22nd Cambridge International Manufacturing Symposium
University of Cambridge, 27 – 28 September 2018

Action Plan Simulation for Manufacture2030 bee

Interim report on feasibility of simulating a portfolio of factory energy efficiency actions using a scalable multi-level modelling approach, with integration into an online operational action planning service (M2030 bee)

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Abstract

A report on the progress of a 6 month feasibility study into modelling collaborative operational action plans for energy efficiency.

Action planning is an archetypical practice for operations improvements and Kanban or PDCA boards are commonplace in operations management. However operational action plans are seldom collaboratively developed, shared or effectively deployed for energy, water and materials efficiency improvements and best practices. Collaboration is seen as the key to accelerating the adoption of best practices for resource efficiency and a new platform (Manufacture2030 bee) is a web–based software tool which can enable this.

Manufacture2030 bee has a library of over 300 resource efficiency actions with benchmark data for savings potential. These actions cover cross-cutting utilities and systems, such as boilers, compressed air, HVAC, process heat, refrigeration and others. M2030 bee currently facilitates individual actions to be compared for decision making purposes. However, an opportunity to develop a portfolio approach and tailor a range of anticipated savings to a user's facility has been identified. This tailoring will allow decision makers to study the cumulative effects of improvements.

The aim of the 6-month feasibility study is to develop an innovative approach for improving energy efficiency decision-making with the following outputs:

- A user-tested prototype of a product feature for simulating the effect of a portfolio of energy efficiency improvements in manufacturing

- Analysis of market potential

- Roadmap for bringing a product feature to market

This paper reports on the modelling and simulation approach, with preliminary evaluation of the feasibility. The work is a part of a research partnership between 2degrees and the High Speed Sustainable Manufacturing Institute (HSSMI) and is funded through Innovate UK's Emerging and Enabling Technologies programme.

Keywords: *Energy Efficiency Improvements, Multi-Level Modelling, Agent Based Simulation, Operational Action Planning,*

1. Introduction

Manufacturing companies are under continuing pressure to reduce cost to remain competitive. At the same time, manufacturers are under pressure from their customers to reduce the environmental impact of their products. Programs of resource and energy efficiency are an increasingly important part of manufacturers' response to both these challenges.

It is estimated that the benefit of a non-labour resource efficiency revolution in the UK alone has the potential for over 300,000 new manufacturing jobs, 12% profit increase for manufacturers and 4.5% reduction in GHGs (Lavery et al., 2013). It is the ambition of this work, to contribute to this revolution by showing a much broader market, the portfolios of actions which can reap these benefits.

Considerable efficiency good practice advice resources exist but improvement may come from many relatively small actions and these are likely to interact with each other. This makes it difficult to determine and manage a portfolio of actions that will deliver the desired benefits. Decision-making uncertainty often results in considerable inertia in making the on-the-ground investments and operational changes to unlock the efficiency savings to improve competitiveness.

There is now renewed focus on targeting the scale-up of resource efficiency savings. It has been demonstrated, and there are calls for efficiency savings potential in the order of 7-8% year on year improvement (IET, 2017). However, unlocking this level of resource efficiency requires the perspective of a portfolio of resource efficiency improvements and operational action planning. This work explores modelling and simulation as an approach to more effective decision support for resource efficiency gains arising from a portfolio of improvements.

This paper describes the approach taken with respect to the conceptual model development and the systems integration development for the online service. For the instrumental case design, a compressed air system was chosen. This is a novel approach for simulation in Compressed Air. Circa 20 M2030 bee improvement actions have the potential to be simulated as a portfolio, which is an improvement over the US Department of Energy’s 8 Energy Efficiency Measures in a comparable system (IAC, 2010).

This work is useful to operational researchers and practitioners attempting to develop tailored action plans for energy efficiency in manufacturing and operations. It is also a useful contribution for those who are researching technical building services as part of holistic factory simulation for energy efficiency.

1.1. Purpose

This feasibility study will identify how a technology, which has not existed in the marketplace before, can be matched with a market need to close a digital manufacturing skills gap. Currently, "Systems Modelling and Simulation" has been ranked as a key competency required for the integration of digital technology in manufacturing (IfM, 2016). The M2030 bee has the potential to streamline energy and resource productivity projects and enable more comprehensive analytics on project implementation. This analytic innovation aims to break open a simulation and modelling market that has been traditionally left to bespoke, high cost, high lead-time services, and give a much wider variety of professionals access to insight without needing significant prior expertise.

For users of the M2030 bee, it has been seen (anecdotally), that those with limited engineering expertise can use the product to have more informed conversations with their engineers. Facilitating these discussions can considerably help in demystifying the technical requirements of energy efficiency projects and promoting collaboration across operational and managerial functions. Tailored simulation with results presented in the form of shared action plans can be a key feature of this collaboration.

The work aims to clarify the question of: how can manufacturing facilities be helped to, cost-effectively and with sufficient certainty, identify a portfolio of improvements that will get buy-in and potentially investment funds, to achieve a desired objective such as an ambitious 7% energy reduction target?

1.2. Project Background

M2030 and HSSMI are partnering to bring together deep experience in manufacturing system modelling, with a track record of creating intuitive software products to solve complex problems in industry. M2030 have validated improvement actions across many areas of Energy, Water and Waste productivity and a best practice sharing platform to enable industry professionals to quickly draw up improvement plans. HSSMI have the knowledge of how to simulate production environments to optimize on these types of improvement actions.

By partnering on this project, both companies can bring expertise to model and simulate actions for professionals to develop more robust improvement plans. By using simulation on an ever expanding and improving set of actions, and by sharing relevant insight across an audience of thousands of professionals, adoption can be scaled much more quickly. The work aims to enhance a new platform in a sector where high-cost, long lead-time, bespoke solutions are the norm and comparison of improvement projects is very difficult. There is the potential for an online product, which will give a much broader range of professionals' access to a simulation tool which is intuitive and powerful.

M2030 bee encourages rapid adoption of efficiencies already but what is not currently possible is the evaluation of the cumulative effects of combining different improvements. There is no extant tool which combines actionable interventions with simulation of production processes and resource consumption. The new simulation tool is intended as a key extension to 2degrees' existing M2030 bee product.

1.3. Approach Background

There is a long history of using simulation, especially discrete-event simulation to model manufacturing optimisation. Energy and resource efficiency in manufacturing is not a new issue, and many authors have highlighted how both manufacturing processes and technical building services could be integrated for modelling (Duflou et al., 2012; Herrmann and Thiede, 2009; Thiede, Bogdanski and Herrmann, 2012). Some efforts have examined Lean and Green as an approach to assessing the most relevant strategies (Diaz-Elsayed et al., 2013), they have looked at technical building services in factories (Herrmann et al., 2011) or they have looked more at process-specific energy requirements, such as tooling and how to scale up to systems perspectives (Salonitis and Ball, 2013; Zein et al., 2011). What is generally accepted is that a much more comprehensive understanding of factory and utilities demand coupled with appropriate building information, will yield much more conclusive ideas for resource efficiency improvements (Wright, Oates and Greenough, 2013).

However, one of the great challenges of developing a simulation and modelling approach is matching modelling fidelity and granularity with user needs. In many cases, there can be an over-emphasis on modelling complexity in order to drive accuracy, without due-consideration for user needs or user stories to drive model applicability. There is a danger, that because the demands of modelling resource or energy efficiency actions are so complex, that there is a complete lack of understanding from the target audience. The danger is whether they will actually be able to interpret the results, let alone for the results be applicable enough to give users the confidence to take appropriate decisions.

An alternate approach is possible. Rather than focusing on generalising manufacturing optimisation challenges as a starting point for modelling, this work draws from the actual resource efficiency improvements that have been demonstrated to be possible. By modelling from the bottom-up and specifying the potential portfolio of improvements in advance, the decision making process can be completely tailored to the user's needs. The manufacturing optimisation can then be brought in to simulate the dynamics of specific resource efficiency improvements, rather than having the improvements identified as a by-product of manufacturing optimisation.

There is a long legacy of assessing efficiency improvements in manufacturing. One of the largest such efforts is the US Department of Energy's Industrial Assessment Centre's dataset of over 16,000 energy and resource efficiency audits (EERE, 2013). It is these assessments that have been codified into a list of resource efficiency improvements. The approach taken in this study is to take a list of improvements, similar to the IAC dataset and use it at the basis of defining actions to be simulated in facility models. This approach has been attempted before, such as for Compressed Air (IAC, 2010). However, the compressed air tool is only relevant for 8 compressed air actions, whereas this work has initially identified around 30 actions that would be relevant for modelling.

1.4. Hypotheses Development

The aim of the feasibility study is to assess the technical, operational and commercial potential of a factory energy simulation feature. The key reasons for developing a feasibility study are to assess whether or not there is the potential aiding decision making, for scaling the modelling approach and that appropriate model fidelity and granularity can be achieved in line with user needs.

Throughout the early part of the feasibility study, it is assumed that the user requires more information on a portfolio of energy actions of their choosing, from the dataset available in M2030bee. Part of this dataset – compressed air action - is shown in figure 1. Through the development of the market research, it is anticipated that more refined user requirements can be developed through more specific cases and user stories.

M2030 bee currently allows for savings potential to be assessed on the actions, along with other key data such as payback time, financial savings and industry adoption rate. It was recognised at the start of the feasibility study that there are a large variety of other data which could be relevant for resource efficiency evaluation of actions. However, one of the constraints on the model development is the applicability of data to the current bee system as it is being used. Therefore, the key decision making data has been limited to energy savings only to reduce modelling complexity.

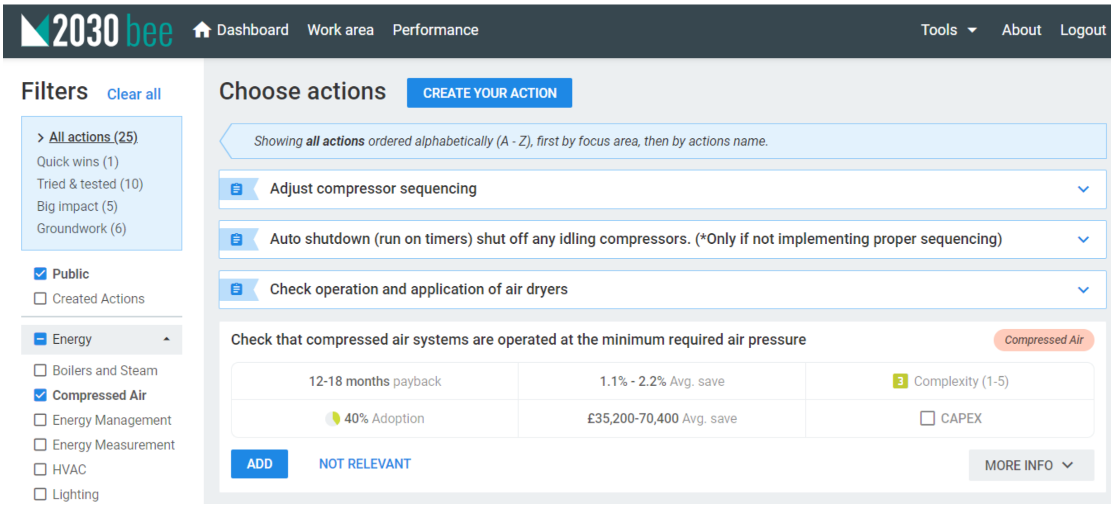

Figure 1 Web-screenshot of M2030 bee, with selected Compressed Air actions and key information. Other Process Areas are indicated in the filters. Image downloaded from https://bee.manufacture2030.com/ ©Copyright Manufacture 2030.

The key hypotheses are:

A. Factory modelling and simulation of M2030 bee actions are of potential operational decision making value to bee users who are appraising a portfolio of actions (primary decision making assumed to be based on a combined actions savings assessment)

B. A useful modelling and simulation approach can be specified that is applicable to factory energy analysis with modular elements and appropriate granularity (i.e. non-bespoke, modular model elements)

C. A useful modelling and simulation approach can be specified which can be scalable across different factory process areas

1. A useful modelling and simulation approach can be specified that has the benefit of being potentially applicable to different operational decision making problem domains (such as optimising savings, costs, payback, complexity, resourcing, and environmental targets i.e. CO2 emissions)

An approach has been developed to test whether hypotheses A and B are feasible. Hypotheses C and C1 should be assessed based on understanding of the technical potential of the systems and are not to be explicitly tested within the time frame of the project.

2. Approach

The research has been designed to develop an instrumental case prototype and to assess the technical feasibility of a prototype. Following this, market research can be conducted to verify the technical potential and then evaluate the market potential. The approach for the model development has been of primary concern in the early stages because of the technical challenge in developing a scalable prototype.

Through the development of the generalised modelling process it became apparent that a key factor of the flexibility of the model would be the inclusion of modular modelling components. This would allow the specificity of the model to the key user-defined actions in a portfolio. In order to execute this, an agent-based simulation environment was chosen. This would allow for modularity of system components, such as compressors, control logic and profile information to be chosen in relation to the user-defined actions.

Beyond this, the challenge of integration of the model components became a key issue for simulation build. Not only because of the limitations of the agent-based simulation software, but also because of the complexities in designing experiments for more than 20 actions. This was overcome through the development of a multi-level approach in which different factory physics can be evaluated – with appropriate granularity of data - at different levels of the model.

The final part of online systems integration for both the M2030 bee system and the simulation server is an added layer of complexity. The task of codifying and sequencing the user-workflow between the M2030 bee system and the simulation server is a key constraint on the technical feasibility. However, as a key constraint, it also offers an opportunity, in that through necessity, it was decided to use an approach of defining key parameters of a general physical model to be incorporated into flexible experiments, rather than defining rigid experiments for each action. This means that the inputs and output of the simulation server can be limited to evaluating the physics of the model, such as flow rate, pressure, temperature etc. rather than having to define actions in the simulation model itself. Through an interpretation process, the key parameters of the physical model can be defined on the M2030 bee system and kept independent, thus reducing complexity.

2.1. Stage 1 - Instrumental Case Design

The key motivation for the instrumental case design is to develop an approach which is scalable. Part of the early work was to develop an approach which is replicable across the different M2030bee process areas. Scalability can then be determined, in part, through the application to the different process areas. These include, but are not limited to Process Heat, Boilers and Steam, Compressed Air, HVAC, Refrigeration and Lighting. Scalability is also determined by the applicability of the system to future integration of actions and modelling components (i.e. equipment).

The generalised process identified is to develop a set of actions, a corresponding generalised factory physical model, outlining the general characteristics of the physical equipment for the process area, and then build a model. The model build phase includes a set of generalised experiments that can run model perturbations on equipment configuration, environmental variables and key action parameters. Once these parameters and key action attributions are identified, they can be simulated and then certain varieties of experiments optimised for parameter and model refinement. This generalised process is shown in figure 2.

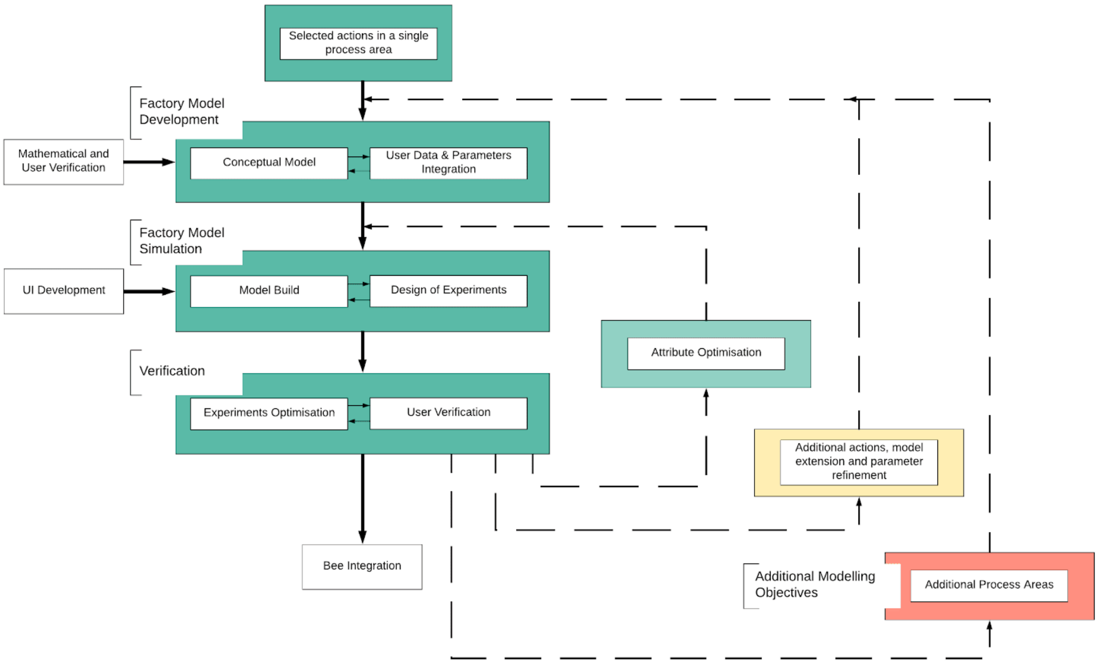

Figure 2 Generalised Modelling Process

2.2. Stage 2 – Multi-Level Conceptual Modelling Development

The main focus of the work to date has been to develop the conceptual model. This work has been on two aspects; the factory multi-level conceptual model and the systems integration workflow. The multi-level model was developed as a way of integrating both flexible build custom models; i.e. models which can be tailored to the user's facility; and custom design of experiments. Flexibility is important in order to develop the dynamic analysis of improvement actions.

It was found that this aspect of the study is also pushing the limits of the dynamic simulation software as custom classes have had to be designed to define the most appropriate physics for the model. Original planning was to arrive at a basic model, in line with anticipated user workflow, but the actual design has been to lay the foundations for a more dynamic integrated system. This is because in order to achieve multi-level modelling method in the simulation software, it was found to be much more effective to build at the highest level of granularity and specify most of the model than to follow the most simplistic user-workflow. This, in turn, allows for the modular components to be specified at lower levels of granularity much more easily.

The build of the multi-level model comprises four simulation levels, with an added M2030 bee evaluation level on top. The M2030 bee evaluation level, is where each process area is specified as a component of overall energy consumption. Below this, at Level 0 of the simulation model, which is a simplified model of a compressed air system across three zones; A Supply Zone a Distribution Zone and an End Use Zone. Within each zone, generalised equipment can be specified, such as compressors and controllers in Level 1. In level 2, variants of the equipment can be specified, such as fixed or variable speed compressors. In Level 3, other type of physics can be evaluated, for heat recovery and air quality simulation. Figure 3 shows the layout of the first few levels of the conceptual model and shows the modularity of the design, coupled with a consideration of granularity.

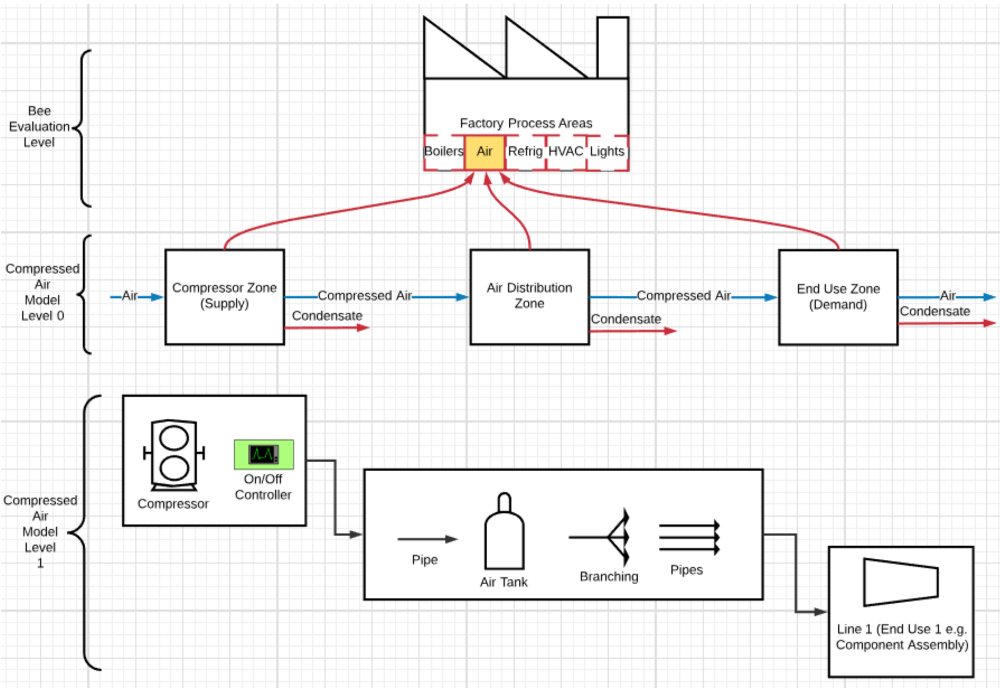

Figure 3 Multi-Level Model of Compressed Air System showing first couple of levels with high-level component fidelity

Following the definition of key levels of the model, it is then possible to correlate actions with the key modular components. This is a vital step in understanding which key parameters are to be modified by the actions. In figure 4, some key actions have been specified (green) in relation to the key components of the model. The process of defining how actions are connected to the evaluation of physics on key components is the vital step in defining simulation experiments.

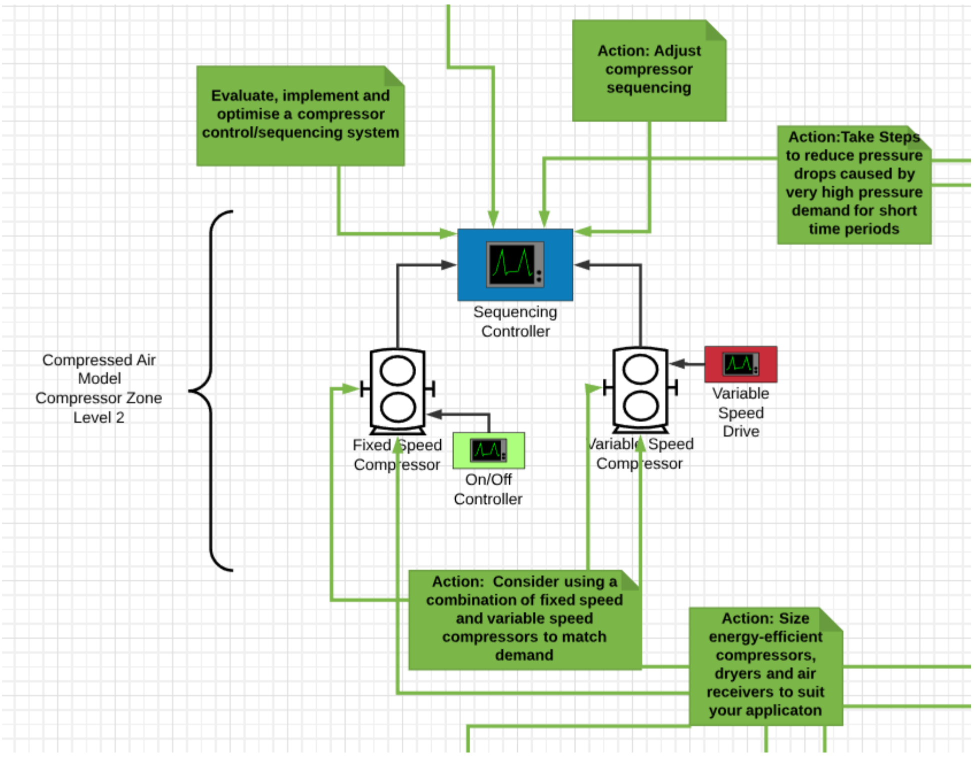

Figure 4 Snapshot of conceptual application of actions to a Level 2 Compressor Zone

2.3. Stage 3 – Agent-Based Simulation Integration

Agent-based simulations are used to test the feasibility of potential resource efficiency actions within the M2030bee model (described in Stage 2). The reason for using agent-based as opposed to traditional discrete-event tools is that agent-based models have the ability to simulate simultaneous flows, specifically fluids such as compressed air. Additionally, they are appropriate for analysing interactions of multiple agents (such as thermodynamic changes) in an attempt to simulate existing and proposed phenomena.

The agent-based simulations use a novel systems architecture (figure 5). This systems architecture provides users with the ability to build and run the model based on designated compressed air actions set within the M2030bee database. These actions are specified with additional model parameters (e.g. tank capacities, pipe diameters, compressor pressure range etc.), and are sent through the communication interface using requests sent from the HSSMI server.

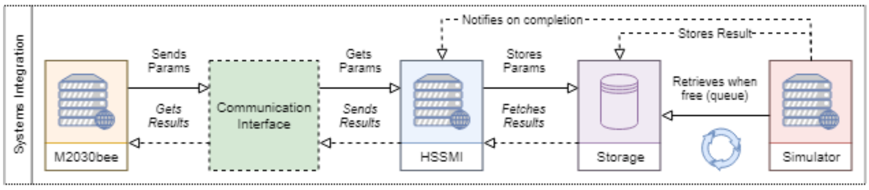

Figure 5 Systems architecture linking M2030bee with an agent-based simulator

This server translates the requested packet into a structured XML for use within the modelling interface. The server uses the data granularity of the packet to interact with the models API, allowing an autonomous model build and run process. This workflow is based on the application of parameters and custom java classes (described in 2.2). All model run parameters and outputs are stored within a queue (for use in Stage 4).

2.4. Stage 4 – Modular Design of Experiments Development

The Design of experiments is in development, based on key action parameter specification in the model. Users will be able to specify generalised modelling data based on the key equipment they would like to model. From this, different combinations of actions will be modelled, with other parameters being modelled as part of the analysis. Part of the output of the simulation runs is expected to be reporting on a set of parameters that the user may want to re-specify for future simulation runs.

2.5. Stage 5 – Evaluation of Approach

Evaluation of the technical approach will be conducted during user testing research. A key consideration for the research is whether or key customers stories can be identified inside manufacturing companies. This phase of the research will involve both interviews and guided user testing for use cases identified by each of the users.

3. Interim Results & Further Work

It has been found that a multi-level modelling approach is technically feasible and applicable to a portfolio of actions in a compressed air system. It is anticipated that more energy efficiency actions can be simulated than are currently possible in comparable simulation packages. A systems workflow has been found which it is anticipated could work by with running asynchronous requests from the M2030 bee system via a communications interface to a simulator server. This would run independently and be anonymised from the M2030 bee system to minimise various data protection risks.

In regard to the project hypotheses, work towards hypothesis A is ongoing, and decision making value with be assessed through user-interviews. Work towards hypothesis B seems promising as a flexible and modular approach seems to be technically feasible. Validation and user-testing are important to determine whether the modelling is applicable for various levels of granularity. Further testing would be required on what levels of accuracy the user requires and therefore specifying the appropriate level of granularity within the design of experiments.

As an early output, it has been found that hypothesis C is already feasible. This is because of a necessary modification to the modelling approach for a more flexible and scalable workflow design because of the constraints on systems integration.

Further work in the study is summarised as follows:

- Approach for modular design of experiments based on action portfolios is in development
- Approach for modular design of experiments based on action portfolios is in development
- Simulation findings forthcoming
- Optimisation findings forthcoming
- Integration findings forthcoming

Work will continue on evaluating the market potential and technical roadmap based on user stories from user testing.

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