Query-Based Approach to Workflow Process Dependency Analysis

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Abstract

Dependency analysis is important in all of the stages of workflow processes. An appropriate analysis will help us to identify the potentially affected entities if changes occur. In this technical report we thoroughly analyze the critical entities of workflow processes and their dependency relationships, and propose a multi-dimensional dependency model, that includes *routing* dependency, *data* dependency and *role* dependency. We further build a knowledge base to represent the multi-dimensional dependency model using the logic programming language *Prolog*. We then develop a set of query rules that can be applied to the well-defined knowledge base at both activity and process levels to retrieve the potentially affected entities. Finally we use a case study of workflow processes in the healthcare domain to show how our dependency analysis methodology works.

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Motivation and Background

1.1 Motivation

Like any other system, a workflow process is composed of different kinds of components or entities. These entities play different roles in a workflow process and they also interact with each other in all aspects. That is, entities in a system are not independent of each other and there always are relationships among these entities directly or indirectly. One of the most commonly identified relationships is a dependency relationship, which means an entity depends on other entities. This fact naturally leads to a requirement in system's analysis, i.e., dependency analysis. Our work in this paper is about the change impact analysis of workflow process through dependency analysis methodology.

Before we explain more about dependency analysis in workflow processes, we provide the following healthcare scenario that will give us insight concerning dependency relationships in and among workflow processes.

1.1.1 A Dependency Scenario of Healthcare Workflow Processes

The figure below (Fig. 1-1) is a scenario including three workflow processes: Pharmacy, Clinic and Lab processes. Through this scenario we can identify several things:

First we can see there exist two kinds of dependency relationships. One is dependency within a process, which we call intra-dependency, and the other is dependency among processes which we call inter-dependency.

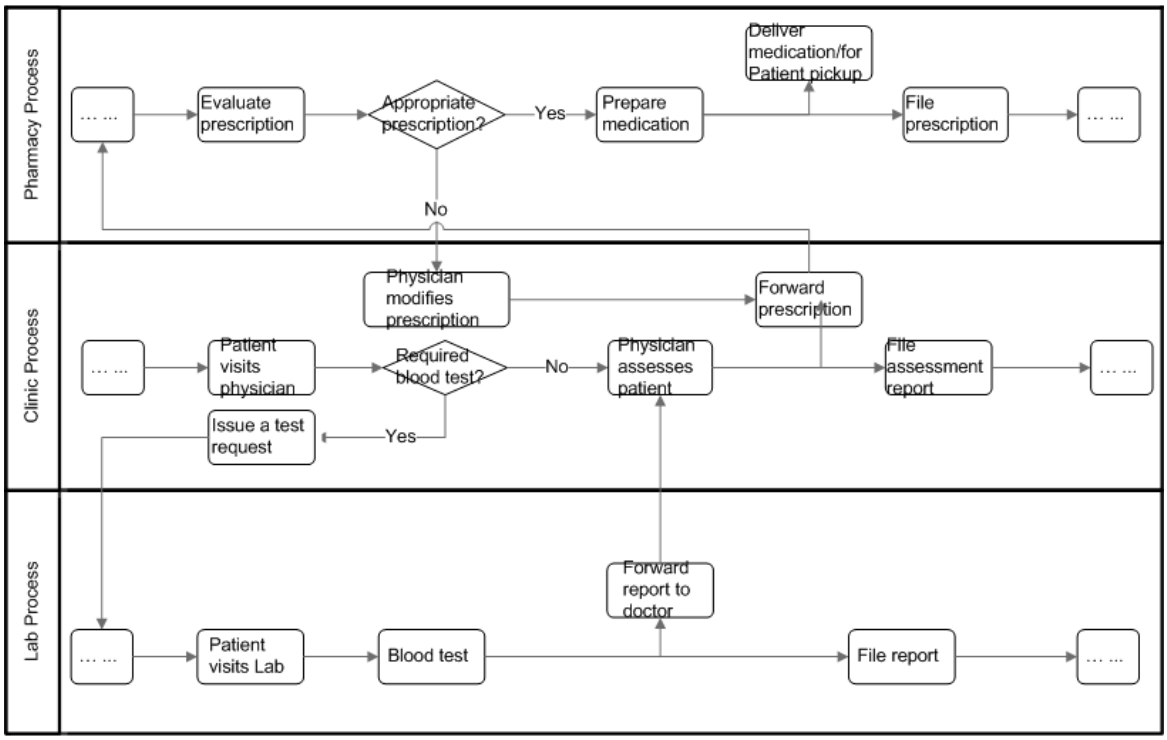


Figure 1-1 A Dependency Scenario in Healthcare

- Intra-dependency refers to routing relationships between neighboring activities within one process. For example, in the Clinic process, both activities "Forward prescription" and "File assessment report" depend on the activity "Physician assesses patient", which has to finish first before these two activities can start in the Pharmacy process, the activity "Deliver medicine" depends on the activity "Prepare medicine", etc.
- Inter-dependency is the dependency relationship between different processes and, furthermore, an inter-dependency relationship is concretely represented by the routing relationship between activities in the corresponding processes. In our scenario, both the Pharmacy and Lab processes depend on the Clinic process. The initiation of the Pharmacy process depends on the "Forward prescription" activity in the Clinic process and the start of the Lab process depends on a request from the Clinic process. In addition, when a patient needs a blood test, the activity "Physician assesses patient" in the Clinic process depends on the activity "Forward report to doctor" in the Lab process. We can find other inter-dependency relationships in this scenario.
- These dependency relationships are not always limited to one-way dependencies, as just described. We can see for some cases in the Pharmacy process, before the delivery of medication to the patient, we may need the activity of "Prescription modification". This leads to a *Loop* inter-dependency between the Clinic and Pharmacy processes. We can understand the same *Loop* dependency can occur in an intra-dependency relationship.

The dependency relationships we just have mentioned are mainly the routing dependency which described the activity and process execution order. These execution orders are defined by the developers or designers of workflow processes based on technical requirements, business regulations, management policies, etc. If two activities are executed in a sequential way, it means one of two activities will only start to execute after another one is executed and finished.

The second thing we can identify from our scenario is that there is another dependency relationship determined by *data* dependencies that have not been explicitly represented in our flow chart. For example, a physician without a blood test report, which is the data created by the Lab process, cannot assess the patient. A pharmacist without a prescription, which is data created from Clinic process, cannot prepare or dispense the medication. We also can see that a clinic nurse cannot file anything unless an assessment report from a physician is available, etc. Actually, the dataflow built on data dependency has generally been neglected in workflow research, which usually focuses on activity routing dependencies only [2, 11, 12, 19, 28]. Through our on-site documentation of the Medical Image Department of Grand River Hospital, it was interesting to find that data dependencies do not always correspond to the routing dependency. That is, the data flow may not match the execution order of activities and processes. We will provide a detailed example in Chapter Two in which it will show exactly this situation. This conclusion tells us that in our dependency analysis, we have to analyze the data dependencies separately from routing analysis, instead of concentrating on routing dependencies only.

Although here we have used input and output data to illustrate the important role of *data* in this dependency scenario, in this technical report the *data* refer to both input data/output data and meta-data of input/output data. For example, if we say d is an output data of activity a in a process p, then d

denotes both output data and the meta-data of this output data. Hereafter, we will not include meta-data in our analysis separately. That is, if we say there is a data change, it could be the output data itself changed, e.g., a data element may be unavailable or one output report becomes several output reports; or the meta-data changed, e.g., the role that generated the data is changed, the time when the data is generated is changed, the location where the data is available is changed, etc. The purpose of this definition is to simplify our discussions later and keep our notations concise and consistent. We will discuss *data* dependency again in the following sections and further in Chapter Two when we analyze our multiple dimension dependency relationships, i.e., routing, data and role dependencies.

1.1.2 Workflow Process Change Background

In the real world, there are causes of changes to existing workflow processes. For example, the modification of laws or regulations may require the workflow process to be changed to comply with the new laws or regulations; new medical or healthcare knowledge may require healthcare providers to make corresponding changes in their health service process implementations; new technologies may be introduced into business processes, which replace the jobs previously done by humans to increase efficiency; new systems may be deployed to upgrade old ones in current workflow processes, etc.

As we have discussed, there are many factors that change a process. Usually these factors are of two types, which lead to either *intentional change* or *non-intentional change*. *Intentional change* means the change is purposefully undertaken and its effects expected; while *non-intentional change* may be caused by human mistakes or unpredictable system errors, e.g., coding bugs, hardware configuration errors, etc. Although we realize that *non-intentional change* may impact the activities and processes, they are not the point of impact analysis. In this technical report, we will focus on *intentional change* since its impacts are predicable through our system dependency analysis that will be described in later chapters. Hereafter, when we say *change*, it means *intentional change*.

Regarding change, typically it occurs in several stages of a process life cycle: during the design, reengineering/redesign, and maintenance of the process. During the design stage, change is usually driven by the customer requirements, as typical in system and software design domains. However, even with today's modern design methodologies and tools, we still face challenges in dealing with change.

On the other hand, after a process is designed and is deployed in a specific domain, sometimes because of the significant alteration in customer requirements on the domain environment in which the process is deployed, the process may need reengineering. Process reengineering refers to a systematic approach to modifying or redesigning an existing workflow/business process [23, 46]. The purpose of process reengineering is to achieve improved performance often because of competitive pressures. There are two stages involved in a reengineering procedure: analysis and redesign. Analysis means documenting, dissecting, and assessing an existing process and identifying which activities or processes should be modified, replaced or eliminated, while redesign involves modifying an existing activity or process, or designing a whole new activity or process from scratch, depending on our reengineering objectives.

Finally, the same challenge also occurs in workflow process maintenance. As we mentioned before, a workflow process consists of different entities. In addition to activities, there are other entities within a workflow process, e.g. roles, resources, events, control data, applications, etc. In order to make

processes satisfy new expectations and requirements, i.e., efficiency and effectiveness, sometimes a modification to an existing process is required. These changes could happen in many ways, for example, tasks could be supported by upgraded systems, human jobs could be replaced by automated applications, new business or industrial standards could be introduced, traditional data/document media could be changed to electronic media, etc. All of these occur after a (re)designed process is deployed and potentially generate impacts on part of or the whole process.

1.1.3 Motivation Analysis

Based on what we have observed and discussed in the previous sections, first we know there exist various dependency relationships among workflow processes, and second there always are changes to processes. These two facts naturally lead to the conclusion that there could be impacts on other activities and processes if we change some activities or processes. For example, if data produced by a preceding activity, say *a*, are for any reason not available, the activities depending on *a* cannot be activated. This may lead to the whole process not being executed. Another example can be seen in our previous scenario such as when the lab changes the way a report is made available to a physician, e.g., by uploading it to a webpage instead of forwarding it by mail or fax. In this case the medium that carries the data is changed from paper document to web-based electronic document. Such a change will require the physician to make a corresponding change or modification in his/her process, such as setting up an Internet connection to access the laboratory's webpage. In this case it is the meta-data of the blood test data that is changed, not the contents of the report, i.e., the data itself. In the future when we say *data* changes, it means either the input/output data changes and/or the meta-data changes. Here both of these are data dependency examples. However, in Chapter Two we will see there are other kinds of dependency relationships.

Since these changes will continue during the entire process life cycle, an analysis is needed when we handle the impacts of changes at different stages and levels. Moreover, given these examples, and the fact that there often is a complex dependency relationship among workflow processes and activities, we think a workflow Process Impact Analysis (PIA) is an effective way to predict what kinds of impacts we will have. Through PIA, we can identify the affected activities and processes and adapt our process appropriately to satisfy new requirements. In addition to this, new business/workflow processes are being deployed everywhere in order to deliver competitive services to customers or clients. Our objective is to help organizations save effort and time, where the alternative can be business failure. It is for this reason we propose dependency analysis.

1.2 Related Work on Impact Analysis

Workflow process research has existed for more than thirty years and is gaining increasing attention from both industry and academy. However, we find that little work has been done on workflow process impact analysis. In [4, 39], the authors have categorized current workflow process research into the following areas: workflow modeling and validation, workflow performance analysis, and process reengineering. Another area of workflow research addresses the design of workflow management systems, which provide runtime environments for workflow execution. Even the dependency relationships within and among workflow process have been identified in [2, 11, 12, 19, 20, 28]. However, these authors focus on workflow modeling or representation, and most of their dependency

relationships are limited to process structure dependency, i.e., control or routing dependency. We also notice that these structure dependency relationships are limited to intra-dependency without consideration of inter-dependency, as in our example scenario. We can see the limitation of focus to process structure dependency leads to an incomplete understanding of dependencies. In another paper [29], the author introduces a dependency analysis framework consisting of four separate dependency nets, i.e., activity, role, data and actor. However, the goal of this framework is not to deal with changes to processes and the analysis of their impacts, but rather to generate a set of "transition conditions" that later are deployed in a distributed workflow enactment system, i.e., a management system for process execution.

Although there are few references for workflow impact/dependency analysis, we can take advantage of methodologies and techniques widely applied in software impact analysis, as we can note that a workflow process and a software system share many common characteristics. For example, a software method built on another one is like a complex activity composed of simple ones; interaction between different applications or classes is like interactions among activities or processes; a branch path in code is like parallel control flow, software application deployment and execution is like process deployment and execution, etc. Actually we can treat a workflow process as a variant of a software application. Another interesting similarity between software and a process is the stage at which change occurs. Changes usually occur at the same stages of a process life cycle as they occur during the software life cycle, i.e., design, redesign and maintenance. Furthermore, the reasons for changes in software application are the same as those of workflow processes, and these changes have led to today's research activities in software impact analysis. From this point of view, we believe that the workflow process impact analysis deserves the same attention in workflow process research as impact analysis in software research.

1.2.1 Software Impact Analysis

Software impact analysis is often used to assess the effects of a change on a system after that change has been made. However, a more proactive approach uses impact analysis to predict the effects of change before it is instantiated [9, 10]. In fact, currently the main goal of impact analysis is to identify the software products and entities affected by proposed changes and to produce a list of entities that should be addressed during the proposed change process. As a result, we can evaluate the consequences of planned changes as well as the trade-offs among the approaches to implement the changes. Finally, we decide whether or not to make the changes, or we find other ways to make the changes based on our evaluation.

Most researchers follow the partitions in [10] which classifies impact analysis techniques into two broad categories: *dependency analysis* and *traceability analysis*. For *dependency analysis*, tools are developed to detect and capture dependency information in the system source code artifacts. It includes three subcategories: data, control, and component dependency relationships. Among these relationships, data dependencies are relationships among program statements that define or use data. That is, the data dependence exists when a statement provides a value used by another statement in a program. Control dependencies are relationships among program statements that control program execution, while component dependencies refer to the general relationships among source-code components, e.g., modules, files, etc. *Traceability analysis* generally is manual work that focuses on

modeling dependencies from the perspectives of software-engineering environments and documentation systems that contain varied levels of software information. Examples include requirements traceability that identifies parts of the software that may change with changed requirements, software documentation traceability that identifies the component relationships through the use of a document repository, project information database traceability that provides database-query mechanisms to help software engineers determine the potential impacts of changes based on the project management database, etc. Meanwhile some document management systems have been developed to assist this analysis, e.g., document browsers. Although dependency analysis [1, 15, 22, 31, 38, 43] and traceability analysis [6, 7, 30, 35] can be used separately, they also can be used together to achieve an analysis goal as in [32].

1.2.2 Dependency Analysis and Our Approach

As an effective and proven methodology, *dependency analysis* has been the most mature technique available in impact analysis. The dependency relationships are typically represented as graphs or tables that assist people in understanding the dependencies. Dependencies are stored in a dependency graph in which usually each node represents an entity and each directed edge represents a dependency relationship between entities [10].

On the other hand, we can see that the procedure to identify the affected entities, the types of changes, the effects of a change, etc., is time consuming and costly if handled manually as the analysis domain may be contain many entities and have various dependency relationships at different levels. To deal with this problem, researchers have developed various query or lookup mechanisms that usually are associated with the dependency representation, which provides a foundation for the query. These query mechanisms enable users to select the types of dependencies to be analyzed from the identified dependency relationships and infer the affected entities [1, 10, 15, 22, 42, 43] automatically. There are two advantages of using query mechanisms. First, they make the analysis and identification procedure more efficient than the manual procedure because of the well defined dependency representation. Second, we can realize a more accurate identification as manual identification may lead to some affected entities remaining unidentified because of errors, such as missing some relationships.

As we can see in Figure 1-1, the basic flowchart is a graphical representation of dependency relationships within processes and among processes. We have input/output data associated with activities and the whole process. This is the same as would be associated with software applications. From the perspective of control dependency analysis, we also have the routing entities described in Chapter Two that help to decide the execution paths of process instances based on corresponding decisions. Thus, for our purposes, a *dependency analysis* focused on data, control and component or entity analysis is a natural choice for our impact analysis of changes in workflow processes. Furthermore, we take the advantage of a query mechanism to automate our analysis procedure. We will discuss this in detail in Chapters Two and Three.

1.3 Contribution

Our contribution includes a multi-dimensional workflow process dependency model that includes the critical aspects of dependency relationships existing in workflow processes: *routing*, *data* and *role* dependencies. We then formally represent this model by a logic programming language that is *Prolog*,

through a well-defined knowledge base. Furthermore we develop an effective methodology, the use of query rules, to identify the potentially affected entities in the process analysis domain.

1.4 Technical report Outline

In the next chapter, first we give a formal description of a workflow process and its graphical representation. We then show the hierarchical process or subprocess architecture. We further introduce our multi-dimensional workflow dependency model based on a multiple perspective of workflow processes. In Chapter Three, we take the advantage of *Prolog* to define a knowledge base that represents our dependency model. On the basis of this well-defined knowledge base, we develop a set of query rules that can be applied to querying our multi-dimensional dependency model. In Chapter Four, we apply our knowledge base and query rules through case studies through a *Prolog* tool XSB [51] which provides a runtime query environment of *Prolog*. Finally we give our conclusions and discuss future work.

Chapter 2
Workflow Dependency Analysis

In this chapter, first we give an introduction to workflow processes and their graphic representation, i.e., flowcharts. Second we analyze workflow process dependency relationships based on an activity-based view of processes.

2.1 Background on Workflow Process

As a concept and technology, workflow processes, or simply "workflows", have been developed and deployed in industry, business, government, healthcare and other domains. The evolution of workflow processes from traditional manual processes to today's technology assisted or automated processes has been underway for a long time. The primary goal of workflow has remained the achievement of effective and efficient ways to provide customers and clients with products or services that satisfy their needs. The benefits of workflow processes can be summarized as reduced cost, improved productivity, better service quality and error control, and improved inter-communication [5].

2.1.1 Workflow Process Definition

Although people usually have their own intuitive understanding of workflow, *What is Workflow? (Process)* is a question people have been trying to answer since this concept was introduced. One of the widely accepted definitions is provided by the *Workflow Management Coalition* (*WfMC*) [49]. *WfMC* is a non-profit international organization primarily engaging developing workflow standards and technologies. It has over 300 members worldwide representing all facets of workflow, from academia to industry, from workflow system vendor to user. It has published a range of documents about workflow representation and implementation. One of the documents is a collection of glossary of all useful terms related to workflow. In the latest version [48], it defines workflow as:

> The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.

In this definition, *WfMC* defines a workflow process as the automation of all or part of a business process. So what is a business process and what is the difference between business and workflow processes? Actually, there is much discussion and there exist many views about the answers to these two questions in the academic and industrial worlds. In [3, 27, 39], the authors consider "business process" and "workflow" as synonyms, and the author in [3] sees business process as being a marketing concept. This definition has been proven very successful since workflow vendors are renaming their products to be "business process" products. Some see a business process as a model representation at the abstract and conceptual levels, while they consider a workflow process as a representation at the implementation level with enabling technologies such as *workflow management systems* (*WfMS*) [8, 11, 13, 21, 26, 36, 37, 41] that execute business process. We can see that the terms workflow process and business process are used ambiguously.

In our work, we follow the definition of *WfMC* and understand a workflow process as a representation of a business process where all or part of it is supported and executed by automated technologies or systems. At the same time, we consider a workflow process and business process to be the same. In this technical report, we will use workflow process instead of using both in order to make a clear and consistent expression.

We define a workflow process as consisting of a set of entities at different levels, i.e., subprocesses, activities (tasks, steps), roles and control routings, etc., where routing decides the execution order and behavior of activities. An activity is a unit of functionality or unit of service that may be entirely automated or can involve manual interaction with a user or workflow participant to achieve a business goal or objective. Control routings are defined in association with business rules or constraints. A workflow (process) instance or case is executed through the workflow management system with or without interacting with human roles, depending on whether or not there are human roles involved in the workflow process. A workflow management system is a system that defines, creates and manages the execution of workflows through the use of software [48]. Modern workflow processes usually are deployed in a distributed environment. One of the examples is the integration of web services. We will see that this trend may lead to more complex entities in workflow processes and make process analyses a greater challenge.

2.1.2 Control Routing

In this section, we introduce the basic routing entities of workflow process defined in the *WfMC* "Terminology & Glossary" [48]. A routing represents the transition type or control flow between activities. These routing entities are important when we analyze the dependency relationships. Additional term we will use in this technical report are described in Appendix A.

Five control routing types are defined in [48] as follows:

- **Sequential**: A segment of a process instance in which several activities are executed in sequence under a single thread of execution.
- **AND-Split**: A point where a single thread of control splits into two or more threads which are executed in parallel, allowing multiple activities to be executed simultaneously.
- **AND-Join**: A point in the workflow where two or more parallel executing activities converge into a single common thread of control.
- **OR-Split**: A point where a single thread of control makes a decision upon which branch to take when faced with multiple alternative workflow branches.
- **OR-Join**: A point where two or more alternative workflow branches re-converge to a single common activity as the next step within the workflow.

To understand the difference between the *AND-Join* and the *OR-Join*, the *AND-Join* requires synchronization while the *OR-Join* does not require it. Synchronization means the activities that follow can only be executed when all the preceding activities are finished. In this technical report, except for *Sequential routing*, all other routings are represented as boxes containing the corresponding routing type (Fig. 2-1). Since a *Sequential routing* is trivial, we usually use only the edge with an arrow to represent it instead of using an explicit entity. In [48], the authors define a special routing

"*Iteration/Loop*" which means a workflow activity cycle involving the repetitive execution of one (or more) workflow activity(ies) until a condition is met. However, it is a routing implemented by the combination of "*OR*" or "*AND*" routings. Thus, we do not treat "*Iteration/Loop*" routing as an independent routing. Among these routings, *OR-Split* routing is a conditional routing and the activities that follow are selected according to the result of the evaluating of the associated conditions.

2.1.3 Graphic Representation: Activity Flowchart

As we mentioned in dependency analysis, dependency relationships can be represented by a graph. The graphic representation in this technical report is an activity flowchart, which is easy to build and understand. In fact, an activity flowchart is the most often used graphic representation in workflow process research. In an activity flowchart we have two kinds of nodes, one is used to represent activities or (sub)processes; the other is routing entities. Meanwhile, the directed edges show the activity execution order of a process instance determined by the routing entities. Figure 2-1 is a flowchart example with all types of routing entities. Hereafter we will use "flowchart" instead of "activity flowchart".

In this example and any following workflow process flowcharts, we will use gray boxes to represent activities and (sub)processes while clear boxes represent routings; arrow edges represent the control flow. Figure 2-1 is a simple flowchart example without associated entities. In the following sections, this flowchart construct may be extended when additional entities are introduced.

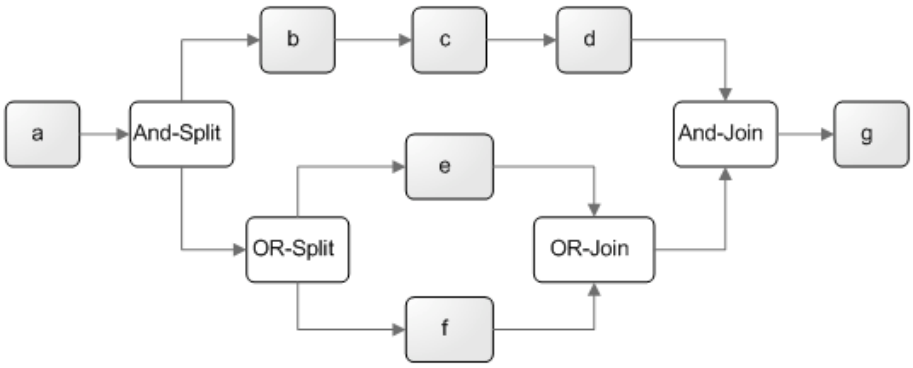


Figure 2-1 A Flowchart Example

2.2 Hierarchical Process Structure

As many researchers [16, 17, 18, 26, 33, 34, 36] have shown, a workflow process can be decomposed to different degrees. That is, a process may have a hierarchical structure across any number of levels by assigning more detailed processes until one arrives at atomic activities. For example (Fig. 2-2), in the Medical Image (MI) Department of Grand River Hospital, we can describe a root level process as: ***…… → BOOKING → REGISTRATION → EXAMINATION → REPORTING → ……***. Some activities in this process can be expanded into a more detailed process or implemented by calling other (sub)processes. In Figure 2-3, the activity ***BOOKING*** can be expanded into the ***Booking*** process while ***REPORTING*** also can be expanded into the ***Reporting*** process. In the ***Reporting*** process, the activity ***Transcribe*** can be replaced by a *Transcription* process at level 2 in this hierarchical structure. The

same things can be done to other activities in the top level process. However, we don not explicitly show them all.

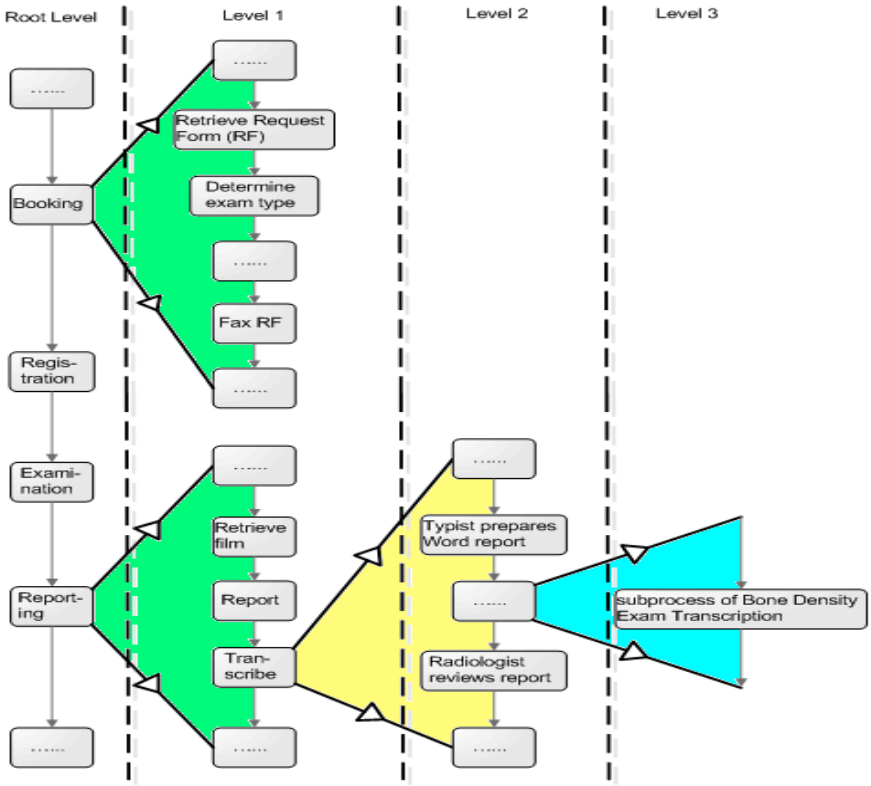


Figure 2-2 A Hierarchical Structure of Workflow Process in the MI Department

Meanwhile a process instance during its execution can call other (sub)processes. In Figure 2-3, we can see that a subprocess call occurred at level 2. The *Bone Density Exam Transcription* subprocess is called from an activity in the expanded activity ***REPORTING*** in the root process, i.e. the *Transcription* process. A subprocess is a process that is called from another process (or subprocess), and which forms part of the overall process [48]. In our work, we consider a subprocess as a general workflow process which cannot be initiated by itself. A subprocess call could be quite complex. For instance, same subprocesses may be called in different processes. Figure 2-3 is an example of such a situation. Two subprocesses *Film Retrieval* and *Film Filing* can be called from three processes in the MI department of GRH, i.e., the *Film Management*, *Film Loan* and *Report* processes. From a dependency analysis perspective, if a change is applied to these subprocesses, it may impact the calling processes.

This process structure provides additional insight into our dependency analysis: a dependency analysis can be applied at different levels.

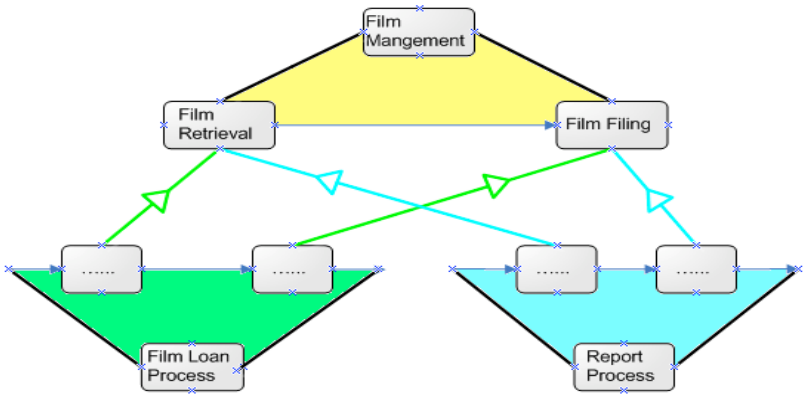


Figure 2-3 A Subprocess Call in the MI Department of GRH

2.3 Workflow Process Dependency Analysis

Until now, we have reviewed the related background and knowledge which will be used in our dependency analysis. The most important entities, *activity* and *routing*, have been introduced and we can use these entities to build a graphical dependency representation, i.e., an activity flowchart.

Besides activity and routing, depending on the modeling methodologies [19, 26, 27, 28, 34, 36, 45, 48, 50], researchers have identified other entities or elements existing in processes, e.g., role/agent, actor, object, resource, event, rule, goal, exception, organizational unit, enact service, etc. These elements have a common property: they usually cannot exist in a process independently and usually are associated with activities. In workflow process modeling, these elements, under a variety of different names, have been used to represent the workflow processes. We believe that these entities also may have various dependency relationships among them. However, in this technical report we build our dependency analysis model based on a *Multiple Perspective Modeling* which we describe in detail in the next section.

2.3.1 Multi-Perspective Workflow Process

One of the most thorough and detailed modeling views is proposed by Jablonski and Bussler [25], which they call *Multiple Perspective Modeling*. Actually, many others [28, 36, 47, 40] have used this multi-perspective of workflow process modeling in their workflow process research.

These perspectives are explained below using our own terms:

- *Function Perspective*, which describes the (recursive) composition of a workflow process out of its subprocesses and activities.
- *Operation Perspective*, which describes, for each part of the process (subprocesses and activities), which operations it supports and which applications implement these operations.
- *Behavior Perspective*, which defines the execution order of the workflow process entities (subprocesses and activities).
- *Information Perspective*, which describes which data is consumed and produced by workflow process and it entities (subprocesses and activities).

- *Organization Perspective*, which specifies which role is responsible for each of the activities in the workflow process.

There is another multi-view modeling framework described in [8] including *Function View*, *Data View*, *Organizational View* and *Control View*. The description of these views is similar to the perspectives, except that the authors use *Control View* instead of *Behavior Perspective*, and *Data View* instead of *Information Perspective*. The difference is there is no corresponding *Operation Perspective* in this multi-view model.

2.3.2 Comparison with Previous Work

Although these process representations or other representation methodologies cannot be used directly for our impact analysis, we may be able to learn lessons from them that can be applied to our impact analysis. First we examine previous work on these representations related to workflow process dependency relationships.

All of the representations have control flow relationships that exist among the process activities which determine the execution order of activities using routings, e.g., [8, 25, 28, 36, 40, 47]. These control relationships through routings may be represented using formal or informal methods, for instances, Petri-Net, State Machine, rule- or calculus-based, declarative representations, etc. Among these representations, we notice that most have ignored an important control flow fact: the *complex routing control* or the *complex routing type*. The *complex routing control* means that a control flow dependency relationship between activities is not determined by one basic routing, but by more than one routing potentially of different types. The *complex routing type* is a composition of basic routings. In Figure 2-1, we can find multiple such complex controls. For example, there is a complex routing composed of both an *And-Split* and an *Or-Split* routing between activities *A* and *E*, as well as between *A* and *F*, *E* and *G* and *F* and *G*. Actually, real world process may have even more complex routings. We will propose a solution to deal with complex routing control in a convenient way in our dependency relationship representation and impact analysis in the next chapter. Complex control also may occur between processes. Figure 1-1 actually contains this kind of complex control, but we have not made it explicit. We will revisit this Clinic-Lab-Pharmacy example later.

The activity data relationship is also an important relationship as seen in previous work [8, 24, 25, 28, 34, 36, 40, 44, 47]. In some reports, data refers to objects that are manipulated by activities [23, 36, 45]. Generally *data* refers to the input data for an activity and output data generated from an activity. Sometimes data are also called values [2]. However, most research focuses on the data relationships between neighboring activities. Interestingly we have observed in many cases that output data may not be used immediately by succeeding activities. The data could be carried forward through many activities until it is used by some activity later in the process. Moreover, we see that sometimes the data is carried forward through the whole remaining process and only used by activities in another process.

Another interesting relationship concerns roles which are the agents responsible for executing the activities. We can see that a role is always associated with an activity and the same role may be associated with multiple different activities. On the other hand, the same activity may have different roles associated with it. This role and activity relationship has been identified by many researchers using different terms [14, 25, 28, 29, 36, 40, 47], e.g., organization, agent, etc. An interesting paper

addresses Agent Assignment [14], i.e., only specific qualified roles can be assigned to or associated with an activity. The reason might be that a business regulation requires a person with certain qualifications to perform a task. This means the change in or replacement of a role is based on whether or not the new role is qualified to perform this activity, i.e., whether or not the new role can carry out the activity with the same features or functionalities as the replaced role. Furthermore, we can imagine that, if an improper change of role in a process occurs, it may lead to unexpected effects on the implementation of the activity or process. The result is either an activity cannot be executed properly with the expected results/output data, or we have to modify the current activities or process to achieve our activity/process objectives. This understanding of the effects of changes in roles is the foundation of our dependency analysis.

We do not include other types of relationships in and among processes in our dependency analysis as separate relationships since they can be understood through other relationships. For example, in the *function view/perspective*, activity is usually represented in combination with the behavior/control relationship.

As we can see, activity and routing are critical entities in a workflow process and no intra- and inter-process relationships can be built without them. We will next discuss the dependency relationships directly associated with *activity* and *routing* and which affect their behaviors.

2.4 Dependency Model for Impact Analysis

Based on both the *Multiple Perspective Modeling* and our analysis of the relationships that are fundamental to our analysis of the impacts of changes in workflow processes, we propose the following multi-dimensional dependency model. It includes three critical dependency relationships: *activity routing dependency*, *data dependency* and *role dependency*. Although we have mentioned other entities and there may exist more dependency relationships, here we focus our analysis on this three-dimensional dependency model other than on every possible dependency relationship. Our purpose is to build an effective and valid model for preliminary impact analysis and thereby establish a solid foundation for future work to include additional dependency relationship analyses.

In this section, we describe thoroughly our dependency model by explaining each dimension of the relationships. The complete formal representation using *Prolog* will be presented in the following chapter.

2.4.1 Routing Dependency

A *Routing Dependency* describes or defines the execution order of activities in a process. In fact when we look at a process activity flowchart, we can conclude that the order of activities represented by a directed edge corresponds to the routing dependency relationship. However a directed edge not only defines the activity execution order of workflow process instance, but also defines the semantics of execution order. For example, for an *And-Join* routing of the three-activities *A*, *B* and *C*, *A* and *B* will execute before *C*. Either *A* or *B* may be finished first, but *C* cannot be executed until both A and B are finished, i.e., there is a required synchronization of *A* and *B* before start of *C*.

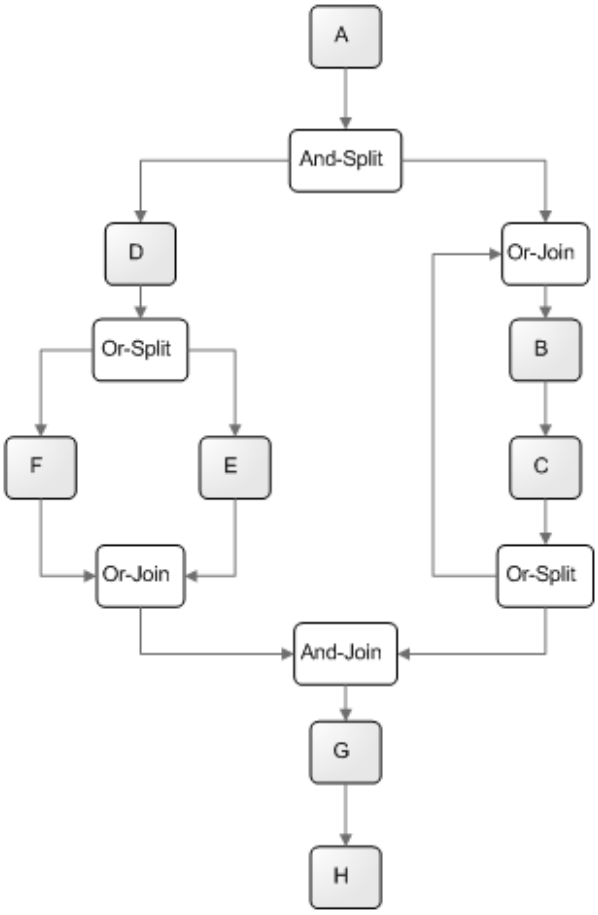


Figure 2-4 Simplified Version of Auto Manufacturing Process

2.4.1.1 Complex Routing Dependency Analysis

As we have mentioned before, there often exist complex routing scenarios in a workflow process or among processes. To illustrate the difficulty of representing the dependencies in complex routings, we use a workflow process flowchart of auto manufacturing as an example in Figure 2-4 which was originally used in [16] and that we have modified for our purposes here. In this modified version, we include more activities and create an *iteration* routing in one of its branches. The flowchart with concrete activity names is shown in Appendix B. In Figure 2-4 the concrete activity names have been replaced by letter symbols from *A* to *H* to allow our explanation to be concise and clear. We can see that this example includes all the five routing types, *Sequential*, *And-Split*, *And-Join*, *Or-Split*, *Or-Join*. We can also see that *Iteration* actually is replaced by a combination of *Or-Split* and *Or-Join*.

As we can see the routing dependency relationship among activities is determined by the basic routing types or by complex routing types. For complex routing types, in addition to include the basic routings, we also need to indicate the order of these routings. The fact is that the order of basic routing types in the dependency representation is critical since different orders will lead to different dependent semantics for these neighboring activities. For example, complex routing type "*Or-Join*, *And-Join*" is

different form "*And-Join*, *Or-Join*". In "*Or-Join*, *And-Join*" complex type, a *synchronization* is required just before the succeeding activity's execution, while in "*And-Join*, *Or-Join*" complex type, the *synchronization* occurs just after the preceding activity's execution and the succeeding activity does not depend on a *synchronization* since the "*Or-Join*" is a *non-synchronization* routing type. In our example (Fig. 2-4), we can see number of complex types, such as an *And-Split* followed by an *Or-Join*, an *Or-Join* followed by an *And-Join*, etc. The dependency relationships of neighboring activities, i.e., A → B, E →G, F → G, C → B and C → G, are determined by more than one basic routing activity. Among them, the dependency between *E* and *G* is determined by two routing types: *Or-Join* and *And-Join*. Meanwhile, we can see the same routing entities also are shared and used to determine the dependency relationships between other activities, e.g., E → G, C → G, etc. Although this complex dependency relationship can be understood through a graphic representation, i.e., a flowchart, we can see it leads to a complex and challenging situation when we attempt to describe it formally. This is because a simple combination of multiple routing types cannot give us all of the information related to these routing entities, as we just saw. We are looking for a straightforward dependency representation that enables a clear and unconfused understanding of the complex dependency relationships. We will see in the next chapter that we can take the advantage of *Prolog* data structure *List* to represent both the routing combination and order of complex routing types.

2.4.2 Data Dependency

As we pointed out, most research on workflow dependency focuses on activity dependency relations, i.e., routing control. However, if we look at the intrinsic features of a workflow process, what we are most concerned about is the *Data* associated with each activity, and the flow from the start of a process to the end. An activity takes input data and produces output data. The data output from the last activity usually represents the achievement of a process, e.g., a radiology exam report, a set of developed X-ray films, a booked appointment, a clinic prescription, etc. Even data flow dependency sometimes corresponds with an activity routing dependency. We will see later that an activity dependency representation as its own is not enough to represent the dependency relationships of the workflow processes. We need to include the data flow dependency relationship as a separate dimension of workflow dependency analysis.

Data flow dependency means that the input data of one activity depend on the output data of other activities. The output data of an activity may consist of a set of data elements or types (e.g. d_1, d_2, d_3, ...), some of which can be used as input data by succeeding activities. These succeeding activities may exist in the same process as the preceding activity or in different processes. From our experience and observation, it is possible that an output data element from one activity is an input data element for activities in a non-neighboring process. If a process does not directly interact with another process, we say these two processes are non-neighboring processes. We find that output data of an activity in a process, e.g., process *P1*, are not always used as input data by other activities in the same process, or even neighboring processes, say process *P2*. This output data from *P1* might be carried forward through part or all of process of P2, to some time later being forwarded and used as input data for another process (e.g. *P3*) that is not a neighboring process of *P1*, but is a neighboring process of the process *P2*. This scenario further demonstrates we need a separate data dependency representation rather than routing dependency only.

2.4.2.1 A Data Dependency Example in Medical Image Department

The following figure (Fig. 2-5) shows the scenario we just described.

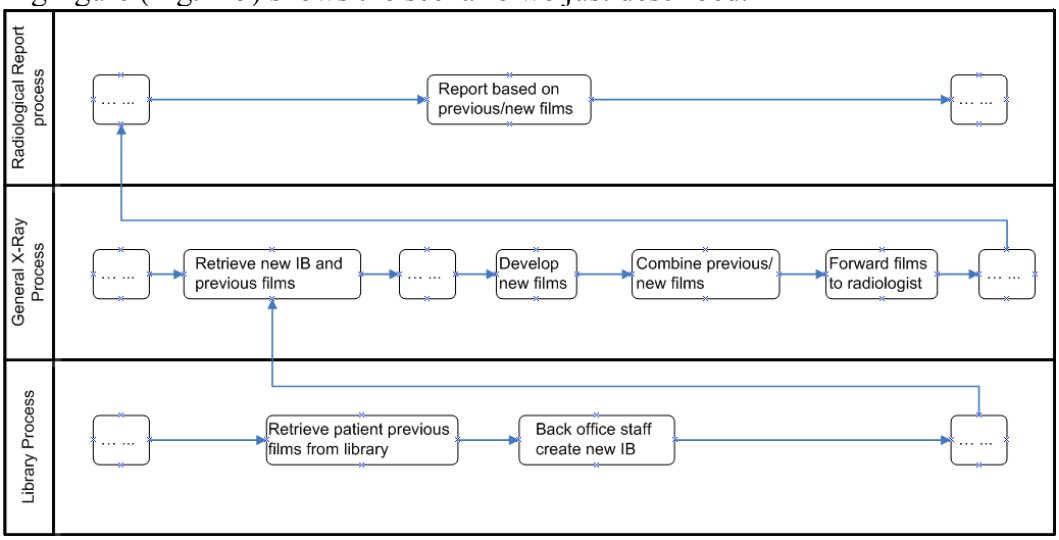


Figure 2-5 Data Dependency Example in MI Department of GRH

We can see that there are three processes, i.e., the library, radiological report and general X-ray exam processes. These processes were documented in the Medical Image Department of Grand River Hospital, a community hospital in Kitchener, Ontario. In this institution, based on a request for previous films used later by a radiologist for comparison purposes when preparing a patient's examination report, a librarian retrieves the patient's previous films from the film library or storage room. A technologist will later pick up a newly-created inner bag (IB) and the patient's previous films. The inner bag will be used to hold the new films produced during the current patient examination. Finally, the new films and previous films for a patient will be forwarded to a radiologist who will do the reporting for the patient based on both previous and newly developed films.

In this example, beyond the many different activity and process dependencies we can see, we realize that the "previous films" retrieved by the librarian and then later forwarded to a radiologist by a technologist have not been used in the current X-ray examination process since the technologist does not need the "previous films" as input data for any activity in his own process. To further drive this home: an emergency patient examination may be carried out without any previous films being available to the technologist. These films, retrieved during the library process, are generally not used until they enter the radiological report process where they are required by the radiologists as comparators for the current examination. The reason why the technologists carry "previous films" forward through their activities without using them is to support the radiologist's work.

2.4.2.2 Data Dependency Analysis

In this example, we can see that a dependency analysis limited to *activity dependency* may not provide enough information and description to determine all existing dependency relationships. A *routing dependency* can only describe the dependency relationships among neighboring activities and processes, not for non-neighboring activities and processes which may have a *data dependency*.

Therefore we should include a separate *data dependency* view to supplement our *routing dependency* for dependency analysis. The activity ***Reporting*** in the *Radiological Report* Process depends not only on the ***Forward Films to Radiologists*** activity in the *General X-Ray* Process, which is a neighboring process to *Radiological Report* Process, but also on is an activity in the *Library* Process which is a non-neighboring process to the radiological report process. If we only represent the activity and process dependencies between the *Radiological Report* and *General X-ray* processes, we neglect the data dependencies between the *Radiological Report* and *Library* processes, an important factor in our impact analysis.

Supposing a PACS (Picture Achieving Communication System) is introduced, we can predict that, within the library process, some activities could be affected since part of the functionality of library process will be replaced by PACS. For example, ***Retrieve Film***, ***File Film*** will be affected. However from a data dependency view, the non-neighboring process, the *Radiological Report* process, is also possibly affected because its input data depend on the *Library* process. We can see this data dependency between the *Library* and *Radiological Report* processes requires the radiologist to find another way to get the "previous films". The solution is that the radiologist can retrieve this patient's previous films by accessing the PACS.

Meanwhile we should realize a dataflow can only exist in association with activity routing control flow, i.e., the input and output data must be associated with activities and processes. Since data cannot exist without activities, for data dependency we can consider it is a dependency relationship associated with the activity routing dependency relationship. Similar to control flow depending on routing dependency relationships, dataflow also depends on input/output data dependency relationships among activities in the same process or different processes. Figure 2-6 is a graphical representation between routing control flow and dataflow.

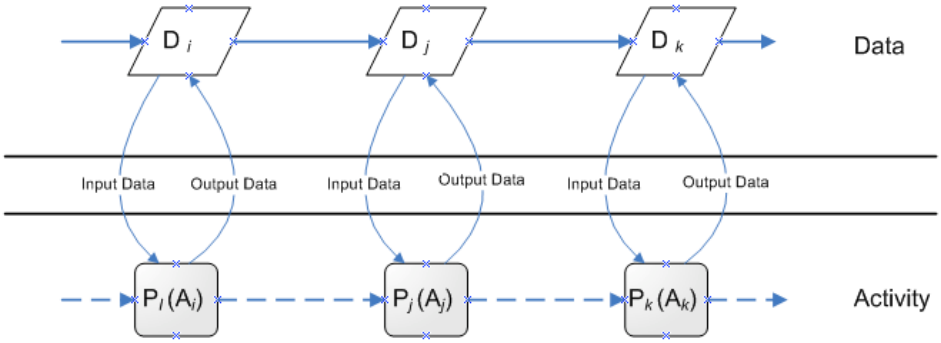


Figure 2-6 Data Dependency & Activity Dependency

In this figure, the top layer represents the data dependencies, where the solid line means these data are dependent directly and the dotted lines between activities in the bottom layer means these activities may not be neighboring activities. Each data element is associated with an activity of a process and consists of both input and output data. Curved lines with arrows represent the input and output data for an activity. For example, the input data of D_j associated with activity A_j is part or all of the output data of D_i which is associated with activity A_i in P_i. In our example, there only is one data dependency relationship between activities, while in fact there may be more than one dependency relationship

among multiple data elements, i.e., many to one or one to many. For example, the input data for the activity A_j may come from more than one preceding activity including the activity A_i.

2.4.3 Role Dependency

In [29] the author has described the *role dependency* through a role-net where the implementation of a role-net is achieved by replacing the activity with the role associated with that activity. That is, the activity-based flowchart becomes a role-based flowchart while at the same time the dependency relationships still depend on routing entities. However we will take a different view of role dependency based on the hierarchical structure of organizations and functions rather than using the same flowchart.

2.4.3.1 Hierarchical Structure of Organization Role

There are different roles which execute the activities in the processes. From an organization's point of view, these roles provide corresponding functions in an organization which has many different workflow processes. The dependency relationships among these roles can be constructed based on the relationships of the role's functionalities which can be induced from the organization's hierarchical structure. Meanwhile, although this approach is an effective way, we will see later in this section that we also need other information to build the complete *role* dependency relationships in the dependency analysis domain. Figure 2-7 is the organizational structure of the Medical Image Department of GRH. This figure only represents part of the organizational structure and some different but similar roles are omitted.

As we know in a hierarchical organization structure, the roles at higher levels usually have more responsibilities or functionalities, which means that they can replace the roles at lower levers of the structure. Covvey et al [52] pointed out that roles have competencies which are determined by their skills, knowledge, etc. Their competencies enable them to perform functions or activities. In fact the hierarchical structure is just the result of the role's competencies. For instance, in figure 2-7, the chief radiologist can be assigned to the role of CT radiologist or MRI radiologist, the leading technologist may do the job usually done by general technologists, etc. This hierarchical structure provides a foundation for the dependency analysis caused by the change of role. If the new assigned role can execute the same activity as the "lower" role, we do not need to worry about the impacts of a role change.

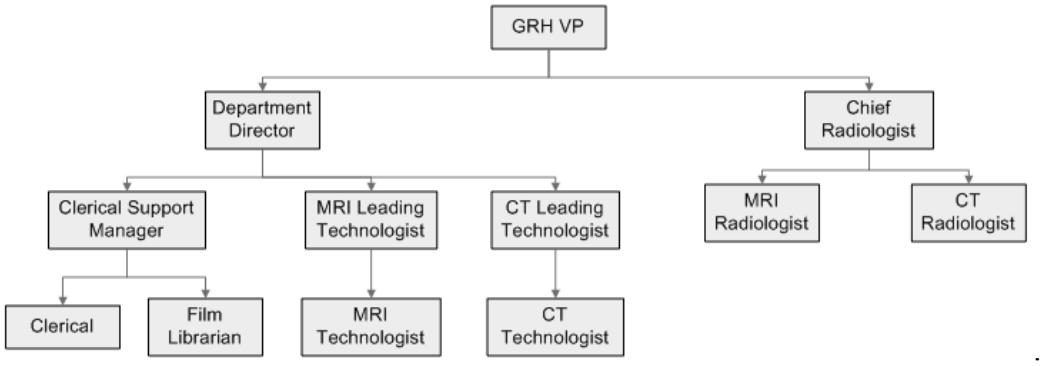


Figure 2-7 A Hierarchical Organization Structure

Now we have seen that our *role dependency* relationships are not based on the flowchart but on the organizational structure. Based on this structure we can identify the relationships among roles. On the other hand, as we previously mentioned, although we are able to utilize the organizational structure to identify the relationships among roles and furthermore to implement our dependency analysis, we also note that in this organizational structure, a role at higher lever may not always be able to implement the functionalities which the role at lower levels usually do. Since the organizational structure is developed by including a management view of roles, i.e. supervision. For example, a MI department director needs to report to the GRH VP because he or she is under the supervision of the VP, but the VP cannot do the job of a department director even that in the figure the VP is at a higher level than the director. To build an appropriate hierarchical role dependency structure, we can start from an organizational structure by combining it with the function view of each role.

2.4.3.2 Dependency Analysis of Role Change

The dependency relationships among roles which we have previously described can be explained as follows. If a role, *Role A*, can be assigned to the same activities that are being executed by another role, *Role B*, we will say *Role B* has a dependency relationship on *Role A*. We can imagine that in some situations, multiple roles, which may be at different higher levels, can be assigned to the activities which are currently executed by another role at a lower level in their hierarchical organizational structure. That is, in role dependency analysis, we may have a one-to-many relationship. In other cases, the same role may be assigned to different activities to replace the current roles, this may lead to the scenario where more than one replacement can occur at different activities of the processes.

Although we can build our *role dependency* relationships from the organizational and functional hierarchical structures, this kind of dependency still is an *activity-based* relationship. When we say there is a role dependency, it means this dependency is for a specific activity in a specific process. This exactly corresponds to the fact of role-activity relationship, i.e., a role must be associated with an activity. In next chapter, we will give an example to explain this scenario in detail when we develop our role dependency queries.

In this chapter we have given a clear and complete view of the workflow process and the entities existing in the processes, especially dependency relationships regarding *routing*, *data* and *role*. Meanwhile we also identified some valuable and interesting aspects which have not been identified or clarified in previous research work.

Chapter 3
A Logical-Based Dependency Representation and Query

In chapter two, we identified and explained our multi-dimensional dependency relationship through a graphical representation. There are three activity-based dependency categories: routing dependency, data dependency and role dependency. In this chapter we first introduce *Prolog* and its application. We then provide a formal description of workflow process entities and further define a knowledge base using *Prolog*, which describes our multi-dimensional dependency relationships. Finally, we develop a query mechanism which will be used to retrieve the potential affected entities if changes occur. The defined knowledge base covers the three identified dependency relationships both within process and among processes.

3.1 *Prolog* Introduction

Prolog stands for PROgramming in LOGic which originated in 1970s. The basic idea behind Prolog is that of *logic as programming*, which sees computation as controlled logical inference. The inference of Prolog is based upon the resolution principle together with mechanisms for extracting answers using linear resolution procedures.

Prolog is a declarative language used to describe problems. It contains *facts* and *rules*, where *facts* state properties which are true of the system we are describing and r*ules* give us a way of deducing new facts from existing ones. A *Prolog* program is often called a knowledge base because it gives information about a system. This makes a *Prolog* program different from other programs since we do not "run a program", instead we query the knowledge base. Given the knowledge base, Prolog will then answer "yes" or "no" to our query. An additional feature of *Prolog* is that it is a relational program. When we run a query it not only tells us if it is true, but it also lists all the situations which make it true.

Prolog has been widely used in system development and analysis, e.g., expert systems, system simulation, software analysis, etc. In software dependency analysis [1, 10, 15, 22, 42, 43], people usually build a knowledge based model which describes the corresponding dependency relationships among the specified entities, then they define a query or lookup mechanism, e.g., a query manager, query language, impact query rule, etc. The impact analysis is implemented by applying the query mechanism to the knowledge based model. The potentially affected entities are returned or identified through the query. *Prolog* is a convenient tool to build the Knowledge Base (*KB*) through defining a set of proper predicates, i.e. *facts*. A query mechanism can then be developed through existing defined predicates.

3.2 Formal Description of Dependency Entities

In this section, we provide a formal definition of dependency entities for workflow processes in the impact analysis domain that we have identified and discussed in previous chapters.

The domain to which we will apply our impact analysis consists of a set of processes or subprocesses. In our work, we will treat a subprocess as a special process which is called from or shared by other processes. It is convenient for us to represent a subprocess as a general workflow process in our knowledge base, instead of specifying the subprocesses using a different formalism. Most importantly, this option helps us solve the challenge caused by the need to represent multiple levels of subprocess calling or sharing, e.g., Figure 2-3. We will discuss this again later in the routing query section. In addition to processes in a specific domain, we also have an organizational structure from which we can infer our *role dependency* relationships through a combination with the *role functionality* relationship.

As previously mentioned there are many entities that can exist in a process and many potential dependency relationships that can exist among them. In this technical report, we focus on the entities which are directly and internally related to our dependency relationship analysis, i.e., the routing, data and role entities. Among the three entities, the *activity* is the core entity and other entities are associated with the activity.

The formal description is defined as follows:

If M represents the analysis domain and P is the set of processes in M, we can represent the analysis domain as $M = \{p\}$ where p is a process in P.

Let E denote the set of entities of process p where p is in P, we have $E = \{A, C, D, R\}$ where A, C, D and R are four finite sets of entities in process p, A is the set of activities, C is the set of control routings, D is the set of output data associated with activities of p, and R is the set of roles associated with activities of p.

We further define each of A, C, D and R as below:

$A = \{a\}$ where a represents an activity in process p.

$C = \{c\}$ where c represents a basic control routing in process p.

$D = \{(d_1^a, d_2^a, ..., d_3^a)\}$ where $(d_1, d_2, ... d_n)$ denotes the set of output data generated through the execution of activity a in process p.

$R = \{r^a\}$ where r denotes the role assigned to activity a in process p.

In addition to these formal descriptions, we also clarify the following scenario for our knowledge base development. We give the control routing entities in a process unique identifications, even if they are of the same routing type. This is because being of the same type does not indicate they have the same meaning. For instance, routing type *Or-Split*, depending on the conditions applied to it, will have different semantics for neighboring activities. We give routings in a process their own identifications to differentiate them from one another.

We will use these concepts and definitions in the following section.

3.3 Knowledge-Based Dependency Relationships

In this section, we explain the knowledge base through well-defined *Prolog* facts that we will apply to describe each aspect of our multi-dimensional dependency relationships. All of these well-defined facts are shown in Table 3-1. The following section will explain the meanings of these defined *Prolog* facts.

Table 3-1 Defined *Prolog* Facts for Multi-dimensional Dependency

#	Fact	Arity	Argument Types
1	Process	1	*P*
2	activity	2	*A, P*
3	routing	1	*structure(C, P)*
4	data	3	*D, A, P*
5	role	3	*R, A, P*
6	routingDep	5	A^1, P^1, *[routing]*, A^2, P^2
7	dataDep	3	A^1, P^1, *structure(D,* A^2, P^2*)*
8	roleDep	4	R^1, *A, P,* R^2

- **process**: Process `p` in an analysis domain, i.e., *process(p)*.
- **activity**: Activity `a` in process `p`, i.e., *activity(a, p)*.

  To describe an activity in our knowledge base, we always include the process information, e.g., process name, ID, etc. to build a complete identification or description for this activity, since we have observed that the same activity may exist in different processes. For example, activity *Film Retrieving* in MI Department of GRH is an activity in both the *Film Loan* and *Examination* processes.
- **routing**: Control routing entity `c` in process `p`, i.e., *routing(structure(c, p))* where *c* refers to the routing identification in process *p*.

  The argument type is a *Prolog structure* where the concrete structure name is one of the routing type names. In this technical report, we have five routing types, i.e., *sequential, and-split/join* and *or-split/join*. The purpose of using routing type as the structure name is to explicitly represent the corresponding routing type of a routing entity. For example, *routing(orsplit(c, p))* indicates an *or-split* type routing entity *c* in process *p*.

  As above with activity, we also include process information to represent a unique routing entity. We can imagine there are scenarios in which two neighboring activities are located in different processes. For these two activities, we know there exists a control routing between them. In this case, we have to specify explicitly to which processes this routing belongs.
- **data**: Output data `d` generated by activity `a` in process `p`, i.e., *data(d, a, p)*.

As we often see, multiple data can be generated from one activity. In our defined *Prolog fact*, one fact denotes one output data. If we have more than one output data, more facts are used to represent these data. For example, if activity *a* in process *p* has two output data elements *d1* and *d2*, two facts are required: *data(d1, a, p)* and *data(d2, a, p)*.

- **role**: Role r assigned to activity a in process p, i.e., *role(r, a, p)*.

  In the real world, for the same activity, it is highly possible that more than one role could be assigned to execute it. For instance, the activity *Taking Photo* in the process *Medical Imaging Examination* can be done by roles either *Technologist* or *Radiologist*. There are two facts to represent this scenario, i.e., *role(Technologist, Taking Photo, Medical Imaging Examination)* and *role(Radiologist, Taking Photo, Medical Imaging Examination)*.

- **routingDep**: Routing dependency relationship between two neighboring activities a^1 and a^2 in corresponding processes p^1 and p^2.

  In a routing dependency relationship, there are three entities involved: process, activity and routing. Since there may be more than one control routing entity between two neighboring activities, we introduce a *prolog list* [] to denote these routings. In *Prolog*, a *List* represented in [] means an ordered sequence of elements. In our case, the elements refer to basic control routings from pre-activity to post-activity. Meanwhile, we know these basic routings also have to be ordered to express the correct dependency relationship as pointed out in Chapter Two (Section 2.4.1.1). The "ordered" property of *List* in *Prolog* exactly matches the "ordered" requirement of routing entities. For example, we can represent the routing dependency between activities *a* and *f* in Figure 2-1 as *routingDep(a, p, [andsplit(id1, p), orsplit(id2, p)], f, p)* where *id1* and *id2* refer to the identifications of corresponding routing entities *and-split* and *or-split* in process *p*.

- **dataDep**: Activity a^1 in process p^1 depends on the output data d from activity a^2 in process p^2. The *structure(D, A^2, P^2)* in fact *dataDep* is defined as *input(d, a^2, p^2)* which indicates the input data *d* for activity a^1 is generated by activity *a* in process *p*.

  It is evident that one activity may depend on multiple input data, i.e., the output data from preceding activities in the same or other processes. To represent this case, we apply our defined fact *dataDep* in the same way as fact *data*. E.g., suppose in process *p*, if activity *c* depends on the output data *d1* and *d2* from activity *a* and output data *d3* from activity *b*, we can represent these data dependency relationships as *dataDep(c, p, input(d1, a, p))*, *dataDep(c, p, input(d2, a, p))* and *dataDep(c, p, input(d3, b, p))*. Each fact only represents one input data element.

- **roleDep**: Role r^1 assigned to activity a in process p can be replaced by role r^2.

  The dependency relationship among roles is a *replacement* relationship, i.e., one role assigned to an activity can be replaced by another role. Sometimes one role can be replaced by more than one role. Multiple *roleDep* facts are required to represent this situation. Moreover, we notice this dependency relationship is an activity-based replacement, which means this replacement can only occur related to a specific activity in a specific process. The scenario in Figure 3-1 shows that role *r1* can execute and be assigned to two activities *a1* and *a0*. Meanwhile role *r2* is

capable of implementing two activities *a2* and *a0*, and *r2* is only assigned to activity *r2*. Both role *r1* and *r2* can do activity *a0* indicating that role *r2* can replace *r1* for activity *a0*, not *a1*. This scenario tells us that, even though role *r2* can replace role *r1* for activity *a0*, it does not mean it can replace all *r1* assigned to other activities, i.e., activity *a1* in our example. Thus we can say this *replacement* relationship is activity-based. For example, in an ultrasound examination process, a radiologist can take examination images for the ultrasound technologist but cannot prepare a technical report for this patient because only the technologist can do this. This dependency can be denoted as: *roleDep(ultrasound technologist, technical report preparation, ultrasound examination process, radiologist)*.

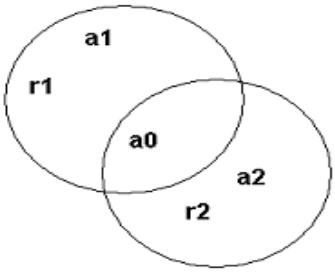


Figure 3-1. Role *Replacement* Dependency Relationship

Until now we have introduced all the defined *Prolog* facts that can now be applied to the entities in the workflow processes and the corresponding dependency relationships we proposed in Chapter Two. In the next section we will describe a query mechanism that will be used to identify the entities that will potentially be impacted if a change occurs.

3.4 Query Rules

In this section, we develop a set of query rules for each of our dependency relationship dimensions. The following subsection will give the query rule definitions and their corresponding semantics. The complete and detailed *Prolog* definitions are included in Appendix C. We will show how to apply these query rules in the next chapter through case studies.

Among the query rules for routing dependency and data dependency analysis, we develop queries at *activity* and *process* levels in both the *forward* and *backward* directions. It is easy to understand a query at the activity level because the planned change may be limited to an activity. However, sometimes we may think about a change to the whole workflow process instead of an activity. In such a situation, we should find all the dependent entities to this whole process. A *forward* query means the query returns the succeeding entities based on the given activity or process. Therefore we refer to it as a *forward* query at the *activity* or *process* levels respectively, as we hope to find all the succeeding dependent entities that may potentially be impacted. For a *backward* query, the query returns the preceding entities of the given activity or process and is referred to as a *backward* query at the *activity* or *process* levels. This *backward* query is as important as the *forward* query. For example, this would be needed when upgrading a system that supports an activity which requires the input data in an electronic table instead of a traditional paper table. In this situation we may have two options. One option is that we can pre-process the data in the paper table, i.e., enter the paper table data into an electronic table. The other

option is to find the preceding activities which generate the paper table to see if they can create an electronic table directly to supply the specific activity's input data. In such a situation, we can see a *backward* query is necessary at both *activity* and *process* levels.

3.4.1 Routing Dependency Queries

A routing dependency relationship represents the execution order relationship of both the activity and process. In fact this order is determined by technical and business requirements as mentioned in Chapter One. When a change occurs to these requirements, the execution order may also require change. If this happens to an activity or a process, we must identify the current routing dependency relationship at both activity and process levels. Based on the results of this identification, we are further able to decide whether the execution orders of activities and processes should be modified to meet the new requirements or not.

Our developed query rules support both f*orward* and *backward* queries at the *activity* and *process* levels respectively. The *forward* rule queries the succeeding executed activities while the *backward* rule queries the preceding executed activities. Besides querying the activity routing order, we can also utilize query rules to identify the process execution order and the corresponding activities to which the routing connects, i.e., where this routing dependency relationship exists among the processes. In addition, through a process query, we can identify similar relationships among processes and/or subprocesses. For example, we can determine which processes call a subprocess through a *backward* process query or which (sub)processes are called from a specified process through a *forward* process query, etc.

Finally, we define a unique query rule to determine if two given activities are *reachable* from one to the other. This *reachability* query is important for impact analysis and has been used in dependency analysis. If the target activity is reachable from the source activity, the target activity then has a direct or indirect routing dependency relationship with the source activity. Otherwise, if a change occurs to the source activity, we do not worry about the potential affect on the target activity since in any case the target activity is not reachable from the source. That is, there is no chance these two activities are executed on the same routing path.

The dependency query rules are included in Table 3-2. The symbols or names in column `Type` representing arguments or variables refer to different entities and relationships. The variables are required to hold the returned query results in *Prolog*:

- *A* and *B* denote the given activities while *P* and *Q* denote the processes in our analysis domain.
- The variable *Results* refers to the returned results from corresponding query rules.

Table 3-2 Query Rules for Routing Dependency Analysis

Query Rule	Arity	Type
postActivityRouting	3	A: argument P: argument Results: Variable
preActivityRouting	3	A: argument P: argument Results: Variable
postProcessRouting	2	P: argument Results: Variable
preProcessRouting	2	P: argument Results: Variable
activityReachPaths	4	A: argument P: argument B: argument Q: argument

We explain the semantics and usage of each rule below:

- **postActivityRouting(A, P, Results)**

  Given an activity $a \in A$ and a process $p \in P$, this query rule will return both succeeding activities and the corresponding routing relationships between a given activity and returned succeeding activities. Multiple activities may be returned since the relationship may be a one-to-many, i.e., multiple activities depend on one activity.

- **preActivityRouting(A, P, Results)**

  Given an activity $a \in A$ and a process $p \in P$, this query rule will return both preceding activities and the corresponding routings between preceding activities and a given activity, respectively. Multiple activities may be returned since the relationship may be a many-to-one, i.e., one activity depends on multiple activities.

- **postProcessRoutingDep(P, Results)**

  Given a process $p \in P$, this query will return succeeding processes that depend on process p, the locations where these dependency relationships occur, i.e., the activities in succeeding processes and the corresponding routings. More than one value may be returned because of one-to-many relationship, i.e. multiple processes may depend on one process or subprocess.

- **preProcessRouting(P, Results)**

  Given a process $p \in P$, this query will return preceding processes that process p depends on, the locations where these dependency relationships occur, i.e., the activities in preceding processes and the corresponding routings. Many values may be returned because of many-to-one relationship, i.e., one process may depend on multiple processes or subprocesses.

- **activityReachPaths(A, P, B, Q)**

Given two activities, source activity $a \in A$ in process $p \in P$ and target activity $b \in A$ in process $q \in P$. Process p and q may refer to different processes. This query will return a *Prolog List* or *Nothing* where the *List* indicates it is reachable from source activity *(a, p)* to target activity *(b, q)*, while *Nothing* indicates there is no *reachability* between these two activities. In addition to indicating if they are *reachable*, the *List* also contains the paths which start from the source activity and go to the target activity. Each path consists of all of the activities from the source activity to the target activity determined through routing dependency relationships. Multiple paths may be returned since from the start activity we may take different paths to reach the target activity.

The query rules **`postActivityRouting`** and **`postProcessRouting`** are *forward* queries at *activity* and *process* levels respectively while the rules **`preActivityRouting`** and **`preProcessRouting`** are *backward* queries at *activity* and *process* levels. Chapter Two described the hierarchical relationships among processes and subprocesses. The **`postProcessRouting`** and **`preProcessRouting`** query rules will help us identify the dependency relationship existing in this structure.

3.4.2 Data Dependency Queries

In previous chapters we showed that *data dependency* is a critical dimension in our dependency analysis. A change to data has a direct impact on dependent entities. As we have observed that data dependency is not always the same as the dependency relationships of control routing, we develop a separate set of rules to implement our queries.

A data dependency relationship exists because an activity's input data is the output data of another activity. Since a change to an activity may lead to a change of all of its output data or a specific output data element only, our query rules support both cases. In the former case, all activities depending on any output data will be retrieved. For the latter case we will retrieve only the activities which depend on a specific changed output data element. Meanwhile, similar to routing dependency query rules, we also develop the data dependency query to support both *forward* and *backward* queries at the *activity* and *process* levels. At the *activity* level, the *forward* rule queries the succeeding data-dependent activities, while the *backward* rule queries the preceding output-data-generating activities. On the other hand, the process level queries will help us identify the data dependency relationship between a given process and other processes. A more detailed description of these queries is given below.

The query rules for data dependency analysis are shown in Table 3-3. As described in the previous section, the symbols or names in column `Type` representing arguments or variables refer to different entities and relationships. There is a new argument *D* which denotes the input data or output data depending on the query rules.

Table 3-3 Query Rules for Data Dependency Analysis

Query Rule	Arity	Type
postActivityData	3/4	A: argument P: argument D: argument Results: Variable
preActivityData	3/4	A: argument P: argument D: argument Results: Variable
postProcessData	2	P: argument Results: Variable
preProcessData	2	P: argument Results: Variable

The semantics and usage of each rule are described as below:

- **postActivityData(A, P, [D,] Results)**

  This query has two rules with D as an optional argument indicating a specific output data element of the given activity $a \in A$ in process $p \in P$. (1) Without argument $d \in D$, this query returns a set of activities in the same process or other processes which depend on *any* output data of the given activity *a*. (2) With argument $d \in D$, we can query for those activities that depend on a *specific* output data element *d* of activity *a*. In fact we can see the second rule is a more granular query rule. For both query rules, multiple activities may be returned. In our knowledge based *fact* representation, we know an activity may have multiple output data and more than one activity may depend on one output data element of this activity. This query is an *activity* level and *forward* query.

- **preActivityData(A, P, [D,] Results)**

  Like query rules **postActivityData,** this query also has two rules with D as an optional argument indicating an input data of the given activity $a \in A$ in process $p \in P$. (1) Without argument $d \in D$, this query returns a set of activities where the output data is the input data of an activity *a*. (2) With argument $d \in D$, we can query to find those activities whose output data is the specified input data element *d* of activity *a*. For both query rules, multiple activities may be returned. Because the input data of an activity may be generated by more than on activity, even the same input data could be from different activities. For example, in the Grand River Cancer Center, a *modified chemotherapy order* may be produced from different activities implemented by pharmacist or physician. This query is an *activity* level and *backward* query.

- **postProcessData(P, Results)**

  Given process $p \in P$, this query returns a set of activities in different processes which depend on the output data of process *p*, i.e., the output data of activities in *p*. Multiple

activities may be returned since more than one activity may depend on the output data generated from process *p*. This query is a *process* level and *forward* query.

- **preProcessData(P, Results)**

  Given process $p \in P$, this query returns a set of activities in other processes where the output data is the input data of process *p*, i.e., the input data of activities in *p*. Multiple activities may be returned since the input data for the given process *p* may be from more than one activity in different processes. This query is a *process* level and *backward* query.

3.4.3 Role Dependency Queries

In the *role dependency query*, we will identify whether a role replacement is acceptable or not. As previously discussed, we know that a role replacement may occur in one activity or multiple activities and more than one role can replace another role assigned to a specified activity. We will cover these requirements in this section.

The query rules of *role dependency* are shown in Table 3-4. A new argument *R* is included to represent the *role* entity in our analysis domain.

Table 3-4 Query Rules for Role Dependency Analysis

Query Rule	Arity	Type
roleReplaceable	4	R1: argument R2: argument A: argument P: argument
roleActivityReplace	2	R: argument Results: Variable
roleReplace	4	R: argument A: argument P: argument Results: Variable

- **roleReplaceable(R1, R2, A, P)**

  Given role $r2 \in R$ assigned to activity $a \in A$ in process $p \in P$, this query will return "Yes" or "No" to indicate whether $r1 \in R$ can replace role $r2$. This query answers our question: if we need a role replacement for a specified activity, is this replacement allowed or not.

- **roleActivityReplace(R, Results)**

  Given role $r \in R$, this query will return a set of roles including corresponding activities and processes in which a role can be replaced by r. For example, if we plan to use role *r* to replace all the roles in our analysis domain where this replacement is feasible, this query will identify all those roles and their locations, i.e., activities and processes.

- **roleReplace(R, A, P, Results)**

This query will return a set of roles which can replace the given role $r \in R$ assigned to activity $a \in A$ in process $p \in P$. If we are looking for the roles which can replace a specified role *r*, this query will tell us all the roles currently available in our analysis domain which are qualified to replace role *r*.

3.5 Inter-Dependency among Processes

Through our knowledge base definition and query rules, we have described each aspect of our multi-dimensional dependency relationship and shown how to apply query rules to corresponding knowledge bases. There is another query requirement we haven not fully addressed, i.e., a query about the dependencies among processes. In many cases, a workflow process does not stand alone, but interacts with other processes. In this section we will identify our concerns and explain our solutions for inter-dependency relationship queries.

Since for each entity in our dependency knowledge base we always include the process information, we can take advantage of the process information, i.e., process name or ID, to easily tell the activities located in different processes. For instance, if we have two activities in two processes respectively, i.e., $activity(a1, p1)$ and $activity(a2, p2)$, and there is a sequential routing dependency from $a1$ to $a2$, we can represent the routing relationship as: $routingDep(a1, p1, [sequential(sequential1, p1)], a2, p2)$. Similar approaches can be applied to building the data dependency knowledge bases.

Although this inter-dependency representation is easy to understand, we need to clarify the following two scenarios for the routing control entities by introducing two rules in order to keep a consistent and complete representation of the relationships.

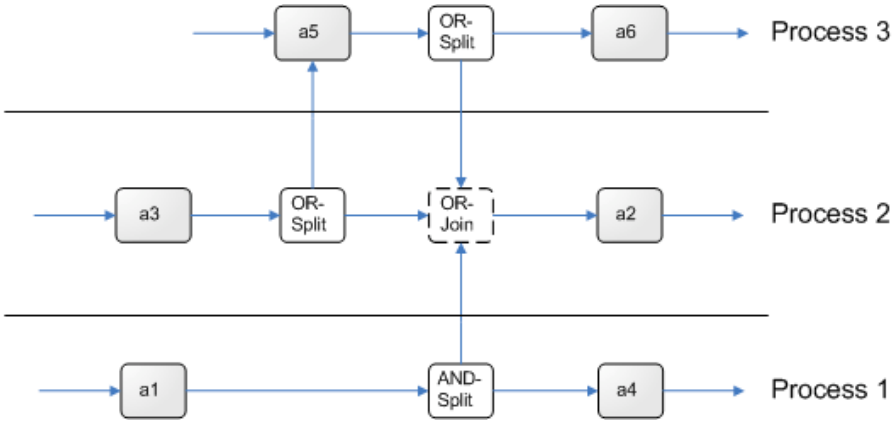


Figure 3-2 Inter-Dependency Routing Entity Identification

- ***Rule One***

  For any types of control routings between two activities in two processes respectively, we define a rule: *if the control entity also determines a routing dependency relationship between two activities both of which are located in one process, we say this entity belongs to this process too*. For example (Fig. 3-2), $activity(a1, p1)$ and $activity(a2, p2)$ have a routing dependency which is determined by *and-split* and *or-join* routings. Meanwhile the routing

dependency relationship between $activity(a5, p3)$ and $activity(a2, p2)$ is composed of *or-split* and *or-join* routings. It is noted that this *or-join* routing is shared by three processes: process 1 (*p1*), process 2 (*p2*) and process 3 (*p3*). We can see that this entity is unnecessary for each process and that it exists because of the inter-dependency relationships among processes as we just described. In such a situation, we need to determine where the location of this routing is, i.e., which process should this routing belong to? After we identify the proper process, we then can represent this routing as a unique entity in our analysis domain. We can see in this example by following Rule 1, there are two activities in the process *p2* only, i.e., $activity(a3, p2)$ and $activity(a2, p2)$, that have a routing dependency relationship containing this *or-join* routing. So we categorize this *or-join* entity as a control routing located in the process *p2*.

- ***Rule Two***

  Given a routing control that exists as an inter-dependency relationship between two processes, if in either of these two processes there does not exist a pair of activities which have an intra-dependency relationship determined by this routing control, we say that this routing entity belongs to the source process, i.e., this routing entity is in the same process as the pre-activity.

The application of a query rule to an inter-dependency in our knowledge base is the same as with intra-dependency. Furthermore, since we include process information in our entity and dependency representations, the returned values will tell us exactly in which processes these entities are located. This is the reason why at the beginning we defined the *Prolog facts* and *rules* by including the process information.

In Chapter Three, we successfully built a knowledge base through a logic programming representation language using *Prolog*. We then developed a set of the query rules which we will see in next chapter is an effective mechanism for dependency analysis.

Chapter 4
A Healthcare Case Study

In this chapter, we introduce a case involving healthcare workflow processes and show how to apply our approach to describe the previously identified multiple dependency relationships. Furthermore we also show the application of our query rules at different levels to identify the entities potentially affected by a change. As intra-dependency and inter-dependency usually occur at the same time in an analysis domain, we will apply these dependency analyses to a case which contains multiple workflow processes.

4.1 Case Implementation Tool and Environment

To implement our case studies, we use a *Prolog* tool XSB. XSB is a research-oriented, commercial-grade Logic Programming system for Unix and Windows-based platforms. It is an extension of the typical *Prolog* system, introducing additional logic evaluation features beyond *Prolog*. Meanwhile it also provides a runtime query environment for *Prolog*. For the purpose of our case study, we choose to implement our dependency analysis queries on a windows-based platform, i.e., Windows 2000 Professional, and start XSB from the DOS command line.

Our knowledge bases for the dependency relationships are stored as files whose names have the suffix *.p* as required by XSB. After building the process dependency knowledge base for our case, both the knowledge base and our defined query rules are compiled and processed in XSB. We then can do the dependency analysis through applying our query rules to the knowledge base.

4.2 Case Study Analysis Domain and Description

For our research purposes, we have documented the current workflow processes of *Grand River Region Cancer Center* (GRRCC). Our case study will involve these processes related to outpatient chemotherapy. Hereafter, we will use the term *patient* instead of *outpatient*. There are four workflow processes in our case study: ***Patient Clinic Process*** (PC), ***Pharmacist Process*** (PH), ***Patient Chemotherapy Process*** (PCH) and ***Chemo Technician (Sub)process*** (CT). Among these processes, the *Chemo Technician Process* is a subprocess since both the *outpatient* and *inpatient* chemotherapy processes use it and share it in their respective processes.

Figure 4-1 shows the detailed activities in each process and the relationships among the activities and processes. In fact, these processes are the simplified versions of the actual healthcare processes. The reason is that the actual processes are very detailed, which would make our case study unnecessarily complex and difficult to understand. On the other hand, although they are the simplified processes, we still retain the critical activities and routings, and we are also able to show typical dependency relationships among them.

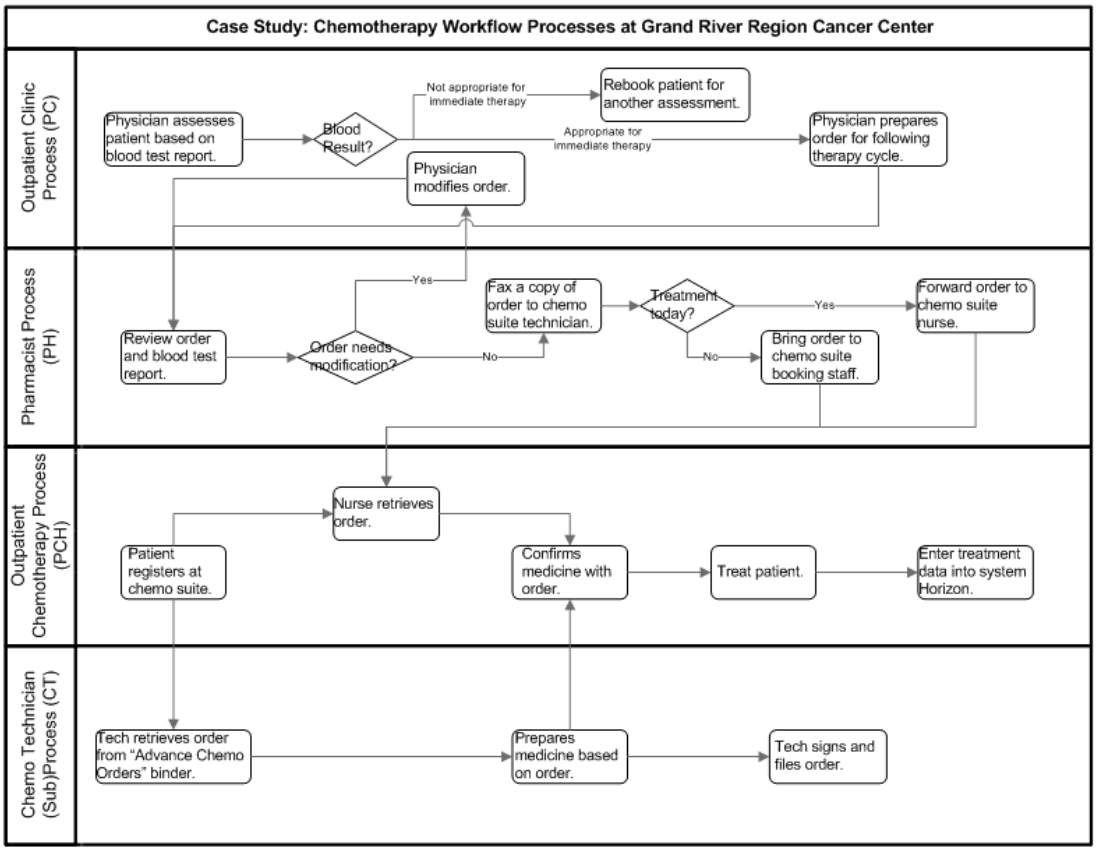


Figure 4-1 Chemotherapy Workflow Processes in GRRCC

Table 4-1 shows the corresponding input/output data associated with each activity in Figure 4-1 and the roles assigned to each activity. In addition, we assign each activity a name which is unique in our analysis domain. In order to achieve this goal, an activity name is a combination of a reduction of the activity description and the process in which the activity is located, with the process name abbreviated. For example, the name for the activity *Physician Modifies Order* in ***Patient Clinic Process*** is *pcOrderModification*.

Table 4-1 Associated Data and Roles of Case Study

Activity(Process)	Activity Name(ID)	Input/Output Data	Role
Physician assesses patient based on blood test report (PC).	*pcAssessment*	Input: ▪ Blood report. Output: ▪ Booking request or ▪ Treatment confirmation	Physician
Rebook patient for another assessment (PC).	*pcRebook*	Input: ▪ Booking request Output: ▪ Assessment appointment	Booking staff
Doctor prepares order for following therapy cycle (PC).	*pcOrderPreparation*	Input: ▪ Treatment Confirmation Output: ▪ Chemotherapy order (simply called order)	Physician
Physician modifies order (PC).	*pcOrderModification*	Input: ▪ Not-Confirmed order Output: ▪ (Modified) order	Physician
Review order and blood test report (PH).	*phReview*	Input: ▪ Order ▪ Blood report Output: ▪ Confirmed order or ▪ Not-confirmed order	Pharmacist
Fax a copy of order to chemo suite technician (PH).	*phFax*	Input: ▪ Confirmed order Output: ▪ Confirmed order	Pharmacist
Forward order to chemo suite booking staff (PH).	*phBooking*	Input: ▪ Confirmed order Output: ▪ Confirmed order	Pharmacist
Forward order to chemo suite nurse (PH).	*phChemoNurse*	Input: ▪ Confirmed order Output: ▪ Confirmed order	Pharmacist
Patient registers at chemo suite (PCH).	*pchRegistration*	Input: ▪ Booked treatment Output: ▪ Order request ▪ Medicine request	Booking staff

Continued in the next page….

Nurse retrieves order (PCH).	*pchRetrieveOrder*	Input: ▪ Order request Output: ▪ Confirmed order	Nurse
Confirms medicine with order (PCH).	*pchConfirmation*	Input: ▪ Confirmed order ▪ Medicine Output: ▪ Confirmed medicine	Nurse
Treat patient (PCH).	*pchTreatment*	Input: ▪ Medicine Output: ▪ Treatment data	Nurse
Enter treatment data into system Horizon (PCH).	*pchEnterData*	Input: ▪ Treatment data Output: ▪ Data stored in Horizon	Nurse
Tech Retrieves order from "Advance Chemo Orders" binder.	*ctRetrieve*	Input: ▪ Medicine request Output: ▪ Confirmed order	Technician
Prepares medicine based on order.	*ctPreparation*	Input: ▪ Confirmed order Output: ▪ Medicine	Technician
Tech signs and files order.	*ctFileOrder*	Input: ▪ Confirmed Order Output: ▪ Confirmed order filed	Technician

We then apply these unique activity names and furthermore include all the routing controls in Figure 4-2 to build the complete case diagram, based on which we can develop our multi-dimension dependency relationship knowledge base. It is worth noting that the routing controls also are assigned a unique name by following the two rules we defined in section 3.5. Each routing control name is a combination of the routing type, the process ID and a description of the routing. For example, *orSplit_pcBlood* indicates this routing is an *Or-Split* type which exists in *Outpatient Clinic Process* (PC) and corresponds with *Blood Results* condition. The inter-dependency routing relationships among processes are shown by the dotted lines.

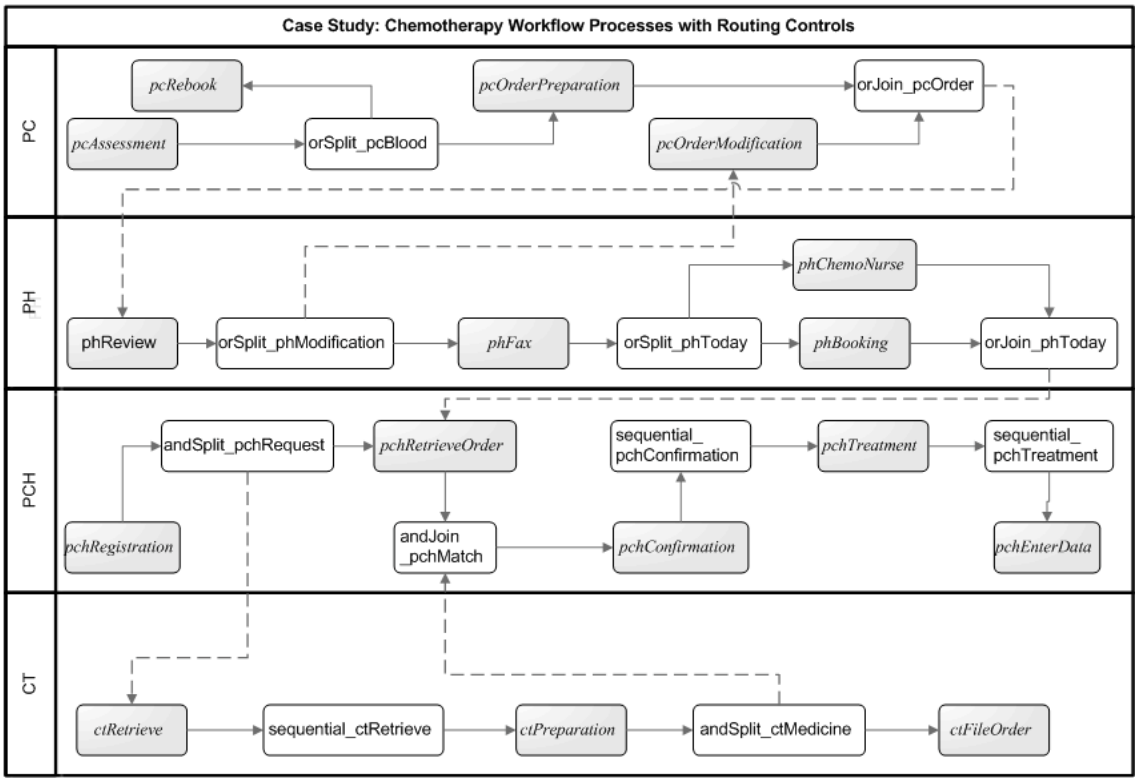


Figure 4-2 Chemotherapy Workflow Processes with Routing Controls

4.3 Knowledge-Based Representation of Dependency Relationships

After we have identified the entities from the previous section, e.g., activity, data, role, we then can build a knowledge base for our dependency analysis. Before we build the knowledge base, we realize there is one data element called *Blood Report* which is an input data element for two activities in our analysis domain, i.e., *pcAssessment* and *pcReview*. If we look through these processes, we can see it is not an output data element from any activity. In fact this data is the output data from a process which we do not include in the Figure 4-1 and 4-2: ***Lab Process***. To build a complete knowledge base, we here define the *Blood Report* to be a data element created by the activity *Test* in process *Lab*. We need this additional information for the development of our data dependency knowledge base.

Another similar situation occurs to the activity *pchRegistration* in the *Outpatient Chemotherapy Process* (PCH). The input data *Booked Treatment* is the output data of ***Booking Process*** which also is not included in the Figure 4-1 and 4-2. Here we define this input data as being from activity *Book* in ***Booking Process***.

Finally in our example case, there only is one role dependency which occurs at activity *pchConfirmation* in the *Outpatient Chemotherapy Process*. The below figure (Figure 4-3) partially shows our knowledge base. The full knowledge base is included as *Appendix D*.

```
… …
% Routing Dependency
routingDep(pcAssessment, pc, [orsplit(orSplit_pcBlood, pc)],
pcRebook, pc).
routingDep(pcAssessment, pc, [orsplit(orSplit_pcBlood, pc)],
pcOrderPreparation, pc).
… …
% Data Dependency
… …
dataDep(pchConfirmation, pch, input(medicine, ctPreparation,
ct)).
dataDep(pchConfirmation, pch, input(confirmedOrder, phReview,
ph)).
… …
%Role dependency
roleDep(nurse, pchConfirmation, pch, pharmacist).
```

Figure 4-3 Partial Representation of Knowledge Base

4.4 Workflow Process Dependency Analysis

In this section, we will apply our query rules to the well-defined knowledge-based dependency model we described in previous sections. The dependency analysis cases will cover all relevant dimensions: routing, data and role. It is noted that we have defined many query rules for various dependency analysis purposes. However in this section we do not apply all of these rules but rather only apply rules that are relevant to typical cases in healthcare.

Table 4-2 is the summary of our analysis of cases. For each case, we specify the corresponding category and the query motivation upon the given entities and the applied query rule. Figure 4-4, 4-5 and 4-6 show the query executions of the analysis cases for routing, data and role dependency analysis respectively. These query executions are in the same order as the cases in Table 4-2.

Table 4-2 Summary of Case Study Analysis

Case	Cate-gory	Given Entities	Motivation	Applied Query Rule
1	routing	activity: *ctPreparation* process: *ct*	Retrieve the routing dependent activities.	*postActivityRouting*
2	routing	process: *ph*	Retrieve the routing dependent processes and related locations (activities).	*postProcessRouting*
3	routing	activity: *phReview* process: *ph*	Retrieve the preceding routing activities and their processes	*preActivityRouting*
4	routing	(sub)process: *ct*	Retrieve the calling process in a hierarchical process relationship.	*preProcessRouting*
5	routing	activity: *phReview* activity: *pchRegistration*	Show that there is no dependency relationship between the given activities.	*activityReachPaths*
6	routing	activity: *phFax* activity: *pchTreatment*	Show that there are two paths from given source activity to target activity.	*activityReachPaths*
7	data	activity: *pcAssessment* process: *pc*	Retrieve all activities depending on any output data of given activity.	*postActivityData/3*
8	data	activity: *pcAssessment* process: *pc* data: *treatmentConfirmation*	Retrieve all activities depending on a specified output data of given activity.	*postActivityData/4*
9	data	activity: *phReview* process: *ph* data: *confirmedOrder*	Show that non-neighbouring activities in other processes have a data dependency on a given activity's output data.	*postActivityData/4*

Continued in the next page ….

10	data	activity: *pchConfirmation* process: *pch*	Retrieve preceding activities whose output data are the input data of given activity.	*preActivityData/3*
11	data	Process: *ct*	Retrieve the activities whose output data are the input data for the activities in the given process	*preProcessData*
12	role	activity: *phReview* process: *ph* role(1): *pharmacist* role(2): *physician*	To see whether given role(2) can replace role(1) assigned to given activity/process.	*roleReplaceable*
13	role	role: *pharmacist*	Retrieve all the roles and their corresponding activities/processes which can be replaced by the given role.	*roleActivityReplace*
14	role	activity: *pchConfirmation* process: *pch* role: *nurse*	Retrieve the roles which can replace the given role assigned to the given activity/process.	*roleReplace*

Figure 4-4 shows the query results for the *routing dependency* analysis. For Case 1, given the activity *ctPreparation*, two activities, *pchConfirmation* and *ctFileOrder*, are returned. We can confirm this result by looking through Figure 4-2. For Case 2, given process *ph*, by comparing the query result with diagram in Figure 4-2, we can see the three returned activities, *pcOrderModification*, *pchRetrieveOrder* and *pchRetrieveOrder* are the activities that have a routing dependency on process *ph*. Cases 3 and 4 are both *backward* queries and also return the expected results. The last two cases, Cases 5 and 6, are reachability queries. From diagram in Figure 4-2, we can see there is no direct or indirect routing dependency relationship between activity *phReview* and activity *pchRegistration*. The query result of Case 5 also indicates this fact. Case 6 returns two paths from activity *phFax* to activity *pchTreatment*, furthermore those activities on these two paths are returned in a *Prolog List*.

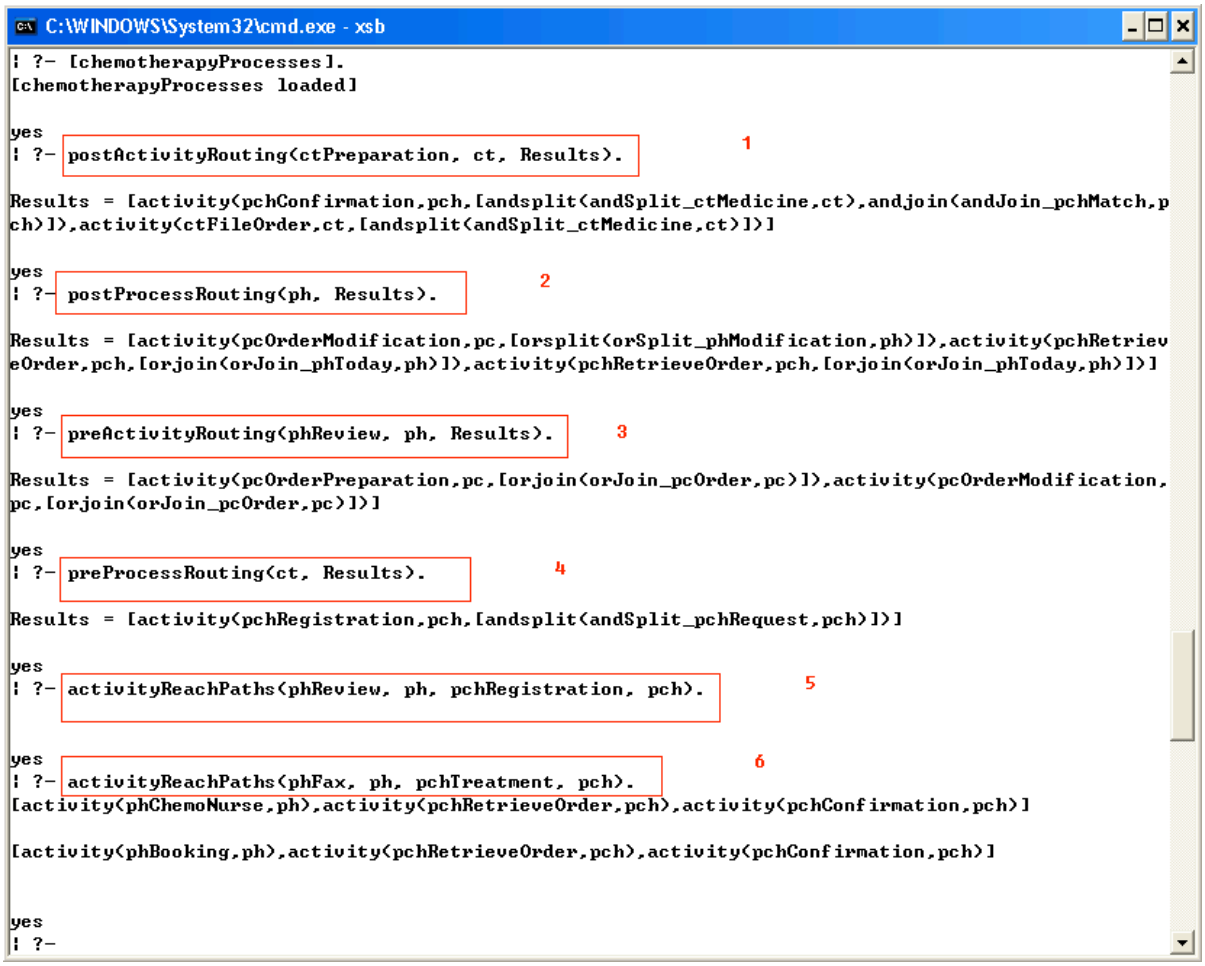


Figure 4-4 Routing Dependency Analysis Query Execution

Figure 4-5 shows the query results for the *data dependency* analysis. Cases 7 and 8 are *forward* queries based on the same given activity *pcAssessment* and process *pc*. The difference between these two cases is that in Case 8 we specify an output data element *treatmentConfirmation* of activity *pcAssessment*. We also can see the difference in the returned query results. Case 8 returns activity *pcOrderPreparation* only while Case 7 returns both activity *pcOrderPreparation* and activity *pcRebook*. Case 9 shows the data dependency relationships for given activity *phReview* and its output data element *confirmOrder* occur at multiple activity locations in non-neighboring processes. Cases 10 and 11 are both *backward* queries with or without a given activity. We can see that both of them return the expected activities by checking Table 4-1.

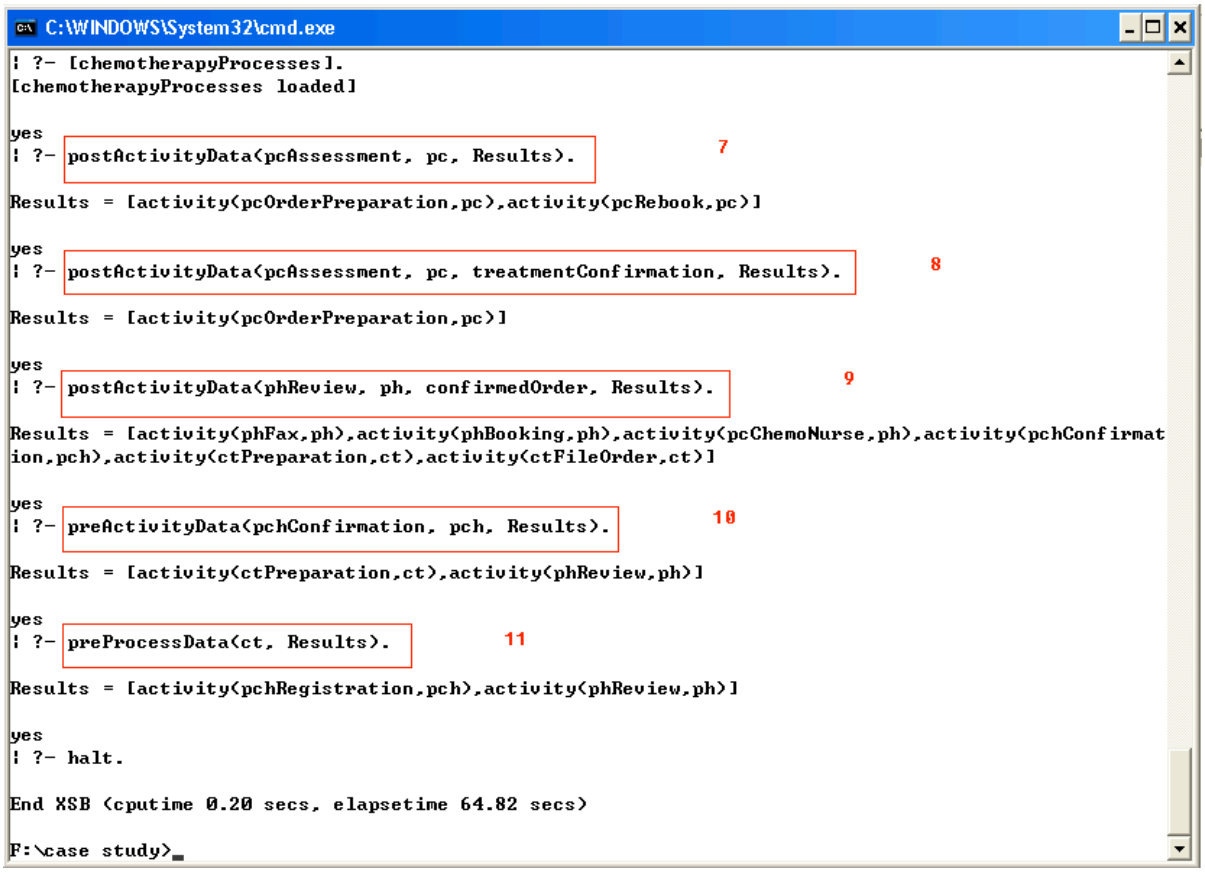


Figure 4-5 Data Dependency Analysis Query Execution

We have three queries in Figure 4-6 that shows the *role dependency* analysis. Case 11's query result indicates the role *physician* cannot replace the role *pharmacist* associated with activity *phReview*. In our analysis domain, it is allowed that both *pharmacist* and *nurse* can execute activity *pchConfirmation* that normally is assigned to role *nurse*, i.e., role *nurse* has a dependency relationship on role *pharmacist*. Case 12 shows this role dependency between *nurse* and *pharmacist*. Case 13 is a reverse query compared to Case 12, it returns all the roles that can replace the role *nurse* assigned to activity *pchConfirmation*. As we already know from Case 12, there exists one role *pharmacist* that can make this replacement.

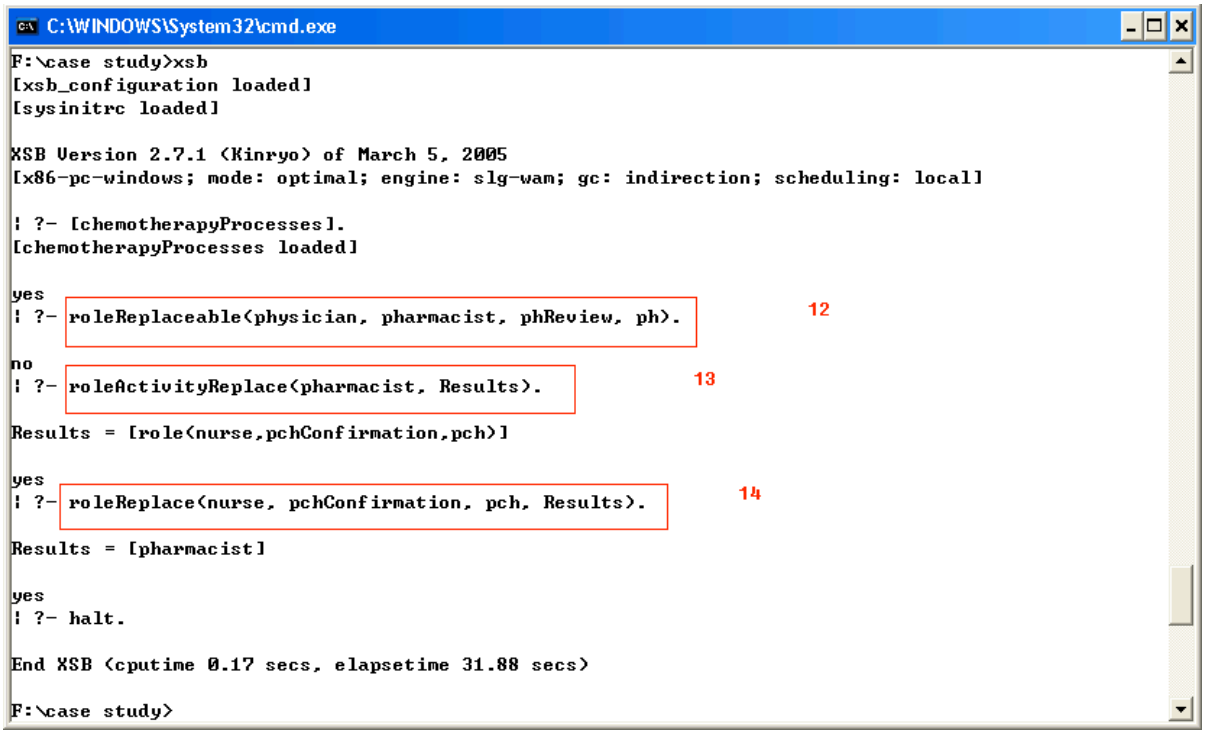


Figure 4-6 Role Dependency Analysis Query Execution

In this chapter, we adapt our documented workflow processes of GRRCC to show how to apply a complete process dependency analysis based on a well-defined knowledge base which is implemented using *Prolog*. Through a set of typical selected cases, we can see that our approach of workflow process dependency analysis works well at different analysis levels and provides a solid foundation for further and advanced analysis.

Chapter 5
Conclusion and Future Work

Although it is widely known that impact analysis is a very important research topic in systems analysis, we have not seen much attention to impact analysis related to workflow process research. Like in any other type of system, changes in workflow processes are unavoidable and these changes occur at all stages of the process life cycle. The purpose of impact analysis is to reduce the "ripple effect" where making a small change to a system affects many other parts or entities of the system. This is done through identifying and tracing the dependency relationships between the changed part and other potentially affected parts.

This technical report contributes to the area of workflow process impact analysis by analyzing and representing the dependency relationships among the process entities. We have proposed a multi-dimensional view of workflow process dependency relationships: *routing dependency*, *data dependency* and *role dependency*. We have then defined a set of atomic predicates in *Prolog* and, based on these well-defined predicates, we have constructed a *knowledge base* for each dimension of our dependency relationships. Finally, we have developed an effective query mechanism, i.e., query rules in *Prolog*, which can be applied to the knowledge bases to identify the potentially affected entities, given a specific change. In addition, a case study involving multiple healthcare workflow processes has been given to show how our analysis works. This has included the development of a dependency relationship knowledge base and the application of query rules.

Although we have achieved our goals in this technical report, we realize there are many other challenges existing in workflow process impact analysis that are worthy of further attention in future research. We discuss them here.

First, in this technical report we focused on the limited entities: activity, role, routing and data only. In section 2.3, in fact we mentioned a number of other entities related to workflow processes. These entities, e.g., goal, rule, resource, event, exception, etc. also have dependency relationships among themselves and those already identified, i.e., activity, role and data. We can see that a further identification and classification of these dependency relationships and their incorporation into a comprehensive impact analysis will be necessary.

Second, our dependency knowledge is generated based on a graphic representation, i.e., flowcharts that implicitly and explicitly contain these dependency relationships. While we can see that flowcharts are very helpful in identifying these relationships, flowcharts are an inconvenient formalism from which to generate these dependency representations automatically. A better choice would be a declarative representation of workflow processes from which we could directly and automatically identify and generate these dependency relationships.

Third, although we take advantage of software impact analysis, the workflow processes are different from a general software application. In most of the cases, a workflow process instance is executed by a combination of humans and systems. This mixture of manual and automatic agents adds more entities into the design and implementation of a process. Meanwhile, we realize a workflow process usually is

deployed in a distributed environment which makes dependency relationships more complicated and harder to analyze. This also makes the dependency analysis more challenging.

Fourth, the building of the dependency relationship among roles is quite complex since the functionalities of a role are not only determined by what this role can do, but also by what this role is allowed to do. Especially since a real workflow process is usually deployed in a distributed networking environment, authentication and authorization are "a must". When we think about the *replacement* relationship of roles, at the same time we also have to think about their authentication and authorization. In this technical report we developed our role dependency relationship primarily from the single hierarchical organizational structure. In the future, we will need to generate the role replacement relationships using a more comprehensive and formal representation of the role functionalities.

There are other dependency relationships. One of them is the routing condition whose evaluation depends on other entities, e.g., data, role, etc. In this technical report we have limited the routing conditions to *Or-Split* routing only. However, in the real world a condition may be associated with other routing controls. For example, a *sequential* routing may have a temporal condition, i.e., a time condition to indicate that the post-activity can only start after some period of time. In addition, this kind of conditional dependency relationship with other entities could be very versatile. In our documented workflow processes of the Cancer Center at GRH, a condition could be the distance of the patient's location form the Center, the execution time of an activity, etc. We think this dependency could be a valuable aspect of workflow process impact analysis.

As we have pointed out, there has not been enough attention and research focused on workflow process impact analysis, although the workflow process research and commercial development are attracting more people from both the academic and industrial fields. Our work is a preliminary view and an early initiative in process impact analysis. We have described some unsolved and interesting questions and challenges related to process dependency analysis, and we definitely have not addressed every aspect of this topic. We look to the future for more systematic analyses and more complete dependency relationship representation as these are essential for the advancement of this field.

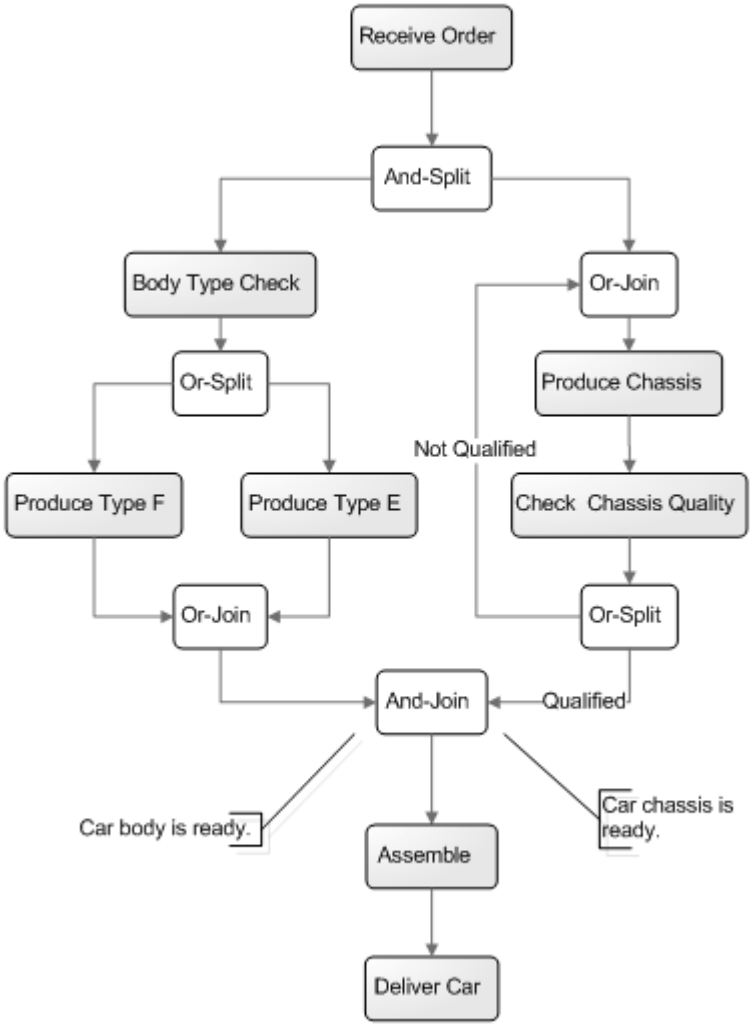
Appendix A
Workflow Process Terminology

The following terminologies are excerpted from [48].

- **Workflow** The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.
- **Workflow Management System** A system that defines, creates and manages the execution of workflows through the use of software.
- **Business Process** A set of one or more linked procedures or activities which collectively realize a business objective, normally within the context of an organizational structure defining functional roles and relationships.
- **Process Definition** The process definition consists of a network of activities and their relationships, criteria to indicate the start and termination of the process, and information about the individual activities, such as participants, associated IT applications and data, etc.
- **Activity** A description of a piece of work that forms one logical step within a process. There are two kinds of activities, manual and automated.
- **Instance** (**Process Instance or Activity Instance**) The representation of a single enactment of a process, or activity within a process, including its associated data.
- **Workflow Participant** (**Role**) A resource that performs the work represented by a workflow activity instance.
- **Subprocess** A process that is enacted or called from another (initiating) process (or subprocess), and which forms part of the overall (initiating) process. In our work, we treat a subprocess as a general workflow process.
- **Event** An occurrence of a particular condition that causes the workflow management software to take one or more actions. An event has two elements: trigger and action.
- **Constraint (Rule)** A condition that must be met during work processing; failure to meet a constraint may causes an exception condition or other defined procedure.
- **Workflow Engine** A software service or "engine" that provides the run time execution environment for a process instance.
- **Parallel Routing** A segment of a process instance where two or more activity instances are executing in parallel within the workflow, giving rise to multiple threads of control.
- **Iteration/Loop** A workflow activity cycle involving the repetitive execution of one (or more) workflow activity(s) until a condition is met.

Appendix B

Auto Manufacturing Flowchart Example



Appendix C
Dependency Relationship Query Rules

```
/* Routing Dependency Query Rules */

/*
 Post-Activity Routing Dependency Query: return both
post-activities and routings between given activity and
returned post-activities.
*/

postActivityRouting(A, P, Results):-
findall(activity(PostActivity, PostProcess, Routings),
postActivityRoutingDep(A, P, PostActivity, PostProcess,
Routings), Results).

postActivityRoutingDep(A, P, PostActivity, PostProcess,
Routings):- routingDep(A, P, Routings, PostActivity,
PostProcess).

/*
Pre-Activity Routing Dependency Query: return both pre-
activities and routings between pre-activities and given
activity.
*/

preActivityRouting(A, P, Results):-
findall(activity(PreActivity, PreProcess, Routings),
preActivityRoutingDep(A, P, PreActivity, PreProcess,
Routings), Results).

preActivityRoutingDep(A, P, PreActivity, PreProcess,
Routings):- routingDep(PreActivity, PreProcess, Routings,
A, P).

/*
Post-Process Routing Dependency Query: return post-
processes, corresponding activities and routings.
*/

/* Routing Dependency Query Rules (To be continues) */
```

Continued on the next page ….

```
/* Routing Dependency Query Rules */

postProcessRouting(P, Results):- findall(activity(A, Q,
R), postProcessRoutingDep(P, A, Q, R), Results).

postProcessRoutingDep(P, A, Q, R):- routingDep(_, P, R,
A, Q), P\==Q.

/*
Pre-Process Routing Dependency Query: return pre-
processes, corresponding activities and routings.
*/

preProcessRouting(P, Results):- findall(activity(A, Q,
R), preProcessRoutingDep(P, A, Q, R), Results).

preProcessRoutingDep(P, A, Q, R):- routingDep(A, Q, R, _,
P), P\==Q.

/*
Activity Reachability: Return a "List" or "Nothing" which
indicate whether in any case two given activities could
be executed on a routing path. At the same time, all the
activities on all possible paths are returned in the
"List".
*/

activityReachPaths(A, P, B, Q):-findall(L,
activityReach(A, P, B, Q, []), Results).

activityReach(A, P, B, Q, L):- routingDep(A, P, _, B,
Q),!, write(L), nl,nl.

activityReach( A, P, B, Q, L):- routingDep(A, P, _, C,
S),  testmember(activity(C, S), L), append(L,[activity(C,
S)], L2), activityReach( C, S, B, Q, L2).

/* End of Routing Dependency Query Rules */
```

Continued on the next page ….

```
/* Data Dependency Query Rules */

/*
Post-Activity Data Dependency Query: return a set of
activities which depend on the data of given activity.
*/

%(1) Without specified output data

postActivityData(A, P, Results):-
setof(activity(PostActivity, PostProcess),
postActivityDataDep(A, P, PostActivity, PostProcess),
Results).

postActivityDataDep(A, P, PostActivity, PostProcess):-
dataDep(PostActivity, PostProcess, input(_, A, P)).

%(2) With specified output data

postActivityData(A,P,D, Results):-
findall(activity(PostActivity, PostProcess),
postActivityDataDep(A, P, D, PostActivity, PostProcess),
Results).

postActivityDataDep(A, P, D, PostActivity, PostProcess):-
dataDep(PostActivity, PostProcess, input(D, A, P)).

/*
Pre-Activity Data Dependency Query: return a set of
activities which the given activity depends on the
output data of the returned set of activities.
*/

%(1) Without specified input data



/* Data Dependency Query Rules (To be continues) */
```

Continued on the next page ….

```
/* Data Dependency Query Rules */

preActivityData(A,P, Results):-
setof(activity(PreActivity, PreProcess),
preActivityDataDep(A, P, PreActivity, PreProcess),
Results).

preActivityDataDep(A, P, PreActivity, PreProcess):-
dataDep(A, P, input(_, PreActivity, PreProcess)).

%(2) With specified input data

preActivityData(A, P, D, Results):-
findall(activity(PreActivity, PreProcess),
preActivityDataDep(A, P,D, PreActivity, PreProcess),
Results).

preActivityDataDep(A, P, D, PreActivity, PreProcess):-
dataDep(A, P, input(D, PreActivity, PreProcess)).

/*
Post-Process Data Dependency Query: Return a set of
activities in other processes which depend on the output
data of activities in the given process.
*/

postProcessData(P, Results):-
setof(activity(PostActivity, PostProcess),
postProcessDataDep( P, PostActivity, PostProcess),
Results).

postProcessDataDep(P, PostActivity, PostProcess):-
dataDep(PostActivity, PostProcess, input(_, _, P)),
PostProcess\==P.



/* Data Dependency Query Rules (To be continues) */
```

Continued on the next page ….

```
/* Data Dependency Query Rules */
/*
Pre-Process Data Dependency Query: Return a set of
activities in other processes which the given process
depend on the output data of the returned activities.
*/

preProcessData(P, Results):- setof(activity(PreActivity,
PreProcess), preProcessDataDep( P, PreActivity,
PreProcess), Results).

preProcessDataDep(P, PreActivity, PreProcess):-
dataDep(_, P, input(_, PreActivity, PreProcess)),
PreProcess\==P.

/* End of Data Dependency Query Rules */

/* Role Dependency Query Rules */

/*
Roles assigned: Return a set (List) of roles assigned to
a given activity in process.
*/

allRoleAssigned(A, P, Results):- findall(R,
roleAssigned(A, P, R), Results).

roleAssigned(A, P, R):- role(R, A, P).

/*
Activities assigned: Return a set(List) of activities
assigned to a given role.
*/

allActivityAssigned(R, Results):- findall(activity(A, P),
activityAssigned(R, A, P), Results).


/* Role Dependency Query Rules (To be continues) */
```

Continued on the next page ….

```
/* Role Dependency Query Rules */

activityAssigned(R, A, P):- role(R, A, P).

/*
Role replaceable: Return "Yes" or "No" to indicate
whether a role "R1" can replace a role "R2" assigned to a
specified activity in process or not.
*/

roleReplaceable(R1, R2, A, P):- roleDep(R2, A, P, R1).

/*
Activity replacement: Return a set of activities and
roles which can be replaced by given role.
*/

roleActivityReplace(R,Results):- findall( role(R1, A, P),
roleDep(R1, A, P, R), Results).

/*
Role replacement: Return a set of roles which can replace
the given role assigned to a specified activity.
*/

roleReplace(R, A, P, Results):- findall(R1, roleDep(R, A,
P, R1), Results).
/* End of Role Dependency Query Rules */


/* Assistant Query Rules */
member(X,[X|_]).
member(X,[_|T]) :- member(X,T).
testmember(A,B):-member(A,B),!,nl,fail.
testmember(A,B).
append(L1,L2,L3) :- L1=[], L3=L2.
append(L1,L2,L3) :- L1=[H1|T1], append(T1,L2,T3),
L3=[H1|T3].
```

Appendix D
Knowledge Base for Case Study Dependency Model in *Prolog*

```
% Processes in analysis domain
process(pc).          % Outpatient Clinic Process
process(ph).          % Pharmacist Process
process(pch).         % Outpatient Chemotherapy Process
process(ct).          % Chemo Technician Process

% Activities in Outpatient Clinic Process (PC)
activity(pcAssessment, pc).
activity(pcRebook, pc).
activity(pcOrderPreparation, pc).
activity(pcOrderModification, pc).

% Activities in Pharmacist Process (PH)
activity(phReview, ph).
activity(phFax, ph).
activity(phBooking, ph).
activity(phChemoNurse, ph).

% Activities in Outpatient Chemotherapy Process (PCH)
activity(pchRegistration, pch).
activity(pchRetrieveOrder, pch).
activity(pchConfirmation, pch).
activity(pchTreatment, pch).
activity(pchEnterData, pch).

% Activity in Chemo Technician (Sub)process(CT)
activity(ctRetrieve, ct).
activity(ctPreparation, ct).
activity(ctFileOrder, ct).

% Routing controls
routing(orsplit(orSplit_pcBlood, pc)).
routing(orjoin(orJoin_pcOrder, pc)).
```

Continued on the next page ….

```
routing(orsplit(orSplit_phModification, ph)).
routing(orsplit(orSplit_phToday, ph)).
routing(orjoin(orJoin_phToday, ph)).

routing(andsplit(andSplit_pchRequest, pch)).
routing(andJoin(andJoin_pchMatch, pch)).
routing(sequential(sequential_pchConfirmation, pc)).
routing(sequential(sequential_pchTreatment, pc)).

routing(sequential(sequential_ctRetrieve, pc)).
routing(andsplit(andSplit_ctMedicine, ct)).

% Data associated with activities
data(treatmentConfirmation, pcAssessment, pc).
data(bookingRequest, pcAssessment, pc).
data(assessmentAppointment, pcRebook, pc).
data(order, pcOrderPreparation, pc).
data(order, pcOrderModification, pc).

data(confirmedOrder, phReview, ph).
data(notConfirmedOrder, phReview, ph).
data(confirmedOrder, phFax, ph).
data(confirmedOrder, phBooking, ph).
data(confirmedOrder, phChemoNurse, ph).

data(orderRequest, pchRegistration, pch).
data(medicineRequest, pchRegistration, pch).
data(confirmedOrder, pchRetrieveOrder, pch).
data(confirmedMedicine, pchConfirmation, pch).
data(treatmentData, pchTreatment, pch).
data(dataStoredInHorizon, pchEnterData, pch).

data(confirmedOrder, ctRetrieveOrder, ct).
```

Continued on the next page ….

```
data(medicine, ctPreparation, ct).
data(confirmedOrderFiled, ctFileOrder, ct).

% Roles associated with activities
role(physician, pcAssessment, pc).
role(bookingStaff, pcRebook, pc).
role(physician, pcOrderPreparation, pc).
role(physician, pcOrderModification, pc).
role(pharmacist, phReview, ph).
role(pharmacist, phFax, ph).
role(pharmacist, phBooking, ph).
role(pharmacist, phChemoNurse, ph).
role(bookingStaff, pchRegistration, pch).
role(nurse, pchRetrieveOrder, pch).
role(nurse, pchConfirmation, pch).
role(nurse, pchTreatment, pch).
role(nurse, pchEnterData, pch).
role(technician, ctRetrieveOrder, ct).
role(technician, ctPreparation, ct).
role(technician, ctFileOrder, ct).

% Routing Dependency
routingDep(pcAssessment, pc, [orsplit(orSplit_pcBlood, pc)],
pcRebook, pc).
routingDep(pcAssessment, pc, [orsplit(orSplit_pcBlood, pc)],
pcOrderPreparation, pc).
routingDep(pcOrderPreparation, pc, [orjoin(orJoin_pcOrder, pc)],
phReview, ph).
routingDep(pcOrderModification, pc, [orjoin(orJoin_pcOrder, pc)],
phReview, ph).

routingDep(phReview, ph, [orsplit(orSplit_phModification, ph)],
pcOrderModification, pc).
```

Continued on the next page ….

```
routingDep(phReview, ph, [orsplit(orSplit_phModification, ph)],
phFax, ph).
routingDep(phFax, ph, [orsplit(orSplit_phToday, ph)],
phChemoNurse, ph).
routingDep(phFax, ph, [orsplit(orSplit_phToday, ph)], phBooking,
ph).
routingDep(phChemoNurse, ph, [orjoin(orJoin_phToday, ph)],
pchRetrieveOrder, pch).
routingDep(phBooking, ph, [orjoin(orJoin_phToday, ph)],
pchRetrieveOrder, pch).

routingDep(pchRegistration, pch, [andsplit(andSplit_pchRequest,
pch)], pchRetrieveOrder, pch).
routingDep(pchRegistration, pch, [andsplit(andSplit_pchRequest,
pch)], ctRetrieve, ct).
routingDep(pchRetrieveOrder, pch, [andjoin(andJoin_pchMatch,
pch)], pchConfirmation, pch).
routingDep(pchConfirmation, pch,
[sequential(sequential_pchConfirmation, pch)], pchTreatment,
pch).
routingDep(pchTreatment, pch,
[sequential(sequential_pchTreatment, pch)], pchEnterData, pch).

routingDep(ctRetrieve, ct, [sequential(sequential_ctRetrieve,
ct)], ctPreparation, ct).
routingDep(ctPreparation, ct, [andsplit(andSplit_ctMedicine,
ct), andjoin(andJoin_pchMatch,pch)], pchConfirmation, pch).
routingDep(ctPreparation, ct, [andsplit(andSplit_ctMedicine,
ct)], ctFileOrder, ct).

% Data Dependency
dataDep(pcAssessment, pc, input(bloodReport, test, lab)).
dataDep(pcRebook, pc, input(bookingRequest, pcAssessment, pc)).
```

Continued on the next page ….

```
dataDep(pcOrderPreparation, pc, input(treatmentConfirmation,
pcAssessment, pc)).
dataDep(pcOrderModification, pc, input(notConfirmedOrder,
phREview, ph)).

dataDep(phReview, ph, input(order, pcOrderPreparation, pc)).
dataDep(phReview, ph, input(bloodReport, test, lab)).
dataDep(phFax, ph, input(confirmedOrder, phReview, ph)).
dataDep(phBooking, ph, input(confirmedOrder, phReview, ph)).
dataDep(pcChemoNurse, ph, input(confirmedOrder, phReview, ph)).

dataDep(pchRegistration, pch, input(bookedTreatment, book,
booking)).
dataDep(pchRetrieveOrder, pch, input(orderRequest,
pchRegistration, pch)).
dataDep(pchConfirmation, pch, input(medicine, ctPreparation,
ct)).
dataDep(pchConfirmation, pch, input(confirmedOrder, phReview,
ph)).
dataDep(pchTreatment, pch, input(confirmedMedicine,
pchConfirmation, pch)).
dataDep(pchEnterData, pch, input(treatmentData, phTreatment,
pch)).

dataDep(ctRetrieve, ct, input(medicineRequest, pchRegistration,
pch)).
dataDep(ctPreparation, ct, input(confirmedOrder, phReview, ph)).
dataDep(ctFileOrder, ct, input(confirmedOrder, phReview, ph)).

%Role replacement dependency
roleDep(nurse, pchConfirmation, pch, pharmacist).

%End
```

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