System Evolution in the Intelligent Enterprise: An Historical Case Study of VISA's Transaction Processing Systems

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Abstract. Intelligent enterprises need systems which evolve well. Systems will increasingly be expected to evolve to meet users' changing needs, and predicting user demand is becoming more inexact. System engineers need to understand why some systems evolve well and put this knowledge into practice. Lessons learned from the evolution of actual systems should be incorporated into system design and development processes to equip the system engineer to meet this challenge.

This paper discusses a case study of the technological evolution of VISA's credit card transaction processing systems. It identifies key principles which were successfully applied to enhance system evolution. The paper discusses observations concerning how generic properties (the illities) relate to one another and how they were achieved in VISA's system design. Related issues of system platforms and component coupling which affect system evolution are also addressed.

Introduction

The US Department of Defense (DoD), like other large organizations, is facing budgetary constraints which are forcing systems to have an increased life cycle and to be adaptable to a variety of missions (Dahlgren 2006). Predicting user demand on new systems is becoming more inexact at best, yet systems will be expected to incorporate new technologies to meet users' needs. System engineers need to understand why some systems have evolved well, why others have not, and to put this knowledge into practice. System design and development processes must be enabled to account for the properties which allow systems to evolve and maintain a longer, useful life.

The illities are generic requirements (e.g., flexibility, adaptability, scalability, reliability) which are not necessarily part of a system's fundamental constraints (Allen et. al. 2001). They can express system requirements that remain valid even while specific user needs change. This makes the illities useful for describing properties that pertain to system evolution. A number of practical research questions come to mind concerning the illities and system evolution. How do the illities relate to a system's ability to evolve? How do they relate to one another (are there tradeoffs)? What are some systems that have evolved well, which illities did they exhibit, and how was success achieved?

The MITRE Corporation and the Massachusetts Institute of Technology (MIT) are engaged in collaborative research to address these questions for the benefit of the DoD community. A significant part of this effort involves case studies to determine the factors that contributed to successful system evolution. This paper presents a case study of the technological evolution of VISA's credit card processing systems. It notes principles which were successfully applied to enhance system evolution.

What VISA Does

Long before Dee Hock became the CEO of VISA International, and even before he founded VISA's predecessor organization, he concluded that the credit card business was really about the "…exchange of monetary value" (Hock 1999). Before the necessary technology became widely available, Hock envisioned a ubiquitous electronic mechanism to guarantee, transport, and settle transactions regardless of time, location, or currency. The problem he foresaw was that no single bank or any other known organization could accomplish his vision. However, a large number of cooperating organizations had the potential to succeed.

Simply stated, the product of VISA International is coordination (Senge et. al. 1999). In essence, its employees work to coordinate the efforts of its numerous member organizations by providing the necessary infrastructure. While its members secure the participation of cardholders and merchants, VISA provides telecommunications and data processing systems and sets operating standards to enable its members to work together effectively (Ziff-Davis 1986).

Two fundamental processes in the credit card industry are authorization and settlement. Authorization is the approval process for a cardholder's purchase. Settlement is the process by which the merchant eventually receives payment for a purchase. These processes illustrate the nature of the coordination which VISA provides to its members.

Figures 1 and 2 depict high level overviews of the authorization and settlement processes. The roles represented in the figures are defined as follows. Acquiring banks contract with merchants to settle credit card transactions. Issuing banks establish and manage the cardholder's account. The bankcard association (e.g. VISA) coordinates the process of authorizing the charge to the cardholder's account, and also facilitates the transfer of funds from the issuing bank to the acquiring bank to cover payment to the merchant. While the authorization and settlement processes may be complicated by a number of factors due to institutional differences which are not addressed in the figures, the basic principles and VISA's coordinating role remain the same.

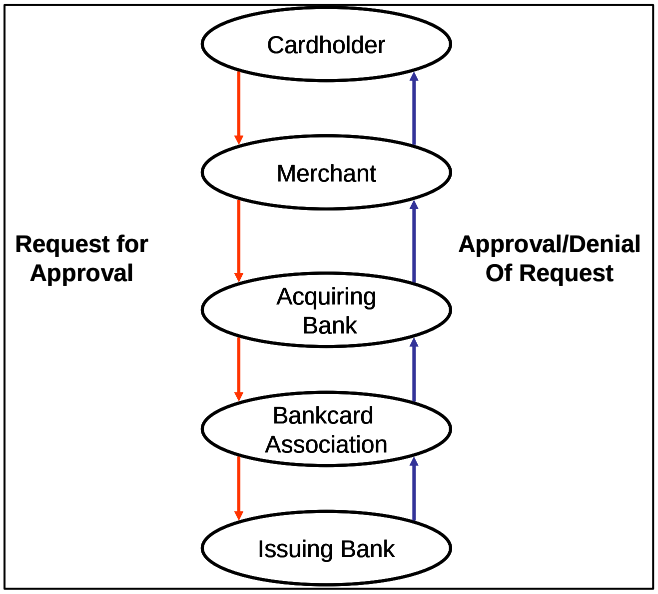

Figure 1 – Credit Card Authorization Process Overview (Office of the Comptroller of the Currency 2001)

Figure 1 shows the credit card authorization process. To authorize a credit card transaction, the merchant needs approval from the issuing bank to ensure payment. The merchant provides the acquiring bank with the cardholder's information and purchase cost. The acquiring bank forwards this information to the issuing bank through the bankcard association. Approval or denial of the purchase is relayed from the issuing bank back to the point of sale through the bankcard association. The merchant then completes or denies the purchase, depending on the approval decision relayed from the issuing bank.

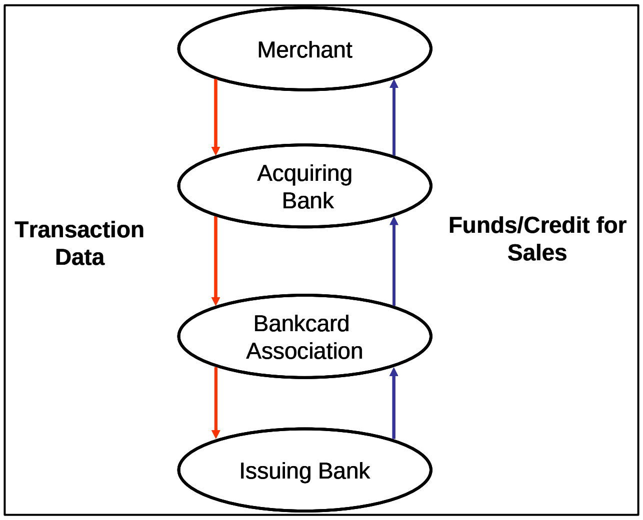

Figure 2 – Credit Card Settlement Process Overview (Office of the Comptroller of the Currency 2001)

Figure 2 shows the credit card settlement process. Settlement involves providing sales information to the issuing bank for collection and payment of funds to the merchant. The merchant submits sales transactions to the merchant bank. The information is then forwarded through the bankcard association to the issuing bank, who posts the charge to the cardholder's account. Funds are provided by the issuing bank, through the bankcard association, to the acquiring bank. The acquiring bank pays the merchant.

VISA is in the business of coordinating the efforts of its members, and it employs technological systems to carry out this business. The next section discusses a useful tool for studying the evolution of these systems.

The Design Structure Matrix

A Design Structure Matrix (DSM) is a matrix representation of a system[1]. It is a compact representation of a digraph (i.e. directed graph) that depicts the relationships among the components in a system (DSM Web Site 2006). DSMs are often used to illustrate relationships among low-level subsystems. They also have utility for clarifying the relationships among higher level subsystems, and this study employs them for this purpose.

The rows and columns in the DSM are analogous to nodes in the digraph and correspond to system components. The cells in the matrix are analogous to edges in the digraph and represent the relationships among the system components. As in a digraph, the relationships tracked by a DSM are directional. Thus the relationship of component A to component B is distinct from the relationship of component B to component A.

This study employs DSMs to articulate how changes made to components affect other components in a system. The relationships in the DSMs indicate whether a given component will require modification if another specified component is upgraded. These relationships are stated as dependencies. Figure 3 shows the three possible types of dependency relationships.

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<tr><th colspan="4">Three Configurations that Characterize a System</th></tr>
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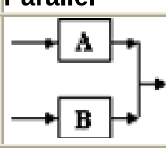
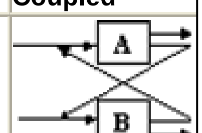
<tr><td>Graph Representation</td><td></td><td></td><td></td></tr>
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Figure 3 - DSM Component Relationships (DSM Web Site 2006)

[1] Note that a DSM can also be used to describe a project, but this use is not within the scope of this paper.

In the first relationship depicted in the figure, changes to the system components do not interact with one another. Thus component B is independent of component A (and vice versa) with regard to modifications. Upgrades to either component can be made independently.

In the sequential (also known as dependent) relationship, changes to one component require modifications to another component in order to maintain a working system. The figure depicts that component B is dependent upon component A. Thus, if component A is upgraded, then component B will require modifications to keep the system operational.

Finally, in the coupled relationship, the interoperation of the components is intertwined so extensively that modifications to either component require modifications to the other. In this case, the table shows that components A and B are interdependent and therefore coupled.

The relationships among components described by a DSM can inform a number of system design and development decisions. One of these is the determination of platforms within the system. Generically speaking, a platform is a set of components within a system that is subject to standardization. A platform divides a system into different modules, such that changes made to a given module will not affect other modules (Allen et. al. 2001). The DSM can highlight system components which have a large number of other components dependent upon them. These may form modules that could be chosen as platforms. Coupled components may also indicate a potential platform.

VISA Systems Evolution

Early credit card transaction processing was characterized by manual processing and primitive, mechanical automation. As time progressed, the technology employed in credit card transaction processing became electronic-based. Throughout its history, it also became increasingly focused on the information needed and on increasing the speed of those exchanges.

It is interesting to note that technological evolution did not lead to significant changes in the physical characteristics of the credit card itself. The card was treated as a platform early on in the evolution of the transaction processing system and its dimensions have remained essentially unchanged. The dimensions of the common credit card are well-suited for the human hand. So much so that there is a correlation between the size and shape of the credit card, the business card, and the playing card. Today, these all have nearly the same dimensions. The reason for this commonality may be historical (Belight 2005).

In the 17th century, social gatherings among the French aristocracy were frequent, and playing cards was a common activity at parties. Part of the culture involved showing up for others' parties if they attended yours, and also making it known to those higher in court that you attended their parties. Since playing cards were always handy, they were signed and left as evidence of attendance. This appears to be the origin of the calling card. In addition, playing cards were also used to create informal promissory notes (i.e. IOUs) when playing for money. This can be thought of as an early form of credit.

The calling card made its way into the American South, where social engagements were seen as important enough to document. It was also a way to formally introduce oneself. Businesses evolved this concept to business cards as we know them. Thus the credit card, based on these same dimensions, was a natural fit for the hand and consequently, the wallet and purse. The dependence of other components on the dimensions of the credit card is indicated in each of the four system configurations considered in the study. The system configurations, presented below, follow a chronological development path, ranging from the mechanical imprinter to making purchases via the world-wide web. Each system is evaluated in terms of the dependencies among its components.

Manual Imprinter

The earliest system for making records for settlement purposes was the manual imprinter. Four components were involved: the card itself, a carbon slip, and an imprinter. The card and carbon were placed into the imprinter in a very specific position. The imprinter was then operated by hand to impress the card's embossed numbers into the carbon to make a copy of the account number. Figure 4 shows the dependencies among these components.

Name		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Hand/Wallet/Purse	**1**	**1**						
Card Size/Shape	**2**	X	**2**					
Raised Characters	**3**			**3**				
Imprinter	**4**		X	X	**4**	X		
Carbon Slips	**5**		X	X	X	**5**		
Telephone (voice)	**6**						**6**	
Files/Printouts	**7**							**7**

Figure 4 – Manual Imprinter DSM

The card, carbons, and manual imprinter component were strongly coupled. There were interdependencies pertaining to the length, width, and thickness of the card and carbon, as well as the dimensions the imprinter mechanism could accommodate. These parameters all had to match closely for the physical imprinting process to be successful. In addition, other physical features of the card mattered, and competing institutions sometimes took advantage of this. For instance, one bank designed its imprinter to work only with its card by putting a steel pin in the imprinter which required a corresponding hole in the card. This imprinter was designed to break competitors' cards (Hock 1999). This is an example of an institution attempting to use their imprinter as a platform and thus trying to get customers to only use that institution's card. This tight coupling between their proprietary imprinter and card actually became a competitive disadvantage because it inconvenienced customers. This was a poor choice of platform strategy.

The carbon slips also made the settlement process unreliable. Cases were reported of large numbers of carbon-paper sales slips which could not be reconciled. Sales drafts worth millions of dollars could not be associated with cardholders' account for billing (Brooker 2004). This was especially true for frequent card users as the imprinter eventually wore down the raised numbers on the card.

Support for authorization was also quite primitive and involved making a series of (oftentimes long distance) phone calls to request a purchase approval. Paper files and computer printouts were used to manually look up account status. Although this arrangement was not coupled, it was expensive and time consuming. The time involved in properly authorizing the transaction inconvenienced the customer and the merchant, leading both to prefer other forms of payment. This was only partially addressed by allowing purchases below a certain limit to be completed without prior approval. However, this practice also opened opportunities for the unscrupulous and a great deal of money was lost due to fraudulent activities involving stolen or counterfeited cards (Mandell 1990).

Magnetic Stripe

VISA chose the magnetic stripe over smartcards because it was "serviceable technology" and would be available to countries with the poorest infrastructure (Senge, Peter, et. al. 1999). This reveals that reliability was a key factor in VISA's decision-making concerning when to upgrade to new technologies. With literally billions of dollars of transactions dependent on its infrastructure, VISA consciously chose to not be an early adopter of new technologies if they could not be universally supported by its members.

Figure 5 depicts the system component dependencies when the magnetic stripe was added to the credit card. Data transmission via telephone or network was also added in this configuration. The database for storing transaction information is dependent upon the information encoded on the magnetic stripe. Changes to that information may require the database to be updated.

Name		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Hand/Wallet/Purse	**1**	**1**						
Card Size/Shape	**2**	X	**2**					
Account ID Meta-data	**3**			**3**				
Magnetic Stripe	**4**		X	X	**4**	X		
Magnetic Stripe Reader	**5**				X	**5**		
Modem/Network	**6**						**6**	
Database	**7**			X				**7**

Figure 5 – Magnetic Stripe DSM

The magnetic stripe and its reader are strongly coupled. Common specifications for low level encoding of character information in magnetic media, as well as the data format used for defining the account information on the magnetic stripe (ISO/IEC 7811) had to be adopted. Whereas early credit card companies attempted to distribute proprietary imprinters for competitive advantage, the use of standards for the magnetic stripe enabled a platform upgrade which benefited the credit card industry as a whole. This commonality enabled the customer transactions to occur much faster, enabled accurate database entry, and meant merchants could use a single machine for all credit cards. It became a facilitator for all credit card companies and users, thereby encouraging the use of credit cards.

RFID

In this system configuration, depicted in Figure 6, a chip which communicates using radio frequency signals has been added to the card. The size/shape of the card and the RFID chip do not need to be closely correlated. The only requirement is that the RFID chip "fit" onto the card. The RFID chip is significantly smaller than the card and there are options for where on the card to place it. Thus we consider the RFID chip not to be significantly dependent on the card dimensions. In fact, a "card", per se, is not even required, as the chip could also be imbedded in a small plastic "bob" and attached to a key chain. Thus, while there is some relationship between the credit card and the RFID chip, the degree of dependence is far less than in the case of the magnetic stripe based system.

Name		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Hand/Wallet/Purse	**1**	**1**						
Card Size/Shape	**2**	X	**2**					
Account ID Meta-data	**3**			**3**				
RFID	**4**			X	**4**	X		
RFID Reader	**5**				X	**5**		
Modem/Network	**6**						**6**	
Database	**7**			X				**7**

Figure 6 – RFID DSM

There is, however, a high degree of coupling between the RFID chip and its reader. Both the chip and the reader must support the same transmission protocol as well as the format for encoding information such as the account number. As in the case of the magnetic stripe, the database for tracking transactions has some dependence on the information relayed by the RFID chip.

Web

Figure 7 shows the system configuration for making a purchase via the World Wide Web.

The relationship between the card and the customer is difficult to define. First, the customer is not "designed" but rather is modeled from experience or human factors studies. Strictly speaking, the card is not even required in this case, as the account number can be stored in another form: written down on paper, retrieved by the online ordering system, or even memorized by the customer. While it seems unlikely that a cardholder would write down their account number, the online ordering application could save the card information for the user's convenience. Any dependence of the user on the card itself is minor.

Name		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Hand/Wallet/Purse	**1**	**1**						
Card Size/Shape	**2**	X	**2**					
Account ID Meta-data	**3**			**3**				
Customer	**4**				**4**			
Web Application	**5**					**5**		
Modem/Network	**6**						**6**	
Database	**7**					X		**7**

Figure 7 – Web DSM

The mechanism which captures the cardholder's information is the combination of the customer and the web application. Both of these components are quite resilient to variations in one another. Humans can adapt while using the web application and can apply experience from using other web-based applications. Web applications can be quickly updated to account for problems discovered in user testing or from problem reports noted by users. There are some factors that cause some interdependence (e.g. language). However, this is usually accounted for in the web application development. The conclusion we reached was that the customer and web application may have some interdependence, but it is also very minor.

Lessons Learned from VISA's Success

Dee Hock's vision was a "…device for the exchange of value" (Senge et. al. 1999). A system that could implement this exchange anywhere in the world required one special characteristic above all - ubiquity. From the history of VISA's credit card processing system, it becomes clear that certain system properties were built into that system to support the goal of ubiquity. Figure 7 depicts the relationships among these systemic properties.

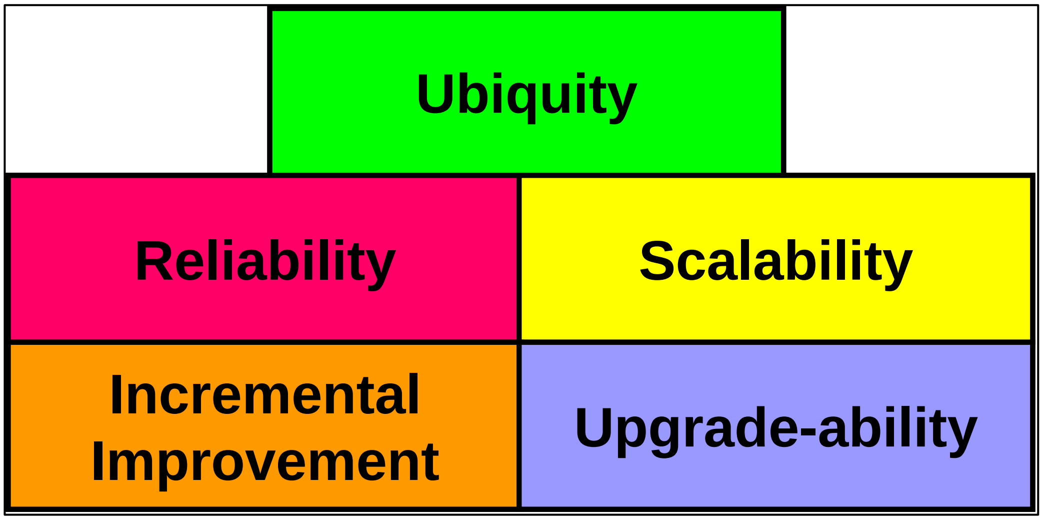

Figure 8 – VISA System Characteristics

At the top of the diagram is the ultimate goal of ubiquity. True ubiquity in the credit card industry, supporting everyone's transactions with all merchants, is a goal constantly striven for. The recent tremendous growth in the use of VISA for transactions costing less than $25 (Chu 2006) shows that VISA, and perhaps the industry as a whole, is moving ever closer toward ubiquity.

The study indicates that ubiquity was supported by reliability and scalability. Reliability was important because a system that could not be trusted would not attract cardholders nor could it achieve profitability. Scalability was also a necessity because a system growing to be ubiquitous would have to service an increasing number of transactions overall. VISA needed to achieve scalability in two senses. Its systems had to be able to accept both a large number of transactions from any given merchant, and small numbers of transactions from a large number of merchants.

To achieve scalability (in both senses) required handling larger transaction volumes in a shorter time period. Hock knew that automation (computers) would be a necessary tool to achieve this. But in addition, the evolving system also employed new mechanisms to achieve authorization and settlement more quickly and in greater volume. Thus, the system had to also be upgradeable. System upgradeability directly supported system scalability, but upgrades had to be achieved without disrupting the entire system.

The addition of the magnetic stripe facilitated the evolution of the card and reader components. It loosened the coupling between the card and the reader by acting as an interface between the two subsystems. This allowed upgrade options (e.g. RFID chip) to the card without impacting existing mechanisms for capturing card information. Credit card usage increased because the newer technology added convenience for cardholders, and merchants using older technology could still participate.

The introduction of electronic data exchange (modem and network) loosened the coupling between the information on the card and the transmission system. The information on the card can change without any impact on the transmission system, as the transmission system can change without any impact on the card. This allowed VISA to upgrade transmission systems without impacting the card holders.

Reliability also supported ubiquity. The accuracy of transactions was resolved with the introduction of automation. However, reliability was also supported by maintaining existing methods of card information capture when new methods were introduced. For instance, when the magnetic stripe was introduced, cardholders still had to be able to use the card anywhere, including stores that still used only imprinters. Merchants had to have backup methods for authorizing and recording sales. So for the sake of reliability, upgradeability was approached through incremental improvement.

By maintaining backup capability VISA also ensured it continued to support as many merchants as possible, even if the cost for processing transactions under the older method was more costly to VISA (although we expect it was still somewhat profitable). VISA's focus on ubiquity meant that it placed continued importance on providing usable services for the benefit of the end users (card holders and merchants).

Conclusion

Intelligent enterprises need systems that can evolve to meet needs which are often unanticipated. System engineers need to be equipped to meet this challenge by understanding the properties which allow systems to evolve and maintain a longer useful life. Case studies of successfully evolving systems, the properties they exhibit, and the means of achieving success contribute to this understanding. The evolution of VISA's transaction systems has offered a good opportunity to increase our understanding of the properties which enhance system evolution. Ubiquity requires system reliability as well as scalability. Upgradeability, tempered with incremental improvements, enables a scalable system.

Examining VISA's history also provided good examples of how loosening coupling between major subsystems, or systems in a system of systems, facilitates overall system evolution and customer satisfaction. Loose coupling provides the opportunity to upgrade components or subsystems with minimal impact to the system as a whole. In addition, it allows older components to co-exist with newer components. This preserves participation for those who cannot support the upgrade.

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