Empirical Modelling for the logistics of rework in the manufacturing process

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Abstract. The application of a new modelling paradigm ("Empirical Modelling") to issues associated with rework in a manufacturing process is illustrated with reference to the construction of an "interactive situation model" for a simple production process. This model is built up incrementally in a manner that is guided at every stage by experience gained though its execution, and in this respect imitates the manner in which systematic processes are generated from interaction with artefacts, other people and the environment that is at first unconstrained. The roles of the producer and the assembler in our model can be performed manually on different clients in a network, and each can also be independently executed automatically. This approach to modelling offers more insight than a conventional process model into how concrete activities underpin the abstract process. It can also be used as to stimulate imaginative problem identification and solution, and to assist conflict resolution.

Keywords: manufacturing process, rework, logistics, Empirical Modelling

1. Introduction

Empirical Modelling is a new paradigm for computing that has been developed at the University of Warwick, UK [1]. It exploits principles for computer-based modelling that focus on identifying patterns of agency and dependency through observation and experiment, and embodying these patterns in artefacts that are constructed in an incremental fashion using special-purpose software tools. Previous papers have described applications of EM to engineering design [2] and product modelling [3]. The aim of this paper is to illustrate, by means of an artificial but instructive example, how EM can in principle be used to address logistic issues in the manufacturing process. Our particular focus is on issues associated with rework.

Rework activities arise in connection with an established process model that operates in the context of diverse real-world factors, such as constraints on assembly, availability of parts, current status of the partially constructed product etc. Routine rework occurs when the relationship between the current stage of the process and the "real-world" state is inappropriate but nevertheless has been anticipated. For instance, a process may make exceptional provision for damage of a part during assembly. More radical rework, potentially involving re-engineering of the process itself, occurs when an unprecedented discrepancy between process stage and real-world state is encountered. The revision of the manufacturing process must typically reflect a yet broader range of factors, relating to cash-flow, employee capability and safety etc.

In a traditional modelling approach, it is difficult to take account of the manufacturing process and the associated real-world factors in a unified way [6, 10]. For instance, the process could be represented by a Petri-net and the partially constructed product by a CAD model, but the precise correspondence between stages in the process and status of the product would typically be hard to represent. In any event, failures in the process might be attributable to other logistic factors, such as the location of personnel. The strength of EM in this context is that it allows real-world state to be modelled in an open-ended extensible fashion so as to take account of new factors as they become relevant. It also enables explicit modelling of singular conditions and gives scope for the opportunistic intervention that is required to model rework scenarios.

1.1. The logistics of rework

Three kinds of practical activity are involved in a manufacturing process: standard work within the normal scope of the process, routine rework where the nature of the rework problem is familiar and remedial procedures are in place, and exceptional rework where unprecedented or ill-understood problems are encountered. The complex interaction between these activities frames the logistics of rework. Typical tasks and objectives to be addressed include:

- monitoring the process in operation and identifying and classifying rework
- setting up new routine rework scenarios and associated administrative and recovery procedures
- improving the manufacturing process to reduce the need for rework
- exploring the implications for rework of changes to the normal process

- decision-making for recovery in the event of exceptional rework.

A major issue in this logistics exercise is that the scope of the factors to be taken into account is exceptionally broad. Many of these factors are not typically referred to in the abstract process. For instance, there are practical considerations affecting the execution of the normal process, such as the capabilities and location of workers, the environmental conditions and the characteristics of the equipment used. There are business issues relating to financial and personnel matters. The decision-making takes place in a context where there are real-time concerns and live issues concerning suspended processes to be reckoned with. There are many viewpoints to be taken into account, potentially involving conflict and the need for diplomacy, and – for exceptional rework scenarios – the issues raised may be outside the scope of normal contractual requirements.

It is instructive to compare the logistics exercise for rework with the traditional requirements analysis and design activity involved in the conception of a manufacturing process. The typical approach to process specification is to make an in-depth analysis of the manufacturing objectives and business needs, and model this requirement before proceeding to implementation. Dealing with rework entails adding error detection and exception handling to this framework – as well as potentially revising the specification of the normal process – in a dynamic fashion that is guided by feedback from the practical execution of the process itself. This poses an exceptional challenge, bearing in mind that the conception of a process and its subsequent execution are activities that are typically associated with entirely different contexts. Taking rework into consideration also promotes volatility in the manufacturing process: minor changes in the manufacturing context that are abstractly insignificant – such as a change in personnel or in the supplier of a component – may expose hidden reasons for consistently successful execution, and motivate process re-engineering.

1.2. Process Modelling

Modelling is a natural way in which to give support to decision-making [9]. The complexity of the issues associated with the logistics of rework pose a particular challenge for a model-based strategy. The principal concern is the feasibility of devising an informative model of rework activity.

Traditional approaches to process modelling are problematic where rework is concerned. Whether our process model is abstract or has the character of a simulation, its construction relies upon comprehensive prior knowledge of the pattern of states and transitions that is to be represented. Whilst this enables us to model routine rework to some degree, it cannot deal with exceptional rework, where the circumstances that arise and the factors that must be taken into consideration are – by definition – not known in advance. The modelling that can be done in a traditional paradigm is an application of the expert's pre-existing knowledge of the manufacturing process, but the model that would be most useful in the logistics exercise must deal with knowledge as it is being discovered by the expert through observation and interaction in the actual manufacturing environment.

To elaborate on this issue, it is helpful to contrast two perspectives on the manufacturing process: the one idealised, the other realistic. In the idealised view, the activities of the process are viewed abstractly with reference to very specific ways of observing the actual activity. Not all the actual activity that goes on in executing the process is seen as significant. In the realistic view, the process is understood with reference to how it is experienced by the participants and viewed by a manager in a specific instance. In the realistic view, the characteristic interactions of the process are only a part of the total observation, some of which may have either hidden or no apparent relevance to the process itself. In normal circumstances, it is natural to think of the idealised and realistic views both separately and as conjoined. For instance: the worker who says 'this is a tricky process' refers to the realistic view; the business analyst who says 'this is a over-complicated process' refers to the idealised view; the manager who asks 'how do we know when to begin the testing phase?' is referring to both views.

In a rework scenario, the normal way in which we can conceive the idealised and realistic views both separately and conjoined is no longer appropriate. Rework relates to circumstances in which the standard relationship between the idealised process and the manufacturing activity itself breaks down, and it becomes impossible to view both together in a coherent way. There are always many ways in which such a breakdown can occur: through flaws in the process, extraordinary events in the actual environment, or human error. The aim of the rework activity is to realign the actual situation with the state of the idealised process, but there is no guarantee that this is possible in general. It all depends upon the severity of the discrepancy, and any process dealing with rework will always have an escape clause (resembling an 'exception handling routine' in a program) to trap problematic scenarios that could not possibly have been foreseen.

This discussion shows that modelling for logistic support in rework must in some way integrate the systematic activity associated with the idealised manufacturing process with realistic observation of the manufacturing environment in a highly flexible and possibly ad hoc manner.

The domains of activity associated with standard work, with routine rework and exceptional rework, as defined by the current process status when viewed from both the idealised and the realistic perspective can be conceived as nested as in Figure 1. The three regions of the figure, from inner to outer, correspond to what an external observer (such as the work scheduling manager) sees in the manufacturing environment when the process is going according to plan, when rework is in progress according to preconceived plan, and when there is an unprecedented discrepancy between the abstract process and what is being actually observed. The outermost boundary, fuzzily defined, delimits those situations from which recovery of the process is conceivable – for instance, a catastrophic event at the factory would create a situation outside this scope.

Traditional process modelling techniques target the activities that can be captured in systematic processes. They can represent what lies within the scope of the work and routine rework processes, and each modelling approach can take account of different aspects abstracted from the idealised and realistic perspectives on these. Many different approaches, including programming models, functional models, plan-based models, Petri-net models and quantitative models, are reviewed in [11, 12], where the prospects for an integration of approaches to take account of transaction processing together with communication and coordination are also examined. In principle – and at the cost of a much greater investment in formalising the manufacturing process – it may be possible for such integration to address a richer range of concerns encompassing to some degree environmental factors and human observation and interaction.

For logistic purposes in dealing with rework, this is not enough. Such techniques for modelling the process cannot take account of the human observation and assumptions about context that are tacit in normal successful execution, nor can they be integrated with the human intervention that is necessary in general to deal with the unforeseen.

1.3. Empirical Modelling

Our approach to tackling the logistics for rework problem is based on a new approach to modelling ("Empirical Modelling") developed at Warwick (cf. other refs on EM for decision-support). EM is unusual in that it first focuses upon modelling the states and potential agency in the environment in which a process is enacted, rather than the pattern of states and transitions that define the abstract process itself. The model of environmental state constructed in EM metaphorically serves the role of a canvas on which the modeller can trace the process, taking account of whatever environmental factors become relevant in an open-ended fashion as the model is being developed. This will be illustrated in our case study.

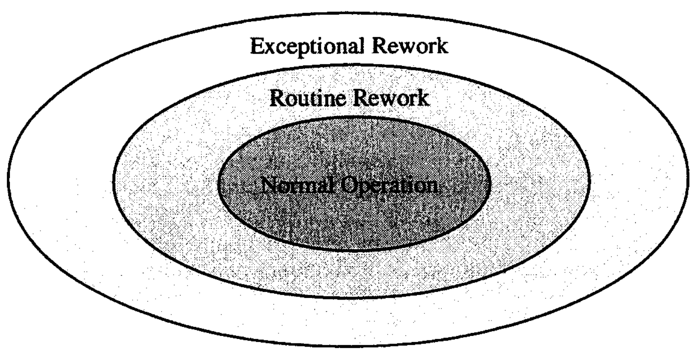

Figure 1. Normal operation, routine rework and exceptional rework

The orientation of EM towards representing the manufacturing process can be best understood with reference to Figure 1. Conceptually, the representation of the manufacturing process in Figure 1 is interpreted by viewing the activities from the innermost outwards. Normal operation of the process takes precedence over (presumably much more infrequent) routine rework, which in turn takes precedence over (presumably very infrequent) exceptional rework. When viewing the manufacturing process from the realistic – and from the EM – perspective, it is more appropriate to interpret Figure 1 from the outermost inwards. For the uninitiated observer in the manufacturing environment, abstracting the observations that are significant in the manufacturing process, and distinguishing those that are associated with instances of rework, is difficult – if not impossible. Identifying the idealised view of the manufacturing process and correlating this with what is observed in practice typically involves a long process of familiarisation and the observation of many instances of the process in operation.

The outermost-inwards interpretation of Figure 1 is also the most relevant to the logistics of rework. The original conception of the manufacturing process and its subsequent evolution are shaped by the identification and systematic organisation of reliable patterns of interaction that are first encountered – in ways that are not clearly differentiated into categories as in Figure 1 – in the experience of the participants. Whereas it is usual in the idealised view to interpret Figure 1 as describing the way in which normal operation degenerates into rework situations ranging from standard to chaotic abnormality, the manufacturing process is seen in the realistic view as emerging through evolution and growing familiarity from chaotic experience. The latter view is characteristic of the ongoing comprehension and re-engineering activities that are associated with the agenda for logistics set out in section 1.

Our principal objective in this paper is to show that, by applying EM principles and tools to an artificial but instructive case study, it is possible to trace the activities that lead to the identification of the work and rework processes, and so provide computer-based modelling support for their execution and development.

2. The production process case-study

2.1. Principles of EM

From a semantic perspective, the models developed in EM resemble spreadsheets, rather than conventional programs with a specific function and behaviour. A spreadsheet is viewed in a particular state, and this state corresponds directly to the state of an external referent. EM exploits scripts of definitions ('definitive scripts') – similar to the network of definitions that connect the values of spreadsheet cells – to represent state. Transitions are then represented both by the redefinition of existing variables in the script and by the introduction of new definitions (the counterpart of extending a spreadsheet through the addition of new cells). This approach to representation of state by computer is exceptionally expressive and powerful – it makes it possible to construct artefacts that imitate the state of a real-world environment in ways that are beyond the scope of computer models targeted at the goal-directed specification of pre-conceived patterns of state change, such as characterise the idealised manufacturing process. The quality of the imitation of state that EM provides is not primarily concerned with realism, but with representing the patterns of agency and dependency that the modeller projects on to the referent. This is similar to what happens in a spreadsheet – the user changes the cost of a component by redefining a cell (exercising agency), and expects the cost of the product and the profit from its sale to change accordingly (through a dependency).

In modelling a manufacturing process using EM rather than a conventional modelling technique, there is a trade-off. Conventional process modelling describes patterns of state change explicitly, but describes the states only in an abstract implicit manner. No matter how rich the choice of observables used to describe the manufacturing process, there will be observables, evident in the realistic perspective, that have not – and, without revising the model, cannot – be taken into account. EM explicitly addresses the modelling of state-as-experienced, but – in the first instance, at any rate – represents processes only implicitly as particular patterns of state change that can be enacted by the modeller. Naturally, no definitive script can take account of all the observables associated with a particular realistic state to which it refers, but the explicit control that the modeller can exercise over the script at any stage allows the choice of observables to be opportunistic rather than constrained by prior commitment. This is similar to the way in which an interaction with a spreadsheet can signify a change of state ("the price of a component has been reduced") or a change of model ("the sale price now takes account of a new tax regulation").

A detailed account of EM principles and tools is beyond the scope of this paper. This section concludes with a brief review of the main ideas needed to appreciate the case-study that follows.

With the concept of the outermost-inwards development of a manufacturing process in mind, the initial focus for EM is on the observables, dependencies and agency in the environment in which the process is to operate. The product of the modelling is a script, together with an appropriate family of automatic agents. This is developed by the modeller stage-by-stage and step-by-step in an interactive manner so as to reflect the emergence of a systematic process from an initially ill-defined environment through observation and experiment. Because of the interactive and situated nature of the model-building activity, the evolving computer model is described as an "interactive situation model" (ISM) [5].

The construction of the ISM exploits a purpose-built software tool – the EDEN interpreter. This allows the modeller to create a definitive script to represent both the internal state of the computer and the state of the computer display, and automatically maintains the dependencies amongst all the ingredients of state prescribed by the script. The modeller can also devise operators to be used in the formulae associated with definitions, and introduce actions to redefine variables in the script automatically subject to appropriate preconditions. EDEN supports several different interfaces through which to extend or amend the definitions in the script. There is an input window, through which the model-builder can act as an agent with unrestricted access to the entire script. There are means within the modelling paradigm to supply customised interfaces designed for specific modes of interaction with the model. The interpreter can also be run in a distributed mode over several workstations in a client-server configuration.

2.2. Case study: a simple producer-assembler process

The case study used to illustrate the potential application of EM to rework in a manufacturing process involves constructing a 'process-rework' ISM – the PRISM – in the form of an abstractly defined producer-assembler process. Where the logistics of rework is concerned, it is more important to model the activities that are involved in the process than the actual nature of the components and assemblies being manufactured. On this basis, the PRISM involves generating characters and substrings – representing the components of an assembly – and combining these to form a sentence – representing the product to be manufactured. The roles of the producer and the assembler in the PRISM are to be played on two separate client workstations, connected to a server that mediates their communication and records the contents of an intermediate store.

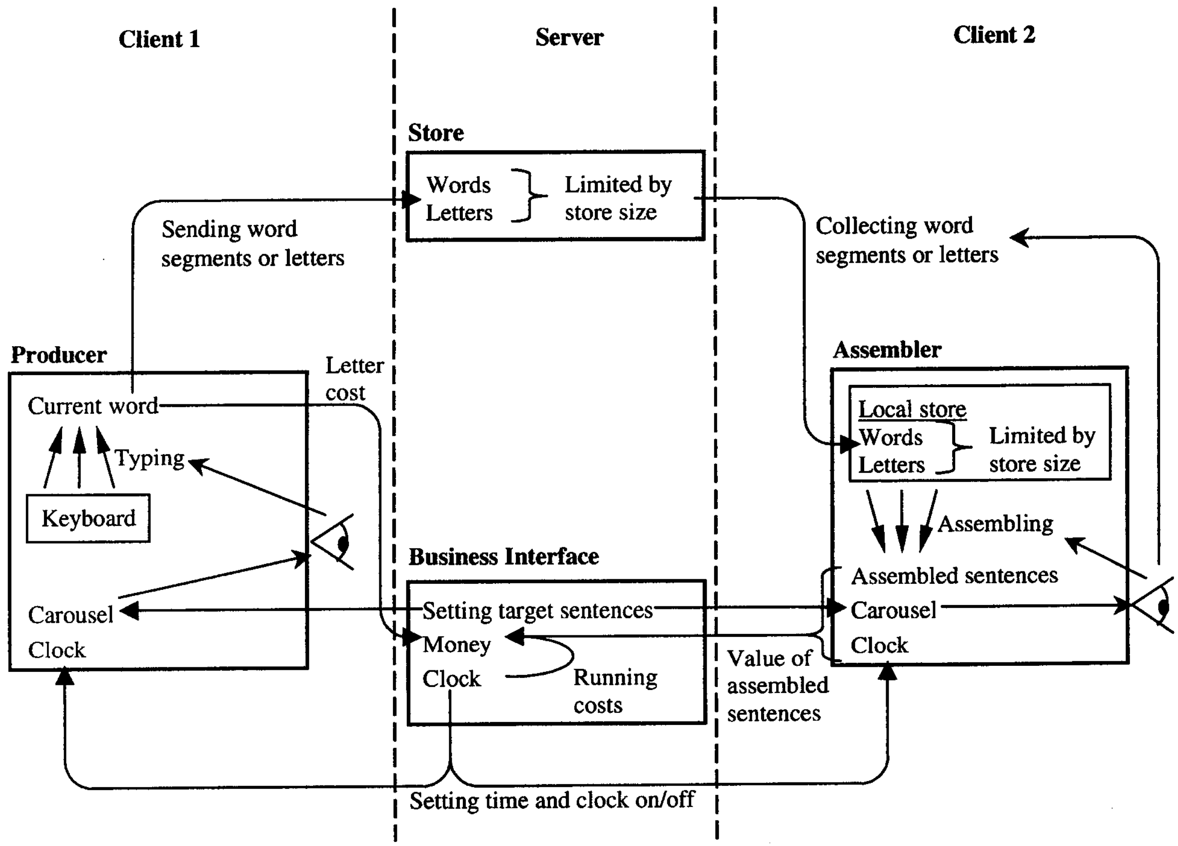

Figure 2. A diagrammatic representation of the distributed producer-assembler PRISM

As will be illustrated below, there is no particular conceptual or technical difficulty in extending the PRISM to handle more realistic components and products. This is just one of many possible extensions of the PRISM that can be developed by elaborating the model of the environmental state to include richer observables – an elaboration that in principle can be carried out by a seamless revision of the definitive script quite unlike the re-engineering of a conventional software model. Without such extension, the PRISM is a suitable metaphorical representation of the production process as it might appear to a manager with expert knowledge of business interaction but only a basic knowledge of the physical mechanisms in the assembly. It might be that even such a manager would in some circumstances need to know more about assembly at this level of detail, and ad hoc extension of the PRISM to reflect this need is also within the scope of the EM paradigm.

The primary motivation for the case study is to demonstrate that the development of an ISM can trace the emergence of a manufacturing process from interaction with the environment that is initially only loosely constrained and structured. This emergence of order from chaos is analogous to the way in which children develop a game out of casual interaction with each other and appropriate artefacts such as walls, tennis balls or toys. In the earliest phase of such development, the focus is on identifying activities that can be performed to a ritual pattern with some degree of reliability, often subject to acquired skill. After a time, a framework informally specified by rules of interaction is established, but these – like the business rules of the manufacturing process – generally need to be reworked as new scenarios are encountered and players become more skilful, or learn to take advantage of flawed rules and concepts. The logistics of re-engineering and refining games is similar to the logistics of rework. By way of illustration, an ISM that can be used to generate a family of games based on principles similar to OXO, including all manner of non-standard variants that can be freely devised by the modeller is described in [4].

The PRISM was developed by Michael Evans. The first phase involved the construction of a suitable artefact to represent the role of the producer. Since the correspondence between the PRISM and its intended referent is shaped by observables, dependency and agency, the goal of this construction was to provide an interface for generating letters that could imitate the production of real components. To his end, Evans experimented with a variety of different styles of keyboard, and with different strategies for displaying the results of actions to the producer. In the current model, as described in more detail below, the producer operates a mobile phone keyboard, and there is no direct indication on the display of which letter has been generated. The development of such a device illustrates the prominent role that experiential concerns play in EM – the response of the keyboard is governed by timing considerations, and has to be tuned to human expectations. It also underlines the shift in emphasis in EM: in abstract process modelling, an event such as the production of a basic component might correspond to any number of experientially different actual processes.

The major phase of the development involved the continuous evolution of the PRISM over a period of about two months. The initial model featured one user acting as both the producer and the assembler, with the construction of the alphabet as the target. The two roles were next separated and distributed to introduction of two roles, and a carousel to allow a sentence to be simultaneously displayed to the producer and assembler was added. Physical constraints concerned with movement between the store and the assembly area, with a restriction on the number of items carried, were then introduced. To reflect the business context, the time taken to assemble a sentence was taken into account, together with a financial model that incorporated a reward for sentence completion that depreciated with time. This was then complemented by the introduction of a richer interface, e.g. to allow access to more than one carousel, include the clock and cash balance in the display. The most significant feature of this development activity was the way in which the precise direction of the extension of the model at each stage was guided by experience of its use, and by the desire to ensure that as many diverse elements of a realistic manufacturing process as possible were represented. There is no conceptual reason why this enhancement of the model could not continue yet further – the chief limitation being the capacity of our modelling tool to record a definitive script and to manage the complex interaction of agents over an extended period of time.

2.3. An overview of the PRISM

Figure 3 is a screenshot of the assembler's interface in the latest version of the PRISM. In outline, the process involves a producer who generates letters and combines them into short segments of words selected from the target sentence, an assembler who combines these into a target sentence. The letters and word segments generated by the producer are passed to the main store depicted at the top right of Figure 3, where they are collected by the assembler to be brought back to the assembling area. The production process is constrained in that letters and word segments once combined cannot be broken apart and that a target sentence must be assembled exactly in order to earn the financial reward.

The producer uses a mobile phone style keyboard to generate letters and word segments that are sent to the main store subject to space being available. This choice of keyboard, and the fact that there is no visual feedback to the producer when letters are generated, promotes errors when the producer's role is enacted manually. As shown in Figure 2, the ISM runs on a client-server configuration where the producer and assembler run as clients to a server that implements the functions of the main store and supports a 'business interface' through which target sentences can be specified and where details concerned with time and money are displayed. The generation of letters and the working time for the producer and assembler are taken into account in the costing model. On collecting letters and word parts from the main store, the assembler retrieves them for assembly from a local store and uses them to assemble a sentence identical to the target sentence displayed on the carousel. The value of the sentence on successful assembly is assessed according to its timeliness. The calibration of the time and costing parameters was another subject for empirical determination during the modelling process.

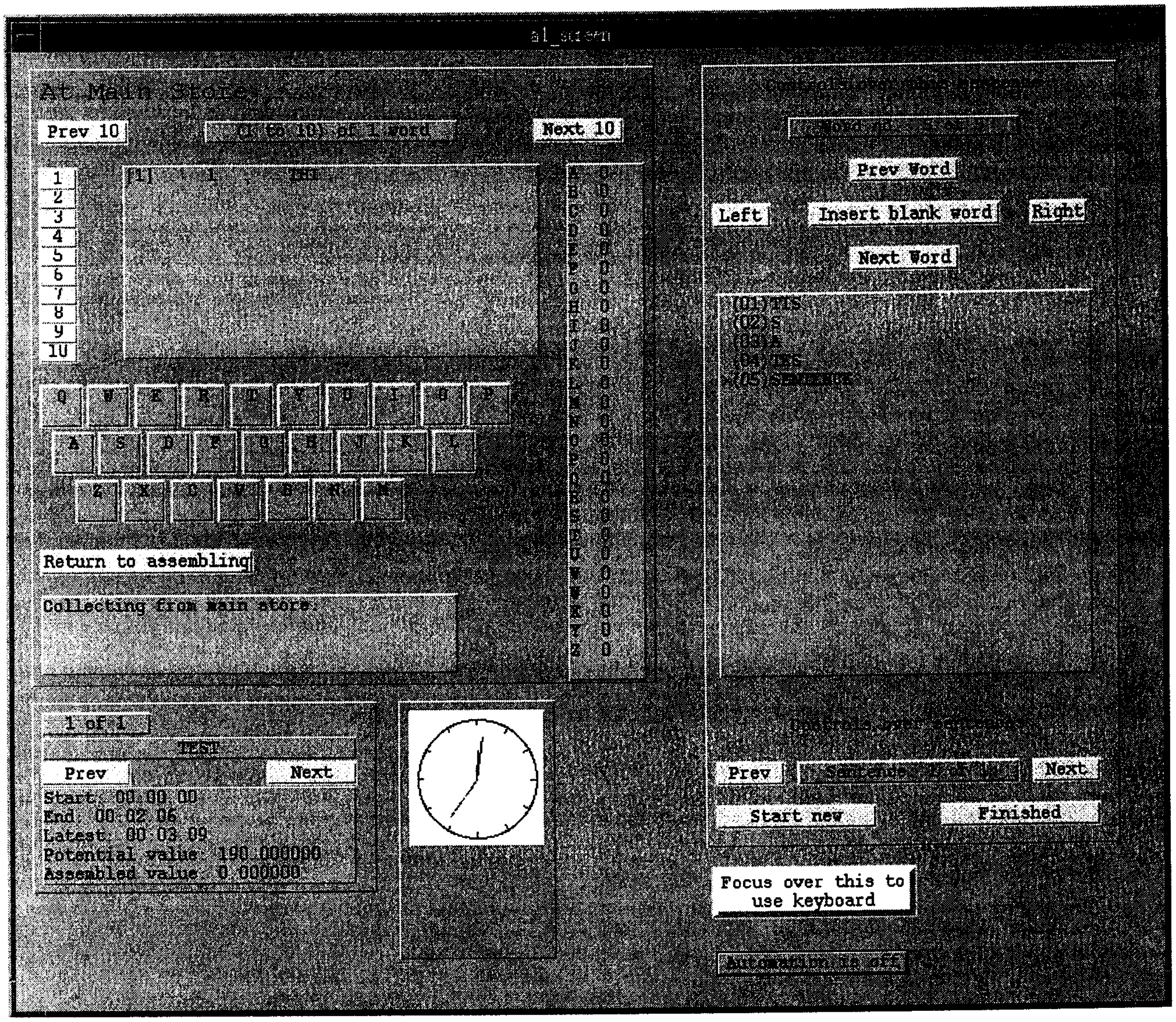

Figure 3. A screenshot of the interface for the assembler

The components of the screenshot include a clock, a carousel which displays the words of the target sentence one at a time, an automation button that allows the role of the assembler to be played either manually or automatically, and a sensitive region that, when in focus under the mouse, allows input from the computer keyboard. Similar components feature in the producer interface. The word segment and letter store features at both the main store and in the assembly environment, and movement between these environments is triggered via a mouse button. The mobile phone keyboard interface in this store region of the screen is used to select components either for collection in main store, or for insertion into a word within the sentence currently under construction. When parts are being collected from the main store, they are displayed in a box. The panel used for assembling sentences is active only in the assembly environment. The lower section of this panel is used to select the sentence currently under construction, or to initiate a new assembly task. The upper section is used for the sentence construction: in this section, blank words can be inserted, particular words can be selected, and the cursor can be positioned so as to indicate the position in which components retrieved from store are to be inserted.

The screenshot in Figure 3 highlights a situation necessitating rework that was first identified through automatic execution of the PRISM. The target sentence in this instance is: "THIS IS A TEST SENTENCE". The assembler composes the word segments "IS" – intended to serve as the word "IS" in the target, and subsequently composes the word segment "THI" as the beginning of the word "THIS". As there is no communication between the producer and the assembler, the assembler is prone to locate word segments inappropriately. In this case, the segment "IS" is interpreted as part of the word "THIS", so that there is subsequently no position in which the segment "THI" can be placed. Rework in this instance can be simulated by intervention on the part of the modeller, acting on behalf of the producer to generate the letters "T", "H" and "I" that the producer can use to complete the target. A side-effect of such a rework problem is that the component "THI" remains unused in store, and the cumulative effect of such problems is eventually to fill up the store with redundant components.

3. Application of the PRISM

This section reviews the development of the PRISM with particular attention to those features that show the potential of EM in providing support for the logistics of rework.

- Exposing the empirical roots of a manufacturing process

It is characteristic of a person with insight into a manufacturing process that they know (or have a shrewd intuition about) what would be relatively easy to change, what would be difficult to change, and why. Where the logistics of rework are concerned, it is vital to have this kind of knowledge so as to be able to discriminate between modifications that can be made without serious disruption and those that involve complex re-engineering. Acquiring this intuition involves understanding the empirical basis for the abstract process. A conventional process model is of limited use in this respect.

The ISM was constructed by tracing the empirical development that might typically lead to a manufacturing process. The product of this activity is an abstract manufacturing process together with an understanding of the empirical and experiential aspects on which it relies, and an ISM that embodies the experimental contexts required to confirm and corroborate this understanding. The development of the PRISM using EM more closely resembles traditional engineering than a business or software process methodology. At each stage, experience of use had to be gained and the reliability of interaction established prior to further development. For instance, the basic form the producer-assembler interaction was established at a relatively early stage, but the experiential aspects concerned with timing and the modes of observation and action evolved from experimental use. Likewise, the implications of machine failures or human error could only to be considered after a reliable and intelligible process had been established. The way in which the development of PRISM creates a legacy of experimental environments is also characteristic of an engineering activity. For instance, PRISM has spawned several alternative models for character input via a graphical interface.

- Stimulating brainstorming through rich and imaginative process analysis

Because of the breadth of issues involved in the logistics of rework, it is essential to view the manufacturing process in an open and imaginative manner. Neither the triggers for rework nor the implications of rework are captured in an abstract process model. If the focus of the decision-maker is on a traditional process model, the idealised view of the manufacturing process acts a filter through which to see the realistic behaviour, and this promotes a closed-world perspective.

A significant feature of developing the PRISM was the way in which the imagination of the modeller was engaged. Conceptual progress towards framing and comprehending possible production processes was typically made by imposing real-world interpretations upon the experience gained from experimenting with the PRISM. For instance, in the assembler's view of the PRISM, the movement from the assembly location to store location is animated in such a way as to provoke the consideration of several questions that are relevant to the real production environment: how long does it take to move between the assembly point and store? What constrains the number of items that can be retrieved from store at one time? When does the assembler have visual access to the store contents, to what extent is this comprehensive, and what is the role and benefit of memorising store contents to the assembler? Automatic execution of the model further highlights activity of this nature – when the automatic process breaks down, it is natural for the modeller to project on to the PRISM explanations that might apply to the real situation. A further benefit of an EM approach in this connection is that minor interactions with the PRISM enable the modeller to modify the relevant features so as to set up corresponding 'what if?' scenarios. This encourages exploration and experiment, and helps to create in-depth understanding of the mechanisms underlying the abstract process.

- Envisioning problems and solutions

A common and taxing issue in dealing with complex processes is the evaluation of potential solutions. It is well-recognised that such evaluation is difficult if not impossible in the abstract, and often has to involve empirical investigation (in the spirit of what Temple Grandin [8] describes as 'envisioning'). Traditional simulation can be invoked in this context, but it is typically a slow and costly activity to be introduced with discretion, as when the implications of a poor decision are exceptionally serious. It is also cumbersome, in that the requirements for the simulation exercise are difficult to anticipate and subject to change dynamically as insight is gained.

The development of the PRISM shows that simulation in EM, though unsuitable for tackling large scale problems that for which traditional simulation is required, can be a relatively agile and lightweight activity. It was possible to take account of additional factors such as cost and time by extending the PRISM, to identify potential problems for sentence construction through the automation of the producer and assembler, and to carry out a range of 'what-if?' experiments to tune the process model for human use. The advantages of the PRISM include:

- scope to combine automatic manipulation and manual interaction with state in an opportunistic and efficient manner,
- means to revisit conceptual threads in an analysis without any dislocation of thought, and to further develop or adapt associated components of the PRISM,
- a coherent and integrated framework within which to conduct simulations to investigate a family of related problems.

This encourages a pro-active approach to the identification of possible pitfalls in a process specification. For instance, within PRISM, by judicious superagent intervention, it is possible to simulate the theft of components from store, human errors or equipment faults in the component generation, and synchronisation problems generated by mismatched workers.

- Conflict identification and resolution

The need to take account of so many different perspectives on the manufacturing process is a major issue in the logistics of rework. The view of a business analyst who focuses on the efficiency of an abstract process may well be a conflict with that of an actual participant, and take little account of the potential implications for rework. When a need for exceptional rework arises, the perceptions of the interested parties are not in general consistent, and stem from different kinds of knowledge and levels of understanding. A hierarchical personnel structure may be subverted in such scenarios – the least privileged worker may be the one who is best informed to make a decision.

The distributed and open-ended nature of the PRISM is well-suited to the investigation of such issues. By adopting the role of superagent, it is possible to simulate actions on behalf of all the participants, as if from their personal perspective. For instance, when – as can happen in the absence of communication between the assembler and producer – it becomes impossible for the assembler to complete the current sentence without improvised action on the part of the producer, the superagent can step in to resolve the problem by manual interaction.

4. Conclusion

Many processes in science and engineering are precisely prescribed by theories and equations. Business processes are much less tightly prescribed, and cannot be completely closed in character – in particular, it is impossible to give a full account of the role of human agents. The solutions to problems in science are generally precisely determined by mathematical reasoning. In contrast, business solutions admit myriad minor adaptations. The distinctive characteristics of business processes are not reflected in the paradigms that are most commonly applied to process modelling and problem solving, which – following the example of science – can only take account of empirical evidence and techniques in a limited and predetermined way. The concept of an ISM offers an alternative paradigm in which automatic problem-solving activities and the intelligent intervention of human agents can co-exist harmoniously. By exploiting the way in which model-building in EM records the interdependency between different pieces of knowledge, and their relationship to experience, it becomes possible to explore many processes and many possible solutions in an integrated fashion.

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