

FACTORY MODELLING: DATA GUIDANCE FOR ANALYSING PRODUCTION, UTILITY AND BUILDING ARCHITECTURE SYSTEMS

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ABSTRACT

Work on energy and resource reduction in factories is dependent on the availability of data. Typically, available sources are incomplete or inappropriate for direct use and manipulation is required. Identifying new improvement opportunities through simulation across factory production, utility and building architecture domains requires analysis of model feasibility, particularly in terms of system data composition, input resolution and simulation result fidelity. This paper reviews literature on developing appropriate model data for assessing energy and material flows at factory level. Gaps are found in guidance for analysis and integration of resource-flows across system boundaries. The process for how data was prepared, input and iteratively developed alongside conceptual and simulation models is described. The case of a large-scale UK manufacturer is presented alongside discussions on challenges associated with factory level modelling, and the insights gained from understanding the effect of data clarity on system performance.

Keywords: Data Guidance, Factory Modelling, Resource efficiency.

1 INTRODUCTION

Global energy use has risen by 70% since 1971 and is set to continue its steady 2% increase over the coming decades, fuelled by economic expansion and global development (Clarke and Trinnaman, 2007). Along with increasing energy use comes consequent emissions of green house gasses and the depletion of finite natural reserves (Sorrell et al. 2010). Current rates of consumption are unsustainable, finite resources formed by the Earth over millions of years are being expeditiously exhausted by rising global population and associated increases in manufacturing to cater for our growing dependence on energy-intensive products (Al-Shemmeri, 2011 pp.13).

Energy consumption within industrial buildings equates to about a third of global energy use (Saygin et al., 2010). Around 70% is supplied by fossil fuel, which contributes 40% of CO₂ emissions (Brown et al., 2012). Analysis of current trends have incentivised legislative policies in sustainability, including the UK's Climate Change Act (CCA) (2008) and Carbon Reduction Commitment (CRC) Energy Efficiency scheme (2010). The CRC aims to reduce the use of energy intensive resources by specifying mandatory carbon allowances to industrial companies exceeding electricity consumption of 6,000MW/h, and applying financial penalties to those that overstep set limits (DECC, 2011).

Implementation of strategies concerned with the conservation of energy, materials and sustainable development have become increasingly important topics among governments, businesses, local communities and researchers (Pauli, 2010 pp.247). In factories, resource reduction activities have previously focused on point-solutions for discrete processes within manufacturing and building systems independently. However, new legalisation; such as the CCA and CRC, are motivating factories to establish greater resource efficiency across their functional boundaries. Increasingly, these efficiencies are being sought at a system level, encompassing energy, material and waste flows across production, utilities and building architecture domains. This paper discusses current modelling and data analysis approaches within literature and applies this guidance to the afore mentioned case study.

2 LITERATURE REVIEW

Systemic resource efficiency opportunities need to be found. These require detailed factory level analysis of resource consumption across domains and the introduction of inductive management methods to deal with data variability. Given the complexity and interconnectedness of resource flows at this scale, simulation has become an important ‘state of the art’ technology to aid design, analysis and testing of scenarios. The use of discrete event simulation can be extended to analyse energy, material and waste across domains. However, this gives rise to a number of data and modelling issues that are described below and classified in Table 1.

Model scope addresses the management within and between the production, utility and building-architecture domains, by using energy, material and waste flow data. This type of analysis could be used to identify interactions and determine potential variations in resource flows across system domains. Consecutively these analysis results could be used to determine improvement opportunities based on the tactical application of best practices (Smith & Ball, 2011). Modelling at this level provides contextualisation and control of system infrastructure (Herrmann, 2011), incorporating a realistic evaluation of energy and resource costs (European Commission, 2005), environmental impacts and technical performance. It allows for the derivation and selection of energy efficiency measures, beyond single machine improvement (Patterson, 1996). However, many large factories host a range of different system interactions, making data analysis and representative modelling of energy, material and waste at this level an elaborate process. Therefore, the model scope should account for preliminary qualitative analysis of data associated with these flows within a conceptual model (Figure 1). Definition of resource allocation and consumption across system domains allows for identification of when and where significant resource flows occur, as well as their duration, and whether they represent opportunities for improved resource efficiency (Oates et al., 2011).

Examining factories as an integration of production, utilities and building systems is necessary to consider the flow of all resources (Ball, 2013). When modelling complex interconnected systems a careful balance between feasibility, validity and utility is vital for achieving credible outputs. In order to achieve a representative model, definitions for both the scope of analysis and level of data are required. Existing frameworks for modelling and simulation provide a distinction between model scope and level of detail. The former identifies the boundary of the model, whereas the latter defines its depth (Robinson et al., 2011 pp.85). Simulation models can be conceived with four main component types: entities, active states, dead states and resources (Pidd, 2004). Mapping of these components within a conceptual model will inform key inclusion areas for further analysis and help refine the model scope. Once selected determining the level of analysis will require decisions to be taken about amount of data and detail to include for each component. The inclusion of these components within the conceptual model impacts all aspects of the study, in particular detailed data requirements, the speed at which the model can be developed, its validity, speed of experimentation and the confidence that is placed in simulation results (Robinson, 2011). Although effective conceptual modelling is a vital aspect of a simulation study it is probably the most difficult and least understood (Law, 1991). There is a paucity in literature for conceptual modelling applied to factory level, energy material and waste flow analysis.

Resource reduction in factories is dependent on the availability of data and sufficient automated or manual tools to enable collection. Typically collection is carried out by automated supervisory control and data acquisition (SCADA) and Energy Management Systems (EMS). However case experience has shown that available data can be incomplete or inappropriate for direct use and manipulation or modelling assumptions are required. Identifying new improvement opportunities requires clarity in the usability and fidelity of data being collected and analysed. This is particularly relevant in the experimentation stage of simulation when input granularity and quality, will have a direct effect on the ability to manipulate the model and provide valid outputs. The impacts of “big-data” gathered from current SCADA systems and manual data loggers on factories are twofold. The first is that volume data availability has increased but the usability of this data is sometimes questionable. Secondly, there is the increasing importance in using the appropriate level of data (resolution) to produce effective results. As a consequence of unclear data guidance and a lack resolution specifications for producing models, companies collect large volumes of data from loggers and SCADA systems, but the level and quality can be bi-polar. Either the depth of data is not detailed

enough across the scope of the system to provide a realistic representation, or the fidelity of the model created can become too-detailed, time consuming and unnecessary for producing the required simulation output. Additionally, even with the development of improved SCADA and EMS systems (Thomas et al., 2004) errors can still occur, leading to corrupt, rogue and unusable data. There are also techniques outlined to improve the performance these collection systems (Afkham et al., 2012). As an alternative, combining production data with machine consumption specifications (available from equipment manufacturers) allows usage assumptions to be made within the model (Nellore et al., 2001). Modelling assumptions may also need to be taken in the absence of data by using subjective methods such as snap-shot modelling. For this type of modelling to be effective action research, documenting all possible data is required. However, simulation outputs may lack objectivity and validity (Desa and Christer, 2001).

Data resolution characteristics (granularity and quality) are important in defining a models interoperability, experimental configurability and performance. Data granularity and quality are linked to analysis level decisions, which directly effect model fidelity and composability. Granularity can be defined as the subdivision (detail) of system components, whereas quality relates to the time-step intervals (depth) of measurement taken from selected subdivisions. At Factory level the integration of data from domain sub-systems can create modelling complexity and compatibility issues due to heterogeneous sub-system data resolutions. Combining these different model data types poses a variety of challenges depending on the system being modelled (Sarjoughian, 2006). Therefore, consideration and further guidance on composability; defined as the capability to select and assemble simulation components in various combinations within valid systems to satisfy specific user requirements (Petty and Weisel, 2003), is essential in developing representational factory models, with the ability to identify resource efficiencies.

Data accuracy is key to producing feasible and verifiable simulations. Identification of errors is dependent on the modellers ability to investigate the data and there sources. Analysis of system data (traces) can be carried out using range of static distribution methods (empirical, statistical, etc.) (Robinson, 2004 pp. 99). Mass and energy balance checking is another way to validate the accuracy of model data. This technique uses thermodynamic processes to define system exergy and losses, providing a measure for efficiency of the resources transformations (Bakshi et al., 2011).

Table 1: Summary of issues identified in the literature for guidance on data and model development.

<i>Aspect</i>	<i>Challenges</i>	<i>Guidance</i>	<i>Source</i>
Model Scope	Establish boundaries	Define data within conceptual model	Oates et al. (2011)
	Resource Flows	Allocation across conceptual model	Hermann et al. (2012)
Analysis Level	Detailing components	Mapping entities, inform development areas	Robinson et al. (2011)
Data Collection	Automated	Analysis of SCADA and EMS data volumes	Afkham et al. (2012)
	Manual	Analysis of portable metering gathered data	Case experience
	Estimation	Model assumptions due to unavailable data	Pidd (1999)
	Documentation	OEM specification, collation of data sources	Nellore et al. (1999)
Data Resolution	Completeness	Modelling with a lack of data	Desa & Christer (2001)
	Model Composability	System granularity and integration across model	Sarjoughian (2006)
Data Accuracy	Time steps	Data quality and normalising across model	Turner et al. (2011)
	Errors & Cleansing	Logged data accuracy	Robinson (2004)
	Model Validity	verify model outputs with process experts	Case experience
	Mass Balance	Efficiency of resource transformations in model	Bakshi et al. (2011)

3 CASE APPLICATION

Resource flow data has been gathered from a large scale UK manufacturer and is presented in the form of a conceptual model (Figure 1). This model was developed in iterative manner alongside data capture. Challenges from Table 1 were used to inform conceptual model properties such as model scope, analysis level and system data collection, with an aim of determining specific focus areas for further analysis within a detailed simulation model. Refinement of model focus areas within the simulation software (Figure 2) encountered a number of data collection, resolution and accuracy challenges. All case application modelling results are discussed below against each aspect of Table 1.

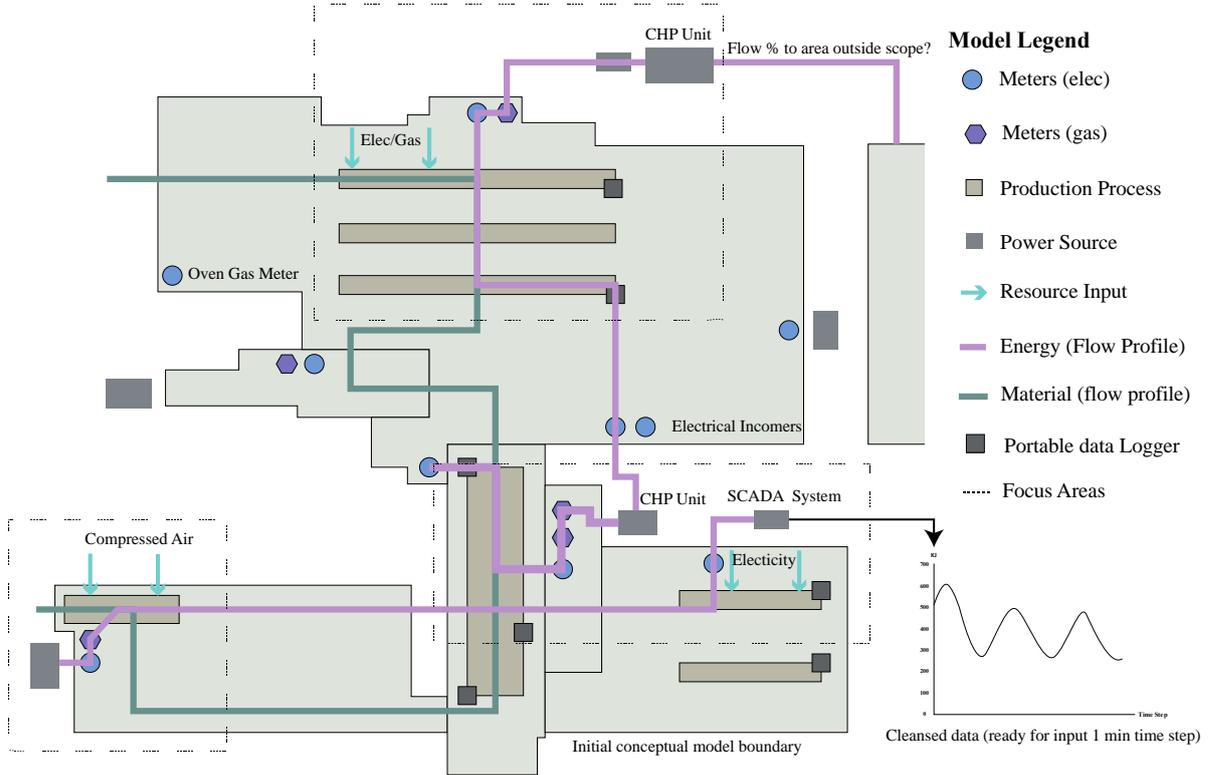


Figure 1: Conceptual model boundary, level components, qualitative resource flows and focus areas

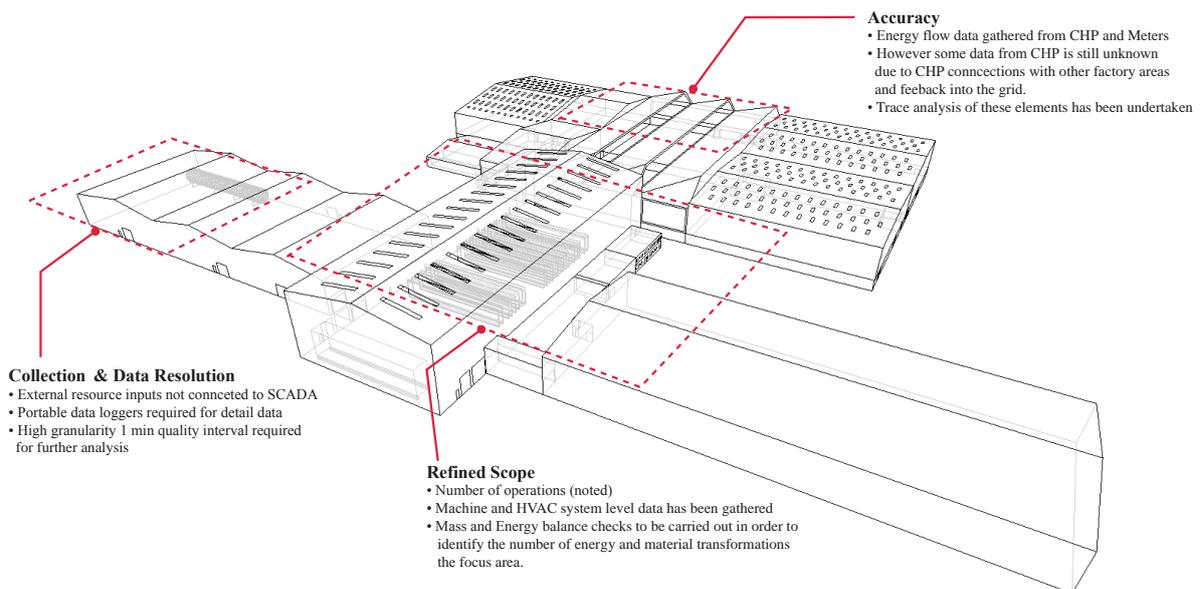


Figure 2. IES-VE model, showing refined model scope, data resolution and accuracy challenges

Model Scope: Initially defined by project goals, the conceptual model provided contextualisation allowing for the interactions of energy, material and waste flow data to be presented across domains. The model boundary along with definition of analysis level components was used to determine system areas for resource improvement opportunities, leading to a refined model scope within IES-VE suite.

Analysis Level: Collection of model components (e.g. processes, meter locations etc.) was based upon initial definition of model scope. Visual representation of flow allocation across the system was carried out within the conceptual model. The results yielded sufficient evidence of potential focus areas (detailed data collection) where high concentrations of energy and material resources were being consumed.

Data Collection: Based on analysis level and model refinement within IES-VE further detailed data was collected from on-site SCADA systems. Data accuracy checks were undertaken and some cleansing was required mainly due to human input (formulae) and sensor (missing detailed data) errors.

Data Resolution: Machine and HVAC system level data has been gathered at 1 minute intervals for focus areas. Although result output for this phase is still being undertaken, previous work undertaken (Turner et al., 2012) has shown that normalisation and data quality loss occurs at time-step interval over one minute. This shows that lower resolution data can detrimentally effect simulation feasibility.

Data Accuracy: currently a static trace analysis has been undertaken on detailed data. This revealed several pieces of rogue and missing data. Rogue data was cross checked by process experts and removed where necessary. Further empirical and statistical distributions of data are being undertaken within the model.

4 CONCLUSION AND FURTHER WORK

Data guidance from literature has aided development of the presented factory level models. The conceptual model was produced by establishing a model scope through goal setting and based upon accessible system data to contextualise the model components. Component data based upon analysis level guidance was used to generate energy and material flow maps across system boundaries. These flows were incorporated into the conceptual model in order to identify focus areas where high concentrations of energy and material resources were being consumed. Identification of these focus areas determined the refinement of model scope and the creation of a detailed simulation model. They also revealed where acquisition of detailed data was necessary, in order to create a representational model that would provide feasible resource efficiency opportunities. While developing the simulation model a number of data challenges occurred such as availability, resolution and composition of different system level data sets within the integrated model. Additionally, data accuracy has also affected the feasibility of the simulations. Further empirical and statistical trace tests to refine data within the model are required, in order to produce verifiable and valid output results. This research has identified guidance sources applicable for factory modelling and has developed an iterative approach for concurrent model building and data analysis. However, much work is still required in terms of developing a thorough modelling methodology that can be applied to factory level resource efficiency projects. Further work includes the development of a dynamic conceptual tool for representing interconnected components, systems and resource flow variability across the integrated production, utility and building architecture domains. It is also the researchers intention produce a set of guidelines outlining data typologies, showing how different data resolutions will directly affect simulation outputs and the application of resource efficiency tactics for factory level sustainability.

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