Applying the Process Interchange Format (PIF) to a Supply Chain Process Interoperability Scenario

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Abstract.
The goal of the PIF Project is to develop an interchange format to help automatically exchange process descriptions among a wide variety of business process modelling and support systems such as workflow software, flow charting tools, process simulation systems, and process repositories. As an example of such an exchange, a demonstration scenario has been created which describes the use of PIF in the modelling and simulation of an integrated supply chain where different companies co-operate through a global supply chain management procedure to deliver commercial electronic goods. This scenario coordinates the exchange of process knowledge between a business process modelling tool/library (Massachusetts Institute of Technology's (MIT) Process Handbook) and a process simulation package (Knowledge Based System Inc.'s (KBSI) ProSim) with PIF acting as the interlingua.

1 INTRODUCTION

There have been a number of initiatives to standardise shared languages and ontologies within the general subject area of activities and processes. These include

- Enterprise Processes
  - Process Interchange Format (PIF) [18]
  - Enterprise Ontology [7, 27]
  - Toronto Virtual Enterprise (TOVE) ontology [6]
- Workflow Processes
  - International Workflow Management Coalition's Workflow Process Definition Language (WPDL) [28]
- Manufacturing Processes
  - NIST's Process Specification Language [25]
- Case Tools
  - Case Data Interchange Format (CDIF) [23]
- Planning
  - Shared Planning and Activity Representation[5] (SPAR) [26]

During the various stages of design, development, deployment, extension and maintenance of these languages (and their underlying ontologies) it can be very helpful to engage in some form of scenario analysis [10, 13, 15]. Scenario analysis has been defined in a software-engineering context as

> "the process of understanding, analysing, and describing system behaviour in terms of particular ways the system is expected to be used." [13]

In the case of shared representation languages (e.g. PIF), we can amend this definition of scenario analysis to read

> "the process of understanding, analysing, and describing knowledge representation in terms of particular ways the language/ontology is expected to be used."

The goal of the PIF Project is to develop an interchange format to help automatically exchange process descriptions among a wide variety of business process modelling and support systems such as workflow software, flow charting tools, process simulation systems, and process repositories. As an example of such an exchange, a demonstration scenario [24] has been created which describes the use of PIF in the modelling and simulation of an integrated supply chain (cf. [8, 1, 17]) where different companies co-operate through a global supply chain management procedure to deliver commercial electronic goods. Specifically, PIF acts as a common, shared language between tools used in the re-engineering of these business processes which occur between a manufacturer, retailer, distributor, warehousing company and transportation company[6]. This scenario illustrates the fact that PIF is primarily a translation language, not an executable language or even a modelling language except to the extent that is needed for translation. As a consequence, its design philosophy favours generality over efficiency, minimal core over redundancy, and allowance for multiple alternative extensions (see section 2.1). It should also be noted that PIF's insistence on formal semantics (for translatability) is unique as compared to other "process languages". This is discussed in section 5.

This work represents one of the initial attempts at defining a realistic business scenario in which PIF may be applied. Previous efforts focused on a simpler example in the domain of civil engineering design. This was used to assist in the construction of the set of PIF core elements. The recent scenario work provides a framework for evaluating, challenging and extending the elements defined within the PIF-Core. This paper presents a couple of examples from this

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[5] Details on the Shared Planning and Activity Representation are available at: http://www.aiai.ed.ac.uk/ arpi/spar/

[6] This scenario was adapted from the Workflow Management Coalition's (WfMC) workflow interoperability demonstration presented at the 1996 Business Process and Workflow Conference in Amsterdam.

scenario and discusses the application of PIF and extensions to it for a supply chain domain.

1.1 What is a Supply Chain?

A supply chain is essentially a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers [16]. There are supply chains in both service and manufacturing organisations. The complexity of the chain may vary greatly from industry to industry and company to company. Traditionally marketing, distribution, planning, manufacturing, and purchasing organisations along the supply chain operated independently. This independence typically meant that there wasn't a single, integrated plan for the organisation. There were as many plans as businesses. A need existed for a mechanism which integrated these different functions. Supply chain management is now referred to as the strategy through which this integration can be achieved. This has become an important issue for many organisations as they rethink the way they do business. For example, Hammer and Champy pointed out a need for radically changing the processes of a manufacturing logistics supply chain in their pioneering book on Business Process Re-engineering [11].

The overall objective of the supply chain for the scenario referred to in this document is: to obtain benefits by rapidly getting manufactured commercial electronic products from the production line into retail stores. In order to ensure that this objective is met in an effective way, these processes may need to be modelled and simulated across organisational boundaries. This process may be facilitated by providing a way to assist in the automatic (or semi-automatic) exchange of process descriptions between a modelling tool and simulation tool using PIF.

1.2 Utilising Process Tools

We consider the following scenario in order to illustrate interoperability between these tools: A hypothetical consulting firm has been hired to both model and simulate the proposed supply chain activities. The business consulting team would like to utilise MIT's library of business processes found in the Process Handbook (PH) [20] as a basis for process specification. The PH may be used to analyse tradeoffs and alternatives for the supply chain processes. The team would then like to transfer the process descriptions to KBSI's ProSim[7]. As is typically the case, this would require manual rebuilding of the model. Modelling and simulation activities are often part of an iterative cycle and could potentially require significant effort to manually synchronise changes between separate process and simulation models. A shared, common language between these two tools could significantly reduce the consulting team's time and effort in engineering these processes.

1.3 Interlingua, Modelling, Simulation

PIF is proposed as the interlingua between the consulting team's process modelling tool and process simulator. One of the advantages of using PIF is that each system will only need to have a single translator for converting process descriptions into and out of the common PIF format rather than having to write ad hoc translators between these (or potentially more) systems (i.e. reduces the number of translators needed from $O(n!)$ – pairwise to $O(n)$). Both tools are capable of expressing the model in their own linear, declarative format. MIT's Process Handbook uses the Process Handbook Representation Language (PHRL) and ProSim can accept a generic representation of an IDEF3 [22] model. This translation process is based on various techniques for translating between groups using different class hierarchies (e.g. pairwise mapping, translation via external common language, translation via internal common language) so as to exploit the benefits of each when most appropriate [21]. PIF translation rules can be defined which serve to guide translation methods executed while importing and exporting with PIF. PIF also provides a general scheme for minimising information loss when processes are translated back and forth between different tools[8]. ProSim can then be used to compile a simulation model that will run on Lanner Group, Ltd.'s WITNESS[9] simulator.

[7] Details on Knowledge Based System Inc.'s ProSim are available at: http://www.kbsi.com/products/products.html

2 Scenario Description

As stated above, this scenario addresses the processes for managing an integrated supply chain. This section presents some of the central entities and relationships that are involved in this domain. These required elements can be viewed as domain-specific objects which require PIF core extensions, which are called Partially Shared Views (PSVs) [21], in order to express the processes found in this scenario.

2.1 Extending the PIF Ontology

The conceptualisation process [5, 9] performed during the development of the domain-specific ontological extension (PSV) for this scenario was guided by a verb-noun phrase extraction technique. This is similar to other approaches for identification and classification using grammars (cf. [14, 2]. The original WfMC document was treated as a "requirements specification document" from which phrases such as, "accept order", "load truck" and "prepare payment" were extracted. Over 100 such phrases were assembled and reviewed for close matches in both object or activity type. These filtered verbs and nouns were then used as the terminology for the implementation of the supply chain PSV. The processes, or verbs, were then generalised using the Process Handbook hierarchy of processes.

In trying to represent the scenario processes, we not only needed additional activities but also additional objects (e.g. ORDER, PRODUCT). These objects were incorporated via extension modules. Entity attributes and relations between entities were added based on individual requirements expressed in the source document. However, there exist several object ontologies such as CYC [19] and the Upper Penman Ontology [3]. We acknowledge the need for a PIF description to recognise objects from these external ontologies as well. For example, one may want to use an object exactly in the sense defined in one of these external ontologies. It may also be the case that the way it is defined externally is good enough for one's purpose and not worth the effort of defining the object ontology within PIF. Therefore we decided that a PIF description may include an object with reference to an external ontology (including the information about the version used and how to access it). The exact mechanism for expressing this link though is still under consideration. Section 3 outlines the objects used in this scenario (all of which are included in a PIF extension) while section 4 overviews the processes that are

[8] For more information on this knowledge preservation process, see the PIF summary document [18]

[9] Details on Lanner Group's WITNESS simulator are available at: http://www.lanner.com/product.htm

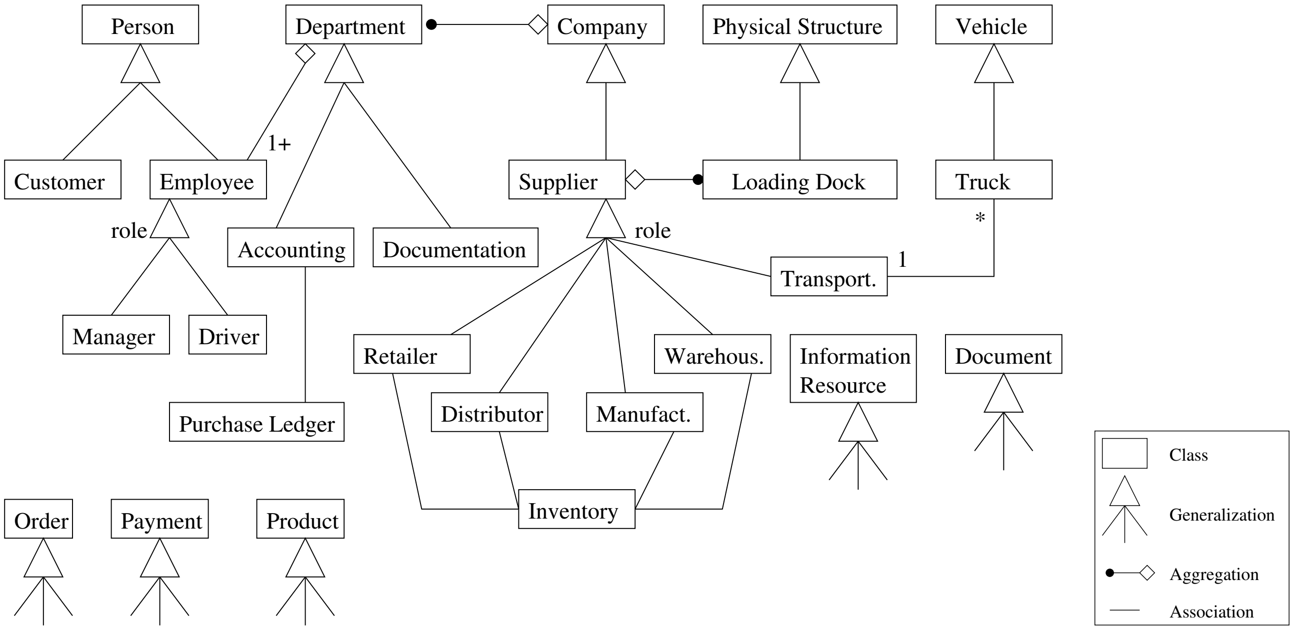

Figure 1. Partial UML Object Model of the Supply Chain Entities

executed using these elements during the enactment of the material and product flow for the supply chain.

3 Object Overview

In this section, various scenario element descriptions are presented to provide a high-level summary of the scenario domain items. We initially focus on the responsibilities of the companies which are involved in the modelled supply chain. We then widen the scope to present the additional elements which are needed to represent these processes.

- The **Manufacturer** produces goods and delivers products from factories based upon orders received from distributors. Delivery is mainly handled through transportation companies which ship products from the manufacturer to the distributor.
- The **Retailer** receives orders for goods. Orders may be translated into a distributor order as the retailer holds limited stock. Distributor orders require payment preparation and release of payment from the retailer to the distributor.
- The **Distributor** takes orders from the retailer and arranges shipment of the ordered products. The distributor has limited inventories of its own. It can rely on a manufacturer's inventories and production for large retailer deliveries.
- The **Warehousing Company** stores supplies of product inventories for the manufacturer which can be shipped directly to distributors when requested from the manufacturer.
- The **Transportation Company** handles most tasks related to transport in an international environment including production of customs documents, shipping forms, etc.

As these responsibilities begin to show, a number of elements can be identified in the supply chain. These objects can be modelled in a simple UML [4] object model to highlight a taxonomy of entities and relations between them. A high-level model showing some of the supply chain scenario objects is depicted in Figure 1. This figure outlines objects that have been introduced by the supplier role descriptions, but also looks ahead towards the objects required for the detailed process descriptions.

Starting toward the top of the model, we can pick out two fundamental classes of entities: **company** and **person**. Supply chains are essentially centred around these basic concepts. People involved in these simplified processes may be **customers** or **employees**. Looking at companies, we can see that a company is typically composed of zero or more **departments**. These departments contain one or more employees which carry out the specific tasks. Employee types are usually associated with the nature of the task which they perform (e.g. a **driver** transports **products**, a **manager** manages other employees, etc.) Departments may require specific objects to carry out their tasks. For example, the **accounting department** requires a specialised record, the **purchase ledger**, for maintaining the company financial records.

Companies involved in supply chain management are referred to as **suppliers**. In this domain, there are 5 supplier types or roles as described above. Suppliers require objects such as **trucks**, **loading docks**, and records of current stock (i.e. **inventory**). Suppliers communicate and perform various transactions by using a variety of **document** types. These physical documents are linked to **information resources** which are, in turn, related to various abstract business objects, such as **orders**, **payments**, etc. The following sections address some of the objects presented in Figure 1 in more detail.

3.1 People, Companies and Departments

As suggested above, supply chain processes are enacted (or "performed" in PIF parlance) by people, departments or companies, depending on the level at which they are described. These agents can be referred to in PIF as actors. In section 3 we looked at the roles of the various companies in this scenario, next we provide a description of these "performing" departments and the people who are the "actors" in this scenario.

Accounting Department The retailer has a department which, among other things, is responsible for preparing/releasing payment to a distributor and maintaining the purchase ledger. So, this department may be assigned the responsibility of "performing" the "Pay Distributor" process which will be presented in Figure 2.

Documentation Department The transportation company has a department which is responsible for completing shipping forms and customs documents if needed for a shipment. So, this department may be assigned the responsibility of "performing" the "Process Documentation Request" process from Figure 2.

Customer The customer places orders at the retailer for some quantity of goods.

Employee Employee is a general role that refers to anyone working for any of the supplier companies.

Manager Some employees are specialised to perform certain tasks. The manager is responsible for overseeing the work of other employees.

Driver Driver is also a specialisation of employee. A driver performs a specific task of transporting goods using a transportation vehicle.

3.2 Role-Defined Relationships

In figure 1, we labelled certain classifications of object types with a "role" discriminator. This discriminator is an indication of the basis of the sub-typing. In PIF, we treat this by both deriving a new class (e.g. supplier, employee, etc.) which is a sub-type of the parent class, but also by adding a reified relation type which clarifies the nature of the role. So, for instance, a supplier object, S, may be a "Supplier-Of" some other company, C, which we would define with the binary relation: Supplier-Of(S,C). Likewise, an employee E, may be an "Employee-Of" a company, C: Employee-Of(E,C).

3.3 Dates and Times

Many activities within the supply chain processes are temporally dependent. These activities may reference a specific calendar date (e.g. Jan 1, 1998, Every 2nd Wed. of the month), a specific time of the day (17:00:00 hrs EST) or both. These dates and times appear on most of the documents that are manipulated throughout the process as well (e.g. due date, shipping date, expected arrival date and time, etc.). The supply chain extension for this scenario addresses this requirement by proposing a "calendar" object which may related to various "date tokens" or "time tokens" which represent the metric dates and times. These tokens may then be related to the timepoints (i.e. begin or end points) of the processes or activities.

3.4 Business Objects

While documents are typically used to perform various transactions between companies, as well as to communicate requirements and the occurrence of events between people/departments/companies, it is important to identify the underlying ontological elements which are connected to such artifacts. For example, the notion of a "sales order" may mean the physical document which the customer signs, but it may also refer to the abstract notion of an "order" which is manipulated by the company. We prefer to reserve the term "sales order" to mean the abstract business object, whereas a "sales order document" refers to actual document (Documents may be in paper form or they may be an electronic artifact.). We can also point out that a document has a relationship to some set of "information resources". In CYC terms [19], we would say the "sales order document" is an "#$StructuredInformationSource" whereas its associated informational resources are "#$InformationBearingThings".

The following descriptions outline some of the business objects utilized by the processes in section 4.1 and 4.2.

Payment A payment represents a monetary transaction between two companies. For example, the retailer prepares this payment and releases it to the distributor for providing the required goods.

Product Replenishment Order A product replenishment order represents a transaction between the retailer and the distributor. The retailer initiates the request to have a product list delivered. The order may be translated into a Manufacturing Order based on decisions made at the distributor.

Retail Sales Order The retail sales order represents a transaction between a customer and a retailer. The order is initiated by a customer due to a purchase of some list of products. This order may be translated by the retailer into a Product Replenishment Order in order to receive the products from a distributor which will satisfy the request.

Prepare Payment Request This request is issued within the retailer and is handled by the accounting department. This document is used in order to authorise the creation of a payment which may subsequently be released to the distributor.

Release Payment Request The payment release request is generated within the retailer and is handled by the retailers accounting department.

3.5 General Objects

A number of general objects are created, required, used, and modified throughout the enactment of the supply chain processes. Some of these elements were briefly introduced in the overview of the object model in figure 1. A slightly more detailed description of these objects helps to clarify the salient properties of these objects (e.g. capabilities: a truck can "carry" products, synonyms: product collections may be referred to as a "shipment" or "delivery", etc.)

Products Products are items created by the manufacturer. The supply chain is centred around the production, storage, shipping, etc. of these items. A collection of products is sometimes referred to as a shipment, delivery, goods, or order.

Vehicles Some vehicles are objects that can used to transport products. A truck is a specialized vehicle that is used to do all of the transportation in this scenario.

Physical Structures Some companies are required to have particular physical structures that permit the performance of some activities. In this scenario, the distributor is required to have an available loading dock which can be used when a shipment arrives.

Plans Both the distributor and the manufacturer maintain plans that specify future and current activities for their company. The Manufacturing Requirements Plan (MRP) describes when individual orders will be started and finished during the manufacturer's production runs. The Distribution Requirements Plan (DRP) maps out the activities needed to supply retailers with products.

Ledger Ledgers are general structures which are used to store information related to various quantities. The retailer has a purchase ledger which is used to record payments (among other things).

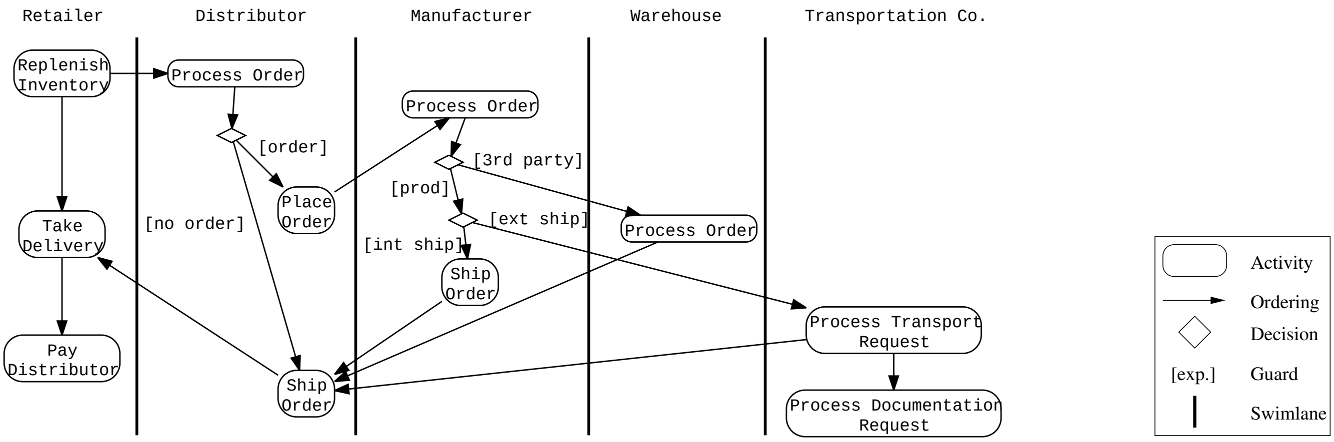

Figure 2. High-level UML Activity Model of the Supply Chain Processes

Inventory All of the suppliers, except for the transportation company, also maintain a count of the number of products they currently possess. This is referred to as the inventory.

4 Process Overview

A high-level model of the required cross-organisational supply chain process is shown the UML activity diagram in Figure 2. This diagram has a "swim lane" layout which identifies the temporal ordering of the processes across all of the companies. Each process identified in this diagram is associated with a particular supplier and is broken down in the source scenario document [24]. Two of these detailed processes are presented in sections 4.1 and 4.2. The process described in section 4.2 is an expansion of an activity described in section 4.1.

The flow of supply chain activities stem from a "replenish inventory" process which is initiated at the retailer. This leads to a cross-organisational activation of a process at the distributor. A key decision taken by the distributor at this point has been highlighted. This decision involves either satisfying the order via existing stock or by requesting products from the manufacturer. While the former simply requires a shipment to the retailer, the latter involves placing an order with the manufacturer. The manufacturer, in turn, makes a couple of important decisions while processing an order. These decisions are to either request stock to be sent from a third party warehouse or to satisfy the order via a scheduled production run. For orders completed at the factory, a decision is made as to how the product will be shipped to the distributor. The manufacturer typically requests pickup and delivery from a transportation company, but it also has a limited capacity to deliver products on its own (usually only performed for smaller orders). The transportation company handles the documentation for product shipment along with providing the transport service. Once the distributor receives the products, they are sent along to the retailer. The retailer completes the modelled process by sending payment for the goods to the distributor.

While the complete PIF supply chain scenario description details all 11 processes depicted in Figure 2, in order to fit within the space constraints for this paper, we will only be looking at aspects of two related processes: Replenish Inventory and Take Delivery[10]. Each process is described in a paragraph of text. This description is then modelled using a UML activity notation and a brief description of the analysis. Activities in this notation are represented via a rounded box (as in Figure 2). A solid dot and a dot enclosed in a circle represent the begin and end points of the overall process, respectively. Arrows represent a simple ordering of the activity execution. A decision is modelled with a diamond and labelled arcs (using "guards") which indicate the nature of the alternate path. A solid horizontal line represents an "and" split or join in the activity network.

Following the scenario description, we present a figure showing the processes modelled in the process handbook. A simple PIF excerpt is then presented, along with a partial description of the PSV elements used for this process. Finally, an IDEF3 representation of the processes, along with an overview of the translation process is described. In section 5 we discuss some of the underlying semantics of the PIF representation using the current axiomatization of the PIF core elements.

4.1 Replenish Inventory (Retailer)

4.1.1 Scenario Text

Inventory replenishment is triggered at the Retailer based on a balance between sales volume and inventory. An order from a customer may generate a request from the Retailer to the Distributor to supply a quantity of product on a given date. The Retailer next starts a subprocess with the Accounts department to prepare a payment for the Distributor. Inventory is updated and payment is released when the goods have been received and checked.

4.1.2 Analysis

Figure 3 illustrates the current structure of the modelled "replenish inventory" process. This process contains eight activities (e.g. Receive Order, etc.). The decision represents a conditional flow of activities based on an evaluation of current sales volume and inventory given the retail order details. "Request Prepare Payment" and "Send Order" may be executed in parallel. The "Take Delivery" activity is actually a composite activity which is further defined in section 4.2.

[10] These excerpts are rather short and simple for exposition purposes. More complex translation examples involve a discussion of tool ontologies, mapping between concepts, meaning-preservation processes, etc.

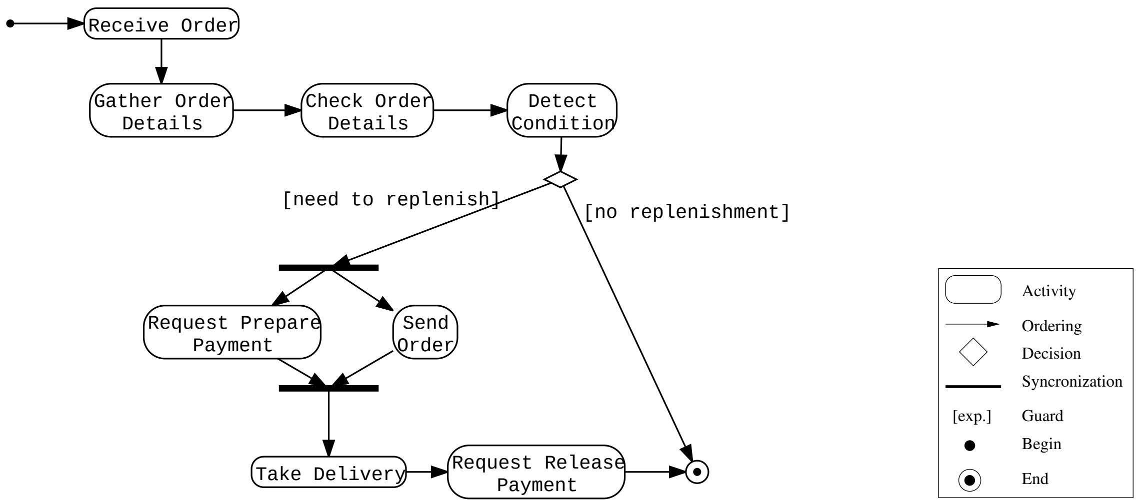

Figure 3. Replenish Inventory (Retailer) Diagram

4.1.3 Process Handbook

The process description is modelled in the Process Handbook (PH) tool (see appendix C). The consultant or business process engineer may utilise the PH library of processes to consider various configurations which may improve the overall effectiveness of the process. Once this process (or all of the processes) have been satisfactorily prepared, they may be translated (or exported) to PIF. This will enable the exchange of this modelled process knowledge with the simulation package.

4.1.4 PIF Representation

The simulation package, ProSim, is only required to know about its own language, IDEF3, and PIF, the interlingua, in order to interoperate with other tools like the Process Handbook. A preprocessing translator will transform the PIF into a declarative, IDEF3 format. Space constraints for this paper prevent the complete PIF representation from appearing here, but two sample frames are included below. The first sample frame illustrates the compositional relationships of this activity specification. We can also see that this particular process, "replenish inventory" is in fact a specialization of a more generic activity which relates to "receiving inputs".

```
...
(define-frame REPLENISH-INVENTORY
  :own-slots
  ((Instance-Of RECEIVE-INPUTS)
   (Components
    RECEIVE-ORDER, GATHER-ORDER-DETAILS,
    CHECK-ORDER-DETAILS, DETECT-CONDITION,
    REQUEST-PREPARE-PAYMENT, SEND-ORDER,
    TAKE-DELIVERY,REQUEST-RELEASE-PAYMENT)
   (Name "Replenish Inventory")
   (Documentation "Inventory Replenishment
    is trigerred at the Retailer based on a
    balance between sales volume
    and inventory")))
...
```

The temporal relationships between these activites is expressed via a series of "successor" frames as shown below. The relationships that these activities have to other PSV elements, such as the "actor", or to those PSV objects it "uses", etc. is expressed in other frames included in the PIF file as well.

```
...
(define-frame SUCC-1
  :own-slots
  ((Instance-Of SUCCESSOR)
   (Preceding-Activity RECEIVE-ORDER)
   (Succeeding-Activity
                GATHER-ORDER-DETAILS)))
...
```

4.1.5 IDEF3 Representation

During the translation process, elements from the PIF representation are mapped onto a linear, declarative version of IDEF3[11]. For example, if a PIF frame is identified as a specialization of an activity then it is translated into a "unit of behavior" (UOB) in IDEF3. A list of PIF successor relations, along with the uses, etc. relations which are relevent to this activity are gathered to populate the UOB class and instance frames. PIF frames which can be traced back to the PIF object, will appear as "define-object" frames in IDEF3, and so on... Here is a sample of the IDEF3.

```
...
(define-process Replenish-Inventory
  :components
   Receive-Order-1 Gather-Order-Details-1
   Check-Order-Details Detect-Condition-1
   Request-Prepare-Payment-1 Send-Order-1
   Take-Delivery-1 Request-Release-Payment-1
  :constraints nil)
...
```

[11] This IDEF3 textual format is based on an inital specification by Chris Menzel at Knowledge Based Systems, Inc. (KBSI).

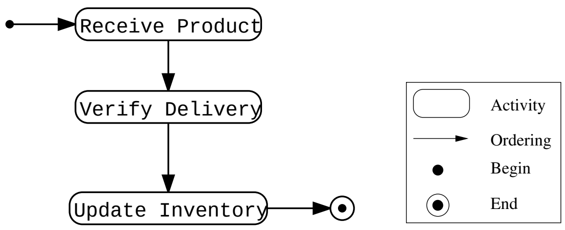

Figure 4. Take Delivery (Retailer) Diagram

```
;;; classes of "unit of behavior"
(define-UOB Receive-Order
  :object sales-order
  :facts
  :constraints)
...
;;; Objects
(define-object sales-order
  :constraints)
...
;;; UOB instance
(define-UOB-use Receive-Order-1
  :use-of Receive-Order
  :successors Gather-Order-Details-1
  :decomp nil)
...
```

This representation is then imported into ProSim and is presented in the more familiar IDEF3 graphical notation. Units of Behavior are presented as boxes and the successor relation is drawn as directed arcs between UOB's. This is illustrated in appendix C.

4.2 Take Delivery (Retailer)

4.2.1 Scenario Text

The process of taking delivery (from section 4.1) can be further detailed by considering the sub-activities which are executed during its enactment. Inventory is updated at the Retailer when the goods have been received. The delivery must be verified first though in order to ensure that it properly meets the requirements of the order.

4.2.2 Analysis

"Take Delivery" is modelled as a simple three-step process in which the goods are received and checked and inventory updated. This process is a decomposition of the take delivery process introduced in section 4.1.

4.2.3 Process Handbook

This process is modelled in the Process Handbook as an alternate decomposition for the abstract "Take Delivery" process (see appendix C). The PH library may be used to perform various reengineering tasks such as suggesting missing activites or other alternate deployments of "taking a delivery". Again, this particular decomposition may then be selected for export, perhaps along with the other modelled supply chain processes.

4.2.4 PIF Representation

```
...
(define-frame TAKE-DELIVERY
  :own-slots
  ((Subclass-Of RECEIVE-PHYSICAL-GOODS)
   (Components RECEIVE-PRODUCT,
    VERIFY-DELIVERY, UPDATE-INVENTORY)
   (Name "Take Delivery")))
...
```

4.2.5 IDEF3 Representation

```
...
;;; UOB instance
(define-UOB-use Take-Delivery-1
  :use-of Take-Delivery
  :successors Request-Release-Payment-1
  :decomp Take-Delivery-Alt1)
...
(define-process Take-Delivery-Alt1
  :components
    Receive-Product-1
    Verify-Delivery-1
    Update-Inventory-1
  :constraints nil)
...
```

5 PIF Semantics

PIF is based upon a precise mathematical first-order theory, i.e., a formal language, a precise mathematical semantics for the language, and a set of axioms that express the semantics in the language. This approach helps to ensure clarity and consistency in the interpretation of these supply chain processes. Here we will provide a brief informal sketch of the semantics and we list the basic axioms for that semantics in the appendix. There are three basic classes and four basic relations in the semantics, (or "ontology") of PIF. The classes are Object, Activity, and Timepoint, and the relations Participates-in, Before, BeginOf, and Endof. Activities, timepoints (or "points", for short), and objects are collectively known as entities, or things. These classes are all pairwise disjoint.

Intuitively, an object is a concrete or abstract thing that can participate in an activity. The most typical examples of objects are ordinary midde-sized dry goods, like people, chairs, car bodies, NC-machines, and the like though very small things, very large things, and abstract objects like numbers are not excluded. Objects can come into existence (e.g., be created) and go out of existence (e.g., be "used up" as a resource) at certain points in time. In such cases, an object has a begin and/or end point. Some objects, e.g., numbers, do not have finite begin and end points, and in some contexts it may be useful to model certain ordinary objects as having no such points either.

An activity is a limited, temporally extended piece of the world, such as the first mountain stage of the 1997 Tour de France, or the eruption of Mt. St. Helens. Not any such chunk should be thought of as an activity, however, nor should it be presumed that activities cannot include abstract objects like the equator. Rather, an activity is simply taken to be characterized chiefly by two things: its temporal extent, as determined by its begin and end points (possibly at infinity), and the set of objects that participate in that activity at some point between its begin and end points.

Timepoints are assumed to be ordered by the Before relation. This relation is taken to be a transitive, irreflexive, total ordering. It is not assumed in PIF that time is dense (i.e., that between any two distinct timepoints there is a third), though it is assumed that it is infinite. Points at infinity are assumed for convenience. (Denseness, of course, could easily be added by a user as an additional postulate.) Time intervals are not included among the primitives of PIF, as most of the roles of intervals can be subsumed by activites themselves. Time durations are included in an extension of the PIF core. This work builds upon [12]. These informal notions are made precise in PIF by defining the notion of a formal model structure for the PIF core. Details are omitted here.

The basic notions of the PIF core are axiomatized formally as a first-order theory. These axioms simply capture in a precise way the basic properties of the PIF ontology. The basic axioms for activities, objects, and timepoints are listed below. The definitions listed in appendix A simplify the axioms.

6 CONCLUSION

In this paper, we have described the application of PIF in a knowledge-sharing effort to facilitate the business process reengineering of supply chain activities. Specifically, PIF acts as the interlingua between two separate tools used in the modelling and simulation of the proposed processes. Meaning-preservation translation between representations is made possible by PIF's explicit definitions of the terms and concepts used in the core as well as in the extensions. These extensions specialize the core for an application to the supply chain domain. This scenario illustrates the applied business benefits of a process ontology which can be used to capture domain knowledge in a generic way so that it can be reused across applications and shared across groups.

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A Formal PIF Definitions

Definition 1 Timepoint q is Between timepoints p and r iff p is before q and q is before r.

```
(defrelation Between (?p ?q ?r) :=
  (and (Before ?p ?q) (Before ?q ?r)))
```

Definition 2 Timepoint p is BeforeEq timepoint q iff p is before or equal to q.

```
(defrelation BeforeEq (?p ?q) :=
  (and (Point ?p) (Point ?q)
       (or (Before ?p ?q) (= ?p ?q))))
```

Definition 3 Timepoint q is BetweenEq timepoints p and r iff p is before or equal to q, and q is before or equal to r.

```
(defrelation BetweenEq (?p ?q ?r) :=
  (and (BeforeEq ?p ?q)
       (BeforeEq ?q ?r)))
```

Definition 4 An object Exists-at a timepoint p iff p is BetweenEq its begin and end points.

```
(defrelation Exists-at (?x ?p) :=
  (and (Object ?x)
       (BetweenEq (Beginof ?x) ?p
                  (Endof ?x))))
```

Definition 5 An activity Is-occurring-at a timepoint p iff p is BetweenEq the activity's begin and end points.

```
(defrelation Is-occurring-at (?a ?p) :=
  (and (Activity ?a)
       (BetweenEq (Beginof ?a) ?p
                  (Endof ?a))))
```

B The PIF Core Axioms

Axiom 1 The Before relation only holds between timepoints.

```
(=> (Before ?p ?q)
    (and (Point ?p) (Point ?q)))
```

Axiom 2 The Before relation is a total ordering.

```
(=> (and (Point ?p) (Point ?q))
    (or (= ?p ?q) (Before ?p ?q)
        (Before ?q ?p)))
```

Axiom 3 The Before relation is irreflexive.

```
(not (Before ?p ?p))
```

Axiom 4 The Before relation is transitive.

```
(=> (and (Before ?p ?q) (Before ?q ?r)
         (Before ?p ?r))
```

Axiom 5 The timepoint inf- is before all other timepoints.

```
(=> (and (Point ?t) (not (= ?t inf-)))
    (Before inf- ?t))
```

Axiom 6 Every other timepoint is before inf+.

```
(=> (and (Point ?t) (not (= ?t inf+)))
    (Before ?t inf+))
```

Axiom 7 Given any timepoint t other than inf-, there is a timepoint between inf- and t.

```
(=> (and (Point ?t) (not (= ?t inf-)))
    (exists ?u (Between inf- ?u ?t)))
```

Axiom 8 Given any timepoint t other than inf+, there is a timepoint between t and inf+.

```
(=> (and (Point ?t) (not (= ?t inf+)))
    (exists ?u (Between ?t ?u inf+)))
```

Axiom 9 Objects, activities, and timepoints are all distinct kinds of things.

```
(and (=> (Activity ?x)
         (not (or (Object ?x) (Point ?x))))
     (=> (Object ?x)
         (not (Point ?x))))
```

Axiom 10 The Beginof and Endof functions maps entities to timepoints.

```
(and (Point (Beginof ?x))
     (Point (Endof ?x))))
```

Axiom 11 The begin point of anything is before or equal to its end point.

```
(BeforeEq (Beginof ?x) (Endof ?x)))
```

Axiom 12 The begin point and end point of a timepoint are the timepoint itself.

```
(=> (Point ?t)
    (and (= (Beginof ?t) ?t)
         (= (Endof ?t) ?t))))
```

Axiom 13 The participates-in relation only holds between objects, activities, and timepoints, respectively.

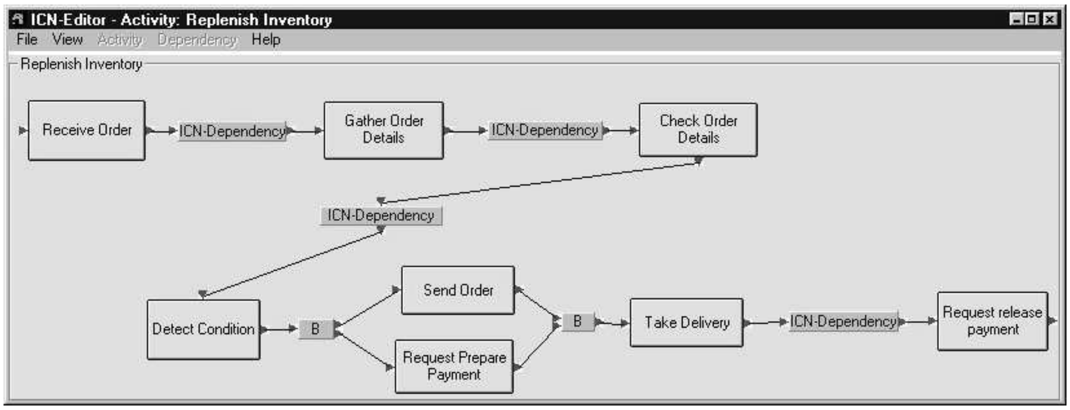
```
(=> (In ?x ?a ?t)
    (and (Object ?x) (Activity ?a)
         (Point ?t)))
```

Axiom 14 An object can participate in an activity only at those timepoints at which both the object exists and the activity is occurring.

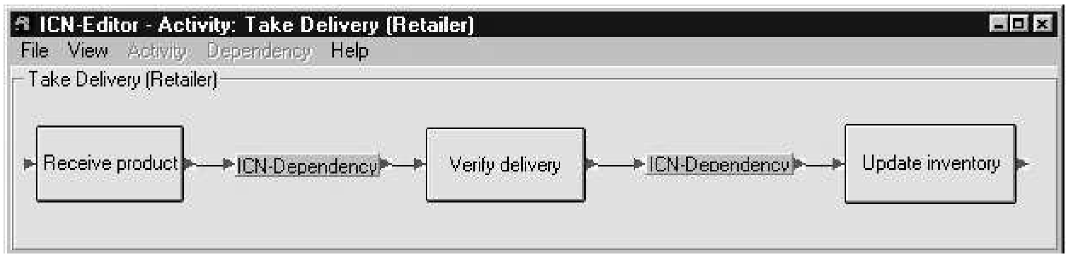
```
(=> (In ?x ?a ?t)
    (and (Exists-at ?x ?t)
         (Is-occurring-at ?a ?t)))
```

C Viewing Processes in Process Handbook (PH) and IDEF3

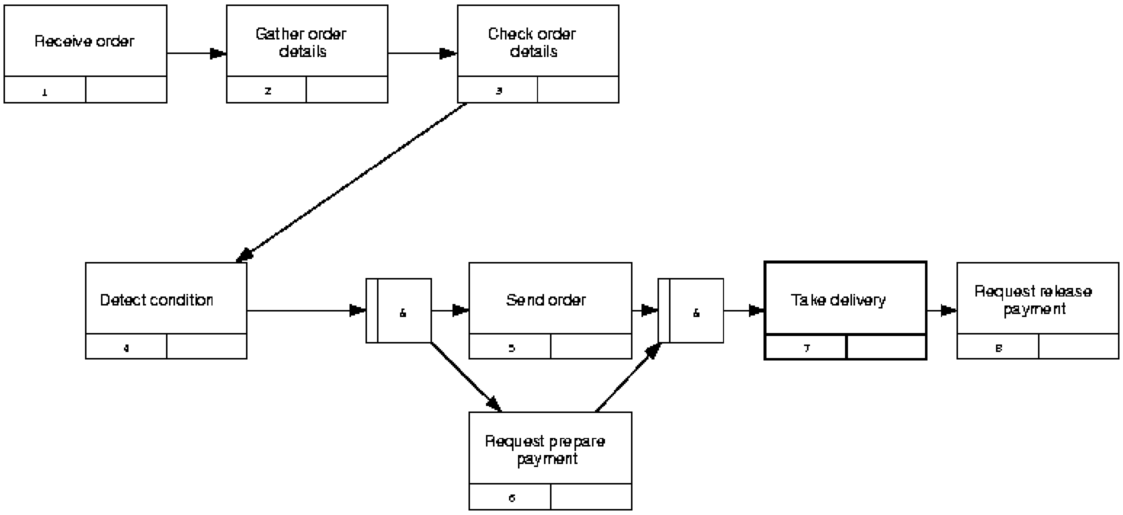
The source and target process diagrams from the excerpt of the PIF supply chain scenario discussed in this paper are shown below. These diagrams display the "Replenish Inventory" and "Take Delivery" processes as viewed in both the Process Handbook (PH) and IDEF3.



Process Handbook - **Replenish Inventory**



Process Handbook - **Take Delivery**



IDEF3 - **Replenish Inventory**

IDEF3 - **Take Delivery**