Framework for analysis of coupling and openness in AutoID- and RFID systems

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Abstract: In this framework, we create an approach to analyse coupling and openness of state-of-the-art logistics systems. The basic idea is 1) to understand how different environments have succeeded in supporting the adoption of tracking-based value offerings to consumers, contractors, and designers in the application area, 2) to investigate what mechanisms are used in the state of the art examples to make the environment an open-source, distributed, collaborative, self-adaptive, or otherwise easy-to-use application environment for SMEs. The analysis approach is based on the required effort invested in modifying the implemented services in order to make them function in a newly defined manner, and extending the implemented services to new participants. Also, the required effort for switching to another system or system supplier is considered a valid criterion.

1. INTRODUCTION

A system in this context means a logistics tracking system. This can be, for example, a proprietary system with a centralised database used by a large product manufacturer to track its own products, or an open standard based distributed system shared by many different companies. The system uses RFID, bar code or some other means to automatically identify the products. Information concerning the product flows is then stored and transmitted within the system, as well as displayed to the legitimate users.

Since the world is dynamic, there is always a need for modifications in the systems.

Usually any kind of changes in a system require some amount of modifying effort. For example, in systems manifested in many different locations and consisting of several databases, this effort increases compared to very simple and concentrated systems, as it is not enough to implement the changes in one place only. However, if distributed systems are conceived in a *loosely coupled* and *open* way, they can actually offer lower required effort compared to complex and concentrated proprietary systems. The objective is to achieve a divide-and-conquer situation where changes in one part of the system do not affect all other parts. Usually, this is done by utilising a modular structure. The advantages can be quantified e.g. by a user benefit/ development effort -ratio. With this framework, we evaluate the effort as a function of the degree of coupling and openness of a system.

The idea of *coupling* is closely related with modularity. By making use of modularity, we can create a huge number of different systems with a relatively small amount of different modules (cf. [1]). In the extreme case, loose coupling makes it possible to use any combination of the available modules in the same way as Lego building blocks can be combined to form almost an infinite number of "systems". On the other hand, if we only have one or few modules to connect with (tight coupling), there is practically no variation in the system structure and all system modifications require a large amount of effort. The more couplings the entity has with other entities and the tighter the couplings are, the higher the probability of increased effort for implementing the required changes. This also applies if the systems are designed to have a proprietary structure. For example, if the system can only be used in a certain environment, such as in connection with the equipment of a certain company, this means that either you have a high modification effort to make it work in another environment, or you have to use another proprietary system for these other cases. Furthermore, if the system is designed to support only a single organization, the modification effort to make it fit a multi-organisational environment can be very high. In other words, the *openness* of the systems is poor.

In addition to the structure of the system itself, also the system development community should be considered when evaluating coupling and openness. It might be difficult to compare the developing effort in large corporations versus the open markets of small companies, but in the latter the work is distributed over large developer pools, which gives certain benefits. For example, the development can be done faster in the large community, it can be more adaptive and creative, as well as consider a wider range of input, which makes is more versatile and open. Also the price can be much lower, as there are no monopolies based on high switching costs, and the structure of the software is transparent in the open source development community.

The intention of the framework proposed in this paper is 1) to allow organizations to identify their current situation in terms of coupling and openness and 2) to allow organisations to identify the situation where they would like to be or expect to be in the future. The cost related to this transition depends both on the amount of changes required and on the degree of coupling and openness in the current situation.

The framework is based on a five-level hierarchy, where the next higher level always contains the building blocks and functionality of the lower levels (see Fig. 1). As the framework is meant for analyzing coupling and openness of industrial cases, some examples are provided to elaborate the analysis. As a research material, we used 18 different cases collected from literature, from which we selected one for each level providing that such a case was available. However, the literature cases described only the users of the systems, not the development communities or system suppliers. Hence, the analysis could only be performed based on the end-user point of view. The cases were divided in layers based on a) the number of databases (none, single, multiple), b) whether they were local or distributed, and c) whether they were used within one organization or shared between multiple organisations.
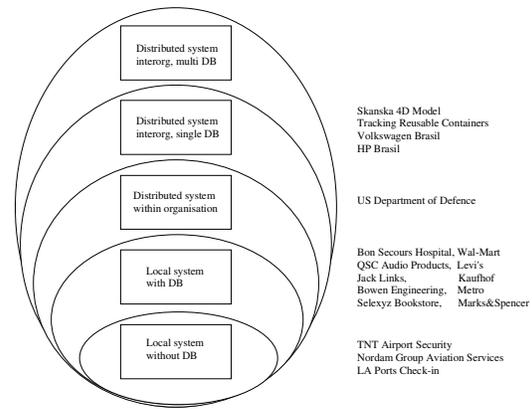

Figure 1. The basis for analysis and cases from the literature. The analysis is based on holons [2], each of which contains the building blocks of the previous levels.

The structure of the paper is as follows. First we introduce the evaluation model, which provides an understanding to the required modification effort related with coupling and openness. In other words, the amount of effort required to modify the system to fit another environment or to upgrade it to another level in the holonic model. At the moment, the model gives only a rough idea of the effort, but it could be developed further. Next we describe each level of the holonic model and give examples of coupling and openness related with the particular level.

2. THE EVALUATION MODEL

The evaluation model is based on the idea that the individual efforts required for modifying any part of the system can be measured based on e.g. man work days. Effort in general consists of various things in addition to that, but the other factors might not be very easy to quantify. It is possible to use cost as the measure, but this is also mostly based on the development effort. In equations 1 and 2, we can see the sum of individual efforts for coupling (Equation 1) and openness (Equation 2).

$$E_c = E_{c1} + E_{c2} + ... \qquad \text{(Eq 1)}$$

$$E_o = E_{o1} + E_{o2} + ... \qquad \text{(Eq 2)}$$

The components can also be considered to represent different aspects of coupling or openness. For example, we can study

separately coupling related with different system modules, coupling of different vendors, coupling of different standards, etc. Respectively, we can study openness of different modules, systems, developing techniques, etc.

In any case, to get the total effort (E), we would then sum up these two intermediary components. To characterize the easiness of system modification and portability, we can also define a quality factor (Q) for system comparison by taking the reciprocal of the sum total (see equation 3). In other words, the higher the required effort, the smaller the quality factor in coupling and openness sense.

$$Q = \frac{1}{E_c + E_o}$$ (Eq 3)

We might also have to consider the mutual relationship of coupling and openness. As we usually have several standards instead of only one, the loosest possible coupling is not achieved by adhering to one standard only. Although, following only a certain standard might improve the openness of the system, it could simultaneously be detrimental in coupling sense. For example, you could be tightly coupled with a certain standard and then have to adopt a new one for developing the system further. In this case, a rather low effort related with openness would be accompanied by high effort related with coupling. However, the mutual discrepancy of coupling and openness is probably not a major concern.

3. LOCAL SYSTEM WITHOUT DATABASE

The simplest tracking systems are local systems utilizing the traditional location centric approach. The ideology is based on the use of identification technology that enables fast and reliable item recognition in fixed locations. In the framework, the local systems are divided into two categories based on whether or not the system contains a database that can be used by multiple users. In this subchapter, we study the systems not containing databases. The system could be e.g. a manually operated RFID reader (or a bar code reader), which the user deploys for checking data concerning the

items at a fixed location. The automated identification in asset management reveals quite limited information to the user of the system; the basic output is usually in the form of 'operation ok' or 'operation denied / failed'. The user might also be just checking the contents of a shipment without opening the package. The identification system does not pass the identification information forward from the point of identification, and therefore the only output of the system is to the user being identified or to the operator of the identification point.

The TNT case [3] is an example of human assets or personnel management at the logistics centre at the Helsinki airport. The security of the logistics centre and the handled deliveries is controlled with security guards patrolling the facilities along a planned route. The guards' work performance is controlled with RFID tags placed in several locations along the route. The guards performing the surveillance patrol have portable RFID readers, which they use to verify their presence at the locations. The information on the route is recorded into the reader and it can be unloaded to a computer afterwards. The reverse design of the system with portable readers makes the reader a mobile identification-point, and the supervisor of the guards the ultimate user of the information collected.

3.1. Coupling and Openness
This kind of a very simple system does not offer a large variety of functionality, but the benefit of simplicity is easy modifiability. Since this is a local system, we do not have to consider connections to other places and systems either. As the system is very small and simple, also the effort required for any changes is minute. Modifying the service requires only data changes on the tags or, at the most, modification of the post-analysis software. Adding a new check point for the security guard does not even require a tag data change – you just place a new tag for the newly added check point and the extended route is implemented. A similar system can be taken into use anywhere quite effortlessly, and thus the openness is also very good.

4. LOCAL SYSTEM WITH DATABASE

The next, more sophisticated local system is the one containing a multi-user database. In this system, the collected data can be accessed locally by many users within the organization. The system can consist of e.g. manual or automatic RFID readers feeding the information to a local database for common access and automatic processing.

The operations in the supply chain that require most of the manual handling are usually shipping, receiving, and inventory counting. Fig. 2 presents an overall picture of the generic demand-supply chain of a retail store demonstrating the parts of the chain where example companies have improved their manual operations with automated identification techniques. The faster handling of goods has not changed the role of receiving or shipping operations but the less time-consuming inventory count has reduced the amount of work and created new possibilities to the experimenting companies. The new possibilities are based on the more reliable shelf account information, which enables more accurate replenishment orders than the point-of-sales data.
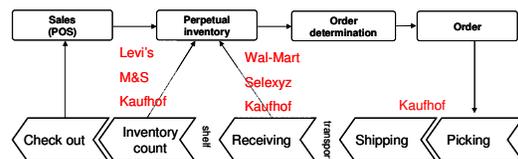

Figure 2: Logistics operations that have gained benefit from automated identification

Case Selexyz [4] offers a good example of reduced manual work in its pilot project on the marking of incoming books with passive RFID-tags. The books headed to the pilot store were tagged before packing at the distribution centre of a third-party-logistics service provider specialized in books. The tagging made it possible to automate the receiving of the books at the store, which was previously based on manual bar-code reading. The automated reading of the RFID-tags is now handled very efficiently with an RFID reader port, through which the unopened cartons of books pass. The second major

area of improvement is the inventory counting, which can be performed with portable RFID-readers in a few hours instead of having to close the store for a day. Due to these improvements the need for staff in the book store has dropped from 22 to 15, and Selexyz has decided to expand the system to other stores.

4.1. Coupling and Openness

Adding a multi-user database to the system increases the complexity somewhat, since we have to provide connection links to the information source for many different users. The added complexity of the system increases the functionality and potential usefulness of the system with the cost of higher effort for the possible system modifications. The addition of a database brings along some additional modification effort in the event of changes, since any format alterations in the tag must be accompanied by corresponding changes in the database. Major format changes might also require some system software changes. Adding a new check point requires the same equipment for the new location, as well as a connecting link to the database. If new users are added into the system, this is relatively easy by adding a link to the database and giving user rights to the new participant. Ideally, taking this kind of a system into use elsewhere in a similar application does not require a large amount of effort. The implementation effort consists of installing the check points, database and links, as well as some software modifications. The modification effort increases of course, if the desired functionality is very different. There might also be some compatibility issues to consider, if the system is proprietary or not following standards.

5. DISTRIBUTED SYSTEM WITHIN ORGANIZATION

The next level in the hierarchy is the distributed system used by a single organization. The difference compared to the previous level is that now the system is manifested in several geographical locations, although the system still uses a single concentrated database. The system could be e.g. a large chain of retail

stores having a common database for material handling.

An effective automatic identification system is the basis for building track and trace operations in a network of locations. The additional functionality of the tracking based operations is achieved by gathering the identification information from various points over time and location into a centralized database, which can be used to analyze and manage asset or material usage. Providing the information to its users therefore requires information management structures that collect the identification data across time and place and provide it in a suitably aggregated form to its authorized users. The access to the tracking database in tracking based operations is limited to company inner operations and benefits are a consequence of improved managerial decision making.

U.S. Department of Defence (DoD) started tracking with active RFID-tags on container and air pallet level, and is currently also implementing passive tagging on pallet / case-level [5], [6]. Due to its bargaining power as a large volume buyer, DoD has been able to mandate its suppliers to perform the actual tagging of incoming pallets. The usage of complementing techniques on containers and pallets provides the operators of DoD's field inventories in different stages of the chain far superior visibility over the materials compared to the old system. The RFID readers in the permanent logistics hubs are fixed, while the ones used in the field inventories are mobile. The mobility of reading active tags can be improved even further by mounting the reader on a Jeep and thus creating a mobile identification point. The identification information from the points of identification is gathered into a centralized tracking database where the members in the supply chain can perform queries. Currently the tracking information is shared mainly with warehouse and distribution hub operators to provide them the visibility over goods in the pipeline. The improved visibility of materials has made it possible to supply a larger share of the demanded goods from the different field inventories in the same operational area, and the visibility over ordered goods in the supply

chain has reduced the double-ordering. The faster identification of the contents of incoming shipments has also cut down the time spent at the hubs and depots along the chain. Due to the improvements, inventory levels at multiple points of the complex supply chain have been reduced considerably and the delivery accuracy to the end users has improved.

5.1. Coupling and Openness

Ideally, moving on to a distributed system within a single organization brings along only a moderate amount of additional effort related with coupling. It requires basically the same amount of modification effort as the previous case, but now the same modification work has to be done in several places. Tracking changes can be done quite easily, at least for the mobile locations – you just move the check point to a new location. Permanent locations are not quite as easy to relocate, but from a software point of view there is no difference. Adding new instances and new suppliers is relatively straightforward requiring only entering new data or links into the database. Of course, the new suppliers must equip the items with tags to be compatible with the existing system.

Presently, this kind of systems with a large concentrated database are typically proprietary (refer to ERP, Enterprise Resource Planning systems) having a relatively high coupling to the system supplier. This means for example, that there is quite a high barrier for the users to switch to another system. This reduces the competition and increases system prices. Since the systems are proprietary, and hence the system information is not freely available, the users also need the supplier to implement the changes in these large and complex systems. The design philosophy has also been such that they offer the tracking capability to a single organization only. In this sense, the openness is also very limited.

6. DISTRIBUTED INTER-ORGANISATIONAL SYSTEM WITH DATABASE

A more complex version of the distributed system is created when sharing the database with several organizations. At

this level, either all or part of the gathered information in the database is shared with many different companies. Partial access can be based e.g. on user profiles and protected by passwords.

The Skanska case presents a pilot of an advanced tracking system in a construction project environment [7]. The central feature of the system is a 4D Building Information Model (BIM) of the construction project, which unites the designers and planners of different areas of the project. The model is a dynamic 3D-model of the construction site, which shows the progress of the project in real time. The model gives the designers a shared document which improves and accelerates the information sharing inside the designer team. The improved visibility of the BIM is beneficial not only to the planning part of the project but also to the management of the project supply chain. The supply chain management module of BIM is based on RFID-tagging of the major components, which are tracked from the suppliers' factory to the time they are installed and approved by the jobsite supervisor. The status and location of the identified components are read at predefined stages of the supply chain with RFID-readers embedded in mobile phones. The mobile phone generated tracking messages are directed to the BIM server and the updates in the component information are automatically added in the model. The mobile readers provide thus real-time visibility of the component status from the jobsite to the entire project organization. The improved demand visibility from the BIM helps the suppliers of the components to easily check whether the tasks relating to their delivery schedule are delayed, ahead of the schedule or on time. The visibility over demand conditions helps the suppliers in improving the production planning and thus avoiding buffer inventories at the factory. Consequently the deliveries arrive at the jobsite at the time they are needed and in the right sequence, which helps to cut down the difficult and costly on-site inventories. The delivery accuracy improves also due to the identification of the components at arrival to the site, helping to direct them to appropriate locations.

6.1. Coupling and Openness

Presently, the step to this level requires rather high amount of additional effort to implement. This is due to the fact that the mindset of people has been against sharing the information beyond the company borders. It has led to the situation where there is no commonly shared tracking infrastructure. This is also the reason why the large proprietary systems are doing so well. In the current situation, the end users of these systems are very tightly coupled with the system suppliers, and it is not easy to switch the supplier.

Extending the system over the organisation borders increases the modification effort. In this case, the major additional technical obstacle is perhaps the firewalls at the company interfaces. Of course, distrust of people might be even a more serious impediment in creating inter-organisational systems. However, technically thinking there is very little difference in the system compared to the distributed single organisation system. For example, adding new users or data items is done in the same way in both systems. Openness of an inter-organisational system can be considered to be rather good, as it must already be compatible with a number of different environments. Theoretically, we could still have a proprietary system adopted by several companies in close relationship. However, the probability of this decreases as the number of organizations increases.

7. DISTRIBUTED INTER-ORGANISATIONAL SYSTEM WITH MULTIPLE DATABASES

At the uppermost level of the hierarchy, we would have the distributed, inter-organisational systems utilizing several databases. However, none of the studied cases was truly representing this category, and it seems that they do not exist in practice yet. From the system structure point of view, this type of systems offers a great potential for loose coupling and high openness. This is based on the high degree of distribution and multi-organisational structure. If the system parts are also designed and constructed as loosely as possible in the open SME

community following open standards, this potential can be realized.

The interface for the sharing of tracking data depends on the needs of the user. Functional complexity of the information sharing varies from a plain web-portal to more complex system integration. Usually a web-portal can be sufficient for end-users that use the service on irregular basis. More stable business-to-business environments on the other hand can benefit from system integration, which reduces the manual work in repetitive operations of larger material flows. Both of the mentioned options allow information to be shared in both directions between the service provider and customer. The possibility in two-way traffic enables the designing of more complex service offerings, such as customized orders and automated handling according to order status and location.

A limited scenario using multiple databases in an inter-organisational environment could be the following case. A product supplier brings a delivery to the unmanned customer site. An automatic reader based on, for example RFID technology, reads the tag on the shipment. Now the system sends a confirmation message to the supplier's database to inform about reception of the goods and another message to the receptor's database to inform about the availability of the goods. The system itself can be owned and operated by an independent tracking system operator, who offers the tracking service to a multi-organisational community and provides visibility to the flow of any goods to any legitimate parties.

7.1. Coupling and Openness

Theoretically, this could be the most loosely coupled and open system of all the considered possibilities, since it does not depend on the user company or the environment. Also the information is distributed along the system thus providing low coupling with any certain place or company. A full-blown distributed system can be used by any company in any environment and is capable of providing very good visibility for the tracking of any product from any location in the world

having an Internet access. If the system is developed in a large open source community, the adaptation rate can be high. The high switching costs and compatibility problems of large proprietary systems can also be avoided.

8. CONCLUSIONS

It is quite obvious that the development and modification effort increases as the system size and complexity increases. However, we have to remember that the potential benefit to the users also increases. In addition to the system structure, we should also consider the way the product development is done – whether it is proprietary development done by an individual system supplier or open standard development of a large community. Generally speaking, the system modification effort in complex proprietary systems increases more rapidly as a function of system size than in open systems, since the former ones are more individually tailored for each case, and there is no large community to cover all conceivable variations (see Fig. 3).
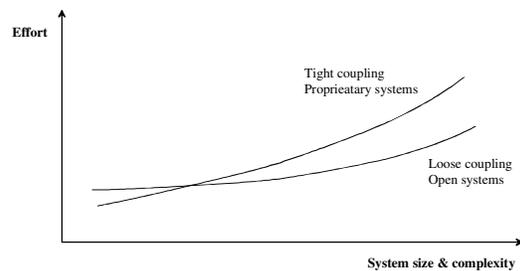

Figure 3. The required development & modification effort as a function of system size and complexity.

In the large development communities, where open standard development is done, there is such a versatility of modules available that any features can be implemented quite fast by creating a suitable combination of modules. If the development is done in this way, the coupling effort can be minimized. Conversely, if the development is done in the conventional manner by a few individual system supplier companies, even in the best case there is still some coupling involved, since usually the suppliers do not agree on all the characteristics of their systems and hence

their systems are not quite compatible. This also means that not just any kind of functionality can be provided in any single-supplier-system – it always contains a certain package of features, the modification of which is not easily done in a large system. Many times, the development is done in such a way that no features are ever removed, but new features are appended on top of the old ones thus increasing the system size and complexity year after year [8]. This habit can form a vicious circle. The larger and more tangled the system becomes, the more development effort it requires, and the less the system can be modified in a given time. In the worst case, the system is a large monolithic construction without any kind of modular structure. In such a case, the company has quite likely passed the point of no return a long time ago: it would take too much effort to redesign the whole system. Now the company is headed for a complexity catastrophe, as it keeps adding new features to the system indefinitely. Conversely, if the development is done in a large open developer community by composing the systems from small modules, the system coupling can be kept loose, and the mentioned problem can be avoided.

In the proprietary systems case, there is also a rather tight coupling between the users and suppliers of the systems, which makes switching of the product or supplier difficult. Typically, the systems are very large and expensive so that they are not even in the reach for SME companies. System openness is also rather limited, since these large and complex systems require a lot of effort to modify for another environment. Another aspect of openness is the single/multi-organisation point of view – whether the system is used by one or many different organisations. The present systems are quite poor in this sense. They do not offer visibility to product logistics for all interested parties.

For organisations that need to operate in a distributed and inter-organisational context, it is essential to avoid tightly coupled and/or proprietary systems. We hope that the framework and the case examples presented in this paper will provide elements for organizations to estimate the degree of coupling and

openness of their systems, as well as give indications on how to increase both aspects. As a subject of future work, we hope to develop a more formal framework for estimating the degree of coupling and openness and how that affects transitions from one level to another in the framework.

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