KNOWLEDGE REPRESENTATION AND COST MANAGEMENT FOR SUPPLY CHAINS

K. Donald Tham
Dept. of Mechanical and Industrial Engineering, Ryerson University, Toronto, Ontario, M5B2K3, Canada

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Abstract: The intent of this research is to make a contribution to SCEM (supply chain event management) and SCM (supply chain management) systems. nowledge representation (KR) of a supply chain is modelled by the "linking" of activity-state-resource clusters that represent activities of the supply chain. A formalization of the costs of resources (i.e., resource cost units) is presented. Traditional overhead costs entities are represented as period and non-period cost resources that may be deployed consistently, unambiguously and with high traceability in Temporal-ABC^{TM} (registered trademark of Nulogy Corporation). KR and cost management enhances the effectiveness and efficiency of SCEM and SCM systems.

1 INTRODUCTION

Supply chains "link" enterprises together locally and/or across the globe. SCEM is an application that supports control processes for managing events within and amongst companies. It consists of integrated software functionality that supports five business processes: monitor, notify, simulate, control and measure supply chain activities. SCM is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. To improve SCEM and SCM systems, this research puts forth:- (i) a KR for supply chains; (ii) a formalization of resource costs units and overheads for Temporal-ABC so that activity costs are consistent, unambiguous, accurate and traceable throughout the supply chain.

The basic or primitive cost value of 1 unit of a resource consumed or used by the enabling state of an activity is defined as the resource cost unit of the resource for the activity. Overheads are comprised of the more "nebulous entities" of traditional overhead and indirect costs such as depreciation of factory/office buildings and equipment, taxes on real estate, rent, insurance on factory building and equipment, supplementary employee benefits for management and unionized personnel, salaried and non-salaried personnel, and similar expenses that are incurred by enterprises.

2 TOVE, RESOURCE COST UNITS, TIME AND COST BEHAVIOUR IN TEMPORAL-ABC

Supply chains link different enterprises together based upon various activities performed by each of the enterprises. Enterprises are action oriented, and therefore, the ability to represent action lies at the heart of representing a supply chain through the activities of these linked enterprises. At the Enterprise Integration Laboratory (EIL) of the University of Toronto, a formal approach is taken to the modeling of enterprises. Formal models do not refer to analytical models as found in Operations Research, but to logical models as found in Computer Science. The TOVE (TOronto Virtual Enterprise) Project at EIL includes two major undertakings: the development of an Enterprise Ontology and a Testbed (Fox et al., 1993).

The formal activity-state-resource cluster (Fig. 1) of TOVE is deployed for the representation of each activity of the supply chain. In TOVE, action is represented by the combination of an activity and its

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corresponding enabling and caused states. An activity is the basic transformational action primitive with which processes and operations can be represented. An activity specifies a transformation of the world. Its status is reflected in an attribute called status. The domain of an activity's status is a set of linguistic constants:

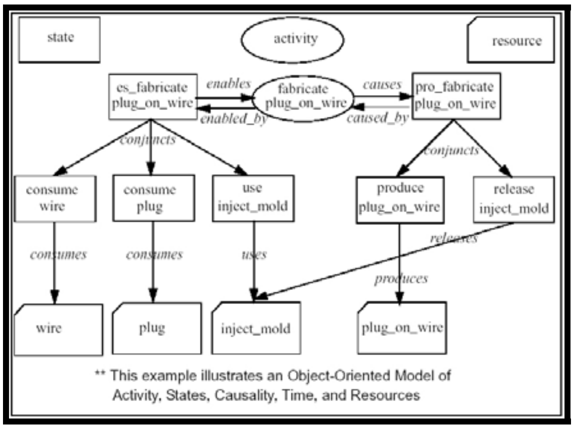

Figure 1: Activity-State Resource Cluster.

- Dormant – the activity is idle and has never been executing before.
- Executing – the activity is executing.
- Suspended – the activity was executing and has been forced to an idle state.
- ReExecuting – the activity is executing again.
- Completed – the activity has finished.

"Being a resource" is not an innate property of an object, but is a property that is derived from the role an object plays with respect to an activity (Fadel et.al, 1994). The resource ontology includes the concepts of a resource being divisible, quantifiable, consumable, reusable, a component of, committed to, and having usage and consumption specifications.

A state in TOVE represents what has to be true in the world for an activity to be performed. An enabling state defines what has to be true of the world in order for the activity to be performed. A caused state defines what will be true of the world once the activity has been completed. An activity along with its enabling and caused state is called an activity-state resource cluster (Fig.1) or simply activity cluster.

The status of a state, and any activity, is dependent on the status of the resources that the activity uses or consumes. All states are assigned a status with respect to a point in time. There are five different status predicates:- (i) committed - a unit of the resource that the state consumes or uses has been reserved for consumption or usage; (ii) enabled - a unit of the resource that the state consumes or uses is being consumed or used while the activity is executing; (iii) disenabled - a unit of the resource that the state consumes or uses has become unavailable and the activity is suspended; (iv) reenabled - a unit of the resource that the state consumes or uses is re-available for the activity to resume or reExecute; (v) completed – a unit of the resource that the state consumes or uses has been consumed or used and is no longer needed.

The resource cost unit of a resource is the cost of a unit of the resource in the state that it exists in the real world at some time point. The commit-resource-cost-unit, the enabled-resource-cost-unit, the disenabled-resource-cost-unit and the reenabled - resource-cost-unit are respectively associated with the commit, enabled, disenabled and reenabled states associated with a resource.

For SCEM, representation of time is essential. As in TOVE, time is represented by points and periods (intervals) on a continuous time line (Fig.2) based on Allen's temporal relations (Allen, 1983).

Previously introduced, the Principle of Temporal-ABC (Tham & Fox, 2004) states:- "A cost object, i.e., a product or service, is the reason why activities are performed. The assignment of costs to activities is based upon their requirements of resources and the possible changing temporal states of those resources, thereby resulting in temporal costs for activities. The cost of a cost object is based upon the temporal costs of activities that produce it."

In keeping with the Principle of Temporal-ABC, the KR of activity, state, resource and time explicitly recognizes the temporal status of the states associated with the resources required by an activity, which in turn affect the status of the activity.

To understand cost behaviour in Temporal-ABC, resource cost units of a resource are explained as follows (Fig. 2):

1. *Committed Resource Cost Unit:* A resource that is committed to an activity may be viewed as "inventory committed to the activity". From a costing standpoint, the cost of borrowing the money must be charged as the cost of capital (usually expressed as some percentage factor) against the activity to which the resource is committed.

2. *Enabled Resource Cost Unit:* The enabled resource cost unit metric is taken to be equivalent to the committed resource cost unit metric as each unit of resource required by the executing activity costs an amount equal to its commit resource cost unit.

3. *Disenabled Resource Cost Unit:* A disenabled resource brings about the suspension of an executing activity that requires it. The enterprise experiences “lost opportunities” during this suspension. Hence, from a costing standpoint, a lost opportunity cost factor (usually some percentage factor) must be taken into consideration when computing the disenabled resource cost for an activity.

4. *Reenabled Resource Cost Unit:* The "repair" of a disenabled resource, reenables the resource. Hence, the cost value of a reenabled resource is greater than that of the initial enabled resource simply because the cost of "repair" activities must be sunk into the disenabled resource. An enterprise may consider cumulatively incrementing the value of the reenabled resource cost unit with each iteration that a resource is disenabled and then reenabled.

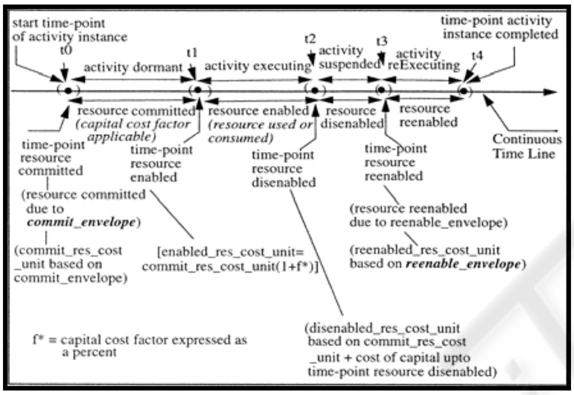

Figure 2: Activity Instance on Continuous Time Line.

3 KR OF A SUPPLY CHAIN WITH ACTIVITY CLUSTERS

Activities of a supply chain are represented through the activity-cluster representation. As illustrated in Fig. 3, the activities of a supply chain are formed through the linkages of the activity clusters. By way of explanation, the activity, act_1, consumes a resource, int_res_1. The activity, act_2, produces int_res_1. More precisely, the enabling state of act_1 is linked to the caused state of act_2, thereby forming an enable_cause link between act_1 and act_2. However, the activity, act_2, requires the resource, int_res_2. The resource, int_res_2, in turn is produced by the activity, act_3. We now have an enable_cause link between act_2 and act_3. Thus far, the two links form the enable_cause chain to consist of three activities sequenced as (act_3, act_2, act_1). In order to produce the resource, int_res_2, the activity, act_3, requires resources, ext_res_3 and

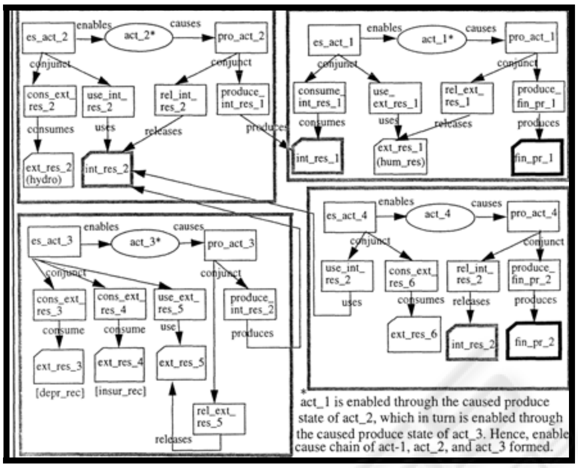

Figure 3: Activity Clusters of Supply Chain (activity clusters boxed).

ext_res4 and ext_res_5. For this illustration, assume that ext_res_3, ext_res_4 and ext_res_5 are resources that are supplied from sources (or companies) external to the enterprise modeled.

4 COST FLUENTS AND OVERHEAD TAXONOMIES

In AI, *a fluent is a condition that can change over time.* In logical approaches to reasoning about Temporal-ABC costs in a supply chain, cost fluents can be represented in *first-order logic* (FOL, i.e., a formal language which supports expressing propositions as well as predicates, where predicates may have quantified variables as arguments) by predicates having an argument that depends on time.

Period cost external resources are defined as nonactivity cost fluents f based upon traditional time period related overhead cost categories such as building depreciation, equipment depreciation, property taxes, borrowed capital interest, insurance, salaries, wages, management/union supplemental benefits, (refer Table 1), where:- *f* is a predicate denoting class of nonactivity cost fluent for overhead cost; *tps* denotes the time period under study (e.g., 1 year, 6 months, etc.); *tc_ext* is an externally given total nonactivity based cost applicable to tps (e.g., if the fixed overhead of depreciation is under study for tps = 1 year, then tc_ext would be the annual depreciation cost); *tt_act* is a total actual time or total estimated time for the number of instances that occur in tps; *r* is the name of the external resource associated with the nonactivity cost fluent. If an enterprise has other overhead cost entities, e.g., training, safety, etc., a corresponding class of nonactivity cost fluent of the form *f(tps, tc_ext, tt_act, r)* may be defined.

Table 1: Nonactivity Cost Fluents for Time Period Overhead (OH) Costs.

Period Overhead Cost	Nonactivity Cost Fluents
Building depreciation	bldgDepCost(tps, tc_ext,tt_act, r)
Equipment depreciation	eqDepCost(tps, tc_ext,tt_act, r)
Property taxes	propTaxCost(tps, tc_ext,tt_act, r)
Borrowed capital interest	borCapCost(tps, tc_ext,tt_act, r)
Insurance	bldgDepCost(tps, tc_ext,tt_act, r)
Salaries	salaryCost(tps, tc_ext,tt_act, r)
Wages	wageCost(tps, tc_ext,tt_act, r)
Management benefits	mgtBenCost(tps, tc_ext,tt_act, r)
Union benefits	unnBenCost(tps, tc_ext,tt_act, r)
Leases	leaseCost(tps, tc_ext,tt_act, r)

Non-period cost external resources are defined as cost fluents f based upon traditional non-period overhead cost categories such as material costs, and utility costs like hydro, heat and water. The non-period nonactivity cost fluents are shown in Table 2, where tc_ext denotes a specified nonactivity-based total cost parameter distributed over the total quantity parameter tqty_ext associated with the particular cost category.

Table 2: Nonactivity Cost Fluents for Non-period Overhead (OH) Costs.

Non-period OH Costs	Nonactivity Cost Fluents
Hydro	hydroCost(tc_ext,tqty_ext, r)
Heat	heatCost(tc_ext,tqty_ext, r)
Water	waterCost(tc_ext,tqty_ext, r)
“indirect materials”	matlCost(tc_ext,tqty_ext, r)

First, the Cost Fluent Taxonomy (Fig. 4) classifies cost fluents as being activity-based or nonactivity-based so that unit costs of resources may be deduced based upon some period of time or some quantity associated with a resource, thereby drawing upon the distinction between period cost resources and non-period cost resources respectively. Second, this taxonomy contains several defined classes of nonactivity-based cost fluents to formalize the concepts of the ever increasing traditional overhead costs that are typically difficult to trace, allocate and accurately compute otherwise (Tham, 1999).

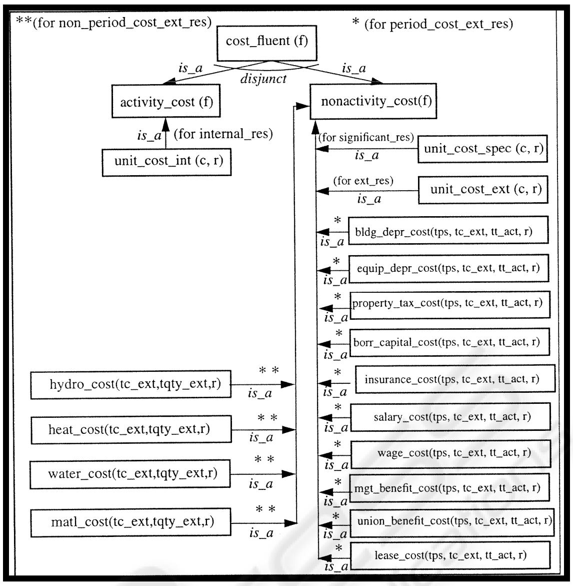

Figure 4: Cost Fluent Taxonomy with Associated Resource Classes.

5 CONCLUSIONS

By linking activity clusters, KR of supply chains is achieved. The cost fluents introduced promote reasoning of costs with Temporal-ABC and make overheads traceable in activity clusters of a supply chain.

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