

Supply Chain Modeling with REA

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Abstract

Lack of transparency and integration between different tiers in supply chains prevent companies from realizing the large economic benefits of their collaboration. Several standards are being developed in parallel but there is still no consensus on a general inter-organizational modeling approach to solve these problems. In this paper we propose the Resource-Event-Agent (REA) model as such an approach. By extending and implementing the model we show that REA can represent SCM problems in a way that supports operational applications and performance measurements. Specifically, we introduce the concept of Location and Transport in the REA ontology.

This paper assumes a basic knowledge of the REA model as explained in [1; 2]

1 Introduction

Traditionally, Enterprise Resource Planning (ERP) systems have focused on issues relating to a single company. Optimization of intra-organizational structures and business processes are among the main concerns of such systems. Supply Chain Management (SCM) presents a new set of requirements and problems to be addressed. These requirements and problems extend beyond the scope of ERP systems. SCM deals with inter-company optimizations of supply chains or networks. The central assertion in SCM is that collaboration between supply chain partners potentially has greater benefits than the traditional focus on individual tiers. Optimization of individual tiers only lead to sub-optimizations whereas optimization from a global perspective maximizes the economical gains for all involved tiers.

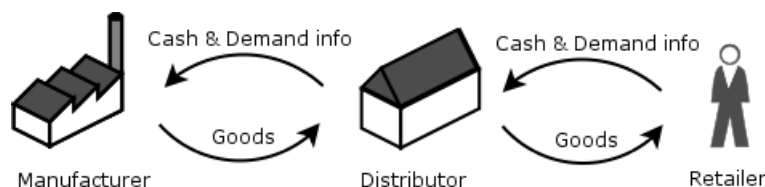


Figure 1: The supply chain

The Resource-Event-Agent (REA) model that was introduced by William E. McCarthy has primarily been used to model accounting phenomena in information systems [1; 2; 3; 4]. It is well-suited for ERP systems where the basic REA template can be used to capture the economic transactions in a single company. REA models can be distinguished by their perspective. Traditional REA models are dependent on the context of the individual company and take the perspective of that company. This is called the trading partner view [5]. Another

class of REA models which might be called global models can encompass several companies and do therefore have a global perspective [6].

When expanding REA models to encompass entire supply chains the "trading partner view" is not sufficient. The supply chain tiers has to be viewed in a global perspective. REA in its current state is not suited to be part of the transition from local ERP systems to global SCM systems. Previous work [7; 8] has suggested the possibility of SCM modeling with REA but failed to offer a concrete approach.

In this article we will propose extensions to REA that will enable the model to represent and manage the complexities of a subset of SCM called Vendor Managed Inventory (VMI). In section 2 we will explain the VMI concept and problem. In section 3 and 4 we introduce REA extensions that solve the sketched problem. In section 5, 6 and 7 we discuss alternative approaches and explain why they are insufficient. In the last parts of the paper we illustrate the concept of exchange coupling and conclude the work. Further research directions are suggested at the end.

2 Vendor Managed Inventory

The traditional lack of integration between different tiers in the supply chain leads to the Forrester Effect [9]. Demand signals travel slowly through the such chains. The Forrester Effect occurs when small fluctuations in the demand at a downstream tier cause excessive fluctuations in the perceived demand at upstream tiers (see fig. 2). Each tier tries to respond to demand by adjusting the safety stock and inventory level based on their perception of the demand. If the inventory level is set too high due to the Forrester Effect and general lack of transparency then unnecessary storage costs are inflicted upon the company.

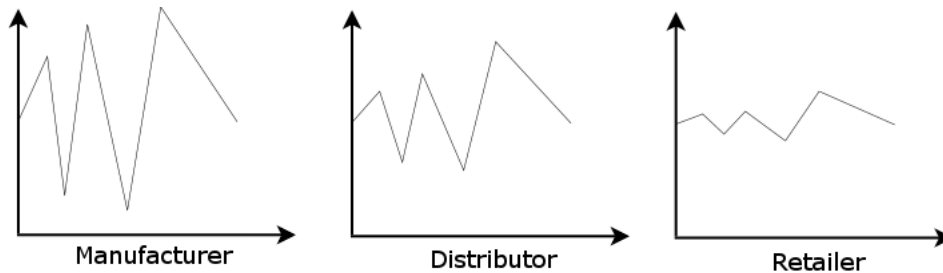


Figure 2: The Forrester effect

VMI attempts to alleviate the Forrester Effect by integrating the supply chain tiers. The manufacturer takes over the responsibility of restocking the inventory at the retailer. In return the retailer supplies the manufacturer with accurate and updated information about the current demand. The manufacturer benefits by being able to decrease his own inventory level and possibly by being able to plan production more efficiently. The retailer benefits by lowering administrative costs and typically also by achieving a better ability to respond to demand - ie. avoid stock-outs.

In order to represent a VMI collaboration in REA it is necessary to include both manufacturer, distributor and retailer in the model. The model must facilitate report generation - or conclusion materialization as it is called in the REA terminology - about inventory levels at each tier, current and previous demand as well as leadtime between tiers. Leadtime is defined as the period from the creation of an order to the delivery of the ordered goods. Since several companies must be modeled the trading partner view have to be replaced by a global model.

3 Location

To track the movement of goods downstream through the supply chain it is necessary with a well-defined concept of location. The physical location of a resource is traditionally perceived as an intrinsic property of the resource instance or sometimes even as an intrinsic property of the resource type. It is not specified how a REA transfer affects the location of a resource. This prevents us from materializing conclusions about the location of dispatched resources. This is especially problematic in the case of consignment stock where the manufacturer transports goods to the inventory of the retailer but postpones the actual transfer until the retailer sells the goods to the end-customers. Consignment stock in VMI collaborations can not be represented using REA transfers since the movement and transfer of ownership of goods are not directly related.

An extended version of REA called Resource Event Agent Location (REAL) has been proposed by Denna et al. [3]. Unfortunately it is not clear exactly how the location entity is related to the traditional REA entities and why it is needed in that context. The semantics of the location entity have been described in a bit more detail in the UN/CEFACT Meta Modeling Userguide [10] where the site and the destination relations are introduced. We believe that the introduction of location as an independent entity is an important contribution to REA - especially in the supply chain context. We will in the following present our concept of location which relies UN/CEFACT but extends location with the capacity relation.

The location entity represents a geographical and physical location. A location can be composed of several other locations such as an inventory that is composed of several storage rooms. A location has individual existence independent of any resource hence it is not an attribute of a resource. In meta-modeling terms, a location is related to resource types, commitments and events through the following relations: capacity, destination and site.

The storage capacity of an inventory is constrained by both physical and contractual conditions. Take the inventory of a bakery for instance: Physically, there is a natural upper limit to how much bread that can be stored in one room. On the contractual side, there is also an upper limit to how much bread it is feasible to store in one room. It is not a good idea to store too much bread since the retailer will not be able to sell it before it is too old. In our extended REA model we propose a capacity relation between a resource type and a location to capture this last aspect of storage capacity.

If a bakery act as a manufacturer and collaborates with a retailer in a VMI collaboration the model can have a capacity relation between the Bread type and the retailer's inventory location. This relation specifies the minimum and maximum inventory level of bread. In accordance with the VMI concept, it is the obligation of the manufacturer to keep the inventory level of the retailer within these limits. The VMI contract can specify several capacity relations between the retailer's inventory and different types of products from the manufacturer, such as the cake type, the doughnut type etc. It is possible to verify that the manufacturer keeps his side of the bargain by comparing the capacity relations with conclusions regarding the inventory level at the retailer.

The location entity is related with commitments and events through the destination and site relations [10]. A commitment to deliver bread to the retailer is related to the retailer's location by a destination relation. If the commitment is fulfilled by an event then this event will have a site relation to the retailer's location indicating where the event occurred. The site relation plays a key role in providing track and trace functionality in the model as we will show in the following section.

4 Transport

We propose a new exchange type called transport to capture the distribution aspect in our model (see fig. 3) and two new event types called Load and Unload. Our transport exchange complies with the traditional REA template [1] by having a dual set of events that affects certain resources and that are initiated by a fixed number of agents. The REA template is extended by the introduction of new event types and integrated with our concept of location.

It is necessary to extend REA with this new exchange to be able to represent the fact that resource instances can move through the supply chain.

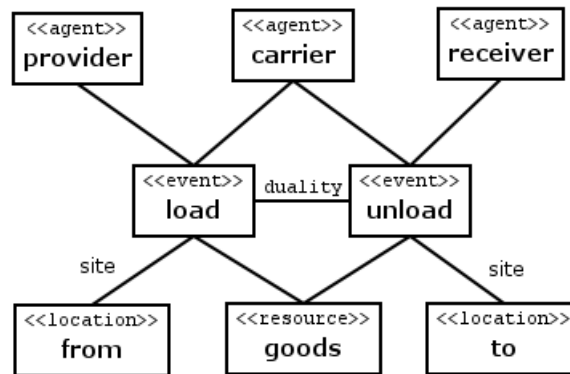


Figure 3: The transport exchange

Dispatch of goods is represented by a load event. The load event moves a resource instance physically away from a location. Receipt of goods is represented by a dual unload event. The unload event delivers a resource instance at a given physical location. Load and unload are related in duality so when we load a set of resource instances it must be expected that these instances will be unloaded at some later stage. The duration of time between load and unload is the transportation time.

The load event is related to two agents: a provider and a carrier. Similarly the unload event is related to a receiver and a carrier. The load event physically transfers the resource instances to the carrier. Although the load event is primarily concerned with physical aspects of the exchange it might also transfer liability of the resource to the carrier. We might propose a hypothesis where transfer of liability and the act of physically handing over goods were represented by the same event. This would imply that the carrier is responsible for the resource instances even though he does not own them. This liability could be delegated on to the receiver when the unload event occurs. The transfer of liability in load and unload events would be immediate, similarly to the transfer of ownership in traditional transfer exchanges.

An interesting aspect of the transport exchange is its granularity. If a company transports silk from China to Venice we might merely model this as a load event in China and an unload event in Venice. If the silk passes through several tiers or carriers on its way then we might model this transport as several load and unload events where the silk is transported in small steps until it reaches its final destination. The granularity of our model should be adjusted in accordance with our requirements for the concrete context.

The precise location of any resource instance with the stated granularity of the model can be derived by examining its load and unload events. Each resource instance has a history of load and unload events which determines the location of it at a given point in time. If the liability aspect is included in our view of the transport exchange then we might also materialize conclusions about liability regarding the resource instance at a given point in time. If a resource instance disappears or is spoiled we could assign blame based solely on transport exchanges and regardless of ownership.

5 Related Approaches

Currently, the generally accepted version of REA [2; 3; 4] has two types of exchanges which are used as the cornerstone of every model: transfers and transformations. In the following sections we will briefly sketch these exchanges and explain why they are insufficient as representations of the movement of goods.

Transfers deal with the exchange of rights to certain resources. A sale of a bread is best modelled as a transfer since the seller exchanges rights of ownership with a buyer. The buyer

receives ownership of the bread and the seller in return receives ownership of an agreed amount of money. Transformations on the other hand deal with changes in the features of certain resources. The production of a bread is an example of a transformation. A set of input resources such as water and flour are consumed in order to produce an output resource such as bread. The baker gives up the raw materials to gain a resource with a new set of features.

Both exchanges are compliant with the basic REA template and exhibits the characteristic simplicity that is the essence of REA. Similar to transport both transfers and transformations consist of a set of dual events that affect the resources involved. In the trading partner view the events either increment or decrement the resources involved. The baker increments his amount of money and decrements his amount of bread each time he takes part in a transfer. If the same exchange is viewed independent of perspective each event is both an increment and a decrement. When the baker hands over bread then this event simultaneously decrements his stock of bread while incrementing the buyer's stock of bread.

This leads us to conclude that the semantics of events are not necessarily identical in the trading partner view and independent of perspective. Where transfer events are either increments or decrements in the trading partner view they can potentially be both when viewed independent of perspective. We call such events bidirectional events since they are related to both an ingoing and an outgoing stockflow.

The dual events in transformations (consume and produce) are different since they are always either increments or decrements. When the baker consumes water and flour in a consume event then this is a decrement of his stock both in the trading partner view and independent of perspective. The duality of the transport exchange is similar to transformation in this respect since the load event is decrementing and the unload event is incrementing both in the trading partner view and global view.

In the following two sections we will show why neither transfer nor transformation are sufficient to represent the VMI concept.

6 Transfer

Is transfer suitable as a representation of the VMI model? Transfer seems an obvious choice since it can be used to model how the ownership of goods is transferred downstream through the supply chain. The vendor transfers goods to the customer. The duality in transfer is always between flow of goods and flow of cash. These transfers must keep the inventory level at the customer within an agreed range. Apart from the special contractual obligations of the vendor this model would be similar to ordinary REA models for sale. It is possible to materialize conclusions about previous and current demand on the basis of such a model.

The transfer exchange suffers from two related problems: First of all the model can not be used to materialize conclusions about leadtime. Having detailed information about the leadtime of different types of goods is necessary to guarantee a high service degree. In order to be able respond to demand the vendor has to know average time span from the transfer of a resource until it is available in the next tier. Since transfer events are instantaneous by nature it is not clear whether the event signals a dispatch of goods from the vendor or the receipt of goods at the customer. In other words it is only in legal and accounting terms that a transfer event immediately affects two different inventories. The transfer exchange does not represent the actual physical state of the inventories.

Secondly the transfer exchange does not affect the location of resources. The site of a transfer event is in contrast to that of transformation and transport events rarely relevant in ordinary business contexts. Since the transfer exchange is concerned with purely legal and accounting issues it can be signed basically anywhere and still retain validity. A transformation or transport event on the other hand directly affects the physical state of the involved inventories. These exchanges are therefore dependent on the location to a higher degree than transfers.

7 Transformation

An alternative solution is to use transformation exchanges as the cornerstone in a VMI model. Transformations do not deal with cash flows so we will leave out the flow of money for the time being. Since transformations by definition affect the features of resources this can possibly solve the problem of tracking and tracing the individual resources. Furthermore the special duality in transformations is also suitable for materializing conclusions about the duration of the process since consume and produce events does not necessarily occur at the same point in time.

Transformation traditionally relies on one of the following location concepts: First, a location can be considered a property of the resource type. In this case, bread at the manufacturer and bread at the retailer are two different resource types. Alternatively if location is considered a property of the resource instance, then bread at the manufacturer and at the retailer are resources of similar type but with different features. In both cases the transformation exchange can be used to represent the movement of resources from manufacturer to retailer. Bread at the manufacturer is consumed or dispatched and at a later stage it is produced or received at the retailer. The duration of time between consume and produce event can be used to materialize conclusions about the leadtime of bread.

The transformation exchange can account for movement of goods between inventories both within the same company and in different companies. It solves the previous problem of consignment stock because goods can be moved from vendor to customer without transferring rights of ownership.

This VMI model would not solve our problem, though. It suffers from problems that in our view renders it unqualified. Since transformation by definition changes its resources it is not possible for a resource instance to retain identity through a series of transformations. Every transformation consumes the resources involved and produces a new set of resources based on this input. This implies that we cannot directly relate goods at the manufacturer with goods at the retailer through a serial number for instance. The relation has to be derived on the basis of the transformation events. This is not the case in transports where the resource at the manufacturer is identical with the resource at the retailer after a transport.

A second problem concerns the balance between input resources and output resources in transformations. If the baking process consumes 20 kilograms of flour then this does not automatically imply that the product will be 20 pieces of bread. There is no general way of relating the quantity of input goods with the quantity of output goods in transformations. This balance might vary from resource type to resource type and even vary for each concrete production. Transport exchanges does not face this problem. If the manufacturer dispatches 20 pieces of bread then the duality can only be balanced if the retailer receives 20 pieces of bread. This direct correlation stems from the fact that transport exchanges primarily deals with the physical state of things and are subject to the laws of nature.

8 Exchange Coupling

As we have now argued that the standard transfer and transformation exchange are not suited for the VMI scenario one might raise the question whether the proposed transport exchange is sufficient. We have argued that transport accounts for the physical aspects of the flow of goods through the supply chain. This is actually sufficient to provide operational support for a wide variety of VMI applications since these are often merely concerned with the flow of goods. In order to get to the full benefit of REA in the VMI context we think that it is necessary to add the aspect of cash flow and orders.

We propose a coupling of different exchange types by the means of the agreement entity in REA [2, p. 11]. The agreement entity is composed of a set of commitments and encapsulates one or more interactions between manufacturer and retailer. If the manufacturer agrees to restock the retailer's inventory then this collaboration covers two important areas: flow of goods and flow of cash. The flow of goods is represented by a transport exchange that shows when and where resource instances are located. The flow of cash is represented by

a traditional transfer exchange such that there is duality between the transfer of ownership of bread and the transfer of ownership of cash. These two exchanges are tied together in a agreement between manufacturer and retailer.

This set of coupled exchanges are important in our leadtime calculation. The leadtime equals the duration between the creation of the transfer commitment and the occurrence of an unload event. In other words the leadtime is the time from the retailer requests a bread until it is physically delivered. It is only possible to materialize such a conclusion based on our coupled exchange.

We might imagine a concrete scenario where the manufacturer agrees to restock inventory of the retailer. Since the manufacturer assumes responsibility of the inventory level, he has to create an order at the correct time such that the inventory level never goes below the safety stock. The order, which is an agreement in REA terms, specifies that the manufacturer has to dispatch bread Monday night and deliver bread at the retailer Tuesday morning. A third-party distributor transports the bread. From the loading of the bread at the manufacturer until the unloading at the retailer the distributor is liable for the bread. This is the physical part of the order, that is, the transport exchange.

When the bread arrives at the retailer, the liability of the bread is also transferred to the retailer. The ownership of the bread still belongs to the manufacturer. Depending on the specific agreement, the manufacturer may choose to collect his payment at delivery, or in the case of consignment stock, when the retailer sells the bread. The transfer of ownership is performed in the transfer exchange where ownership is exchanged for ownership of cash. This transfer exchange does not necessarily have to coincide with the transport exchange. They are related through the agreement, and fulfillment of this agreement happens when the dual events in each exchange has occurred.

9 Conclusions

Our work has shown that it is possible to capture the central operational aspects of a VMI collaboration in an extended REA model. By introducing the location entity with well-defined semantics we can lay the foundation for a completely new exchange type. The transport exchange which consist of two new events - load and unload - is ideal for representing the flow of goods through supply chains. Our VMI model enables conclusion materialization about inventory levels at each tier, current and previous demand as well as leadtime between tiers. Taken together these parameters allows us to represent and measure performance in any given VMI collaboration.

During our work which is documented in Balthazar et al. [11] we have implemented a C# prototype application that offers operational support for VMI collaborations. The domain layer of the prototype is based on an adaptive object model of our REA entities and types. This technique was originally proposed by Johnson and Nakamura [12] and has proven very useful when implementing dynamic and extensible REA systems. The prototype can create new types and instances at runtime and thereby adapt to a rapidly changing business environment.

Since the REA model in its nature is focused on economic primitives it was surprisingly easy to integrate it with an existing ERP system. Our prototype was completely integrated with Navision Attain v.3.60 such that both new type definitions and orders could be transferred between the two systems.

Our work actually went beyond the VMI concept that is documented in this paper. We implemented minor parts of the Collaborative Planning Forecast and Replenishment (CPFR) standard [13]. This includes facilities for production planning, composition of bill of materials etc. based on our REA model.

10 Further work

We see several future direction of REA related research. In Balthazar et al. [11] we have proposed a general event classification scheme (see table 1). This scheme makes it possible

to compare different event types in a general way. Each type is classified by name and the way it affects resource instances. The characteristics that we were interested in during our VMI work were ownership, liability, location and direction of the related stockflow. Direction is defined as the direction of the related stockflow of an event type independent of perspective.

	changes ownership	changes liability	changes location	changes existence	stockflow direction
transfer	yes	no	no	no	bidirectional
consume	yes	yes	yes	yes	outgoing
produce	yes	yes	yes	yes	ingoing
load	no	yes	yes	no	outgoing
unload	no	yes	yes	no	ingoing

Table 1: Classification scheme for events and commitments

We believe that future extensions to REA should take this classification scheme into consideration. If a new event type is added on the vertical axis then it should be determined how it compares with other types with regard to ownership, liability, location and direction. One might also extend the scheme in the horizontal axis by adding new characteristics and re-classifying existing events. We might for instance propose insurance liability as a new characteristic and determine for each event type whether it changes insurance liability or not.

SCM is a complex field where there is still no consensus on a general modeling approach. The succes of REA modeling with respect to VMI suggests that further investigations of the relation between REA and SCM are relevant. We propose our REA extensions and the event classification scheme as useful tools in this future work.

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References

- [1] William E. McCarthy. The rea accounting model: A generalized framework for accounting systems in a shared data environment. *The Accounting Review*, LVII(3), july 1982.
- [2] Guido Geerts and William E. McCarthy. The ontological foundation of rea enterprise information systems. <http://www.msu.edu/user/mccarth4/Alabama.doc>, 2000.
- [3] E. L. Denna, J. O. Cherrington, D. P. Andros, and A. S. Hollander. *Accounting, Information Technology, and Business Solutions, 2nd*. Irwin McGraw-Hill, 1996.
- [4] Cheryl Dunn, J. Owen Cherrington, and Anita Hollander. *Enterprise Information Systems: A Pattern-based Approach*. McGraw-Hill Publishing Co, 2004.
- [5] Pavel Hruby et al. *Business Patterns*. Springer Verlag, 2005. to be published.
- [6] Mette Jaquet. Realistic - en rea-model uden perspektiver. Master's thesis, IT University of Copenhagen, Denmark, 2003. In danish. Supervised by Kasper Østerbye.
- [7] Robert Haugen. Radically distributed supply chain systems. <http://jeffsutherland.com/oops1a97/haugen.html>, 1997. published at

OOPSLA 1997, Business Object Design and Implementation III: Patterns, Workflow, Components, and the Web.

- [8] Robert Haugen and William E. McCarthy. Rea, a semantic model for internet supply chain collaboration. <http://jeffsutherland.org/oopsla2000/mccarthy/mccarthy.htm>, 2000. published at OOPSLA 2000, Business Object Component Workshop VI: Enterprise Application Integration.
- [9] Jay Wright Forrester. *Industrial Dynamics*. Pegasus Communications, 1961.
- [10] UN/CEFACT. Un/cefact modeling methodology (umm) user guide 5 - cefact/tmg/n093. Technical report, UN/CEFACT, 2003. http://www.unece.org/cefact/umm/umm_userguide.pdf.
- [11] Stine Balthazar, Ali Chohan, and Anders Hessellund. Supply chain integration. Master's thesis, IT University of Copenhagen, Denmark, 2005. In danish. Supervised by Kasper Østerbye. Not published yet due to a non-disclosure agreement.
- [12] Hiroaki Nakamura and Ralph E. Johnson. Adaptive framework for the rea accounting model, 1998. OOPSLA'98 Workshop on Business Object Design and Implementation IV.
- [13] Global Commerce Initiative. Collaborative planning, forecasting and replenishment v. 2.0 (guidelines). http://www.vics.org/committees/cpfr/voluntary_v2/CPFR_Tabs_061802.pdf, 2002.