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Integration of the Cimosa and high-level coloured Petri net modelling techniques with application in the postal process using hierarchical dispatching rules

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Abstract: Enterprise processes, i.e. business and manufacturing, rely on enterprise modelling and simulation tools to assess the quality of their structure and performance in an unobtrusive and cost-effective way. Each of these processes is a collaboration of inseparable elements such as resources, information, operations, and organization. In order to provide a more complete assessment of enterprise processes, a simulation approach that allows communication and interaction among these elements needs to be provided. The simulation approach requires an analysis of the performance of each element and its influence on other elements in an object-oriented way. It also needs to have the capability to represent the structures and dynamics of the elements mentioned, and to present the performance assessment comprehensively. This will ensure a more holistic simulation modelling task.

These simulation requirements have motivated the investigation of the novel integration of two popular enterprise process modelling methods: Cimosa and high-level coloured Petri net. The Cimosa framework is used to formalize the enterprise modelling procedure in the aspects of representing process elements, structure, behaviours, and relationships. The high-level coloured Petri nets method provides the mechanism to simulate the dynamics of objects and their characteristics, and also to enable communication among the objects. The approach is applied on a postal process model, which involves elements from manufacturing processes, i.e. machine processing (sorting), inventory (storage), product flow, and resource planning. Simulation studies based on the hierarchical dispatching rules show that the integrated approach is able to present vital information regarding the communication method, resource management, and the effect of interactions among these manufacturing process elements, which are not provided by the current modelling system in the postal company. The current paper has presented a novel mechanism, i.e. Cimosa–HCTSPN modelling approach, to extract information on process elements and their interactions. It has also presented the novel hierarchical dispatching rules and contributed to the extension of information that can be represented for a postal process.

Keywords: Cimosa, enterprise modelling, high-level coloured Petri net, dispatching rule, mail sorting process

1 INTRODUCTION

The needs for business and manufacturing process simulation modelling and evaluation have significantly increased owing to globalization, which has created intense competition between businesses. The advances in information technology and its applications, mainly owing to continuous cost-reduction of hardware, have also supported the growth in the application of enterprise modelling and simulation tools. It is vital for companies to be

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able to simulate their own processes perceived from different angles, and to provide performance indications for these different view points. This is to make sure the process, i.e. its design and performance, can be assessed comprehensively by detecting all inefficiencies. This has prompted businesses to look for methods or applications that can sufficiently represent their processes and provide a wider spectrum of simulation evaluation in terms of the process structures and dynamics.

The computed integrated manufacturing open system architecture (Cimosa) framework [1] is a popular formalized modelling technique used in representing the four major facets (i.e. functions, resources, organizations, information) of a generic enterprise process. The framework provides mechanisms to represent a holistic perception of a process and consists of the fourview points. The framework also provides the mechanisms for the model design, reuse, and implementation.

The high-level coloured Petri nets simulation application – ExSpect – provides hierarchical modelling with attributed object flow. Information and characteristics of objects can be represented and simulated as signals or data. An introduction of the coloured Petri net (Petri net that equips tokens with data values, i.e. information, knowledge, and general data types) can be found in reference [2]. The objective of the present paper is to investigate the similarity and possible methods to integrate these two modelling techniques and to apply the resultant integrated approach to a mail sorting process, followed by a simulation study of heuristic dispatching rules.

The Royal Mail Leeds Sorting Office processing operation has been studied. Owing to its diverse products and complex operation pipelines, a simple version of the operation is modelled to study the behaviours of different product streams. The model involved three main product streams and four automated mail sorting machines. Mail arrival is followed immediately by the segregation process where business and stamped (social) mail are separated. Business mail will go through a process called 'revenue protection' to verify and confirm customer payment. Depending on the type of business mail (i.e. printed postage impressions, and meter in this case), further segregation results in first class of the business mail being sent for machine and manual sorting, and second class mail sent to inventory for the next-day processing. The stamped (social) mail will also be filtered with the larger size items (i.e. packets, parcels, flats, etc.) sent to manual sorting, and the letters sent to machine sorting. Unlike the business mail, the further segregation of social mail will result in both first and second class items being sent for machine and manual sorting. The sorted second class items will remain in inventory for the next-day delivery. Manual sorting operations involve items that are unsuitable for machine sorting and rejected mail from machines. Mail can be rejected owing to several reasons such as thickness, size, address, content, and condition.

The three product streams (i.e. printed postage impressions, meter, and social (stamped)) will be competing for machine availability, which is reflected in the model. Each machine will be available for any of the product streams if it is not occupied.

This research presents the following novel contributions:

(a) the integration of the Cimosa modelling concept with the hierarchical coloured time stochastic Petri net (HCTSPN) (ExSpect) modelling application;
(b) the application of Cimosa–HCTSPN in extracting information for mail sorting process elements and their interactions;
(c) the derivation of the hierarchical dispatching rules (HDR) for the mail sorting process simulation.

2 CIMOSA IN SIMULATION MODELLING

Cimosa is an enterprise system that is able to model a design, reconfiguration, and integration framework that was developed by the ESPRIT Consortium AMICE in 1994 as a series of ESPRIT projects (EP 688, 5288, and 7110) [1]. Since then its application has proved to be valuable to many areas of business in the quest to achieve a cohesive enterprise system with competitive edge (e.g. Monfared *et al.* [3] presented their modelling approach for machine production in the automotive industry). CIMOSA has contributed to the different aspects of enterprise engineering and integration such as business process re-engineering, enterprise integration [4, 5], and workflow management [6]. The CIMOSA framework has also formed the design basis for many enterprise modelling applications [7, 8].

Attempts to amalgamate the Cimosa's well-defined formalism with the mathematically sound simulation model formalism of Petri nets are evident [9] to perform analytical analysis as well as statistical and mathematical analysis. The integration is presented through the construction of the systems engineering workbench open systems architecture (SEWOSA) enterprise modelling workbench. The workbench implemented the formalism of Cimosa, generalized stochastic Petri nets (GSTPN), predicate-action Petri nets, object-oriented design, and CIM–BIOSYS (building integrated open system) integrating infrastructure to provide a consistent mapping mechanism between

models across the integrated manufacturing system enterprise modelling life cycle phases.

The few shortcomings of the Cimosa–GSTPN integration are:

(a) token representation can only take one form (i.e. single attribute token);
(b) simulation animation is not available;
(c) there is limitation on the size of the Petri nets model;
(d) the inherent syntactic differences between the two are not included;
(e) the application is loosely integrated across two different platforms (i.e. Windows and Unix).

Another Cimosa-to-Petri nets formalism mapping is presented by Dong and Chen [10]. The mapping results in the derivation of a structured process modelling algorithm for the supply chain business process design. The so-called well-behaved control structures, chaining rule, and modified nesting rules are used to guide the design of a structured process model. Owing to the 'design' issue, a model can only be constructed using the six well-behaved Petri nets constructs (i.e. starting point, ending point, sequence structure, repetition structure, selection structure, and parallel structure) as the argument emphasizes that the direct application of any combination of the Cimosa's nine behavioural rules can be impractical for the supply chain process.

Nevertheless this sets some limitations.

1. The modelling constructs are not flexible enough to model existing systems.
2. This prevents existing systems with 'not well-behaved' processes from being assessed based on their existing structure.

Any performance evaluation on the model created with the well-behaved constructs will be 'unrealistic' in terms of problem identification for an existing system with its unique process and structure that may not reflect 'a perfect model'. The most current research done on the Cimosa-to-Petri nets integration is the work of Cheng and Popov [11]. The Cimosa concept was implemented by modelling the following aspects:

(a) the enterprise process (i.e. functions and enterprise activities) using timed hierarchical object Petri nets;
(b) the organizational, information, and resource aspects by using the object-oriented technique and database.

The predicate–action Petri nets method was also implemented to provide the analytical evaluation for the extended enterprise model. The work did not mention the rules guiding the Cimosa constructs or model transition into Petri nets models.

3 CPN AND EXSPECT APPLICATIONS

Petri nets are a mathematically sound modelling and simulation formalism enabling system structural (e.g. deadlock, reachability, etc.) and behavioural (e.g. make-span, tardiness, work-in-progress, etc.) analysis and can represent systems that demonstrate concurrency, parallelism, synchronization, non-determinism, and resource-sharing features [1]. Petri nets were pioneered by Carl A. Petri and were used as net-like mathematical tools for communication study in 1962 [12]. Since then, many extensions and variations have been developed. In the current paper these extensions and variations will be referred to in two major categories: the non-coloured Petri net (NCPN) and the coloured Petri net (CPN).

Petri nets and their variations have been applied in many fields, mainly in the domain of modelling, simulation, and performance analysis. CPNs are excellent tools for communication and computer network modelling and analysis, owing to their ability to represent data and information flow using attributed tokens [2]. The token does not purely represent an object with name or number in this case, as it can carry information or even knowledge (i.e. belong to the object represented) as much as the CPN tool is designed to allow. It also provides the means to represent a decision-making process in workflow and business operation management.
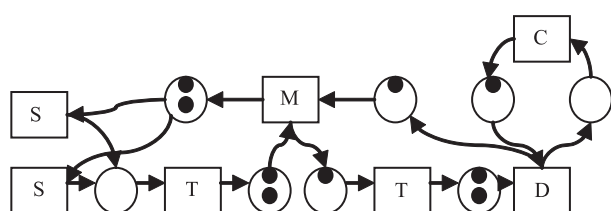
The CPN was first derived from predicate/transition nets by a group of researchers from the Aarhus University [2]. Aalst demonstrates some simple functionalities of high-level Petri nets (HLPN) in terms of CPNs and presenting applications in the area of process redesign, particularly the redesign of logistics and manufacturing systems [13]. He emphasizes that CPN modelling can be the interface between the problem situation and the methods of analysis. Figure 1 shows the logistics chain modelled. Aalst implemented the ExSpect CPN simulation approach in evaluating different workflow qualities in terms of the process performance [14]. A workflow knock-out process is re-engineered according to some heuristics and the performance is assessed by simulation. This approach provides process alternatives for the decision-making processes.

Chen and Chen [15] suggested the object modelling technique (OMT) in representing the different flexible manufacturing system (FMS) objects into classes in a dynamic tool-sharing control environment. The approach is to transform these classes into the CPN. The instantiated CPN objects are then integrated to form the complete system model.

Performance of the system is assessed through the simulation of the tool-sharing rules. The OMT to CPN translation is a time-consuming manual process and the derivation and integration of the object instances using the non-hierarchical representation approach can be unmanageable as the number of objects modelled increases.

Lin and Fu [16] presented the application of the generalized stochastic coloured timed Petri net (GSCTPN) to model an integrated circuit (IC) wafer fabrication system, such as loading, re-entrant processing, unloading, and machine failure. (The IC wafer is a thin slice of semiconducting material, such as a silicon crystal, upon which microcircuits are constructed by diffusion and deposition of various materials.) The GSCTPN is also used in scheduling adjustment. The CPN can represent the manufacturing system in two different dimensions; Zimmerman and Hommel [17] separated the manufacturing system structure model (facilities and resources) from the production routes model (behaviours or process) and allowed the automatic integration of both the models in an effort to evaluate resource utilization. Some of the differences between the NCPN and CPN are summarized in Table 1. More of the important advantages of CPN can be found in reference [2].

With the presented background, a variation of the Cimosa–Petri nets model integration is proposed. The Cimosa framework will be integrated with the adaptive programmable HCTSPN tool (ExSpect). Different mapping rules will be presented to reflect the modelling flexibility. This work will complement the previous work done and fill in some gaps by providing a more granular modelling environment, incorporating colour tokens for information and knowledge flow definition, implementing a more cohesive integration, and applying a more powerful simulator.

4 THE PROPOSED CIMOSA–HCTSPN INTEGRATION

The proposed integration involves a definition of mapping rules for the representation of the Cimosa modelling components with the ExSpect HCTSPN simulation modelling components. Table 2 depicts the modelling components for the two techniques. Both the Cimosa and the ExSpect HCTSPN share some very similar characteristics:

(a) both allow hierarchical and object-oriented modelling;
(b) both reuse the individual hierarchy level of the model.

The lowest level component in the Cimosa framework is the enterprise activity (EA) and this coincides with the ExSpect component processor. The processor is a programmable transition unit as in common NCPN and the place is represented by the component channel.
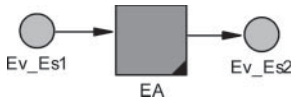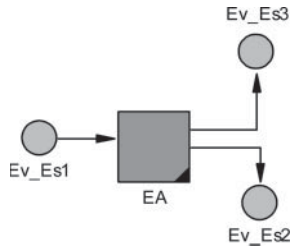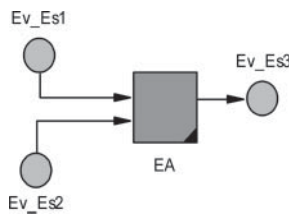
As previous research on the Cimosa-to-Petri net translation has been focusing on the design aspect of enterprise, manufacturing, and supply chain system, the building blocks (models) derived from mapping the Cimosa behavioural rules into Petri nets are limited to certain patterns, i.e. numbers of places and transitions and the way they are connected. This may obstruct any modelling effort for a system that may not display the same patterns but still behaves within the boundary of the Cimosa behavioural rules.

In this case, the approach is to allow both the existing and a new system to be modelled. Hence this calls for more granular and flexible building blocks with fewer components to represent behavioural rules in order to reduce the complexity of the final Petri net model. This approach will allow

S = Supplier, T = Transport, M = Centre, D = Distribution Centre, C = Customer

Fig. 1 A logistics chain modelled with logistics building blocks

Table 1 Comparison between NCPN and CPN

Characteristics	Non-CPN	CPN
Token representation	Data	Data, information, knowledge
Representation size	Complex	Simple
Subnets differences	Not easily distinguishable	Easily distinguishable

Table 2 Corresponding components of the Cimosa and the ExSpect HCTSPN simulation application

CIMOSA modelling components	ExSpect HCTSPN modelling components
Domain	System
Domain process	Processor/system
Business process	Processor/system
Enterprise activity	Processor
Object view	Token attribute(s)
Events	Token
Ending status	Token attribute(s)

Table 3 Cimosa–HCTSPN behavioural rules representation

Cimosa process behavioural rules	ExSpect behavioural rules basic building blocks
Forced sequential/sequential	Sequential routing
	Ev_Es1 EA Ev_Es2
Conditional sequential rule/ spawning rule	OR-Split/AND-Split
	Ev_Es1 EA Ev_Es3 Ev_Es2
Rendezvous rule/ convergence rule	OR-Joint/AND-Joint
	Ev_Es1 Ev_Es2 EA Ev_Es3

Table 4 Cimosa enterprise activity's inputs and outputs definitions

Enterprise activity inputs and outputs	Meaning
Function input	Object views to be processed or transformed (i.e. information or physical)
Function output	Object views produced or transformed
Control input	Informational object views used as control or constraints but not to be modified by the activity
Control output	Ending statuses or events generated by the activity
Resource input	Functional entities (i.e. man, machines, etc.) used as resources required to execute the activity
Resource output	Informational object views used to reflect the status and/or utilization of resource objects

Table 5 The loop and sharing rules

Rules	Model applying sequential routing building blocks
Loop	
	dummy Ev_Es1 EA Ev_Es2
Sharing	
	Ev_Es2 Ev_Es1 Ev_Es3 EA Ev_Es4

business users and modellers to define their modelling target without the constraints of pattern limitation. This is especially true in the case of modelling an existing system that may not be built to behave within the boundaries of the SEWOSA Petri net building blocks patterns and/or the patterns of the well-behaved supply chain building blocks.
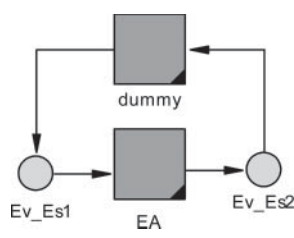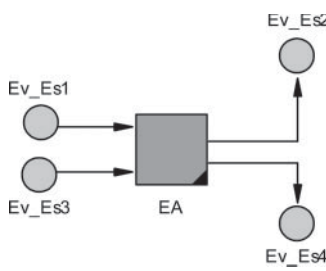
The more granular and flexible approach is achieved by establishing the representation of the EA as the lowest representation building block with its inputs and outputs, i.e. in terms of functions, controls, and resources, using the lowest-level building blocks of the ExSpect tool – the processor. This transition element provides users with the ability to customize the program codes to fit design requirements. Thus a processor can represent any behavioural rules as these can be programmed into the transition.

The mapping rule presented in Table 3 demonstrates the reduced numbers of building blocks that are still able to represent all possible Cimosa behavioural rules. Table 4 presents the types of inputs and outputs accommodated by the Cimosa enterprise activity [1]. These different types of inputs and outputs, which reflect the diverse types of object flows, can be abstracted as the attributed tokens in each of the building blocks.

Besides the three basic building blocks, the Cimosa process triggering rule (Start) and completion rule (Finish) can be represented by a token and a place. Sequential routing building blocks can also accommodate the loop rule and an extra scenario termed 'sharing', where there is sharing of the enterprise activities. The sharing building blocks, which can either be an ANDOR-split or ANDOR-join, allow the user to define an EA that can be shared by many different inputs and outputs of other activities and/or business processes. These two rules are illustrated in Table 5.

The five basic building block structures and the Cimosa rules can be inherited to other ExSpect components. For example, to inherit the structure to a higher level, the EA processor in the previous

tables can be replaced by the system component of ExSpect to represent the domain of an enterprise while retaining the same input (event/ending status) and output (event/ending status). The replaced EA processor however needs to be embedded into the system in order to inherit the Cimosa rules (program coding) for the domain. As a comparison, two example models are used. The model 1 (Fig. 2) is extracted from reference [9] and represented using the Cimosa-HCTSPN building blocks (Fig. 3). The example model 2 (Fig. 4) is using a sample extracted from reference [11].

Figure 4 shows the representation of a one-buffer-three-machines manufacturing cell using the NCPN. A different NCPN (HPSim) editor has been used for the model. With the NCPN model, different products (i.e. part A and part B) have different routes (subnets) and showing similar processing steps (i.e. all the transitions involved) with resource sharing (i.e. robot, machine 1, machine 2, machine 3, and buffer). With this approach the model can be reduced significantly (Fig. 5) in the following procedures. The numbers of components used are summarized in Table 6. It is clear that the latter approach is more flexible and simpler.

With the comparisons shown above and the consideration that both representation tools will require time for parameter setting, the HCTSPN modelling coupled with Cimosa behavioural rule mapping is a more attractive approach to reduce the complexity in terms of building blocks used and visualization of the model. The ExSpect HCTSPN simulator applied here requires program coding in the transition to declare or define the behaviours of token flow. This programming capability also enables the token attribute's state evolution to take place, in which the characteristics, information, and knowledge belonging to the token changes through a transition. These attributes can be used as triggering events or ending status for the process modelled, making the simulator an ideal tool to be integrated with Cimosa.

The proposed Cimosa-to-HCTSPN mapping also provides all the advantages existing in the HCTSPN tool to the process modelling using a reference model such as the one implemented in reference
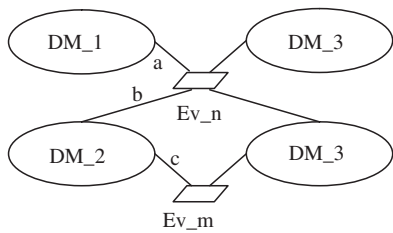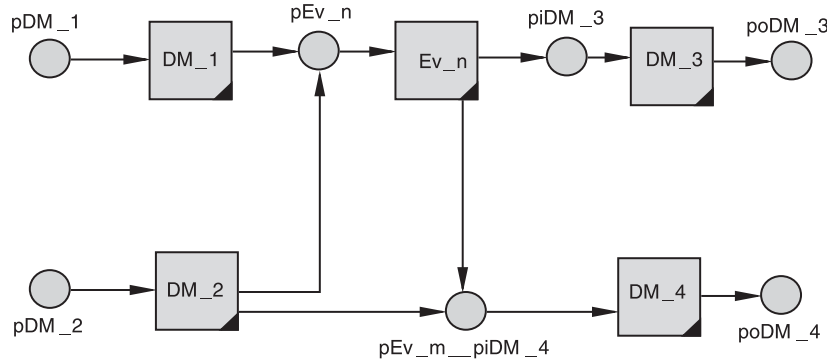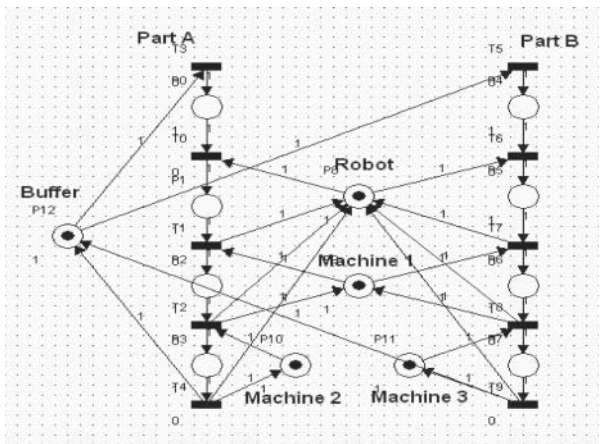

Fig. 4 One-buffer-three-machine NCPN manufacturing cell [11]
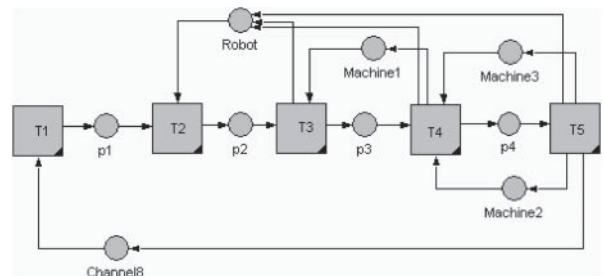
Fig. 5 Simplified one-buffer-three-machine manufacturing cell using the Cimosa–HCTSPN approach

Fig. 2 Cimosa example model 1 [9]

Fig. 3 Cimosa-HCTSPN model 2

Table 6 Components comparison of the GSPN and NCPN representation with the Cimosa–HCTSPN approach

Components	GSPN representation [3]	Cimosa-HCTSPN representation	NCPN representation [7]	Cimosa–HCTSPN representation
Places	10	7	13	9
Transitions	9	5	10	5

[18]. Other advantages of this work are also inherent in the selected ExSpect application that combines both the modelling and simulation task and provides customization capability for an interactive simulation interface.

5 THE PROTOTYPE

5.1 The prototype structure

Figure 6 shows the structure of the prototype implementation. A mechanism is established to simplify the modelling task. It provides a natural language graph entry table (process behavioural definition table) for the user to define the enterprise activities and their inputs and outputs. Each activity and its declared input or output is represented automatically by the respective simulation model's components processor (transition) and channel (place). The mechanism constructs the graph-based model automatically based on recognizing the five ExSpect behavioural rules building blocks. This behaviour mapping mechanism and the natural language process graph approach will help to ensure a more efficient Cimosa-compatible simulation modelling process. At this stage of the prototype it can construct a simple Cimosa-based model. The user needs manually to construct other sub-graphs for a more complex process graph to be modelled. The next section will present a modelling task using the prototype.

5.2 The prototype application example

The mail sorting process to be modelled is shown illustrated as the conceptual Cimosa model in Fig. 7. The social mail type input is the designated event to trigger the process. The annotated arrows after the segregation activity represent the ending status for the previous activity and the triggering events for the subsequent activities. Segregation produces the letters mail type and the LFP (letters, flats, and packets) mail type. The machine and the manual sorting produce mail that is grouped into the classes (i.e. first and second classes).

Applying the process behavioural definitions, the conceptual model is entered into the table in the manner shown in Fig. 8, where the first and third columns are the event or ending status entry and
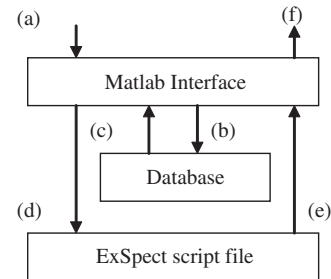

Fig. 6 Prototype structure for the proposed Cimosa–HCTSPN modelling approach implementation: (a) present user's process behavioural definitions; (b) storing and processing the ExSpect script; (c) retrieve the processed ExSpect script; (d) write script to ExSpect file; (e) call the ExSpect file; (f) display ExSpect simulation model
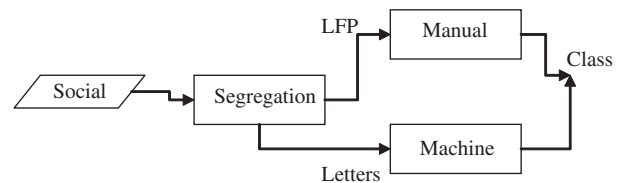
Fig. 7 Cimosa model of social mail sorting process
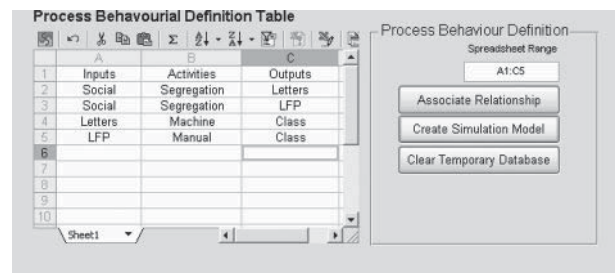
Fig. 8 Cimosa-based process graph entry interface

the second column provides the entry for the activity. The entries are treated as a graph-based model in the program codes and are translated into the ExSpect simulation model components as shown in Fig. 9.

The modelling steps presented previously are executed automatically. Manual intervention is only necessary for the parameters, functions, and routines declaration in the ExSpect model's components, especially the processor (transition), and the subsequent simulation tasks. The prototype is continuously being improved to allow more complicated

Fig. 9 ExSpect simulation model components

modelling involving larger numbers of processors, i.e. enterprise activities.

6 APPLICATION AND DISCUSSION

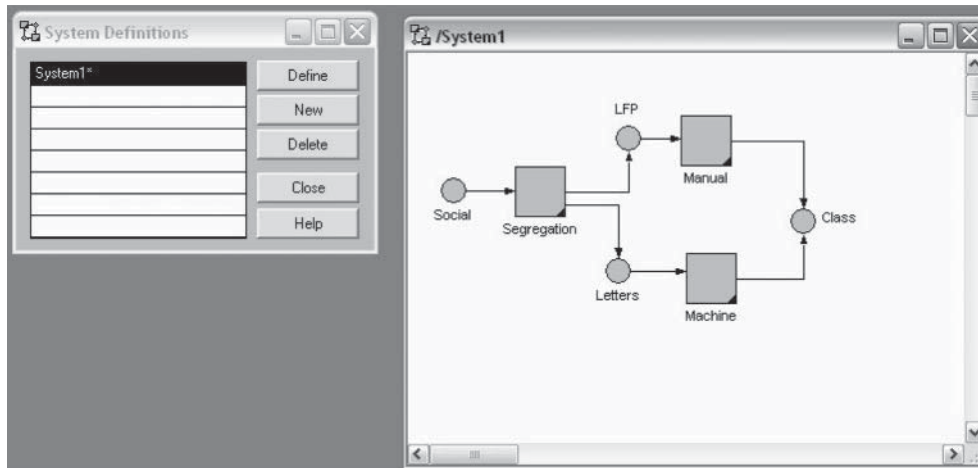The application of a HCTSPN in modelling the postal service process, especially the mail processing operation, has been documented by Wang *et al.* [**19**]. The novel modelling approach demonstrated the simulation of a single machine mail processing operation. The model is not Cimosa-compatible and the simulation presents the novel application of the HCTSPN in the domain of postal industry. Model modification using the proposed Cimosa–HCTSPN modelling approach is manually achieved using building blocks of the five basic behavioural rules.

6.1 The Cimosa–HCTSPN mail processing model

From Fig. 10 of the model shown in section 6.2, each of the building blocks (i.e. each of the coloured Petri nets' transitions represented by the component processor) is an EA with its inputs (represented by the component channel) as events or ending statuses forming the preceding enterprise activity and its outputs as the ending statuses or events that will trigger the succeeding activity. The docking_segregation divides each arrival into two main product streams (i.e. business and social) using the ANDOR-split building block and random probability is used to define the amount of business and social items. The enterprise activities for the segregation process of the PPI (printed postage impression), meter and social (stamped) mail are represented by the more complex sharing building blocks. Table 7 presents the inputs and outputs for one of the enterprise activities (PPI).

The Cimosa–HCTSPN provides adequate considerations on modelling the enterprise system by using the different viewpoints established by Cimosa. For instance in the mail processing model, the application of the informational object views – control input and resource output – highlighted the necessity of a coherent and timely communication method between the machine and the arrivals of the different streams of product, so that any arrival will be routed immediately to available machines without any delay in the first come first served (FCFS) dispatching rule. Another aspect can be the resource management reflected by the resource input. Increasing the resource input for the PPI segregation activity will no doubt reduce the segregation make-span (i.e. time required to complete all jobs), but this will create a queue before the machine process if the resource allocations do not synchronize with the machine availability. Not increasing the resource input for the PPI activity in this case may not be a bad idea, as this can reduce the potential queue size and certainly the resource cost.

6.2 Hierarchical dispatching rules studied through HCTSPN simulation

This section demonstrates the simulation experiment using dispatching rules [**20**] for the performance assessment of the mail sorting process. The dispatching rule heuristics used in solving sequencing and scheduling activities in the shop-floor control environment provide vital performance measures such as product flow time and tardiness [**21**]. Some previous work shows that the dispatching rules can be 'sequenced' to maximize the advantages of the combined dispatching rules applied for a particular process. Chan *et al.* [**22**] presented the dynamic dispatching rules in their study of a FMS. The dispatching rules
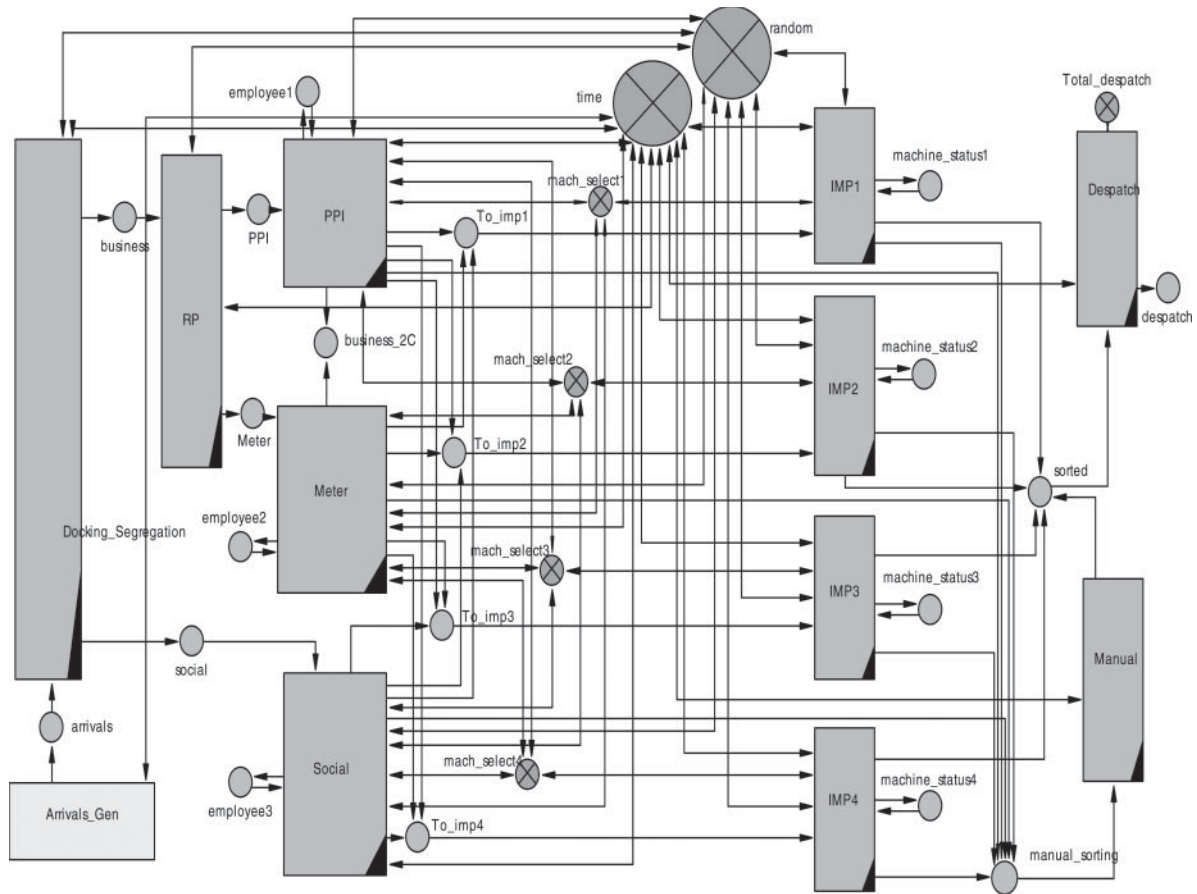
Fig. 10 Cimosa–HCTSPN mail sorting process model

Table 7 Cimosa–HCTSPN representation of the PPI activity's inputs and outputs

Enterprise activity inputs and outputs	Cimosa–HCTSPN Model: PPI activity inputs and outputs (place and token attributes)
Function input	PPI (mail volume)
Function output	To_imp1 (mail volume)
Control input	mach_select1({<<1,'imp1'>>}), mach_select2({<<2,'imp2'>>}), mach_select3({<<3,'imp3'>>}), and mach_select4({<<4,'imp4'>>})
Control output	There is no ending status from PPI but the function output can be the triggering event for the next activity or process.
Resource input	employee1 (number of employee(s))
Resource output	mach_select1({<<1,'not free'>>}), mach_select2({<<2,'not free'>>}), mach_select3({<<3,'not free'>>}), and mach_select4({<<4,'not free'>>})

are changed at a frequency varied by the number of outputs produced by the FMS. Wang *et al*. [23] simulated the double-loop interbay automated handling system in a wafer fabrication facility using the combined dispatching rules. Each combined dispatching rule is determined through three decision points (i.e. loop selection, vehicle assignment, and cassette) where each decision point has its own dispatching

rule. The combined dispatching rule approach is also echoed by Dominic *et al*. [24] where most combined dispatching rules presented better results than single rules in their simulation experiment of the dynamic job shop with continuous arrival.

In this simulation, the control mechanisms with coloured tokens as control signals are used in the study of the hierarchical dispatching rules to investigate their effects on the mail sorting performance. The control mechanisms are built into the generic mail processing model in Fig. 10 to instantiate nine other models that each apply a particular combination of dispatching rules. Nine combined dispatching rules are derived from the general sequencing rules such as earliest due date (EDD), FCFS, shortest processing time (SPT), and longest processing time (LPT). Owing to the nature of the mail processing operations, items arrive at random intervals, volumes, and types.

The data from the subject of investigation (Royal Mail Leeds Sorting Centre) show that three main product types are dealt with, i.e. PPI, meter, and stamped, and are used to determine the predefined volume proportion. The arrival profile that has been determined to be the non-homogeneous Poisson process (NHPP) [19] is a vital part of the simulation

process as it will influence the dispatching rules and other parameters. A predefined arrival volume is used in all the nine models in order to allow the standard comparison of the nine dispatching rules.

The mail streams are specialized into their own operations route at each stage of the whole sorting process, which created a hierarchical structure of mail type's specification. The dispatching rules can be formed heuristically to accommodate this by cascading one dispatching rule after another. Each of the dispatching rules will then represent the sequencing rule used for that particular hierarchy level. For instance the rule EDD–CFS–SPT allows the first stage of the sorting process to be executed with the priority given to mail stream with the earliest due date. This is further illustrated in Fig. 11.

Tables 8 and 9 display the simulation results of the nine dispatching rules on the flow time and tardiness performance criteria. It is clear that the desired dispatching rule is rule 1 since it provides the lowest values in both criteria. However, the utilization level of machines (i.e. four in the present case) is partly compromised owing to the need to achieve the zero tardiness. Rules 1 to 3 are implemented with the main mail streams (i.e. social and business) processed in parallel; whereas rules 4 to 9 executed the process

serially. In the latter case the number of machines used can be reduced (i.e. less machines are standby or idle) to increase the utilization level of the available machines. Hence the more desirable rule is rule 7, which produced the least tardiness and allowed higher machine utilization. The LPT rule applied in the third hierarchy level proved to be unfavourable since it produced the highest mean tardiness compared to other rules that share the same first and second levels. This is because the items with longer processing time (i.e. larger volume) caused the less-processing-time items to be squeezed out into the tardiness time zone. If more less-processing-time items can be processed first before the due date, this would reduce the tardy jobs in general. However, this cannot be adopted universally as it is in contrast to the second-level SPT rule (rules 4 and 5) when compared with the second-level LPT rule (i.e. rules 7 and 8), which shows LPT is more suitable in the second level of the sorting process. This indicates that each hierarchy level (process stages) with process (or product) branches required independent assessment of the process streams using the dispatching rules. Hence a dispatching rule applied in one hierarchy level may achieve a different effect compared with the same rule applied in a different level. The objective is to obtain the combination that provides the optimum performance criteria. Clearly the hierarchical dispatching rules approach with rules (R) and
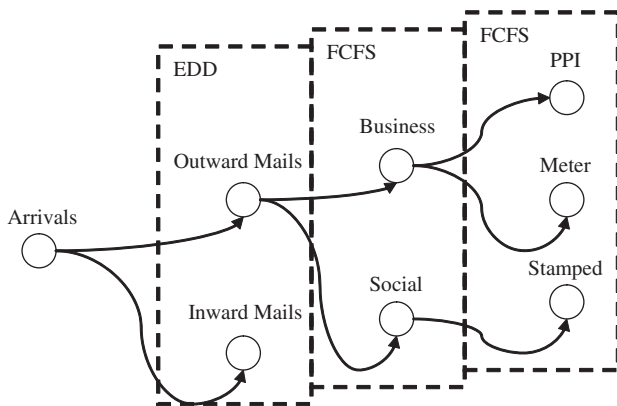

Fig. 11 Hierarchical dispatching rules for mail streams specification

Table 9 Mean flow time and tardiness for the nine hierarchical dispatching rules

	Rules	Mean flow times (min)	Mean tardiness (min)
1	EDD-FCFS-FCFS	1242.75	0
2	EDD-FCFS-SPT	1270.1	5.86
3	EDD-FCFS-LPT	1292.12	26.48
4	EDD-SPT-FCFS	1329.45	42.31
5	EDD-SPT-SPT	1356.8	69.67
6	EDD-SPT-LPT	1378.82	91.68
7	EDD-LPT-FCFS	1279.42	3.81
8	EDD-LPT-SPT	1355.14	58.03
9	EDD-LPT-LPT	1405.45	106.95

Table 8 Maximum flow times and tardiness for the three mail streams (jobs) and nine hierarchical dispatching rules

	Rules	PPI Max. flow time (min)	PPI Max. tardiness (min)	Meter Max. flow time (min)	Meter Max. tardiness (min)	Stamped Max. flow time (min)	Stamped Max. tardiness (min)
1	EDD-FCFS-FCFS	1255.51	0	1251.32	0	1221.41	0
2	EDD-FCFS-SPT	1337.57	17.57	1251.32	0	1221.41	0
3	EDD-FCFS-LPT	1255.51	0	1399.43	79.43	1221.41	0
4	EDD-SPT-FCFS	1385.56	65.56	1381.37	61.37	1221.41	0
5	EDD-SPT-SPT	1467.63	147.63	1381.37	61.37	1221.41	0
6	EDD-SPT-LPT	1385.56	65.56	1529.48	209.48	1221.41	0
7	EDD-LPT-FCFS	1255.51	0	1251.32	0	1331.42	11.42
8	EDD-LPT-SPT	1337.57	17.57	1251.32	0	1476.52	156.52
9	EDD-LPT-LPT	1255.51	0	1399.43	79.43	1561.42	241.42

hierarchy levels (N) provides the R^N possible combinations of sequencing rules for the assessment of multistage processes.

The investigation and implementation of Cimosa–HCTSPN–HDR application in a mail sorting or other manufacturing environment would be extremely beneficial in improving enterprise processes and is subject to further research.

7 CONCLUSION

The Cimosa–HCTSPN representation approach clearly demonstrates the advantages of integrating two popular modelling techniques. The Cimosa framework for enterprise integration provides a holistic perspective and consideration in modelling or designing the enterprise process. This is supported directly by the hierarchical high-level Petri nets simulation tool with token attributes (colours) to represent the four views and the different objects and informational flows in a clear and concise manner. Both the Cimosa and the HCTSPN tool provide object-oriented modelling support, thus allowing the direct association (mapping) between them. The HCTSPN ability to allow 'installation' of its components from one model to another also encourages the reuse of processes, sub-processes, and the individual activity models. Constant reuse will promote knowledge accumulation and analysis refinement. The novel colour tokens simulation modelling of the mail sorting process demonstrated the suitability of the approach to represent complex shop-floor processes. The product sequencing analysis presented the derivation and application of the hierarchical dispatching rules. This combination allows the testing of different priority rules used in each hierarchy of the process. The hierarchical approach provides much more freedom for the product streams routing or arrangement to reduce process flow time and tardiness. It shows that the dispatching rule combinations can achieve optimum performance values once supported by other analysis strategies such as resource management and resource scheduling. This research will further contribute to a better and wider scope of representation, understanding, and analysis of the processes structural design, planning, and scheduling tasks.

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