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An Improved Event Processing Approach for RFID Stream Data and Its Application

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***Abstract*—Radio frequency identification (RFID) technology has been widely used in various fields. In the application system based on RFID technology, mass real-time data is generated by RFID readers. How to deal with and make use of the mass data to serve for enterprises is a great challenge we are facing, and RFID event processing technology can help us solve the problem. In this paper, we will do an in-depth investigation on RFID event processing technology and test its performance in the application of SCM (Supply Chain Management). Firstly, according to the semantic level of RFID events, RFID event can be classified to two categories, that is, RFID simple event and RFID complex event. Secondly, different solutions are adopted in the course of processing of different events. To the RFID simple event, an improved RETE algorithm will be proposed; to the complex event, a novel Petri Net approach will be adopted. Finally, the experiment is carried out in the scene of Beer Game, which demonstrates that RFID event processing technology can mitigate the effects of the Bullwhip in supply chain.**

***Index Terms*—RFID, Event Processing, RETE, Petri Net.**

I. INTRODUCTION

RFID technology has been widely used in various fields, it plays an important role in the solution and the application, and significantly improves the efficiency and performance. RFID offers a possible alternative to bar code identification system. It is known that RFID is one of the most promising technologies. With the widespread application of RFID in different kinds of fields, a large volume of data is generated in the process of application, which has been an enormous challenge we must face in the course of promotion of RFID.

A. RFID Data and RFID Event

In the RFID applications, a large volume of data is generated, which is time-dependent, dynamically changing, in large volumes, carry implicit semantics[1]. In the application, if an item with RFID tag moves into the range of RFID reader, its information will be collected by the reader. Then TagID, ReaderID and Timestamp form the observation which is called primitive event. The primitive event must be filtered, processed, integrated with business information, and transformed into semantic data, which is the RFID event[2]. RFID event is an object recording of an activity or a meaningful change in a system[3] through organizing the RFID data in the RFID system according to some kind of logic. Event can be defined as an active log object in the system[4], and can be interpreted as a change in the real world. Event contains some specific data which could be the execution time of the activity, or the scene of the activity, or the executor of the activity, etc. So event is a form for realizing facts and information.

B. The Reasons for Using RFID Event

RFID data is massive, real-time, dynamic change, and tend to low semantic level of abstraction. However, most analysts are interested in relatively high level dynamic changes, such as trends and deviations[3]. If RFID data is used directly, a lot of problems will be caused, such as data transmission and data sharing between companies, data processing in real time, etc. These problems affect the widespread application of RFID technology among companies. To solve these, EPCglobal[5] introduces the EPCIS (EPC Information Services)[6] Specification that is the primary bridge connecting RFID physical world with the high level applications and facilitating the data exchange between trading partners[7]. EPCIS defines four XML events which are accepted by the capture interface and returned by the query interface and originate from RFID sensor reads and enterprise systems. These events which are delivered to the requestor are semantic data by filtering, processing and abstract massive RFID data. Every enterprise can come up with its own events or extensions from these ones to meet their specific requirements.

RFID event is semantic data, and integrated into business applications, so it can benefit a great variety of industries by improving the efficiency of their operations[8], enable enterprises to make better use of RFID resources, and help managers make better management and business decision. And RFID event is easy to integrate into the whole logistics chain[9, 10], helps enterprises implements the integration of supply chain and form a league. So it can alleviate the bullwhip effect or whiplash effect in supply chain management by information sharing in time, which refers to the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer, and the distortion propagates upstream in an amplified form[11, 12], etc.

C. The Currently Research Status of RFID Event

The main purpose of RFID event processing is detecting event, namely, according to the defined rule and pattern, detecting the relations among primitive events. There are two methods to introduce: data-centric method and event-centric method[13].

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1) Data-centric Method: The data-centric method is the older method of the two in RFID processing system. The application of RFID requires the system to discover the abnormal event from high-speed and great capacity of online event in time, then give an alarm actively. Because of the performance constraints, the data-centric system can only apply to Ad-hoc query on history data or online low speed query, but it is not suitable for high-speed and great capacity of online event[13].

2) Event-centric Method: The event-centric method is a new RFID processing technology, which model and process event directly, based on data source, that is, primitive events produced by RFID middleware[5, 6] and other relevant data, rather than database or warehouse, in order to get higher performance in dealing with event detecting than Data-centric method.

In this paper, we do an in-depth study in this method and discuss a scheme which includes RFID event modeling, RFID event processing, and RFID event application. And these steps will be illuminated in the chapters below.

There are two core problems in event-centric method, one is simple event processing and the other is complex event processing. RFID event is classified to RFID simple event and RFID complex event by its semantic level. RFID simple event is built from primitive events which are events generated during the interaction between readers and tagged objects, and other relevant data or other simple events. A primitive event is a reader observation, in the format of observation(r, o, t), where r represents the reader EPC, o represents the object EPC and t represents the timestamp when the observation is made. A complex event is usually defined by applying event constructors to its constituent events, which are either simple events or other complex events[14]. But in this paper, complex event is defined by the material context and meaning in applications of the scenes and they can come into being from simple events or other complex events.

Simple event processing, namely how build simple event model and rapidly build simple event from massive RFID data using a certain quick matching algorithm. There is little research in the area but I find inspiration from a series of well known pattern matching algorithms, such as RETE[15], TREAT[16] and LEAPS[17], etc. Thinking about the characteristics of primitive events and other relevant data, TREAT algorithm and LEAPS algorithm are not suitable, RETE algorithm is compatible but need to be extended and modified[18 ,19]. Because simple event processing demands that the algorithm can quickly add matching items. So RETE is better than TREAT, and can be compatible with real time system that LEAPS can't. So we choose an improved RETE algorithm in simple event processing.

Complex event processing (CEP), namely how efficiently process a number of basic events to get complex event with more complex semantic context. Some work related to active database discuss the basic model of complex event detecting[20, 21]. There are four main approaches including: the model based on automation, the model based Petri net[22], the model based on matching tree and the model based on direct map[13].

In some applications, the significant information is concealed in the large volume of data from business systems and smart items (RFID, wireless sensor networks). There are few powerful methods to retrieve and present the hidden information, but complex event processing technology can resolve the problem. We find that the complex event detecting based on automation and Petri net can match the basic event which arrive by order, but the detecting based on matching tree and direct map does not consider the order of event or the distance of time order, such as the first event doesn't occur, but the second event may be filtered, so make inessential consumption. We choose Petri net method in complex event processing in terms of its properties of concurrency and efficiency, and its mechanism and algorithm are also suitable.

II. RFID Simple Event Modeling and Processing

RFID is the most widely used in Supply chain management in all applications, and RFID has a significant impact on every facet of supply chain management from the simple tasks, such as moving goods through loading docks, to the complex, such as managing terabytes of goods information data which is collected in real time. It has a potential to dramatically improve supply chain by reducing costs, inventory levels, lead times, stock outs and shrinkage rates; increasing throughput, quality, manufacturing flexibility, inventory visibility, inventory record accuracy, order accuracy, customer service, and the collaboration among supply chain members. So we choose to build simple event model and complex event model in the scene of SCM.

A. RFID Simple Events Modeling

In the course of RFID simple event modeling, we define a series of base events, and other events inherit it. These events contain ObjectEvent, AggregationEvent, QuantityEvent, TransactionEvent, and PathEvent. We obtain material Events from the base events in the scene of SCM: case_commissioning_event, pack_cases_event, pallet_commissioning_event, pick_cases_event, ship_order_event, receive_pallet_event, receive_order_event, store_dist_event, store_retail_event, case_consume_event, pallet_reused_event, and case_path_event. In the next part of the article, we use logogram such as E1, E2. . .E12 to replace case_commissioning_event, pallet_commissioning_event. . .case_path_event for convenience. The relationship of the events is shown in the figure (Figure 1).

B. Improved RETE Algorithm

RETE algorithm is a fast many objects/many patterns match method, which saves time at the cost of more space. The left of a pattern often contains several condition tests. RETE algorithm first separates the left of the rules into several simple single-condition tests, then these simple tests are compiled into a network. When a new fact arrived, it is given a token, which reflects the change of the working memory. The tokens flow

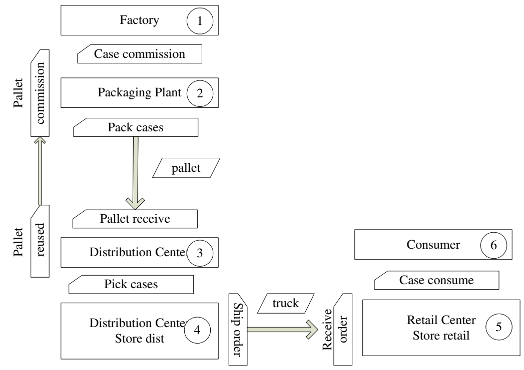

Fig. 1. The scene for RFID simple event modeling

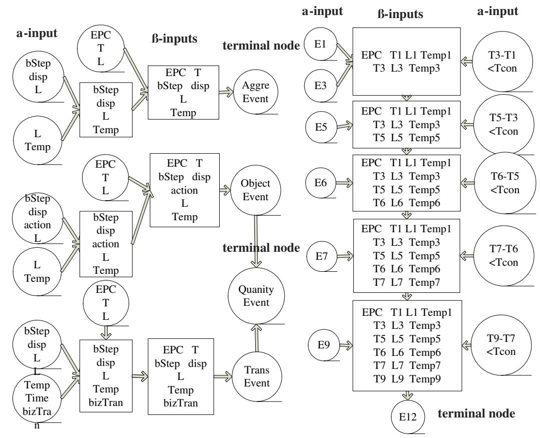

Fig. 2. A RETE matching network

through the nodes of RETE network. The α-input node tests whether the tokens satisfy a condition, while the β-inputs node tests variable consistency of the tokens in different patterns. Some nodes can be share by different patterns. All the tokens which satisfy patterns are stored. If a token has arrived at the "terminal node", it represents that a rule is satisfied[19].

In the algorithm, elements in the working memory can fall into two categories: events and facts. Events are born with timestamps, and they can "expire", while facts do not. When an event is generated, it is stamped with the current time. There are two temporal predications, BEFORE and AFTER, by which we can add temporal logic on rules. There are temporal constraints in most RFID applications. But RETE algorithm does not prepared for RFID originally. So we need to modify RETE algorithm according to the specific scenes.

In our scene, there are three types of objects, the first one is primitive event produced by RFID middleware. It is presented in the format of observation (EPC, T, L), where T represents Time, L represents Location. The second one is changeless object, which is presented in the format (L, bStep, disp) or (L, bStep, disp, action), where bStep represents bizStep, disp represents disposition. The third one which is presented in the format (L, Temp) or (L, Temp, bizTran) where Temp represents Temperature; bizTran represents bizTransaction, only change when a new fact come namely the temperature change. A RETE matching network is shown in this figure (Figure 2).

In the figure, we can see that rotundity represents α-input node or terminal node, rectangle represents β-input node, constraint in time state can be deemed as a token need to be matched in the pattern. Thinking about the characteristics of three objects, we design a RETE matching network. Because the second object and the third object usually do not change, the β-inputs node can exist a long time in the computer memory. We shall do some extra work to implement the temporal constraints such as $T3-T1<Tcon$, here T3 represents the Time of E3, T1 represents the Time of E1, Tcon represents a constant value of time. Through the improved RETE algorithm, we can get RFID simple events from RFID primitive events and other relevant data. These RFID simple events will become the input of RFID complex events.

III. RFID Complex Event Modeling and Processing

A. RFID Complex Events Modeling

RFID complex events occur in the scenes of commerce, supply chain, factory and other situations. The information of these scenes can be defined as semantic space of complex events. In the semantic space, there are three relations between different events, including time-relation, hierarchy-relation and causality. According to the relations, we model RFID complex events. These relations can be represented in the form of rules. All the rules are assembled into a set which is the model of complex events. In this paper, we design a scene including three roles: manufacturer, wholesaler and retailer and a rule set for retailer. Of course, the rule set can be used by wholesalers too. But in order to simplify the system, the wholesaler adopts a simpler strategy. At the same time, we suppose the manufacturer can produce a great deal of goods at any moment, and every role in the scene has enough space of stock.

The model of complex events:

1. If actual sales of the goods rose a% which is over 20% than expected sales for two weeks (P1), then this goods is recent best-selling product (P2).

2. If the number of goods is less than the sum of safety stock and expected sales (P3), then we need to order more products for the goods (P4).

3. If these goods are the products need to order more (P4) and the goods belong to A category of merchandise (P7), then we send an order form to the wholesaler (P5).

4. If these goods are recent best-selling products (P2), then we adjust and replace expected sales with the actual sales for the current (P6).

5. If these goods are recent best-selling products (P2) and the goods belong to A category of merchandise (P7), then rise the inventory of safety stock 2*a% (P8).

6. If actual sales of the goods drop b% which is over 20% than expected sales for two weeks (P9) and the goods belong to A category of merchandise (P7) and the inventory of safety

stock dose not equal zero (P10), then drop the inventory of safety stock 2*b% (P11).

7. If the inventory of safety stock increases (P8), then the goods maybe arouse the Bullwhip effect in the supply chain (P12).

8. If these goods maybe arouse the Bullwhip effect (P12), then send a report to the manufacturer and wholesaler, let them prepay orders and products the number of which is a% plus the inventory to resume safety stock of the wholesaler (P13).

Here we use the symbols of P1, P2. . .P13 to sign complex events. the relationship of the complex events is shown in the figure (Figure 3). In the rules, to judge whether the goods bring the Bullwhip effect or not, we must consider the information of history, price, season, sales promotion, etc about the goods, these commercial information has exceed the category of RFID event. We introduce an example, an analysis of a large consumer goods company's sales showed that the goods can be carved up into four categories: A category merchandise, B category merchandise, C category merchandise and other category. A category merchandise account for 5% amount and 70% sale; B category merchandise account for 10% amount and 20%; C category merchandise account for 65% amount and 10% sale; the other category account for 20% amount and 0% sale. For A category merchandise, we need to check the status of stock everyday. For B category merchandise, we need to check the status of stock every week. For C category merchandise, we need to check the status of stock every month. So we can build different levels of customer service for each category of merchandise. We can judge whether the goods belong A category by combination of RFID technology and business information. For the third rule in the set, if the goods don't belong to A category we don't need to send the order immediately, and wait until the number of the goods under the level of order products.

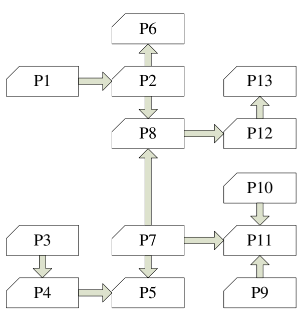

Fig. 3. The relationship of the complex events

RFID simple events are the trigger conditions of RFID complex events. In the rule set of RFID complex events, the sales of the goods are the origin of all the events, and they can be obtained using RFID simple events. For example, E1 and E6 can produce E8, though analyzing about the change of E8, we can get the sales of the goods in the wholesaler; E7 and E9 can produce E11, though analyzing about the change of E11, we can get the sales of the goods in the retailer.

B. Petri Nets Method

Petri Nets is graphical and mathematical modeling tool which is introduced by Carl Adam Petri in 1962 and can be applied informally to a lot of fields or systems. In addition, tokens are used in these nets to simulate the dynamic and concurrent activities of systems. A Petri net is a particular kind of directed graph, together with an initial state called the initial marking. The graph is a directed, weighted, bipartite graph consisting of two kinds of nodes, called places and transitions, where arcs are either from a place to a transition or from a transition to a place. In graphical representation, places are drawn as circles, transitions as bars or boxes. Arcs are labeled with their weights (positive integers), where a k-weighted arc can be interpreted as the set of k parallel arcs. Labels for unity weight are usually omitted. A marking (state) assigns to each place a nonnegative integer. If a marking assigns to place p a nonnegative integer k, we say that p is marked with k tokens. Pictorially, we place k black dots (tokens) in place p. A marking is denoted by M, an m-vector, where m is the total number of places. The pth component of M, denoted by $M(p)$, is the number of tokens in place p. Formal Definition of a Petri Net:

A Petri net is a 5-tuple, $\mathrm{N} = (\mathrm{P}, \mathrm{T}, \mathrm{F}, \mathrm{W}, \mathrm{M}_0)$ where:
$\mathrm{P} = \{p_1, p_2, ..., p_m\}$ is a finite set of places,
$\mathrm{T} = \{t_1, t_2, ..., t_n\}$ is a finite set of transitions,
$\mathrm{F} \subset (\mathrm{P} \times \mathrm{T}) \cup (\mathrm{T} \times \mathrm{P})$ is a set of arcs (flow relation),
$\mathrm{W} : \mathrm{F} \rightarrow \{1, 2, 3...\}$ is a weight function,
$\mathrm{M}_0 : \mathrm{P} \rightarrow \{0, 1, 2, 3...\}$ is the initial marking,

According to the above description of Petri net model, we make places model the complex events and be as containers to store the instances of events, and use transition represent the activation of complex events. If the transition occurs, relevant complex event will be produced. We can get a Petri net graph which is shown in the figure (Figure 4).

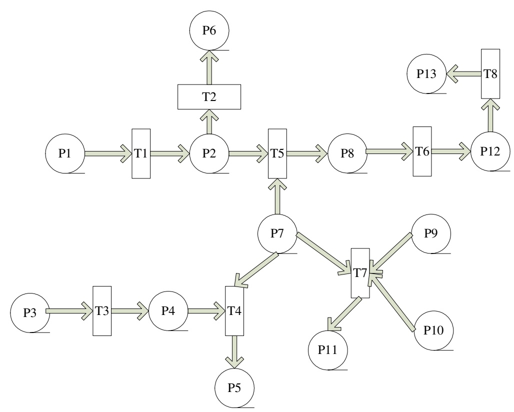

Fig. 4. A Petri net graph for modeling RFID complex events

For P/T system (places/transition system), origin sign and reachable sign has the following relation[23]:

$$M_1 = CU + M_0$$

Here, M_0 represents initial conditions of Petri net about distribution of the Tokens, M_1 represents final conditions of Petri net about distribution of the Tokens, C represents the self-construction of Petri net model, and U reflects the reasoning used in the rules. According to the formula above, the reasoning on the Petri net can boil down to the search for suitable U to complete the matrix computing. We can implement the search by finding all the transitions that have the right to function in the initial condition of Petri net. At the same time, Petri net ensures the solution of the reasoning of the conflict and the impact, does not need outside intervention.

Base on the above example of Petri net model, we suppose the initial condition is as follows:

$$M_0 = (1, 0, 1, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0)^T$$

The reasoning process of U is as follow:

1. Construct the correlation matrix of the Petri net based on the graph, the correlation matrix is as follow:

$$C = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & -1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

2. In the initial condition M_0, find the element that doesn't equal zero and sign the line relevant with the element.

3. From the line which is only signed once, in the sideward direction find the element equals -1.

4. From the element equals -1, in the lengthways direction find the other element equals -1, if the element which is discovered then sign it, else end this search.

5. When every element in this column which equals -1 is signed, find the element in the column equals 1, sign this line and return to the step 3. When this course can't go on, the reasoning process is over and gets the result.

According to the reasoning process above, M_0 and C is known, we can get the reasoning used in the rules $U = (1, 1, 1, 1, 1, 1, 0, 1)^T$. Through the computation in the formula, at last we get the result $M_1 = (0, -1, 0, 0, 1, 1, -2, 0, 0, 0, 0, 0, 1)^T$. We obtain the conclusion of these goods maybe arouse the Bullwhip effect, so we need to send a report to the manufacturer and wholesaler, and retailer need to order more products.

IV. The Experiments of RFID Event

A. The Experiment of RFID Simple Event

We design and implement a RFID event processing system which includes a server to produce RFID data simulating the real environment of supply chain, an event processing client to build RFID simple events from the real-time data simulated in server, and an UI of the system. In the system, there are different caches of system and different RFID data transfer rates to be selected. The size of cache and RFID data transfer rate will affect the system performance. The larger cache, the higher accuracy; the higher transfer rate, the lower accuracy. Finally we select the enough cache and the normal transfer rate, and obtain all the RFID simple events. Here is an example of E1 event (Figure 5):

TABLE I
THE ACCURACY OF THE SYSTEM IN DIFFERENT CACHES AND TRANSFER RATES

	Normal rate *1	Normal rate *10	Normal rate *50	Normal rate *100	Normal rate *10000
Using cache *1000	22.60%	23.60%	15.60%	12.60%	11.70%
Using cache *10000	100%	85.90%	67.30%	44.70%	34.40%
Using cache *5000	100%	100%	100%	100%	100%
Using cache *10000	100%	100%	100%	100%	100%

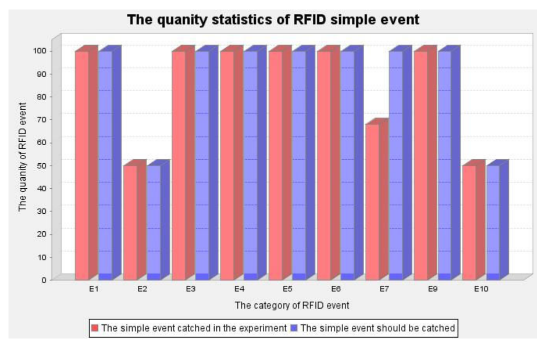

Fig. 5. The statistics of RFID simple event

From the figure above, we can know that all RFID simple events are built and obtained in the client. It illustrates that RFID simple event can be built in RETE algorithm. To test the performance and efficiency of system, we increase the data transfer rate and decrease the cache. The accuracy is shown in the table (TABLE I).

B. The Experiment of RFID Complex Event

We introduce RFID complex event to implementing advanced information technology for enhancing the effectiveness and efficiency of supply chains and alleviating the effect of bullwhip. We choose the well-known Beer Game simulation[24, 25] to identify the issues associated with RFID events. To illuminate the Bullwhip effect, there are three important factors in the figure need to be analyzed, including the level of the stock which shows the amount of the goods in stock, the sales of the goods in every week, and the quantity of the order form for the goods. In the complex event experiment, we analyze the three factors to show that the effect of the bullwhip is mitigated. The following two figures (Figure 6, 7) respectively show the status of retailer not using RFID events and the status of retailer using RFID events in Beer Game.

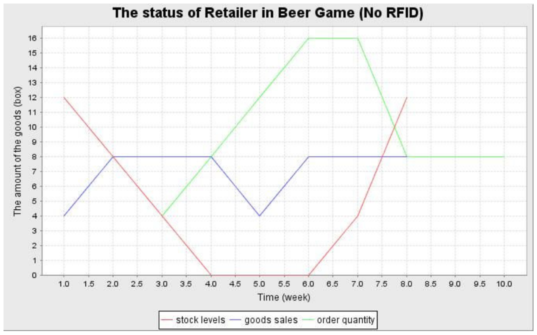

Fig. 6. The status of Retailer without using RFID events

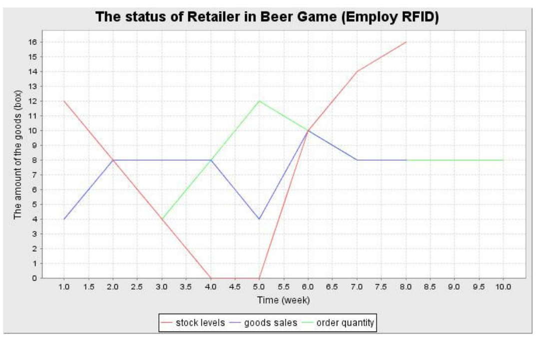

Fig. 7. The status of Retailer using RFID events

As shown in the two figures, for the retailer without RFID events, the time of amount in stock equals zero is three weeks, however, for the retailer with events, the time is two weeks. The sales for the retailer without events are less than the retailer with events. The fluctuation of the retailer without events is too intense. But the one of the retailer with events is less violent and comparatively abate. From the contrast of the two figures above, we get a conclusion that the Bullwhip effect has a greater impact on the retailer not using RFID complex events than the one employing the RFID events.

V. Conclusion

In this paper, we do an in-depth study in the methods of RFID simple events processing and complex events processing for RFID stream data and propose a complete set of solutions to the technology of RFID events that includes RFID simple event modeling and processing, RFID event modeling and processing, and the applications of RFID events. In the course of research for RFID events and the technology of processing, we have encountered many problems, but we finally solve them. The core problem is that how to transform massive RFID data into RFID events carrying semantics. To solve it, we build RFID simple and complex events model at first, and then using an improved RETE algorithm and Petri net method to implement the processing of RFID data and RFID events, we attain RFID simple events and RFID complex events at last. The application of RFID events have been proved to have great practical value of themselves. They can help the enterprises to achieve more value, create more profit and take the preemptive opportunities in the fierce competition in the market.

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