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THE RELATIONSHIP BETWEEN SIMULATION AND EMULATION

Ian M[c]Gregor

Brooks-PRI Automation, Inc.
5245 Yeager Road
Salt Lake City, UT 84116, U.S.A.

ABSTRACT

This paper aims to explain how simulation and emulation are interrelated, and why they are of benefit to Automatic Material Handling Systems (AMHS) projects at different times and in different ways. More specifically, the paper documents current thinking on the use of simulation models to provide feedback to industrial control systems in order to test their logical operation prior to commissioning. The concept of what is meant by emulation in this context is defined, and the differences and similarities between emulation and simulation are detailed. Several emulation case studies are described to illustrate the use of a simulation model in this domain, and an overview of the technical background to emulation is included to aid understanding of how this is achieved. The paper concludes with a discussion of where emulation is most usefully applicable, how current standards have allowed its ready adoption to date, and possible areas of future development.

1 INTRODUCTION: THE CONCEPT OF EMULATION

It serves our purpose here to define an emulation model (as distinct from a "pure" simulation model) as one where some functional part of the model is carried out by a part of the real system.

As all models are approximations of real systems, then there will exist measurable differences between the performance of the real system and the model. These differences often lead to a "credibility gap" that an emulation model attempts to minimize by bringing the model closer to reality by replacing a part of the model with "reality"; a part of the real system.

Bridging the credibility gap is not the only reason for a growing interest in emulation – the above definition of an emulation model remains valid when turned around – an emulation model is one where part of the real system is replaced by a model.

Using emulation models to test control systems under realistic conditions, by replacing the AMHS with a model, is proving to be of considerable interest to those responsible for commissioning, or the installation and start-up of automated systems of many kinds.

2 SIMILARITIES BETWEEN SIMULATION AND EMULATION MODELS

In order to appreciate how emulation models work and identify those properties that give them credibility, it is useful to start by identifying what simulation and emulation models have in common.

2.1 3D Representation

Physical systems designed, built, and operated by man exist in three dimensions. Simulation models and emulation models should also be in three dimensions if they are to be easily and readily understood.

Two-dimensional models may be harder to interpret, especially when actual movement in three dimensions is modeled, and reality may actually be masked (a top view of a sloping conveyor compresses its length).

Iconic models, where objects in a window are not related spatially to one another and where there is no concept of two-dimensional distance between objects, are even more prone to errors of construction and interpretation and so are much harder to work with.

2.2 Accurate Movement

In order to be useful, a model must be accurate. But just how accurate is enough? The most appropriate answer to this is, sufficiently accurate such that the results remain statistically meaningful. If this sounds vague, it is because accuracy requirements are project-dependent, and therefore the level of accuracy required changes from model to model.

To illustrate this, consider a bottling line consisting of conveyor sections, filling machines, labelers and packaging machines. For the model results to be accurate, we may need to take into account labeler breakdowns as well as its normal cycle time, but we are probably not too preoccupied with the actual movement of the labeler mechanism.

Within a larger model of the supply chain incorporating warehouses, truck movements and the production facility containing the bottling line, we may find it acceptable to model the whole line as a resource that outputs product at a certain average rate.

2.3 Zero-Abstraction Elements

The less time an audience needs to understand what they are looking at, the easier it is for them to take new ideas on board. The less time a modeler spends trying to make software constructs behave like real system elements, the easier it is to build, operate and maintain a model. Zero-abstraction elements help to achieve this through providing realistic modeling objects that have the same characteristics as their real counterparts. A conveyor section should behave like a conveyor, and have a motor, photo-eyes, and transfers to other conveyor sections.

3 DIFFERENCES BETWEEN SIMULATION AND EMULATION MODELS

Although a simulation model and an emulation model may look to all intents and purposes the same, and may be built largely with the same building blocks, there are significant differences in usage and operation.

3.1 Different Aims

Simulation models are used to test and develop different solutions in order to arrive at a best solution, based on an accepted set of pre-defined metrics.

Simulation often provides the impartial judge between experience and new ideas, and allows the user to demonstrate functionality and results in a cost-effective and flexible environment. Simulation results help define the physical layout of a system, its operating limits and its control system. Models are used as a basis for extensive experimentation, often using automatic procedures to determine optimal or robust solutions.

Emulation models are used in a much more precisely defined way; in order to test the operation of the control system under different system loading conditions, and as a risk-free means of training system operators and maintenance staff. Emulation models are not used for experimentation in the same way that simulation models are; they are unsuited to this function as they often execute only in real time.

The emulation model reflects more precisely the system that will be implemented, and as such, can be used to carry out a constrained series of verification procedures to ensure the performance or reaction of the control system. Systems exist to automate the execution of these tests, and to run them in parallel in order to carry out more tests than would be practical on the real system.

3.2 High-Speed Execution for Simulation

As the aim of a simulation model is exploratory by nature, the faster it can cover all different possibilities, the better. Simulation modeling software is therefore designed and developed with speed of execution in mind, and the models built with it are also often constructed for fast execution.

3.3 Real-Time Execution for Emulation

The great majority of control systems are designed to operate in real time, and so emulation experiments should be operated in real time.

Although simulation models can obviously provide responses faster than real time, this is potentially a source of error, as control system timers cannot adapt to this, and therefore running at speeds greater than real time should be avoided.

3.4 "Instant" Decisions in Simulation Versus Response Times in Real Systems

A simulation model maintains its own simulation clock. When a decision is taken within the model, the simulation clock does not advance until the necessary calculations have been performed and the decision has been evaluated. This means that simulation time stops whilst decisions are taken.

An example of this is a box on a diverging conveyor belt – the box may be sent one way or the other depending on the contents of the box and its final destination. In reality, this decision may be the result of several steps, each of which takes a measurable amount of time. The box may be scanned, and a bar code read. The information may be sent via a network and used to search a database to identify the contents and the destination of the box, then a control system may verify that a diverter is in the correct position. If it is not, then a pneumatic or electric movement takes place. The initial bar code scan will have taken place before the divert, at a sufficient distance to ensure that the response can be calculated and the diverter moved to the appropriate position before the box arrives.

An emulation model must reflect this reality and incorporate decisions that take a finite time.

3.5 The Importance of Repeatability for Simulation

Two or more model runs will always execute in exactly the same way and produce precisely the same results if no parameters are changed between runs. Any impression of randomness in a simulation model is due to the use of pseudo-random numbers to generate certain events such as breakdowns, cycle times and so on. Repeatability is necessary in order to recreate and understand events during the model run, as well as to debug the model as it is built. All events that influence the model execution are contained within the model and are therefore repeatable.

3.6 The Importance of Robustness for Emulation

Due to the fact that in most emulation models the control system is separate from the model itself, repeatability is uncertain, as communication events are asynchronous and unpredictable. The model and the control system work with different clocks and synchronize via a communications layer, itself prone to the decisions of the operating system. The resulting uncertainty comes as a shock to the simulation practitioner used to the comforting repeatability of the discrete event simulation world, but real world control systems deal with this on a daily basis.

Industrial communications networks are not deterministic, and control systems need to be designed to run reliably under varying load conditions. It therefore becomes important that emulation models be robust, like the control systems that drive industrial processes and Automated Material Handling Systems (AMHS).

4 THE THEORETICAL BACKGROUND TO EMULATION

4.1 AMHS and Control Systems

Automated systems consist of a continuous dialogue between sensors, control systems, and actuators. Changes in the state of the system modify the states of the sensors, these state changes provide input to the control systems, logic is processed to determine the appropriate states of the outputs, and actuators respond to the outputs.

The physical AMHS and the products it carries that trigger the sensors can be replaced by a simulation model to provide the same responses. The opportunity then exists to use the resulting emulation model to test the control system off-line, or to test the control system before the real hardware exists or is assembled on site. Real actuators can be replaced by modeled ones and made to react to output changes in the same way, so the model's behavior is modified to reflect the response of the actual system.

4.2 Simulation Models and System Logic

In order for an emulation model to operate in a way that reflects the reality of an AMHS, it must be possible for the modeler to separate the physical parts of the model from the logical or operational parts. In order for the modeler to experiment with the final model it may be necessary to have a part of the model operate under simulation logic, whilst other parts are under the direct control of an external control system.

This feature also allows the progressive build and debug of a model, which may be necessary for larger models.

4.3 Synchronizing Simulations with Real-Time Control

As has been previously mentioned, both the emulation model and the control system operate from separate notions of time. The control system only knows real time, and cycles as fast as it can. The emulation model is constrained to execute in real time, and then needs to catch up to real time if it has fallen behind due to executing calculations.

4.4 OPC - The Enabling Technology

Linking a simulation model to a real time control system can be achieved in different ways depending on the objectives and the technology involved.

Systems on different platforms can communicate via sockets technology, whereas if all elements are on Windows platforms then communications based on COM would be simpler to implement.

ActiveX or Dynamic Data Exchange (DDE) might be used, but if the control system has an OPC Server, then this technology would be simpler still.

Prior to this development, costly specific code had to be written and maintained between an application and the data source it communicated with. Object Linking and Embedding for Process Control (OPC Foundation 1999) is a non-proprietary, *de facto* standard that greatly simplifies communications between most programmable logic controller (PLC) based industrial control systems and third party applications. The standard defines the services and interfaces the control systems suppliers should support, and the way in which the client can access data.

All clients created to this standard can therefore access all data on OPC compliant servers.

4.5 Semiconductor and SECS/GEM

Within the semiconductor industry there exists a growing need to emulate the AMHS. The paradigm shift from 200 to 300mm diameter wafers suddenly transforms fabs (where semiconductor wafers are processed) from largely manual to heavily automated material handling systems, where only a full understanding of the dynamics of the fab will allow its correct operation. The predictable and reliable operation of the AMHS is an absolute prerequisite to normal production, and so the motivation to test the control system using emulation is strong.

Unfortunately, fab material handling systems communicate using SECS/GEM, a broad standard not well suited to the needs of emulation. The result is that each emulation test system requires extensive proprietary work to connect the model to the control system, and so much of the potential savings are lost.

5 THE STRUCTURE OF AN AUTOMOD EMULATION MODEL

An emulation model has much the same basic structure as a classic simulation model – with the marked difference that most, if not all, of the operational logic is missing.

Initialization of an emulation model involves connecting the model to the control system, establishing the presence of the various items to be read or written to and subscribing to certain data items. This initialization can be carried out line by line, defining the server to connect to, groups of items to communicate with and initial values of these items, or it can be done more conveniently with one function that reads in a structured initialization file. As the model runs, modeled sensors send data to the control system, and modeled actuators transform control system outputs into AMHS movements.

6 APPLICATIONS

The principle of testing control systems by connecting them to accurate models is widely applicable, but here we focus on a few which are particularly adapted to material handling applications.

- Eskay Corporation, an AMHS supplier, employed emulation in order to test the control system for a relatively small project (see Figure 1) before it went on site for commissioning. The conveyors taking pallets of product to and from the Automated Storage and Retrieval System (AS/RS) were controlled by Think & Do™ industrial control software and the Warehouse Management System (WMS) for keeping track of pallets in the AS/RS was proprietary. The simulation model was connected to the Think & Do controller via an OPC server, and to the WMS via sockets. Initially, Eskay used the system to verify the operation of their control systems, as was intended. They localized and eliminated several bugs that would otherwise have been hard and time-consuming to find on-site, which vindicated their approach and use of emulation. The client then became extremely interested in the technology and spent several days on-site testing and checking the operation of the sys-

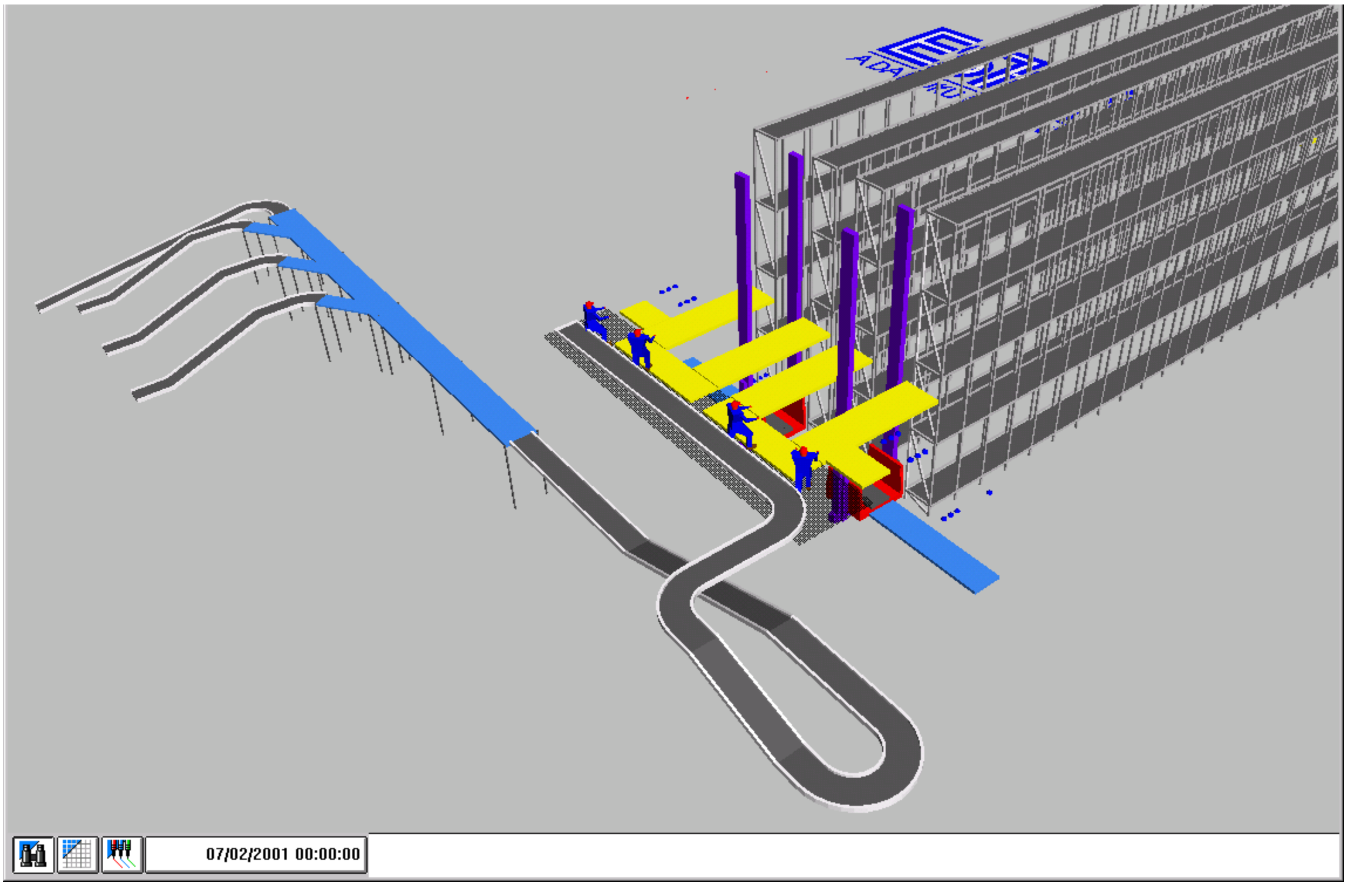

Figure 1: This Eskay Emulation Model Links to Both an OPC Server and a Proprietary WMS Controller Via Sockets

tem before shipping it to site, confident of its correct logical operation. Eskay claims their approach resulted in an easier commissioning phase, a decrease in on-site time, improved system testing and a very content customer (Young and Heider, 2002).

- A major multinational manufacturer investigated the viability of using a simulation model to test a control system by linking a medium sized model to a control system. The testing uncovered numerous problems in the control software and highlighted the value of emulation testing. The company has recently embarked upon an extensive phase of template-model building to accelerate the model build part of their emulation projects.
- E Squared M produces high speed bottling and food packaging lines (see Figure 2), and uses emulation as part of their standard project procedure to minimize control system development and debugging time spent on site during commissioning. Another benefit of testing the control system off-line, prior to commissioning is the higher quality of the result, leading to fewer ramp problems and fewer call-outs during production. E Squared M claims use of this technology compresses start-up by between 15 – 30%, (Mueller, 2001) and allows them to catch and eliminate10 – 20% more bugs than with conventional methods.
- A consulting engineering company in the UK is using emulation to develop and test a control system for an AMHS that they will never see in Mexico. Commissioning of the control system is to be done remotely from the UK, greatly reducing costs all round.

7 CONCLUSIONS

7.1 Where is Emulation Useful?

The testing of control systems using an emulation model is useful (and economically justifiable) under many different circumstances, including:

- When the testing is otherwise due to be carried out on the critical path of a project
- When the time available does not permit full testing before start up
- When the actual system cannot be sufficiently loaded to fully test the control system
- When the cost of real testing is greater than that of emulated testing.

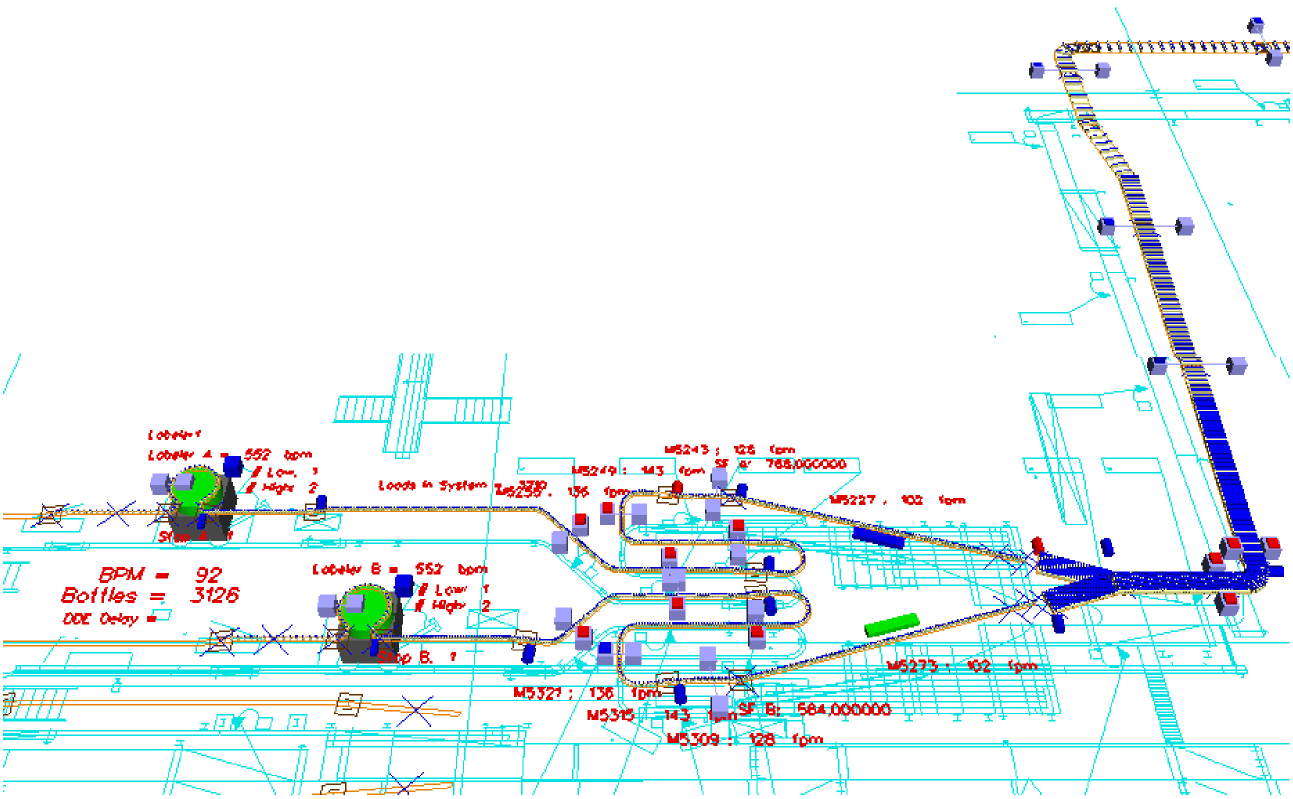

Figure 2: E Squared M Employs Emulation as a Standard Part of Their Offering to the Bottling and Packaging Industries

7.2 How Standards Help

The emergence of OPC was a major step towards the connecting of control systems from different vendors, and it enabled the development of software that could easily access data from a wide range of devices without any manufacturer-specific code from the third party developers.

It is to be hoped that there is sufficient reason and motivation within other data-intensive industries such as semiconductor to promote the development of something as simply applicable as OPC.

7.3 Where the Technology Goes from Here

Early adopters of the AutoMod emulation technology were quick to spot the advantages, both in terms of time and money, to be gained from employing emulation. In several cases they also recognized that the models they were building contained much that was similar, and so a higher level of automation was possible and would further accelerate the build process.

There is a general trend to create "front ends", or specific interfaces for industries or companies, in order to reduce the training necessary to successfully create and operate an emulation model.

One immediate aim of Brooks-PRI Automation is to develop the technology such that control engineers can use it with no formal training in simulation, rather than simulation practitioners. This trend highlights the fact that the testing of control systems using models is moving emulation away from simulation, although the technology necessarily remains embedded within it.

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AUTHOR BIOGRAPHY

IAN MCGREGOR has worked as Simulation Business Development Manager for Brooks-PRI Automation since 1996. He has been posted in Singapore, Japan and Utah. He has an MSc in Computer Integrated Manufacturing from Cranfield Institute of Technology in England, a Diplome d'Ingenieur from the Universite de Technologie de Compiegne in France and a BSc in Production Engineering from Kingston Polytechnic in England. He is a Chartered Member of the Institute of Mechanical Engineers. His e mail is: `<ian.mcgregor@brooks-pri.com>`