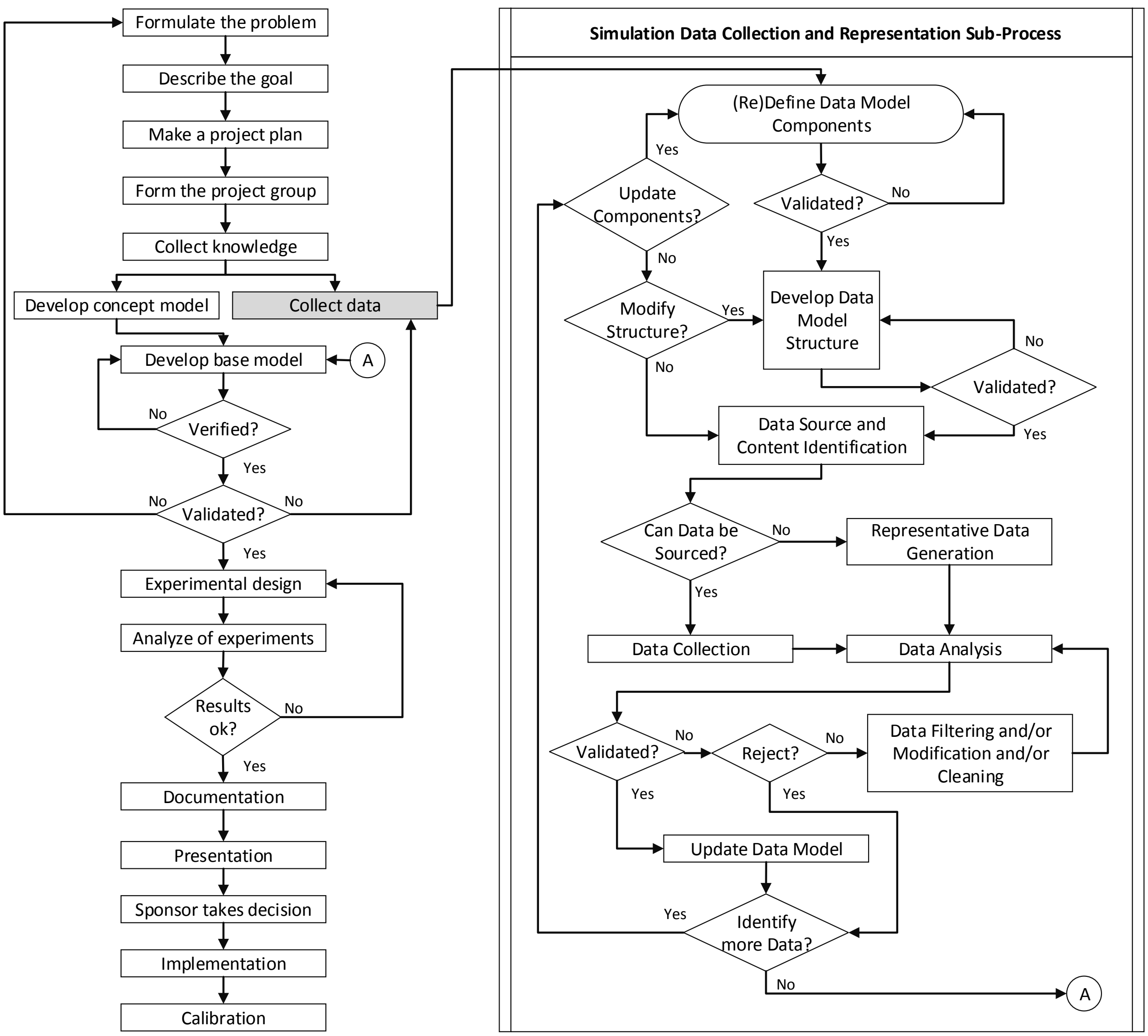

Figure 2: DES data collection sub-process mapped to the Bengtsson et al. (2009) overview framework for a DES project.

Next, the structure of the data model is developed using the components defined in the previous process. This structure defines the data model and the modeller can typically carry this out in parallel with the conceptual model development in the main framework phases. After developing the structure, the next step is to identify both the location of source of the data and to identify what data (content) is to be collected. If the data cannot be sourced, the data will need to be represented in some fashion as it has already been defined as being required by the model, so in this case there exists a gap in the data, or a *data gap*. There are a number of ways that this *data gap* can be filled through generating representative data. One method is to treat the data as a "black box" and make assumptions about this data, parameterising the black box. In this case the data is not available but represented in a simpler form. Another way is to estimate this data using the data modeller's experience. A third way is to use a tool to generate this data that is representative of the actual data that could not be collected. Once the representative data has been generated, the generated data is analysed.

If the data can be sourced, the data is then collected at source. There are a number of ways that the data can be collected. Robertson and Perera (2002) give a good overview of this, whereby (relating to a diagram describing possible data collections for model building) they present four options. The first option is where the data is derived directly from the DES project team (and includes a manual write to the DES model), the second is where the data is automatically read by a computer application into the DES model (from a file such as a spreadsheet), the third is where the data is automatically sourced from a corporate business system into an intermediary DES database to be again read by the DES tool, and the fourth is to directly read the data from the corporate business system into the DES tool. All of these 4 options (apart from option 3) assume that the data model resides within the DES tool/model. Skoogh, Perera, and Johansson (2012) define a similar set of steps. Byrne et al. (2013) also mention web based systems, cloud-based systems, paper based data sources and tacit knowledge as additional sources of data.

The data analysis step follows both the data collection and representative data generation steps. In this step, the data is analysed in order to understand if the correct data is being collected. Some methods that this can be done are through manually looking at the data on paper, analysing the direct data through a screen on a software tool, or analysing and possibly interacting with a visualisation of the data. Following this, the data goes through a validation step, and if the data is incorrect, there is the option to either reject the data or to filter, modify or clean the data for further analysis. If the data is validated at the analysis step the data model can be updated with the data. At this stage, the option is there to identify more data and/or update the data model components and/or modify the structure of the data model. If no more data is to be identified, the modeller exits the sub-process and moves to the base model development process. The DES data collection and representation sub-process can again be re-entered if the base model is not validated, in which case it starts by redefining the data modelling components.

The general DES data collection and representation sub-process presented here is suitable for companies of all sizes, however as noted in both Table 1 and by Byrne et al. (2013) there are a number of barriers in place in enabling SMEs specifically relating to this phase to carry out DES studies. The following section presents work done towards developing a procedure model which describes this sub-process for SMEs in an ideal scenario where support tools are available, and aids in driving requirements for such tools to be developed.

4 SME SUPPORT FOR THE DES DATA COLLECTION AND REPRESENTATION PHASE

Within large organizations, data population of DES models (although complex and iterative) is generally completed through automatic connectivity links between organizational databases and/or manual upload/input to embedded model data tables. As stated previously, large companies generally have larger budgets available to support DES studies, and the required data is typically stored in a more structured way, and is typically more readily available. However, at an SME level, budgets are not always readily available, and in order to perform a DES study time can be taken up in the complexity involved with data identification in relation to the specific problem to be solved, data gathering from a variety of sources and (where data is not available) data generation. This complexity is a barrier to DES adoption by SMEs due to higher costs in relation to time. Referring to Table 1, due to the barriers that typically exist in the data collection and representation phase for SMEs to be able to utilize DES for their benefit, this section presents the sub-process for the data collection and representation in relation to steps required for a DES study in an SME. The case is presented as if there were supporting tools to aid in overcoming these barriers which also aids in driving requirements for such tools to be developed.

The DES data collection phase for SMEs within the wider DES life-cycle is presented in Figure 3. The actors and supporting tools required are defined in a cross-functional flowchart, as well as phases within the sub-process. The actors and supporting tools can be described as follows:

- Client stakeholder: The stakeholder in the DES project, the actor that the will use the results of the DES study to their benefit
- DES model developer: The developer of the DES model
- DES data support tool: A proposed tool to support the DES data collection and representation sub-process
- DES modeling community tool: A proposed community tool to support the DES modeling process
- DES tool/library/engine: The DES tool, library or engine that the DES model developer uses to develop a DES model

There are three sub-phases defined within the SME DES data collection and representation sub-process, and these can be described as follows:

- Problem identification sub-phase: Used to describe activities relating to supporting problem identification within SMEs specifically referring to its proposed use within the DES data collection and representation sub-process across actors and supporting tools
- Data template identification sub-phase: Used to describe activities relating to supporting template identification for data modeling within SMEs through the use of proposed supporting tools
- Data model development sub-phase: Used to represent the development of the data model in terms of the activities, decisions, actors and proposed supporting tools involved for an SME

Referring to Figure 3, the process starts with the DES modeller, who starts the DES study. Typically a DES study will start with problem identification and goal setting. However, in the case of an SME, problem identification is in itself an issue as within SMEs expertise is typically not available to identify problems in which DES can be used as a problem solving support tool. Therefore a proposed feature of the DES data support tool is to provide guidance towards identifying the problem and related set of objective(s) (the support for which could take the form of a wizard like GUI) where the tool has a repository of problem types and related objectives, both vendor-created and community created. Following this, once the problem is defined and selected, it must be verified with the client stakeholder. If it is not possible to define the problem through the guided process, then the users have option of defining the problem and setting the goal themselves. Once this is defined, it can be added back to the community for use by others if desired. Upon the problem being identified, the second sub-phase is the data template identification in response to the defined problem. This template contains the data modelling components required to solve the problem, akin to the *machine* component example described in Section 3. It is proposed that the user is guided through the data template identification process by the DES data support tool, which has a repository of both vendor-created and community-created templates. If a data template to meet the requirements of the problem does not exist, the users can create their own and upload this to the community if desired. Once a data template has been identified, this must go through a verification process with the client stakeholder. Once verified, the problem and objective(s) and the data template with data modelling components are now in place and the DES model developer can continue to the data model development sub-phase.

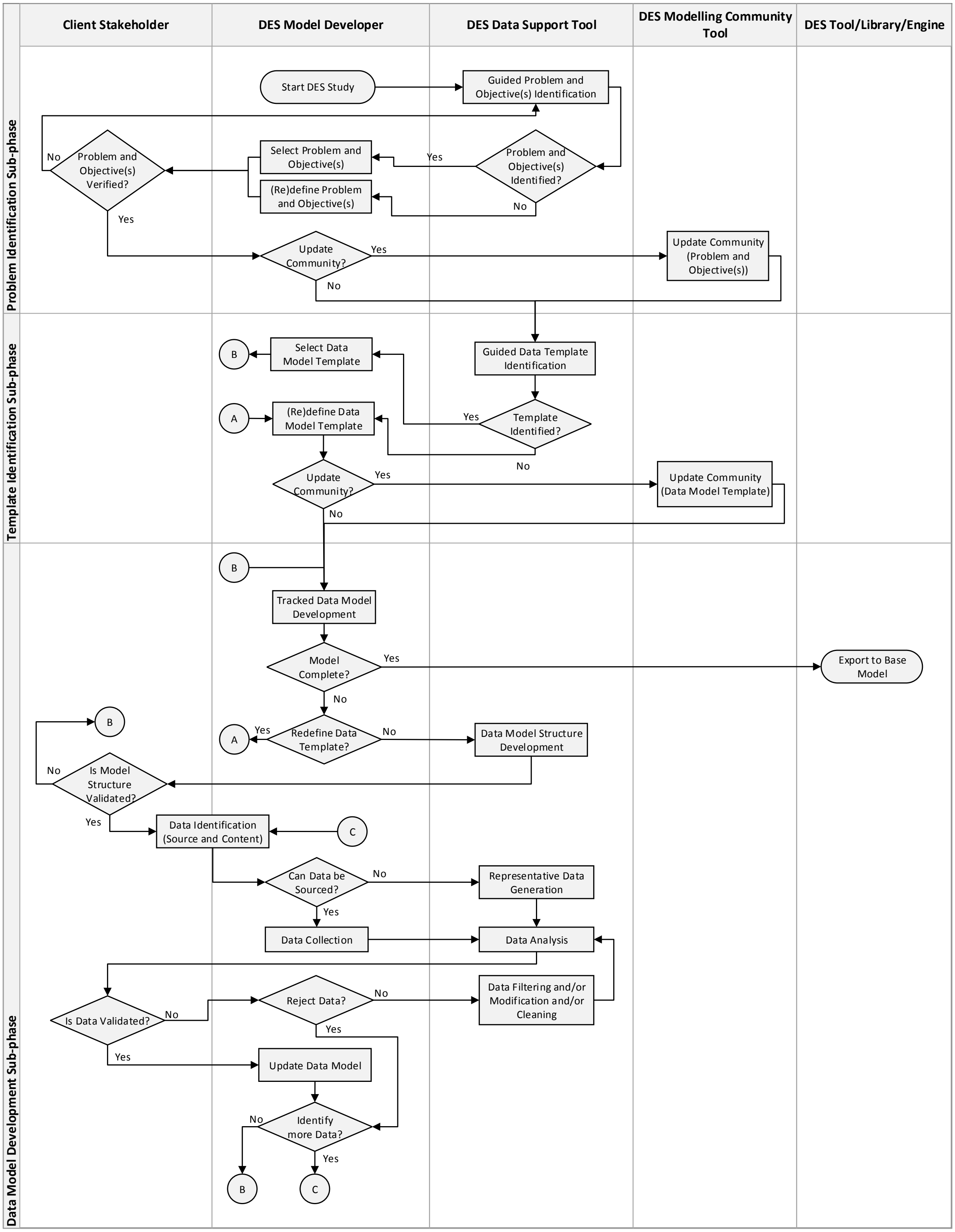

Figure 3: SME DES data collection and representation phase with software tooling support.

The next step is tracked data model development. It is proposed that the data model development is tracked, which means that over time the progress of the data model can be understood in terms of its completion status, driven by user-defined automated data gap analysis through the data template.

After this step, the modeller follows a similar set of steps as presented in Section 3. However, it is proposed that these steps are also supported by the DES data support tool at an SME level. The next step in the data model development is to define the structure of the data model. It is proposed that this is supported through a drag and drop interface in order for an SME to easily create and understand the sources of data required to be captured by the DES model. These individual elements in the structure can be used to drive the collection of relevant data for the DES model. Once this structure is in place, it must be validated.

Once the structure for the data model is in place, the sources of data must be identified. As discussed in Section 3, the sources of data can be in many forms, however in an SME it is typical that the data is either in a non-DES ready format, or not available at all. In this case, it is proposed that the DES data support tool provides the modeller with the features needed in order to generate representative data, whether this is directly inputting data to the tool, uploading representative data to the tool, aiding and guiding in generating estimated representative data or interactive components and visualisations in order to generate the required data. In this case, the provided template can be an aid as the modelling components defined by the template can guide the user as to what data is typically required to be generated. For example, if a specific *machine* data component is provided by the template, and the template and model structure guides that processing times for the *machine* are required in order to solve the specific problem and meet the objective(s) of the DES study, then the data to be generated is restricted to processing times and the modeller can be guided towards generating representative data for these processing times, for example depending on part types or part numbers.

After the data is either sourced or generated, it goes through a data analysis step. In this case, it is proposed that interactive components and visualisations can be provided by the tool in order to increase the ease of analysing data in order to understand and select the appropriate data that is required by the DES study. If the data in its current format cannot be validated, it can be rejected or go through a filtering, modification and/or cleaning step. It is proposed that a similar set of tools be provided in order to support this process. Once the data is validated, the data model can be updated with this data and the progress can be updated in terms of tracking how complete the data is. The modeller then has the option to identify more data, or to export the data to the base DES model.

The next section presents a short overview of a prototype representing the DES data support tool presented in the process in Figure 3, towards meeting the features proposed in this section.

5 CLOUD-BASED SME DES DATA SUPPORT PROTOTYPE

Figure 4 presents a screenshot of a prototype "DES data support tool" as given in Section 4. This prototype is developed as a Cloud-based application, the final tool being developed towards meeting both the features required to support the steps outlined in Section 4 and requirements presented in (Byrne et al. 2013).

Referring to Figure 4, the screenshot represents a "template" to represent a specific problem type with an associated set of objectives, within a Web browser. Annotation "A" gives a tabbed section which gives the user access to specific data modeling components relating to this template. In this case, a resource pool of machines is selected and shown, with one resource pool being available. Annotation "B" gives the structure of the data model, defined in this case by multiple data modeling components with representative arrows describing the relationships between them. The data modeling components in Annotation "A" can be dropped into the section in Annotation "B" in order to form the structure of the data model. Data is then added to the model by first double clicking on any of the data components, which opens a tab (see Annotation "C") relating specifically to the data modeling component that was clicked. These tabs give unique screens per data modeling component for attaching, inputting, importing, manipulating, filtering, cleaning, analyzing and connecting to data. The data can also be tagged in order to make it relevant to other data modeling components. In addition, there is a “model” tab which is used to interact with data at an overall model level. Progress can be tracked towards a final data model.

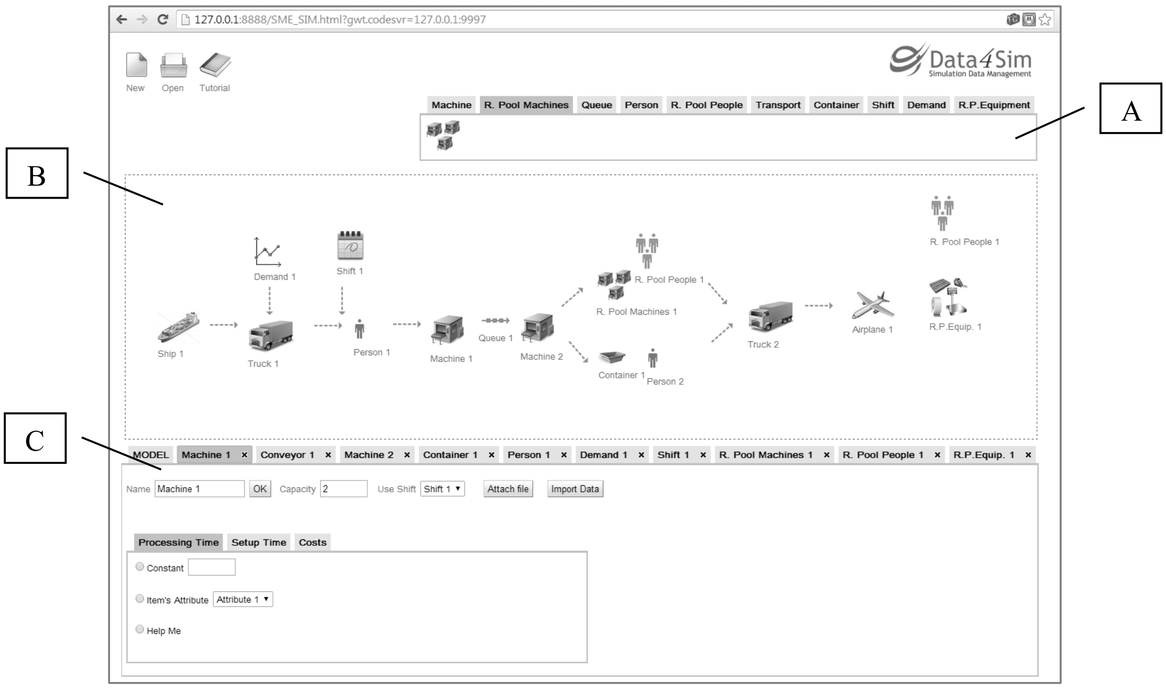

Figure 4: Screenshot of prototype data collection and representation tool for SMEs.

The completeness of the data can be tracked due to the provision of a constricted set of data modeling components that the data template provides, and in addition this allows the modeler to understand where there are gaps in the data that need to be filled. Features for data gap generation are currently under development. Being Cloud-based, users can use this tool from anywhere with an internet connection, and it is envisaged that the benefit in terms of the increased time efficiency that the SME modeler will experience in using this tool for the data collection and representation phase in SMEs will be far greater than the cost of using this tool, as cloud deployment allows the service provider/vendor to provide access to the tool on a lower-cost pay per use basis.

6 CONCLUSIONS AND FUTURE WORK

Within the context of the life-cycle of a DES study, the focus of this work is on the data collection and representation step for DES. Related work has been presented in this area and it has been identified that this research area is under-represented from a research literature perspective. The process of data collection and representation has been presented as a sub-process of the overall life-cycle of a DES study. In addition, it is recognized that for large companies the data collection and representation phase differs when compared to companies at a small and medium enterprise (SME) scale. Therefore an expanded process has been described which includes three sub-phases as well as a number of proposed actors and support tools that would be available to support this sub-process in an ideal scenario. Finally, initial work towards a Cloud-based SME DES data support prototype has been presented which has been developed in response to the perceived lack of tools to support this area.

Future work includes further prototype feature development to support the process at an SME level including further developing data gap filling and generation mechanisms, further export capability to export data in a format usable by DES tools (such as CMSD) and further developing a Cloud-based community support feature to the tool.

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