Real time energy consumption analysis for manufacturing systems using integrative virtual and discrete event simulation

Real Time Energy Consumption Analysis for Manufacturing Systems Using Integrative Virtual and Discrete Event Simulation

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Abstract- **Manufacturing companies need greater capabilities to respond quicker to market dynamics and varying demands. Paradigms such as mass customization, global manufacturing operations and competition provide a platform to meet these needs. Therefore a continuous restructuring and re-engineering of the processes is seen in the manufacturing industries. This is extremely important in cases when automated machines are used in production. Automotive industry is an example of having intensive use of automated processes. During the reengineering of the processes it must be focused to control the factors which add cost during the processes. Energy is one of the important parameter which acts continuously over the process and increases the product price. Therefore, this paper proposes to validate the processes for energy optimization during the design stages well before, to physically build a machine. This could be done by using virtual environment and discrete event simulation integration. The pilot study of an ongoing research has been carried out to identify the level of energy consumption in a case study along with the identification of information to be used in the virtual tool prior to build the models. The adopted approach would propose to identify the processes to keep them off if consuming energy even in idle states. It could be identify through simulation that which one is the energy intensive process when they are idle, and then try it for the option, to keep it off when not working. Utilizing less energy in production helps society to have low cost products as well as to maintain the sustainable resources over a long period of time.**

Keywords- Virtual Engineering (VE); Discrete Event Simulation (DES); Energy Consumptions; Real times Process; Integration

I. INTRODUCTION

Businesses success lies in producing lower cost products with a quality of standards. To remain competitive it is important to strictly monitor and optimise the parameters which add value to the products[1]. Today's automotive industry is one of the industrial sectors which have been transformed towards the automation. Typically the success of such a transformation depends upon, by adopting the emerging technologies to rectify the processes for non-value adding factors. One of the important parameters which acts continuously over the processes and which need to have a strict control on its use is the energy consumed, to run the machine and its internal processes. Typically in automotive industry electrical energy is used in different areas for example it is estimated that about 14% of the total energy is used in HVAC applications, 12% is used in lighting, 25% is used to compress air for pneumatic application, while 49% is used in motors which operate the different processes [2]. This shows the importance to have continuous effort to minimise the wastage of energy being used at the machine process level. Traditionally the efforts have been made in this regards to observe the energy consumption and productivity analysis once the machines are built. But this research proposes to optimise the energy level for different setups of the machine components in a reconfigurable way to optimise the energy in a relation with the productivity prior to build the machine. This new approach has been shown in Figure 1.

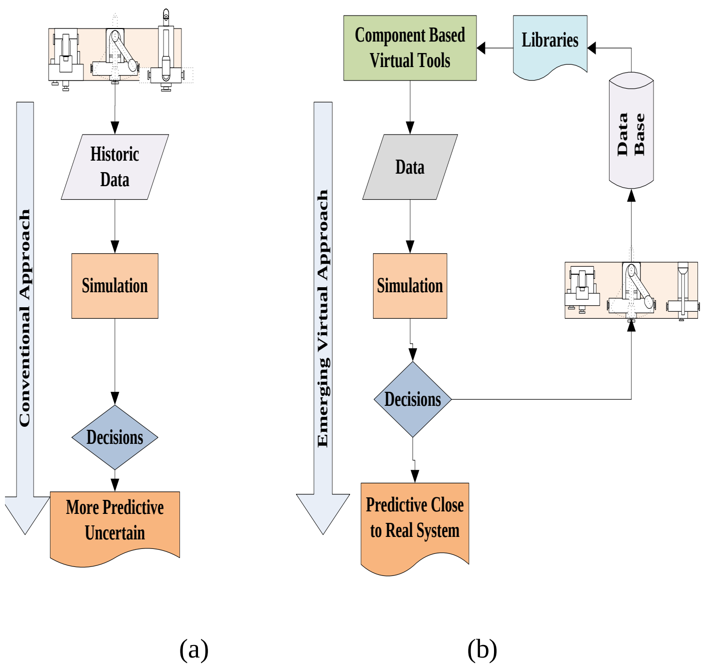


Figure 1 Conventional (a) vs. emerging virtual -DES system (b) [1]

Figure 1(a) shows the productivity analysis for different parameters using simulation techniques to observe the probabilities and statistical effects of variables. The results produced are most predictive, and become mature after the physical building of the machines and production lines. While Figure 1(b) represents the emerging approach of using the virtual machine setups for validation in real time, using the validated data in simulation model could predict the most accurate results. For energy optimisation this research uses the virtual environment data to run the discrete event models for an automotive case study. An important issue for an effective study is to identify the data and information used during the virtual model building. This is done by using the CADs library of the available machine components. The approach adopted for energy analysis must lead to identifying the machine processes and components along with the time for which the processes are running or remains idle. In majority of the automated processes, the motors remain running even when they are idle. Therefore a study has been initiated to find out the possibilities of keeping the motors off when a machine component (perform a process) is in idle state.

II. CURRENT STATE OF THE ART PRACTICES

Today's industries' success lies in having a consistent and cheap source of electrical energy to operate the machines on the shop floor[3]. Profitability is also based on consuming less energy in the processes, for example in assembly process in case of automotive industry[4]. For a competitive position, it is important to explore the opportunities to minimise the energy consumptions at processes level in the overall operation of a machine station [5].

Different research works have been carried out with respect to minimising the energy consumptions in the industries typically at the utilities level. US environmental protection agency research has been proposed, how the environmental impacts of the energies consumption and generation on the environment [4], while United Nation (UN) has carried out an audit on the energy consumption in the building typically for the developing countries[6]. Also G. Boyd developed a performance based indicator with the help of US environmental protection agency to examine the energy saving trends in automotive industry[7]. Energy star schemes have been carried out to generate rules and techniques to control the energy consumption at utilities level typically in automotive industry[5].

Inside-Out is the approach to control the energy consumptions in the automotive plants at utilities level, which emphasis on the identification of energy savings at the equipment level to minimising the losses during the distribution[8].

KAIZEN TEIAN is the approach based on the continuous improvement with the help of increasing awareness among the employees for energy saving importance [9].

So for the efforts are made to save the energy when the factory is installed and machines are operational. But there is limited knowledge to examine and optimise the energy consumption prior to build the machine most accurately. Virtual engineering environments could provide this support, to be used and observe the virtual machine which typically emulates the actual machine in real time. Various tools such as Delmia, V-Sim, UGX technomatix, Core Control Editor (CCE at Loughborough) are available to be used for virtual modelling [10]. As the virtual model is made of the machine components which perform different processes in different times having different types of data such as mean time between failures, cycle times, process times, mean time to repair and energy related data. After validating the virtual model, data could be used to observe the processes effects on the scheduling and productivity with the help of discrete events simulation techniques. Various discrete event simulation tools such as Simul8, Arena, witness etc. are available to be used [11].

Current state of the art has certain limitations regarding the integration of virtual and discrete event simulation as well as about the accurate energy consumption analysis with during the design stages of machine. Therefore a framework has been initiated in this research to integrate both environments and tested as a case study in an automotive industry for the energy consumption during the design phase of an assembly line machine station.

III. INTEGRATION MECHANISM DESIGN

Figure 2 represents the working mechanism of the approach used to emulate and validate the machine component processes virtually and then used the available data for discrete event simulation model to optimise the different production parameters. There must be different parameters to run a discrete simulation environment. This approach is not specific to certain tools but it is open architecture based integration mechanism to be adopted for any of the virtual and discrete environments for such type of analysis. Following steps are required to design and build the complete integration as shown in Figure 2. However, these steps are reported how to bring the approach in practical use and suggest the decision support to choose the options for the processes whether to keep them off if possible.

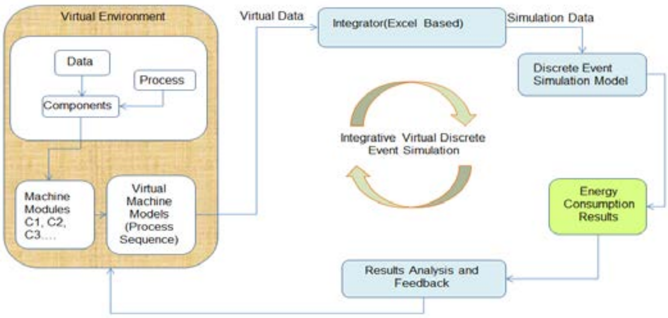


Figure 2 Integrative virtual discrete event simulations for energy analysis

A. *Process Model*

A process is an activity which has been taken place by using a resource in a specific time. The sequence of the processes to accomplish an operation is the most important. Figure 3 represents an example of the processes to be captured in a correct sequence before proceeding towards any further calculations. The process diagram helps not only to develop the cycle time which is the accumulation of the individual processes times, but also could produce the bill of components which perform these processes inside a machine station. For example the start of the processes takes place by pushing a button which consumes energy and acts for the time t1, then the process of lift is triggered in time t2, following with the other two processes executing parallel in time t5 and t7 to rotate the plate and clamp the load. In this example it is clear that a deep understanding about the processes model and its sequence are required to generate the right model for information and data in both virtual and discrete event environments.

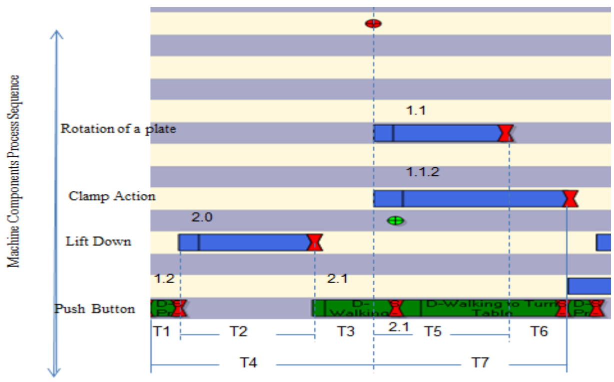


Figure 3 Process diagram for machine components

B. Data Model

A data model must support both virtual and discrete event models simultaneously. Basically the virtual model needs to have right process sequences and the time for which this process acts on. Data should be enriched with the other parameters continuously to enhance the utilisation of data for other applications. This depends on the requirement of the data model application. For virtual model data should be provided along the machine components CAD as a library, as shown in Figure 2. Once the virtual model is validated this data can be exported for the discrete event simulation analysis. Typically data required for discrete event simulation model comprises of mean time between failure, mean time to repair, set up times, human interaction with machine their distributions, inertias of the system, loads and the speeds variation along the process time.

C. Virtual Model

After preparing data model and the process model, the machine station components along with their data in the virtual model are combined for validation purpose as shown in Figure 2, referred to as virtual machine and processes sequence. A graphical representation of the machine component and data has been shown in Figure 4.

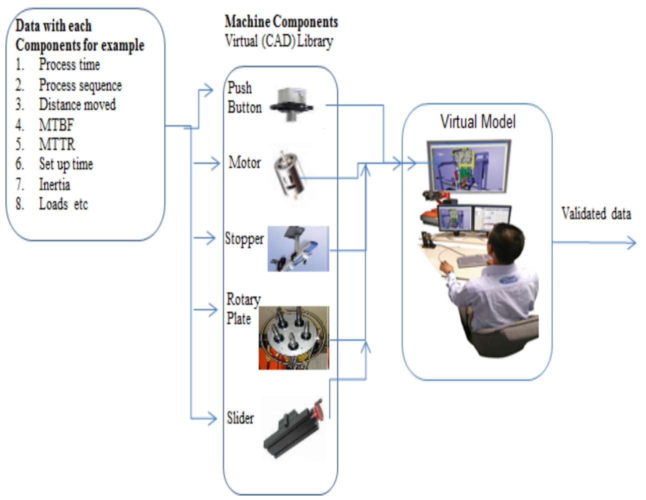


Figure 4 Virtual model developments and data validation

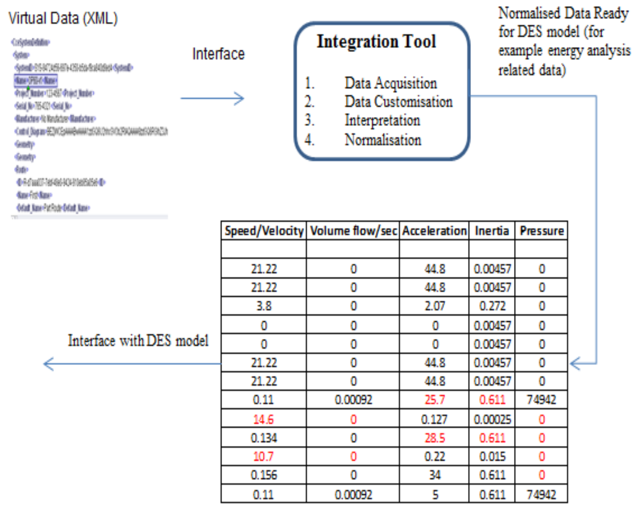
Figure 4 represents the different components as an example to develop the virtual model of the machine station. Every component is allocated with the data, and the use of data depends on the usage of that component for a particular application. If data are available, then the value is assigned. Otherwise it is zero. For example in Figure 4 a push button , motor, stopper, slider and rotary plate are the virtual CADs which are used in the model development to generate a virtually validated data.

D. Discrete Event Model

Discrete event model depends on the process model which is used to generate the correct sequence of the model to run. Typically the DES model is developed in a way to recognise which processes are in parallel and which are in sequential order. Discrete event model can be used to identify energy consumption in a relation with the productivity, and also to explore the method to minimise the energy consumption. Here the right data structure should be imported in the model suitable for the energy analysis. The discrete event simulation model will identify the saving in a scenario to keep the electric motor OFF, when there is no process (out of duty cycle).

E. Data Interpreter Using (Data Integrator)

It is understood that this research is about how to working out the interaction between the two different working domains. The data interaction to be used in both of the model is of different formats and types. Therefore the integration tool as shown in Figure 2 which acts between the two different environments must be capable of normalising data according to the requirements. The data interaction has been shown in Figure 5, and an interface between the virtual environment data and DES data is required.



Speed/Velocity	Volume flow/sec	Acceleration	Inertia	Pressure
21.22	0	44.8	0.00457	0
21.22	0	44.8	0.00457	0
3.8	0	2.07	0.272	0
0	0	0	0.00457	0
0	0	0	0.00457	0
21.22	0	44.8	0.00457	0
21.22	0	44.8	0.00457	0
0.11	0.00092	25.7	0.611	74942
14.6	0	0.127	0.00025	0
0.134	0	28.5	0.611	0
10.7	0	0.22	0.015	0
0.156	0	34	0.611	0
0.11	0.00092	5	0.611	74942

Figure 5 Data compatibility and conversion

The integration tool is typically a spread sheet which is interfaced on one side with the virtual tool and on the other side to the DES model. The xml file has been generated from the virtual model and with the help of interface which must be exported into the spread sheet and interpreted in the data structure according to the requirements of the DES model along with some customisation if required. Example of the energy data normalisation has been shown in Figure 5. Running the model from this data could produce results prior to building the actual machine for different energy consumptions options.

F. Data Analysis

Data generated from the DES model could be collected back for further analysis and feed backs on the virtual systems are shown in Figure 2. As mentioned earlier, the analysis is based on the identification and saving measures for the processes with long "out of duty" durations. The concept has been evaluated in one of the project collaborator site in automotive sector of industry.

IV. PROOF OF CONCEPT: CASE STUDY

Different types of Virtual Engineering applications such as those developed by Siemens and BDA (Loughborough) groups are used in the collaborator automotive production site, for product and production system designs. In addition, witness discrete event simulation software is used by the productivity department to produce the production lines analyses for processes verification and observing the impacts of the machine breakdowns, repairs and human resource performance on the productivity. Therefore a well-known

ALFA automotive engine assembly line was considered as a case study to explore the control over the energy consumptions based on the processes durations. The components of the machine were observed for the time remains busy and the time remains idle. The test case results indicate that the processes done by machine components driven by the motors are still running although there is no process. As a pilot study one station of an ongoing engine assembly line has been considered for this analysis.

As part of this research, the author worked at the ALFA site to understand the existing processes regarding the building of the simulation models and the energy consumption control vision in detail. The following potential limitations were observed:

1. The cycle times at station/machine levels are available to the productivity engineers, however further detailed cycle times for decomposed stations (e.g. component and device levels) are not available.
2. Lacking of additional information for costs typically associated with resources such as machine associated cost, energy consumptions, running cost of the production line, and resources cost. So cost related data should also be provided into the simulation model.
3. Lacking of real time validation of processes e.g. prior to building a machine for energy consumption.

In this research work the use of virtual environment can provide the real time data at the component as well as machine level for validation purposes. The use of this real time data with the help of the approach adopted in this research work, in the DES models could produce valuable results for different productivity measuring factors such as energy consumption.

The framework for energy calculation as shown in Figure 2 is being developed as a pilot study for a machine station known as “Operation 15A”. It is an automated station in which a pallet moves over the rail carrying engine blocks towards the rotary plate for a nut running operation.

All of the processes are fully automated and have a controlled over the motions for all of the components operated inside this station. These motions are driven by electric and pneumatic drives, which produce the required torques to move. Currently, the station cycle time and other breakdowns like data are available but there are lacking data required for energy calculation to run the DES models for energy analysis.

The CCE virtual design tool has been selected to conduct this case study. The virtual model of the OP15A station was produced and the discrete event simulation model of the same station at component level was developed based on the virtual model processes as shown in Figure 6. This model is set to run the energy analysis only and during this analysis it was taken in consideration to categorise the processes which consume power only when they are busy from those which consume power even they are not in duty cycle. In “Op15A” has three components named: Clamp, Rail and Lift use energy because the motors are continuously running even when they are not in duty and dis-engaged from the load.

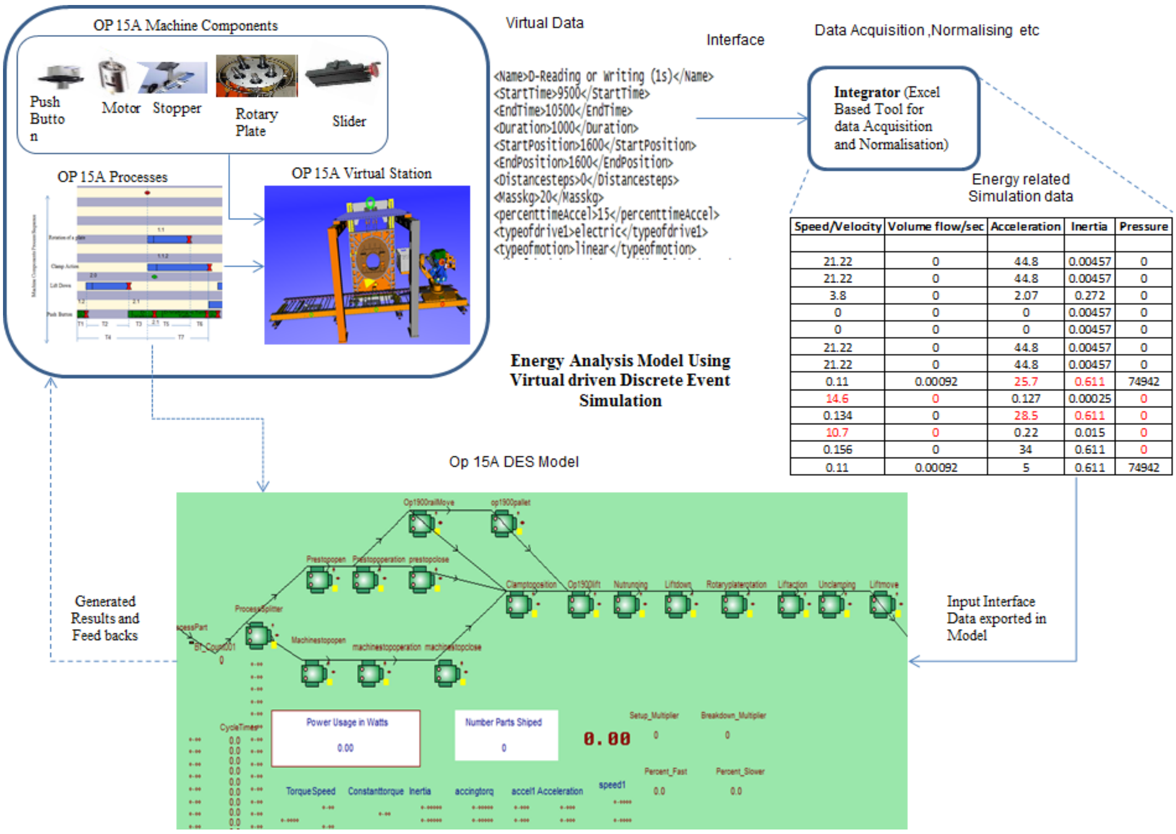


Figure 6 Case study setup: virtual driven discrete event simulation for energy analysis

Although they consume less energy as compared to when the machine component is loaded, but still there is a potential to examine the energy saving if possible. Two types of energy calculation are done for “OP15A”.

1. Energy consumption when the mentioned three components consume energy in busy and in idle states.
2. Energy consumption when the motors are off in idle state and consume only the energy when busy.

A. *Development of Virtual Driven Discrete Event Simulation Model for Energy Analysis of Machine Station " OP15A"*

The complete implementation procedure and data flow sequence of discrete event simulation model driven by virtual data for the "OP15A" designed to analyse the energy consumption are shown in Figure 6.

The VE model of "OP15A" has been developed from the process model and components executing these processes. After validation of the virtual machine model virtual data have been generated inform of structured xml files. This data is interpreted in spread sheet format with the help of coding. The discrete event model has been developed by using the process model (common in VE and DES) as shown in figure, indicating the sequential and parallel activities. The data related to energy consumption analysis are based on the speeds of the components they move, the inertia they have, the load the component carry during the processes. All this data then generate the reflected inertia on the motor shafts, and the equivalent torques is produced to move the loads. Typically all these parameters are exported in the DES model from excel based integrator tool along the components breakdowns, repair and setups data. All of the data related conversion and calculation are done with the help of the internal command language of discrete event simulation tool "Witness". The results analysis is quantified for energy saving if the components driven electric motors are kept off when idle.

B. *Results Analysis and Feedback*

Satisfactory tangible results were collected from the simulation model. These results seconded the viability of the approach adopted to run the simulation model for energy consumption during the design stages of the machine. It was found that without keeping off the motors for this operation "OP15A" for 8 hour shift with the production of 876 engines having a total cycle time of 35.7 sec the energy consumption is 58.3 megawatt. When the simulation model was run for the same condition but kept the motor "off" for the mentioned components, the energy consumption comes down to 56.4 megawatt for an 8 hour shift with the production of 876 engines from this machine station. Thus a significant 3.2 % of energy could be saved, with the help of an arrangement to place in the automation system of this operation to keep off these three components when not doing any job.

V. SUMMERY AND CONCLUSION

With the experience of virtual engineering in automotive industry, the research work discussed in this article not only validate the integration between the VE environment and discrete event simulation (VE to DES) but also extend its application for different direction such energy analysis. In addition, it was proved that pre-commissioning of processes verification and its discrete behaviour for energy analysis are possible, which potentially save time and cost for the automotive engineering projects. Also the reconfiguration of the setups of machine components for energy consumption could be evaluated with the different type of drives.

This is an ongoing project which needs further research work to bring this concept from the machine level to a complete line level analysis.

Approach can benefit both ways for the machine builder as well as for the end user of this machine. These optimised set-ups and energy consumption can provide a base for the financial analysis of the line also in during the validation and design phase of the production line.

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