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Integrated Modeling of Reservoir to Pipeline for Geothermal Field Application

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ABSTRACT

Efficient management of geothermal resources typically requires the use of different softwares to simulate heat and fluid flow through the reservoir, wells and surface facilities. More often, the software parts run independently from each other and require additional processing to make the outputs useful and relate to each other. Furthermore, in certain cases it becomes difficult to ensure consistency and satisfy the requirements of the individual simulators. As an initiative to enhance resource management, seamless integration of these softwares was conceptualized. The primary objective of integration is to combine different steps and processes into a streamlined system. This will minimize the data preparation, processing period and even reconciliation of inconsistencies among the different components. A pilot project was developed using one of the fields of EDC as a test case to demonstrate the capabilities of the integration. Initial results were promising, paving the way for a more widespread application to other fields and even other simulators.

1. INTRODUCTION

With the advancement of computing capability, numerical models have played an important role in project development and resource management. These models help in predicting reservoir responses under different exploitation schemes, and determine output recovery of wells upon workover, project viability and effects, and pipeline sizing optimization. This simulation software may either be commercially available or customized depending on the requirements of the user. There are several softwares available for reservoir simulation like TOUGH2 (Pruess, 1991), TETRAD (Vinsome and Shook, 1993) and the recently developed WAIWERA (Croucher et.al., 2018) and Volsung packages (Franz et al., 2019, https://www.flowstatesolutions.co.nz/downloads). For the case of wellbore modeling, there are a number of available software such as GWELL (Aunzo,1990), WELLSIM (https://www.gsds.co.nz/wellsim/), FloWell (Gudmundsdottir and Jonsson, 2015) and Volsung/Gudrun to name a few. This is likewise the same situation for the surface simulator which is applicable not only for geothermal environment but also in the oil and gas industries.

Currently in EDC, several softwares have been utilized for different types of simulation. For thermal hydrological flow simulation, reservoir models have been developed either in TOUGH2 (Pruess, 1991) or in TETRAD (Vinsome and Shook, 1993), while for the wellbore modeling, SIMGWEL (Marquez, 2015) was the only software utilized. For the case of the surface facility, customized FCRS models have been developed in different platforms but for the field under study, an MS Excel based utility has been utilized. Models are usually run independently and are under the custodian of its developer or group related to the discipline. Even within the same department, interaction between the models or modelers is limited. In some cases, processing output from one simulator into useful data inputs for the next simulation takes a while to process. In addition, ensuring consistency or usefulness of provided inputs could become difficult, and satisfying requirements may not be achieved. In order to streamline the process and aide in simulation and resource management, an initiative to integrate these softwares was conceptualized.

The concept of seamless integration has long been implemented in the oil and gas industry and is referred to as Integrated Asset Modeling (https://www.software.slb.comservices/technology-consulting/integrated-asset-modeling). In one of the case studies, the platform used was ECLIPSE (https://www.slb.com/-/media/files/software-integrated-solutions/case-study/cs-frontsim-chevron.ashx) which is likewise being evaluated for its applicability into geothermal environment. There were recent works of Franz (2015) and Marsh (2015) aiming to develop or implement seamless simulation for a geothermal setting. These works have achieved progress in developing either a prototype of the interface or a new computational software.

The pilot project successfully achieved in developing an interface for all the simulators utilized for one of EDC's geothermal fields. The workflow and the features of this platform demonstrate the applicability and usefulness of a streamlined simulation process. Though there are still areas to improve and minor troubleshooting to be performed, the results are promising and paving the way for a more widespread application to other fields and using even other simulators.

2. SOFTWARE

Three numerical simulators were utilized and integrated in this project. Two of these simulators were commissioned and customized for specific purposes of the company while the other one is commercially available. The numerical simulator TETRAD (Vinsome and Shook, 1993) was used for thermal hydrological flow simulation of the reservoir while SIMGWEL (Marquez, 2015) was used for wellbore simulation, and an MS Excel-based surface facility simulator (Jacobs, 2018). The interface or dashboard that connects these softwares is known as TIM (TETRAD Integrated Modeling) and was developed using C++ and Qt. The description of the software given here is limited, but more complete documentation is available from various literatures.

TETRAD (Vinsome and Shook, 1993) is a multipurpose numerical reservoir simulator that can operate in any of four environments which includes geothermal. It was written in standard FORTRAN77 wherein the conservation equations used are discretized by standard finite-differencing technique. Each mode may be combined with a dual porosity-permeability formulation, and thermal modes may be combined with electromagnetic heating. The simulator has been validated against a number of different problem types, including most of the SPE comparative problems as well as geothermal code comparison study.

SIMGWEL is a wellbore simulator developed by Marsan Consulting Limited, New Zealand and Energy Development Corporation (EDC), to aide reservoir engineers to model well behavior and to predict output under different parameter variations. The simulator was built on GWELL with several core enhancements such as the treatment of effective viscosity, input handling functionalities, and deliverability curve predictions. Several improvements have been implemented to the software since it was released. Although there are still a few shortcomings, it has been successfully applied in wellbore simulation scenarios across all EDC sites over the years.

Although there were several surface simulators that are commercially available, an MS Excel-based simulator was developed by Jacobs (JACOBS, 2018) and EDC for one of its geothermal fields that allows the user to analyze field conditions and develop representative hydraulic calculations. It is composed of several worksheets. These worksheets provide instructions, figures or model view, input decks, and summary of calculated parameters. The model had covered the five sectors of the steamfield and has taken into account any unique feature during the modeling. It should be noted that only one of these sectors was used in this project. Although it provides flexibility to users, the simulator was built specifically for this field and cannot be readily revised to accommodate another pipe system.

The TIM platform or dashboard to bind the input decks and outputs of the three above mentioned software was created in C++. The details and descriptions of its capabilities and limitations will be discussed in succeeding sections.

3. GENERAL WORKFLOW

The project aims to achieve seamless coupling of currently used platforms for simulation or modeling which includes TETRAD, SIMGWEL, and an Excel-based flow simulator. Note that each model has to be prepared separately and outside the developed platform. The general workflow and interaction between the different models is simply illustrated in Figure 1.

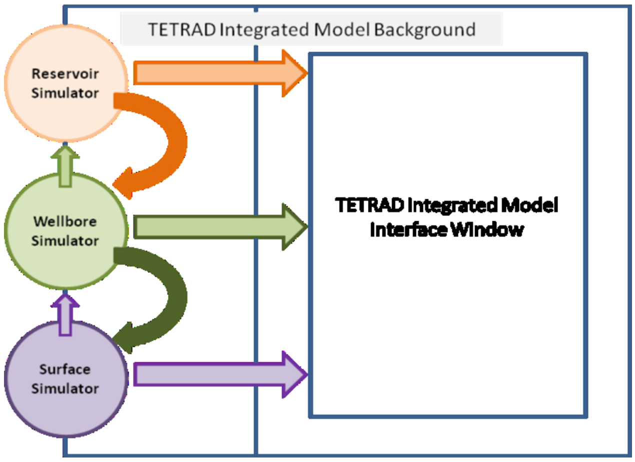

Figure 1. General workflow of TETRAD Integrated Model (TIM) and the other Simulators.

As depicted in Figure 1, the modeling process starts at a stage where the individual models - reservoir, wellbore and surface, exist in their stand-alone version. The reservoir model run in TETRAD provides the reservoir conditions at any point of interest in the lifetime of the field. As mentioned, the reservoir simulator is commercially available; hence, validation of the simulator's equation of state or output was not needed, or has not been performed. In addition, the reservoir model that will be utilized for this pilot has been earlier developed using TETRAD, hence, calibration or adjustments made were primarily on the purpose of troubleshooting the behavior of the simulation runs. The simulation is broken into time steps. At the beginning of the time step the reservoir conditions are established using output from TETRAD. Next, the TETRAD input file itself is analyzed. Wells which we want to explicitly model may already have been present in the TETRAD model and are automatically shut in, so the model will not double their flow rates by having them present twice. The outputs from the reservoir simulation will be processed through the backend by the integrating platform, into input parameters for the wellbore model.

Upon completing the preparation of the wellbore model input file and taking into account the results from the reservoir simulation, the models will then be simulated using SIMGWEL. For each producing well, the template wellbore model is read in. This template contains all parameters to run a SIMGWEL simulation but requires updating of the feedzone pressures and enthalpies. TIM automatically performs this update and runs the SIMGWEL wellbore simulation. Calibration of the models was not thoroughly performed similar to the reservoir model. Minor changes or revisions were made to these models to resolve inconsistencies obtained from the results or the run produced erroneous outputs. Flow parameters and output curves at various openings are collected and stored for the utilization in the next simulation time step. SIMGWEL creates output files containing the wellhead deliverability curve and feedzone specific data. Consequently, a family of output curves will be generated for each well. These curves will be used to establish the required flows from each well as required by the EXCEL spreadsheet model.

TIM fits a cubic function to the output curve for both the flow and enthalpy versus wellhead pressure data to minimize the complexity of handling numerous points from the results of the wellbore simulation into the spreadsheet. The coefficients for this cubic fit as well as the maximum discharge pressure are transferred into the EXCEL spreadsheet. It uses an iterative procedure to calculate pressure losses in pipelines and other pressure constraints, like minimum separator inlet pressures. Once the solution has been found for the flows through the surface network, TIM reads out the flow rates associated with each well. It then uses the well deliverability curves to determine the operating point and uses the associated feedzone data from the wellbore simulation to partition the flow into the individual feeds.

Each time step or specified print out interval from the reservoir simulation generates unique conditions for wellbore and surface flow. These conditions have been captured and represented for each well through the output curves earlier mentioned. On the other hand, the excel-based surface simulator performs the flow simulation and generates corresponding surface parameters. Individual excel files are generated for each condition and are properly saved in a specified folder. Although the excel files can be viewed separately, the dashboard has a capability to allow user replicate in partial or full the surface model, depending on the requirement of the user for easy monitoring of flow parameters. This feature will be discussed further in the succeeding section.

4. FEAURES AND CAPABILITIES

The major hurdle when coupling TETRAD, SIMGWEL and EXCEL is that none of these applications was initially designed with interoperability in mind. The majority of the tasks includes locating, collating, interpreting and modifying data from the individual applications, and brings them into a format suitable as an input for another application. TIM was designed to make these processes as much user friendly as possible. Additionally it performs unit conversions; the user can specify which units are displayed and which are to be used in the EXCEL spreadsheet.

The reservoir model is imported by providing the TETRAD model input file and TETRAD INTERSIM CORE files describing the initial state and the reservoir geometry. Since refined areas can be used in TETRAD we require a small definition of how the refined areas belong to each other and how the model coordinates transform into real-world cartesian coordinates. Wells are created within TIM as part of a well database. Both producers and injectors are supported. Data relating to the well geometry is imported and is used for determining how the well dissects the reservoir grid. Further well parameters are a file name for the SIMGWEL template file and cell references to determine where in the EXCEL spreadsheets the well will place the cubic fit coefficients and from where it will read its required flow rates.

TIM is very agnostic when it comes to the EXCEL spreadsheet surface simulator, i.e. all the calculations therein are outside the concern of the main application. All that is required is that TIM can write data in some locations in the spreadsheet and read its flow rates from specified cells. This approach makes it easy to use TIM with different EXCEL models for other geothermal fields.

4.1 Simulation Log and Run Control

Once the coupled simulation is started, the run control automatically steps through the reservoir/wellbore and surface simulation steps. A simulation log and run control window is displayed in the “Log” tab which is presented into two separate panels. One is for TETRAD simulation and the other is for the Integrated Simulation (Figure 2). This is used to visually track the progress of the simulation. The simulation log primarily displays text output from TETRAD in real time. The user can hence determine if the reservoir simulation is progressing normally. The run control log is used to display status messages for the coupled run, for example how much flow is allocated to a well or which part of the simulation is currently active. If the simulation gets stuck the user can opt to terminate the run in a controlled fashion. At the end of the simulation error and warning messages are displayed in a collated fashion together with performance parameters. One of the important information written in the log is a summary of the elapsed time allotted in completing each stage of the simulation of which a sample is shown in Figure 3. This is important in tracking the performance of the simulator and the difficulty encountered in each respective model.

4.2 Graphical Representation of the Reservoir

One of the intermediate steps in this integration is establishing a Visualization Tool Kit (VTK) unstructured grid and filling it with fracture and matrix properties from the TETRAD output; this VTK grid can also be directly used for visualization purposes. TIM contains a viewer tab where this data can be displayed for each of the printout times of the simulation referred to as the “Reservoir” tab shown in Figure 4. In addition, the welltracks as stored in the database are plotted in the view as 2D line tubes and are a useful tool for orientation in the model. The thermodynamic and auxiliary parameters of each cell can be probed via a tool tip popup. These properties are plotted across the grid and at each print time output. The time of interest can be selected on a dropdown list menu. Delta-values are calculated between the current time and a base time; this is useful for determining areas of change in a particular variable. Similar to commercial post processor, another feature of TIM is a slicing plane which can be used to probe the depths of the grid. The view can be exported to PNG or VTK files.

4.3 Well Output Information

The “Well” tab features several graphical representations based on the combined results from reservoir and wellbore simulations. There are six panels - four graphs narrate historical flows, enthalpy and steam rate while the other two illustrates the bore output curves for mass and enthalpy. Figure 5 shows that aside from manipulating the axis range, comparison from field data and individual feed contributions can be also be monitored. Moreover, individual wells as well as combined sector output or average value is likewise presented in these windows. The other two panels for the output curves shows the output curves used for selected time print outs. It also shows the difference in the match/fit between DC and curve generated from SIMGWEL. The family of curves generated throughout the simulation is likewise shown in thin gray lines and only highlights the one utilized for the selected time print out.

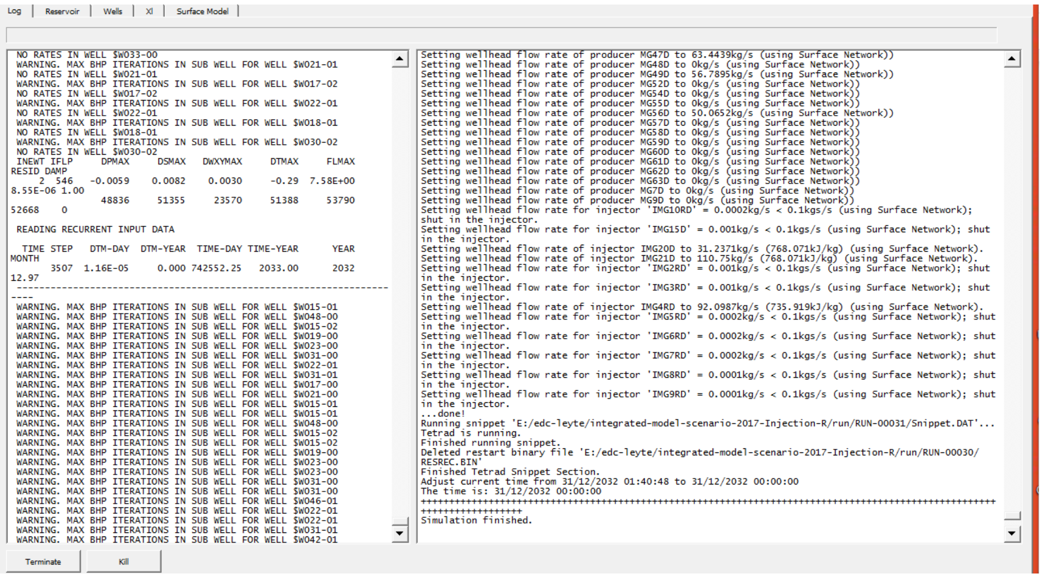

Figure 2. Simulation logs - TETRAD simulation progress (left) and Integrated Modeling progress (right).

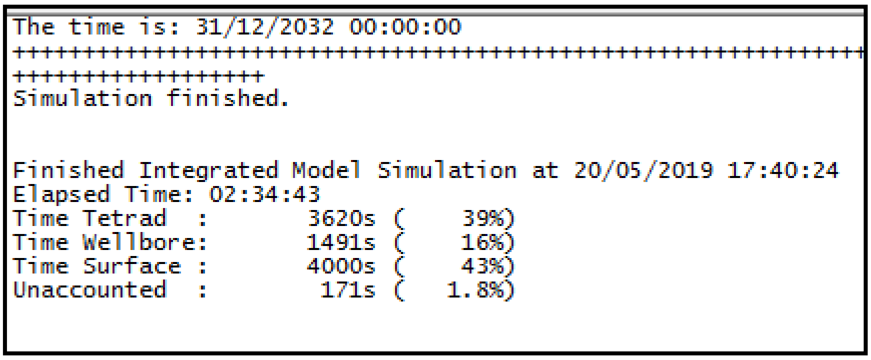

Figure 3. Summary of the Time Allocation during the Simulation process.

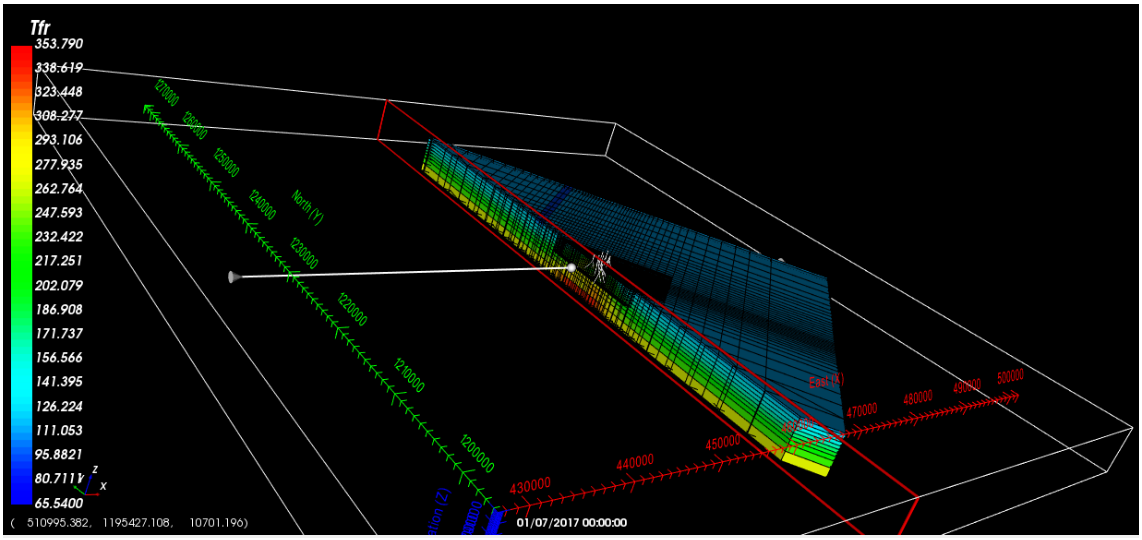

Figure 4. Sample reservoir simulation output visualization.

4.4 Brief Surface Model Representation

Each EXCEL spreadsheet containing the simulation for a single time step is stored in a different run folder. At a point, this might be cumbersome for the user to monitor one or more parameters when flipping through time, since each time the corresponding spreadsheet would need to be opened. To ease the visualization of these parameters, the “Xl” Tab feature comes handy. The platform tags objects that may correspond to any parameter on the spreadsheet such as individual or total flow, pressure or any parameter of interest found in the surface model similar to the one illustrated in Figure 6. TIM can collate the time series for an XlTag by automatically opening all spreadsheets containing data for a single time step and storing the content of the cell in a cache. XlTag data can then be either displayed as a time series in a separate plot, or as part of a node view of the surface model.

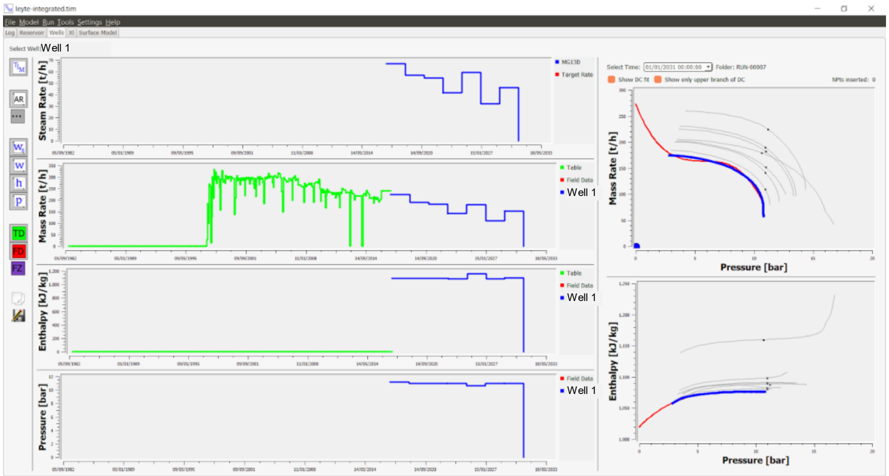

Figure 5. Historical Flow Parameters (Left) and Temporal Bore Output Curves (Right)

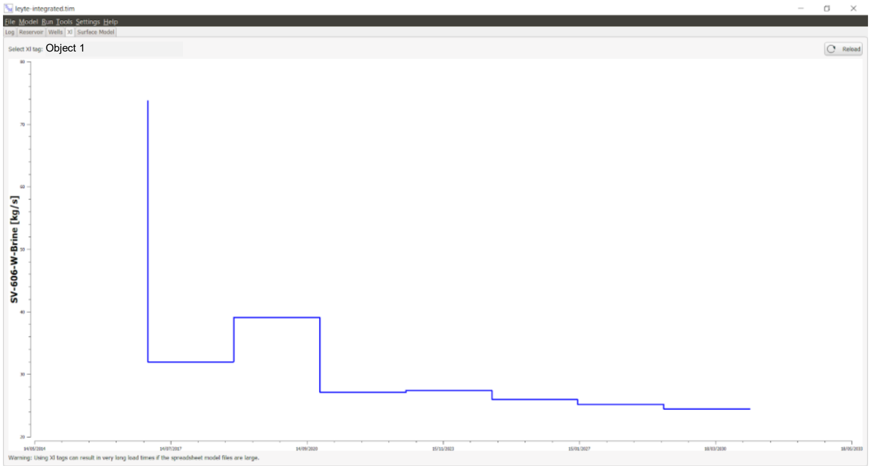

Figure 6. Historical Parameter Values of Tagged Objects in the Surface Model.

On the other hand, the "Surface Model" tab represents the node views which are created by placing node objects on a drawing canvas. This drawing panel may capture a partial or full representation of the surface model found in the excel sheet. Different node types represent producers, injectors, separators, unions etc. The nodes can be connected to each other to provide a visual model of the surface network. However connections between nodes are just visual, i.e. there are no calculations performed based on the topology of the nodes. Unlike the "Xl" tab wherein the value of a single object can full timeline could be plotted at once, the "Surface model" tab can only plot a set of values for created set-up at a particular time only.

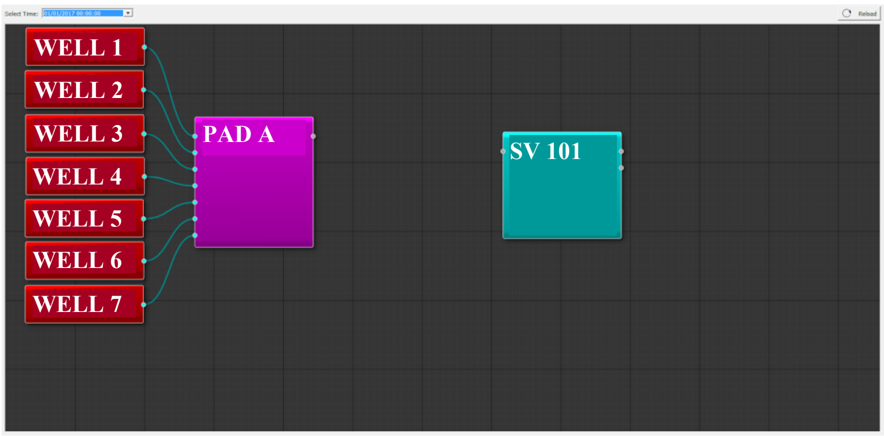

Figure 7. Portion of Surface Model for Node Property Monitoring

Nodes can then display values from XlTags for each time. By flipping through the time selector one can quickly determine how parameters in the surface network change over time.

5. CONCLUSIONS

The pilot project which have the primary objective to combine different steps and processes into a streamlined system have been applied to one of the production sectors in an EDC field. The software utilized at the different stage include TETRAD for reservoir simulation, SIMGWEL for wellbore modeling and EXCEL-based spreadsheet for the surface facility flow simulation. These software were integrated in an interface or platform developed in C++ which is currently referred to as TETRAD Integrated Model (TIM). TIM general workflow have brought advantages to minimize the data preparation, processing period and even reconciliation of inconsistencies among the different components. The dashboard has different features and capabilities that enabled seamless processing of the simulation. In addition, user friendly interface and visualization is also incorporated in the dashboard. Although there are some minor troubleshootings to be performed, the results of this pilot are promising and paving the way for a more widespread application to other fields and even other simulators.

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