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ABSTRACT

This paper presents a design theory for real-time traceability system, which is derived from the chaos theory and from two case studies. We present a design method for supply chain analysis and several design principles for real-time traceability system design. Theoretically, the proposed design theory reveals the design and development process of real-time data capture systems and illustrates a methodology to analyze complex and random behaviors in supply chains. Practically, the design theory provides a robust guideline for practitioners in developing real-time traceability systems to enhance organizational performance. Further, the class of design principles discussed in this paper serves the additional function of explaining the way to incorporate real-time data capture functions in commonly used supply chain systems.

Keywords

Design theory, Chaos theory, Real-time traceability system, Information system research

INTRODUCTION

Disorder and unintended consequences of human actions arising from interactions between individuals and information systems are critical elements of supply chain management. Complex organizational behaviors complicate the problem of uncertainty and complexity within supply chains. Although a number of mathematical models and information systems provide detailed planning and scheduling, they do not solve the uncertainty and complexity arising from the dynamic nature of the environment and the interactions between individuals and information systems during actual manufacturing processes. Therefore, with reference to the chaos theory, this study proposes a new information system design theory for real-time traceability systems.

Real time traceability system is a special kind of transaction processing system, with the ability to track, follow, retrace, and examine in detail the flow of parts and processes through the whole or part of a supply chain (Alfaro and Rabade 2009). Therefore, the success or failure of such system depends very much on the ability to track, follow and retrace the object-of-interest from the point it enters the supply chain to the point it leaves the supply chain. The concept of traceability relates to many aspects of any kind of supply chain management (Regattieri, Gamberi and Manzini 2007). For instance, transportation and logistics adopt traceability systems for the real-time monitoring of container terminal operations, such as tracing of container trucks and quay cranes, and truck dispatching (Ngai, Li, Cheng, Lun, Lai, Cao and Lee 2010). Manufacturing adopts traceability systems and models to manage tooling problems in flexible manufacturing systems or in inventory and work-in-progress along supply chains (Ozbayrak and Bell 2003). However, despite the wide applicability of traceability systems, extant literature lacks a design theory guiding the design and development of real-time traceability systems. To the best of our understanding, there is no article explaining the theoretical underpinnings of how the design and process of traceability systems can be carried out in an effective and feasible manner. This study reveals the design and development process of real-time traceability systems and illustrates a methodology to analyze complex and random behaviors in supply chains based on chaos theory. Further, we provide a robust guideline for practitioners in developing real-time traceability systems.

CHAOS THEORY

The chaos theory is defined as the qualitative study of the unstable aperiodic behavior in deterministic, non-linear dynamic systems (Kellert 1993). Chaotic systems have three characteristics: (1) nonlinear, (2) unstable and shift among different types of equilibria and (3) dependent on and sensitive to initial conditions. McBride (2005) reviewed the chaos theory from extant literature and summarized nine elements, which should be incorporated into an interpretive framework for understanding the behavior of a chaotic system. Table 1 provides the definition of each element in the chaos theory.

Element	Definition
Domain of interaction	Any entity exists within the defined and bounded space. It define the scope of the system and the scope its influences on other elements.
Initial conditions	Set of initial states of the organization and information system at start of period of change. They are critical component in determining how the non-linear dynamic behavior progresses.
Strange attractors	Characteristic, dynamic, semi-stable patterns of behavior that may be changed at any time.
Outcome basin	Subset of the domain of interaction within which the strange attractor iterates.
Events and choices	Incidents, external or internal, planned or emergent, that may amplify the effect of initial conditions on outcome through positive feedback.
Edge of chaos	The point at which the system may shift to a new qualitative state in which it expresses new emergent behavior.
Bifurcation	Point at which qualitative change between two states occurs, leading to an irreversible organizational transformation.
Iteration	Cycle of repeating behavior of a strange attractor and cycle of interaction that provides positive feedback to amplify initial conditions.
Connectivity	Extent and complexity of network of organizational and technological interaction, e.g. interaction between human and machine.

Table 1 - Definition of each element (Mcbride 2005) and examples in the field of warehouse management

The chaos theory has been applied to explain the dynamics of supply chains. Wilding (1998) applied the chaos theory in warehouse supply chains and presented the managerial implications of chaotic systems. Stapleton et al. (2006) argued that the application of the chaos theory in various supply chain issues and functional areas can help reduce ambiguities in the supply chain and can provide insights for supply chain networks management. These studies imply the appropriateness of the chaos theory in explaining supply chain interactions involving different supply chain entities and activities.

In this study, we will apply the chaos theory in analyzing the pattern of “chaos” within supply chains and develop a set of design principles for the design of real-time traceability systems. Our proposed use of chaos theory in real-time traceability systems is based on the assertion that supply chain predictability depends on the function of human interactions and contextual factors. Traceability systems aim to collect real-time information on objects-of-interest and to use the information in achieving better supply chain management. Human interactions, which are unstable, with objects-of-interest and traceability systems will lead to unpredictable outcomes and may result in changes in supply chain behavior that deviates from the noncomplex prediction of the system. On the other hand, contextual variables, such as machine downtimes, interconnections between suppliers, manufacturers and distributors, competitive environment, and rapid IT advancement, have substantial effects on supply chain operations (Pathak et al. 2007) and may lead to the evolution of supply chain behaviors. Therefore, the chaos theory greatly contributes to the examination of important design features of traceability systems by providing a paradox for studying the complex and random behaviors existing in supply chains.

THE CASE STUDIES AND DESIGN THEORY FOR REAL-TIME TRACEABILITY SYSTEMS

Case A

The first case study was conducted in a factory in China (Ngai, To, Moon, Chan, Yeung and Lee 2010b). It is one of the world’s leading circular knitted fabric manufacturers and a major fabric supplier to garments manufacturers in 40 countries. This case study aims to develop a radio frequency identification (RFID)-based manufacturing monitoring system (RMMS) to support real-time data capture in textile and garment manufacturing processes and to provide a set of functions for workflow and inventory management. The workflow management module aims to define, modify, and manage the planned workflow in garment manufacturing and to detect any mistakes or errors in the process. The inventory management module manages the arrival or discharge of stocks at the warehouse.

Case B

The second case study was conducted in one of the leading companies in the terminal operations industry in Hong Kong (Ngai et al. 2010a). The company has 30 quay cranes (QCs) and 106 rubber-tyred gantry cranes (RTGCs) serving the vessels berthed at the port. This case study aims to develop an intelligent, context-aware decision support system (ICADSS) for the management of the terminal operations. ICADSS provides real-time information about the location and status of equipment and trucks in the terminal, alerts users for bottlenecks, supports decision making in equipment allocation, and provides operation data for forecasting and evaluation.

DESIGN METHOD

Design methods describe a set of procedures for the construction of IT artifacts. The design process of the traceability system of the two cases generally follows the Software Development Lifecycle (SDLC), with the results of the supply chain analysis as inputs. Meanwhile, the design product provides implicit guidelines for the system requirements, system design, and system evaluation. The supply chain analysis creates a concrete picture of how the supply chain behaves and supports each phase of the SDLC. Detailed research issues are addressed in each step of the supply chain analysis in Figure 1, which presents the complete design method for traceability systems.

In the two cases, specific steering committees were formed for the collection of supply chain information. We developed clearly defined roles and responsibility agreements to ensure the commitment of the organizational members in disclosing supply chain information. We collected data from various informants, such as senior manager and technician, and conducted field trips to observe the actual operation of the supply chains. We also analyzed past organizational records of the supply chain operations.

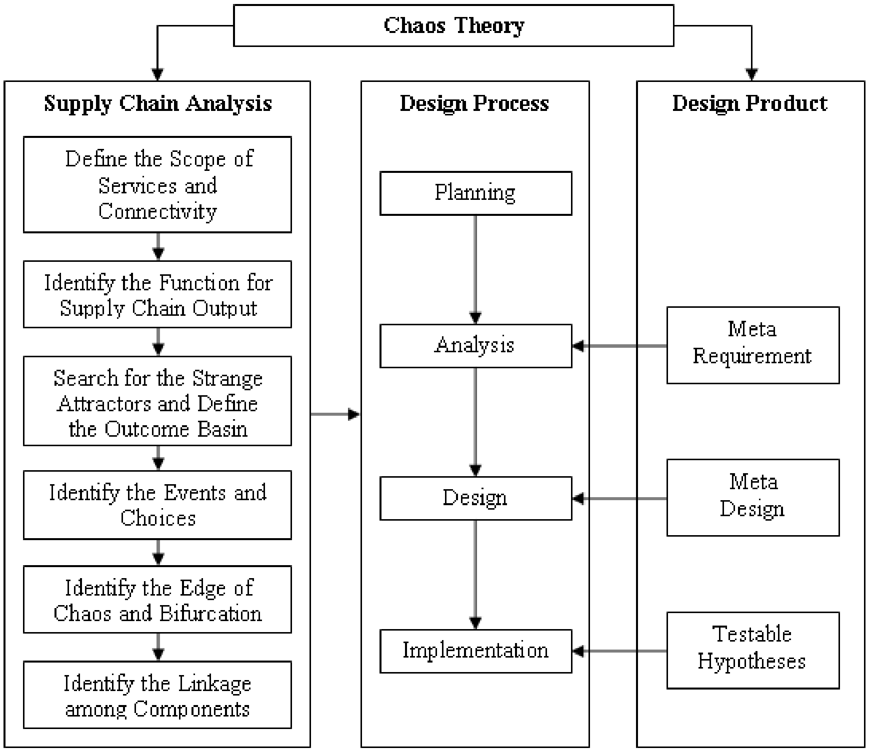

Figure 1 – Design Method for Real-Time Traceability System

Step 1: Define the Scope of Services and Connectivity

The objective of real-time traceability systems is to enhance supply chain transparency and efficiency. Therefore, the first step is to define the scope of service and connectivity for the information system. Scope of services refers to the phase of the supply chain of interest (domain of interaction) and all the entities involved within that phase, while connectivity refers to the different types of variable flows, such as information flow and stock flow, within the identified phase of the supply chain. In the two cases, we asked informants to identify the start point and end point of the supply chain that the real-time traceability system should serve. They were also asked to identify the flow of information and/or goods within the scope. Thereafter, we conducted field trips to observe operations and to identify major entities within the scope.

Step 2: Indentify the Function for Supply Chain Output

Based on the scope of service and connectivity defined in Step 1, the next step is defining the function for supply chain outputs to identify the components of initial conditions. In the case studies, we observed the actual supply chain activities and specified the links among different entities and the corresponding activity for each link. The supply chain process diagram helps us understand the process of transforming inputs to outputs. From the diagram, we identified which entities or activities control the output and defined the set of initial conditions of the supply chain.

Step 3: Search for Strange Attractors and Define the Outcome Basin

The first two steps are similar to those of the typical supply chain analysis methods. From this point onwards, we aim to identify systematically the potential characteristics or patterns of behaviors that may lead to supply chain instability and chaos. The first step is to identify the characteristics or patterns of behavior that may change over time, which are known as strange attractors. These characteristics and patterns of behavior interact within the outcome basin, which means that characteristics and patterns of behavior will lead to variations in the outcome basin. To identify the strange attractors and corresponding outcome basins, we first analyze each entity and activity along the supply chain and identify the set of outcome basin. Thereafter, we brainstorm the potential strange attractors that may lead to variations in outcomes. We also analyze organizational documents on the supply chain to reveal variations that may have happened in the past, which can help us identify strange attractors. It is important to note that not all strange attractors, such as when a manager initiates a change in inventory management policy, can be managed by real-time traceability systems. However, we can identify supply chain characteristics that may trigger such variation, such as inventory storage cost and inventory turnover.

Step 4: Identify the Events and Choices

While strange attractors are already encapsulated within the supply chain operation, events and choices are variables that are out of the boundary of supply chains but significantly influence the operation and output of supply chains. Similar with identifying strange attractors, we have to determine the supply chain entities or activities that can influence human choices when faced with specific events. In this step, we first identify possible events that may influence the effectiveness of supply chain management. Thereafter, we find the supply chain entities or activities that may affect human choices when faced with those events.

Step 5: Identify the Edge of Chaos and Bifurcation

The edge of chaos refers to the point at which the supply chain may turn into a chaotic state, while bifurcation refers to a qualitative change in the supply chain behavior. Both components specify the conditions that will lead to significant changes or an evolution in supply chain operations. Comparatively, the edge of chaos is more explicit than bifurcation because the edge of chaos can be seen as the maximum point of tolerance for dissatisfactory supply chain operations. Hence, in the case studies, the organizational members were asked to set a series of thresholds to identify the edge of chaos. Bifurcation refers to a qualitative change, which is difficult for an information system to forecast. However, we can still identify certain thresholds that may trigger qualitative changes in behavior.

Step 6: Identify the Linkage among Components

Steps 1 to 5 specify the stable supply chain operations, the components that may influence the supply chain stability, and the series of thresholds defining stable supply chains. The last step is to identify the linkage among these variables. These linkages help us identify the effect of variation in one variable on the others so that corrective action can be made accordingly. This procedure produces a diagram presenting the relationship of each component (strange attractor, events, bifurcation, and edge of chaos) with the entities and activities within the defined phase of supply chain and network of connectivity.

Element	Case A	Case B
Domain of interaction	Within an environment with a dock, a warehouse, and mills	Within a container terminal
Initial conditions	Inventory status –location, amount; WIP status – location, time to proceed, next process; Machine (oil removal, dyeing, water absorption, finishing, and drying machine) status – busy/idle, time to finish existing process, queue	Machine [QC and RTGC] status – busy/idle, time to finish existing process, queue; Truck status – location, existing process, time to finish existing process, next process
Strange attractors	Machine processing time; number of machines; Inventory management	Loading/discharging lead time; Number of QC/RTGC available
Outcome basin	Inventory management model – FIFO and LIFO, among others; Combination of workflow; Production lead time	Truck management model – FIFO, shortest time, and others; QC/RTGC management model – fixed location, demand based; Loading/ discharging lead time
Events and choices	System users' compliance with RMMS or work guidelines	System users' compliance with ICADSS or work guidelines
Edge of chaos	Increasing inventory cost; Serious bottleneck; Increasing production time; Increasing production defects; reducing the degree of data accuracy	Increasing waiting time; Reducing the degree of data accuracy; Decreasing customer satisfaction
Bifurcation	Changes in the role or use of RMMS in the production line; Extension of RMMS to other aspects of company A; Advancements in manufacturing technology	Changes in the role or use of ICADSS in the loading/discharging process; Extension of ICADSS to other aspects of company B; Advancements in loading/ discharging equipment technology
Iteration	Planned workflow → real-time information → choices → intervention; change to another behavioral pattern within the cycle of iteration when the cycle meets the above mentioned edge of chaos/bifurcation.	Planned workflow → real-time information → choices → intervention; change to another behavioral pattern within the cycle of iteration when the cycle meets the above mentioned edge of chaos/bifurcation.
Connectivity	Interaction between warehouse and factory; Users and RMMS; Among work processes	Interaction between QC / RTGC and truck; Users and the traceability system; Among work processes

Table 2 - Supply Chain Analysis of the Two Cases

The presented supply chain analysis method is different from the typical method for understanding supply chain operations. This methodology adopts the chaos theory and incorporates the ideas of stability and chaotic states into the supply chain analysis. This can help organizations develop information systems that will alert the organizations when dissatisfactory situations arise, allowing corrective actions to be timely placed. Following the proposed design methodology, we had analyzed the organizational characteristics of each organization. The supply chain analysis results are presented in Table 2.

DESIGN PRINCIPLES FOR REAL-TIME TRACEABILITY SYSTEM

Real-time traceability systems refer to the use of wireless devices to track or trace objects-of-interest and to provide information for system users in dealing with patterned behaviors or chaos existing in supply chain processes. From the users' requirement analysis process, we found that the two organizations under study generally demand the system to provide real-time information on the objects-of-interest to maintain close supervision of the supply chain process and to perform operational planning using real-time information. Therefore, we regard the monitoring and management of complex and random behaviors existing in supply chains as the meta-requirements of real-time traceability systems. Specifically, we derived five functions or characteristics from the chaos theory as the specific meta-requirements of real-time traceability systems: (1) serve the whole domain of interaction, (2) monitor the non-linear dynamic behavior progress in real-time, (3) cover all possible outcomes as defined by the outcome basin, (4) manage bifurcation, and (5) cover the extent and complexity of network connectivity. In the following sections, we will present the design principles for real-time traceability systems.

Principle 1: Design for the domain of interaction by defining the full scope of influence

According to the chaos theory, information systems exist within a defined and bounded space, which encompasses all possible states that a system could be in (Mcbride 2005). Having a clear domain of interaction serves two functions in the design of traceability systems. First, it identifies the full scope of entities that may influence supply chain behaviors and traceability systems. Second, it helps identify the suitable range of possible automatic identification and data capture (AIDC) technologies given the characteristics of the domain of interaction. Therefore, it is important to define a clear domain and boundary of interaction that a particular information system targets. In the two cases, we found that the physical constraints of the defined boundary determine the success of real-time information collection. For instance, in case A, the textile and garment manufacturing process interacts within the environment with a dock, a warehouse, and mills. The environment of the dock, warehouse, and mills is unfavorable for AIDC technology implementation because the temperature and humidity is high, the dust problem is serious, and the voltage has huge fluctuations in certain areas. In addition, there are many different kinds of machines, which may interfere with the signals of the traceability system. Further, because the machines are close to each other, the check points will be too close, and one tag may be read by several nearby readers at the same time. These constraints limit the selection and implementation of AIDC technology under the domain of interaction between the dock, warehouse, and mills.

Principle 2: Design for monitoring nonlinear dynamic behavior progress by real-time tracking of changes in the initial status, strange attractors, edge of chaos, and events and choices

According to the chaos theory, nonlinear dynamic supply chains are determined by different entities within the domain of interaction. The initial status determines how the dynamic behavior progresses, while strange attractors are temporary patterns of behavior that may change at any time. External and internal events and choices drive the organization away from a temporary stable state towards the edge of chaos, where the behavioral system shifts to an emergent pattern of behavior. Therefore, to manage supply chain behaviors efficiently, the design of traceability systems should consider these entities in predicting and in managing the behavior of supply chains.

Through the case studies, we found that the real-time data capture of initial conditions helps organizations implement short-term planning and enhance operational efficiency. For instance, in Case B, the allocation of trucks to QC/QTGC was determined by a function of the location of the trucks and the status of QC/QTGC. ICADSS utilized ZigBee and DGPS technologies to collect real-time data and to support operational decision-making. ICADSS will provide decision support for the terminal operations based on the location (e.g., zone numbers) and status (e.g., estimated processing times of current task) of trucks and QC/RTGC. Therefore, real-time data capture can support operation planning in a "just-in-time" manner and helps shorten unnecessary traveling or queuing time. While real-time tracking of initial conditions enables organizations to enjoy the benefits of short term planning, keeping record of strange attractors helps track variations in behavioral patterns and provides information for system users to determine whether intervention is needed. All cases keep records of the processing time and number of machines or tools available. This helps organizations keep track of temporary patterns of behavior, which may change over time. System users may keep track of these records and determine whether a particular pattern of behavior is out of an acceptable range and intervention needs to be carried out. These records help organizations analyze the dynamic behavior of their supply chains in a more visible sense.

On the other hand, the chaos theory explains that events and choices may bring the supply chain to the edge of chaos. As we confirmed in the case studies, close supervision of potential events, choices, and entities related to the edge of chaos can help keep dynamic supply chains in a state of stability. For instance, in Case B, when the length of the queue or the waiting time of trucks in the queue exceeds the pre-defined thresholds, the ICADSS will automatically generate an alert message. The ICADSS also keeps records of the entities related to the edge of chaos, such as waiting time. System users can introduce timely interventions and reverse the supply chain to a state of stability once the system detects any rise of chaos. Also, system users can make use of the set of operation data to identify the root of the chaos.

Principle 3: Design for outcome basin by incorporating system variability

Strange attractors refer to patterns of behavior that may change over time but are within a defined subset of domain. Therefore, to accommodate potential changes in strange attractors, traceability systems need to incorporate certain levels of variability. This will maintain the ability of traceability systems to manage the dynamic behavior of supply chains. For instance, in Case B, when the ICADSS finds serious bottlenecks or increasing waiting time, the management model of the RTGC can change from fixed location to demand-focused allocation. ICADSS supports the supply chain's need to assign an RTGC to handle the peak of operations in a specific zone. ICADSS can check the status, estimate queue clearing time, locate all RTGCs, and recommend which RTGCs should be sent. The system variability of the ICADSS supports decision making on strange attractors and manages the keeping of records of the entities interacting with strange attractors.

Principle 4: Bifurcation design enhancing the flexibility of systems

As mentioned, bifurcations refer to changes in the behavior of supply chains. We have to admit that anticipating the sudden changes in supply chain behavior is difficult. However, it does not mean that the design of a real-time traceability system may ignore this factor. From the case studies, we found that the common bifurcations that could happen to supply chains include (1) changes in the role or use of traceability systems in supply chains, (2) extension of traceability systems to other aspect of supply chains, and (3) advancements in technology that may influence the operation of supply chains. Therefore, the design of traceability systems should be flexible enough to manage modification or advancements.

Figure 2 and 3 show the system architecture of the real-time traceability systems in the two cases. To prepare for bifurcation, we enriched the traceability systems with high flexibility for modification and extension. In all cases, different data process functions were grouped into different modules, which share the same data repository. Changes in one module would not affect the function of the others. The traceability systems were also equipped with middleware that connect the systems with external systems. This system architecture provides a high degree of flexibility for extension or modification when the supply chains experience sudden changes in behavior.

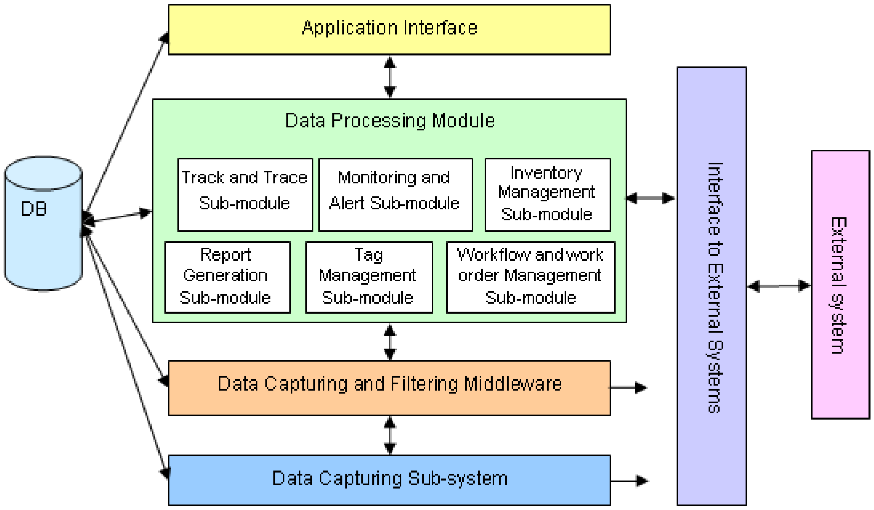

Figure 2 System architecture of RMMS (Case A) (Ngai et al. 2010b)

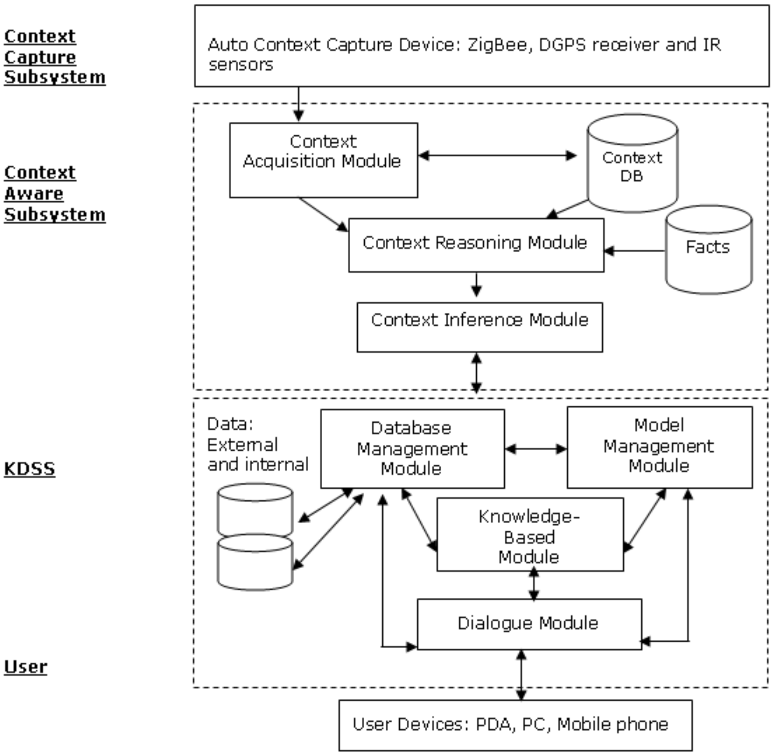

Figure 3 – System architecture of ICADSS (Case B) (Ngai et al. 2010a)

Principle 5: Design for connectivity by incorporating full network interaction

The last design principle that needs attention is the connectivity of traceability systems. Within a supply chain, a real-time traceability system connects many different entities from different aspects of the chain. For instance, in case A, the connectivity of the RMMS includes interactions between the warehouse and factory, among different work processes, and between system users and the RMMS. From the connectivity, real-time data should flow from the warehouse to the factory and to different processes within the factory. After understanding the RMMS information flow, we worked on how information could be effectively transmitted between links and entities to ensure that the identified connectivity would be well incorporated into the RMMS. From the case studies, we found that connectivity ensures that each link is given enough information to maintain system function. Any breaking point within the links of connectivity will affect the effectiveness of information communication within the supply chain and will lead to unpredictable effects on system performance.

SYSTEM EVALUATION (TESTABLE HYPOTHESIS)

Design theories are testable because they are regarded as explanatory and predictive. From the previous literature and case studies we conducted, we found that a traceability system mainly aims to help organizations obtain certain supply chain optimization, such as cost reduction or productivity enhancement, depending on the scale and function of the traceability system (Alfaro and Rabade 2009). On top of the quantitative expectation of performance enhancement, traceability systems have to meet functional requirements. Therefore, we derived a set of six testable hypotheses from the eternal aims and meta-requirements of traceability systems. Table 3 presents the analysis of how the traceability systems in the two cases satisfied the testable hypotheses.

From the evaluation of the two case studies, we found that traceability systems could capture the dynamism and complexity of supply chain behaviors and could help organizations obtain better supply chain performance. First, from the hypotheses testing, we found that real-time traceability systems could provide accurate, complete, and real-time information to system users. They yield high degrees of information quality. Second, real-time traceability systems could provide reliable information on different working environments to system users, timely information to system users by actively searching for signals, a high extent of system variability to accommodate all system changes included in the outcome basins of supply

Testable Hypotheses	Case A	Case B
The proposed design theory is capable of designing real-time traceability system which enhances supply chain optimization	Human resources can be redirected from data capture and entry processes to other productivity-related procedures; supply chain visibility is enhanced and bottlenecks are identified, allowing re-allocation of resources and enhancement of productivity; loss and wastage reduction; provide a set of operational data for supply chain evaluation and continuous improvement.	The average queuing time of trucks is reduced by 13% for loading at the yard, 68% for loading at the quayside, and 48% for discharging at the quayside; the average waiting time of trucks for RTGC is reduced by 25% for loading and 15% for discharging; human resources can be redirected from monitoring and recording of the status of machines and trucks to other productivity-related areas; provide a set of operation data for supply chain evaluation and continuous improvement.
The proposed design theory is capable of designing real-time traceability system which has the ability to work under the domain of interaction	RFID tags were tested and were found to tolerate wet and hot environments and to be capable of batch reading.	DGPS and ZigBee were tested, and it was found that they worked well in the domain of interaction.
The proposed design theory is capable of designing real-time traceability system which has the ability to collect accurate real-time information	Cross-checked with human-recorded data and found that the accuracy of RFID-enabled data capture was at 100%.	Field test was conducted, and results showed that over 88% of the randomly selected operations could identify a correct bay ID of QC/RTGC; by comparison, there exists an average of 5% difference between the data captured (e.g. arrival time, waiting time, and departure time) by the ICADSS and manually generated data.
The proposed design theory is capable of designing real-time traceability system which has the ability to accommodate different interactions of strange attractors	Pilot run was conducted, and results showed that the RMMS could manage different inventory management models and models of machine allocations.	Pilot run was conducted, and results showed that the ICADSS could manage to shift between different management models of RTGC.
The proposed design theory is capable of designing real-time traceability system which has the ability to accept future enhancement or modification	RMMS was built using component-based method, which provides a high degree of flexibility for extension or modification.	ICADSS was built using component-based method, which provides a high degree of flexibility for extension or modification.
The proposed design theory is capable of designing real-time traceability system which has the ability to connect the necessary networks of interaction	Pilot run was conducted, and results showed that information could be communicated accurately and timely between networks of interaction.	Pilot run was conducted, and results showed that information could be communicated accurately and timely between networks of interaction.

Table 3 – System Evaluation of the Two Cases

chains, and a high extent of system integration ability through the use of component-based system architectures. These characteristics show that real-time traceability systems possess a high degree of system quality. Information quality and system quality are two major factors influencing system success (Delone and Mclean 2003). Therefore, we are convinced that real-time traceability systems, which follow the presented design principles, can help organizations attain supply chain optimization. More importantly, we believe that the design principles can be applied to supply chain information systems serving different purposes and in different developmental scales.

CONTRIBUTIONS OF REAL-TIME TRACEABILITY DESIGN THEORY

This paper presents a design theory of real-time traceability systems to provide rigorous and valid guidance to traceability system design and development. This paper has several theoretical contributions. First, this paper reveals the design of real-time traceability systems along supply chains. Second, this paper illustrates a methodology to analyze the dynamism of organizational supply chains. Third, the presented design theory sets an agenda for academic research by creating theory-based design principles, which are subject to empirical and practical validation. Practically, our design theory provides comprehensive guidance to practitioners on real-time traceability system development. Further, the presented design theory shows how the real-time data capture function can be incorporated in supply chain management systems commonly used in the field. The design principles guide practitioners in developing real-time traceability systems or in incorporating real-time traceability features into their existing supply chain management systems. Our design theorizing was stimulated by our experiences with two case studies; we need to address the generality of our study. As for future research, it would be interesting to conduct more field studies or case studies on the proposed hypotheses as stated in Table 3. A wider scale of validity of the design theory remains to be done and we believe that only the accumulated weight either through case studies or field studies will establish the validity of the proposed hypotheses.

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