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FRAMEWORK OF CHEMICAL INVENTORY MANAGEMENT SYSTEM BASED ON ETHNOGRAPHIC RESEARCH

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ABSTRACT

Managing chemical products is a challenge in both chemical industry and academic institutions as the huge amount of chemicals resulted in problems of management, monitoring and stock control of chemicals Despite the fact that chemical inventory can be maintained using a number of software developed by several companies around the world, many tend to concentrate on the basic classification of chemicals for the purpose of systematic storage and retrieval of the chemicals to meet the requirements of users. This study aims to investigate and identify the proactive management of chemicals in order to design a framework for chemical inventory management system (CIMS) that would help improve chemical management by including networking, operating and notification facilities of the stock. The study was conducted in two stages. The first stage focused on designing a framework for the development of a CIMS based on ethnographic study at the Faculty of Science and Technology, Universiti Kebangsaan Malaysia. The second stage involved the development of a web-based CIMS prototype. Ethnographic study was conducted to identify the routines and workflow involved in the management of chemicals. Data was collected through observations, document analysis and interviews with professors, science officers, information system experts, lecturers and students. Based on the analysis of data collected from the ethnographic study, the CIMS framework is designed. In the framework, the key elements identified were metadata from Material Safety Data Sheet (MSDS), acquisition, classification and storage of chemicals. To ensure that stock control can be maintained efficiently, web-based alarm and notification technology are integrated in the CIMS framework. Based on the framework, the CIMS prototype was developed using the Spiral Mode. The result showed that prototype is able to accommodate the process of chemical request and stock control efficiently. The alarm and notification technique used is found effective in monitoring chemicals where the stock level falls below the predetermined minimal level.

Keywords: *Chemical Inventory Management System, Material Safety Data Sheet (MSDS), Notification Technique, Ethnography Study*

1. INTRODUCTION

Managing chemical information and products is vital in many science based industries and departments in academic institutions. In the latter for instance, as chemical products are used by students and lecturers for their research and academic activities, a precise and up-to-date inventory is critical for the institutions' chemical inventory management system (CIMS). At a typical chemistry department in such institutions, chemicals are stored in prep rooms, research laboratories, and chemical storage rooms. The chemical inventory can therefore easily tally 10,000 chemical entries [1]. In such setting where the chemical resources are not centralized, the amount of distributed chemical resources available can be an obstacle for finding the needed chemical. There

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can be problems of excess of certain hazardous materials if there is no central control of the chemical resources. On the other hand, deficiency of certain chemicals in certain chemical storage rooms or laboratories may interrupt the research and teaching activities.

A study Belcker and Elston [2] on chemical management in public institutions found that there are three main categories of problems: the unsystematic storage of chemical, excessive chemical waste and issues on purity, needs and toxicity of chemicals. Some key studies that can help in managing chemicals were studies by Foster [1] on chemical used by students, lecturers and researchers for education and research activities and Cournoyer [3] which explained in detail the proper procedures in managing chemicals. Waters [4] explained some of the terminology commonly used in inventory, including the stock, inventory, items, units and inventory control that can be applied to managing chemical stocks. Gupta and Frutkoff [5] highlighted key elements in chemical inventory management where they identified that chemical inventory management involves the detection, disposal and acquisition of chemicals from suppliers online. Pioneers in this field tend to focus on the basic classification of chemicals for the purpose of systematic storage and retrieval of the chemicals to meet the requirements of users. Foster's studies help researchers identify the key element in chemical inventory management such as the application of chemicals, chemical stock management and supply of chemicals that can be integrated within the framework of the development of chemical inventory management system. Another important area related to inventory management is e-procurement as that includes information on orders and supplier since those information provides the comparative advantage for administrators to select the relevant supplier [6]. Based on these earlier studies, it can be synthesized that chemical inventory management involves the maintenance, supply, storage, procurement and demand of chemical, detection of chemicals, disposal of chemicals and online chemical suppliers.

Other than storage and procurement of chemicals, important aspects that were studied in relation to chemical inventory encompasses Material Safety Description Standard (MSDS), stock control and attribute and entities that are vital in the development of the chemical database [4][5][7]. MSDS was created to set the standard for chemicals management, especially in chemical inventory management. Therefore, it has been the general practice that storage of chemicals is based on the MSDS. Simmon et al [8] for example, had undertaken a wide range of research in the development of attributes in chemical database assisted by the existing MSDS documents. Thus, MSDS has been found to be the most important element in designing chemical material metadata [5].

Chemical inventory can be maintained using a number of software developed by several companies around the world, including Chemoventory [9] and KimiaSis [10]. However, these software often cater only for specific organization or usage and do not meet the overall requirements of users. For example, KimiaSis systems administrative users may encounter problems where in accessing the system database and report on each chemical cannot be generated in accordance to the requirements of specific organizations. The cost to acquire chemical inventory system software is found to be high and not flexible. Very often organizations that manage a lot of chemicals need to purchase more than one system in order to meet all the requirements of inventory management [1].

Stock control processes have always been a problem to the chemical operator whereby the stock does not meet the needs of users and is not in line with the demand due to the absence of an efficient stock control system. Hence, inventory system that uses a more proactive approach is required so that the management of chemical stock can be implemented effectively. Proactive inventory system automatically identifies chemical where the stocks level has reached a minimum level so that an order can be executed automatically. A proactive web-based computerized CIMS would also help improve chemical management to the next level by including networking and operating facilities of the stock.

For efficient stock control and optimization, Kagami et al [11] found that to produce a good inventory control system, information providers and the quantity of a product should be displayed according to a specific class and a certain level to ensure that all stocks are in control. Display stock notification technology can be applied in order to design an ordering point method in which the amount of chemical is monitored and a fixed quantity Q0 of chemicals are ordered when a stock level falls below a fixed value, K. Riva [12] and Mori [13] conceptualized that stock control system

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that integrates web-based environment and alarm technology when stock has reached a minimum level can facilitate users and administrator in the management of chemicals. Agarwal [14] showed the effectiveness of the alarm whereby when stock is at a critical level; a reminder will be displayed on the system for administrator to initiate stock ordering from supplier. Applying the alarm system will help administrator in managing stock [11][12][14][15].

Nevertheless, the prior art solutions have targeted specific solutions for a specific user which makes it very expensive and difficult for many businesses and institutions to meet the comprehensive requirements involved with using toxic and hazardous materials. Furthermore, in many organizations chemical inventory design structure to meet the individuals needs of the divisions and departments within a multifaceted organization. The inflexibility of present system design forces organizations to do either of the following: 1) purchase, maintain, and update more than one system, which increases the overall costs and makes it more difficult to oversee, coordinate, and manage the chemical inventory management needs of the entire organization; or 2) purchase, maintain, and update one system that forces conformity, which does not addresses the individual needs within the organization and can cost an organization in regard to time, money, and increase legal jeopardy [1].

In the development of any inventory system, the needs of users should first be met rather than completely focusing on the computer-based system and forcing users to use in accordance with the system. In designing an inventory system, research on work flow in the manual system should be implemented in detail and depth. System developers need to understand the needs of users of the inventory system by implementing a number of methods such as interviews, discussions with the parties involved and conduct observations on the work flow of the existing system. In recent years, ethnographic research which is a research method developed from social sciences has been incorporated in computer science and information research and studies have found it useful because it can increase understanding of the requirements of system developers and user requirements [16][17][18]. Ethnographic studies in the field of technology are very important because through qualitative data collection, views and ideas about the processes and methods appropriate to the research could be obtained in detail. Development of a variety of ethnographic methods in the field of information science has been overwhelming. Lively [19] designed a suitable framework as a basis for the process of ethnographic research to enable the details of each process to be understood. Lively's framework [19] include the emphasis on literature as elements recommended by David [20] in the initial selection of studies so that researchers can understand and identify areas of research previously conducted in the field of studies. Ethnographic study stressed the importance of social perspectives that aimed to help researchers to integrate social factors in the development of the system. Ethnographic study begins with several questions about the area of study, makes a first impression on the field of study, and then undergoes the study daily routine. All information and documents obtained should be collected and analyzed on an ongoing basis and obtain confirmation from qualified parties through continuous interview process. However, none of the prior studies on CIMS had used ethnographic study to explore the processes involved in the effective management of chemicals.

In order to fill in these research gaps, the objective of this study is to examine and identify effective chemical management using ethnographic study approach in order to design a framework for development of an effective CIMS that integrates alarm technology and to validate the framework through usability testing of the system prototype. The body of this paper is organized as follows: Section 2 describes the methodology used in this study. Section 3 discusses on the Framework of CIMS based on Ethnographic study and the research outcome. The final Section 4 and 5 concludes the study and discusses its limitations and future works.

2. METHODOLOGY

In general, the research methodology for this study included initial analysis, background study, framework and prototype development, and finally validation of the framework through system testing. The study can be described further as conducted in two continual stages of framework and prototype development. The study involved academic staffs and students at the Faculty of Science and Technology, National University of Malaysia (FST UKM).

The first stage aimed at developing a system development framework for chemicals inventory management. Four related areas were explored to

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develop the framework in this stage, namely chemical product inventory management, general system development models, alarm mechanism for stock control and ethnographic approach for real-life system implementation and testing. The ethnographic-oriented study in this stage helped acquire detail knowledge on the chemical management at an academic institution. It included interviews with key personnel and recording their activities, and analyzing the workflow processes and documentations.

In the second stage, the developed framework was then adapted to create a system prototype using the WinWin Spiral Model approach [21]. The system prototype was implemented in the field and its usage was analyzed through observation with feedback sought from the system users via questionnaires. The effectiveness and usability of the system prototype reflected the soundness of the developed framework and the web-based inventory system.

2.1 Chemical Inventory Management System Development Framework

Figure 1 shows the developed CIMS framework based on ethnographic study. The framework development starts with exploring from literature. Based on the literature review, the concepts needed to be analysed and evaluated encompassed: chemical management, stock management including e-procurement, notification technology and ethnographic study. The research framework designed for this study adapted the focused ethnography method as suggested by Knoblauch [22] to enable the researcher to study the workflow process and procedure documents and to understand the management and procurement aspects of chemical products. This process will enable the researcher to identify key elements needed to implement an effective chemical inventory management system. Apart from studying human activities and the workflow process, the chemical information including chemical metadata, categories and MSDS need to be analysed. The details collected in managing chemicals through the ethnographic research procedures will guide the process to design the database structure to store the various type and form of data.

An important aspect in inventory management is stock control and its relation to standard operating procedures in a workplace setting. To overcome problems due to disorderly stock control, the study included analysis of proper stock control technology such as the method by Kagami et al. [11]. This study adapted a method of stock control that can be used in such setting which is based on Periodic Ordering Method and Ordering Point Method [11]. The Periodic Ordering Method describes the stock refill process at a particular time by estimating the current stock quantity, Q0 based on time. The Ordering Point Method on the other hand is based on a fixed formula in which the current stock quantity (Q0) is less than or equal to the minimum quantity of stock (K). These two formulas can be summarized as follows:

Booking = $Q0 \leq K$,
where Q0 (Current stock quantity),
K (Fixed minimum quantity)

Therefore when stock reached a minimum level, reminder and warning would be given to the administrator to initiate the ordering process. The two methods in general allowed for stock level to be maintained at sufficient level through proper management of procurement and usage monitoring.

Based on the framework, the ethnographic research involved observation, document analysis and collection of qualitative data gathered through a series of interviews with the research sample. The sample chosen were administrators, lab technicians, lecturers and students of the FST UKM. The findings from the ethnographic research were used to develop the web-based CIMS prototype. The prototype system was tested and evaluated. Interview sessions were held with the system's users to understand both the technical and social aspects of the system implementation. The process helped the researcher to evaluate the framework and the prototype functionality and identify any error at both technical and workflow level.

3. RESULT AND DISCUSSION

From the initial system prototype and further refinements to the system, the chemical inventory system prototype was upgraded with all the necessary functions and interaction support elements. Modules were further developed in the system to support both data and workflow in the chosen setting. The database structure and contents were also completed with user accounts, chemicals data and management and procurement-related data such as chemical location and vendor information. Chemical requests from users and stock orders from vendors are two inter-related processes that need to be continually managed to keep chemicals stock at

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sufficient level. An alarm technology via system notifications helped to monitor these processes. The alarm technology notifies system administrator when the minimal amount of chemical stock, as determined by the administrator, has been reached.

Two separated modules were developed in the system for the two classes of users, the administrator and the end-users. The administrator modules included several sub modules such as chemical management, user management, request management and vendor management. For the end-users, the system provided search function to facilitate the process of finding and requesting for chemical products. Figure 2 shows the user interface for the search function. A communication module built in the system allowed both automatic notification and manual communication between the administrator and end-users to complete a product request. Upon verification by administrator, the end-users can collect the requested chemical product. The chemical request interface is shown in figure 3.

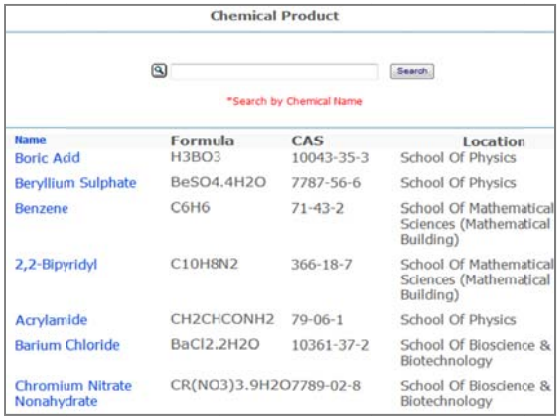

Figure 2: User Interface For The Search Function

Figure 3: User Interface For Users To Request A Chemical Product And Its Amount

If the stock is not available or has reached the minimal level, administrator could replenish the depleted stock by contacting product vendors. New chemical stock information is then updated in the system upon receipt along with its location and storage information. Figure 4 shows the interface for chemical stocks display with alarm integration for the system administrator.

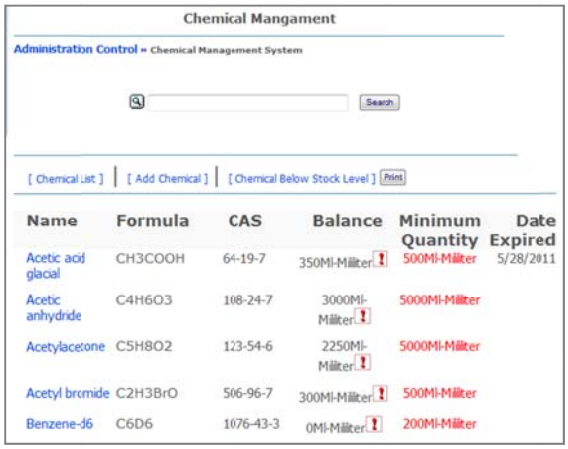

Figure 4: Chemical Stocks Display Interface With Alarm Notification

The CIMS prototype was tested at FST UKM. The deployed prototype tested the chemical request and management modules. This prototype was also evaluated in terms of the relevancy and comprehensiveness of the content, system usability and accessibility. From the system prototype implementation and testing, it was found that the developed modules and functions in the chemical inventory system worked efficiently. The analyses from the system usage and users' feedback were then reflected on the initial four key areas of focus in the framework (i.e. chemical product inventory management, general system development models, alarm mechanism for stock control and ethnographic approach for real-life system implementation and testing). The following section discusses the findings based on these four key areas of focus.

3.1 Chemical Product Inventory Management

Understanding chemical inventory management is one of the key elements in the study. The initial literature review and ethnographic study allowed the researcher to gain more understanding of this aspect. Foster [1] for example, described chemical inventory management as the process of procuring, storing and managing chemicals inventories. However his study did not emphasize on user

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involvement for such system. The researcher used the study as a basis and added the usability aspect to allow for user seamless workflow with the system. The initial ethnographic study also found classes of individuals qualified to manage inventory system in such setting including science officer, assistant science officer, and laboratory personnel. This finding reflected the findings in a study by Cournoyer [3] that highlighted the importance of operating procedures for managing and handling hazardous chemical product.

Four major components were identified from the literatures within the aspect of chemical product inventory management. These components are chemical product classification, chemical product request, stock control and procurement process. From the study, Material Safety Data Sheet (MSDS) is used as a standard reference for chemical inventory management as suggested by Geensberg et al. [23]. In addition, the use of MSDS in this study is consistent with several other studies [24][25][26][27] which used MSDS as the key reference for chemical management.

From the study, the researchers found that chemical product classification is an important aspect of chemical management process in terms of chemical storage and stock control. Classification and storage of chemical product was found in several works [1][3][8][24][28][31]. Foster [29] and Chandra [30] further addressed the important relation between classification and chemical status of in inventory management. Therefore, this study applied the chemical classification based on stock status to help the process of stock control.

The process of chemical procurement was revealed as a key component in stock control by ensuring a stable stock level is achieved. In the process of procuring chemical product, the supplier information was based on the type of chemical products supplied. The results of this study improved the work of Foster [1] that only focused on logging product acquisition and reservation.

Based on the analysis of data from the ethnographic study, this study found that the chemical product acquisition process was unique in each department where the procedures varied according to each respective organization. Though these findings are in line with previous studies [1][6][29]-[35], the ethnographic research approach helped the researchers to acquire details on the workflow process and procedure documents to understand the management and procurement aspects of chemical products. This process enabled the researcher to identify key elements needed to implement an effective CIMS which fulfills the unique requirements of a specific organization. The overall results of this study have achieved the main objective of the study to analyze and identify important components in an efficient chemical inventory management.

Results of Content Analysis for CIMS

In CIMS, the information included in the systems for chemical products were chemical name, chemical formula, synonyms, CAS number, expiry date, temperature, unit of measurement, chemical condition, description, method of disposal, and hazard level. As stated earlier, this study emphasized on using MSDS as the key reference for chemical product information. MSDS is also used as a standard reference for chemical metadata development. Results for content analysis of CIMS found that majority of the users agree with the suitability and amount of information content in the systems. The results are consistent with Sturgeon et al [36]'s findings who similarly studied key contents for a chemical inventory system.

This study also emphasized on information for stock and request management similar to Foster [1]. The results showed that most CIMS users were satisfied with the information provided for the process of requesting and obtaining chemical product. The information for chemical product location also received positive responses from users as the information help users to track available chemicals. The findings on the importance of chemical location information in the management of chemicals echoed the previous study by Cournoyer [3].

Results of Usability Testing on CIMS

The overall usability testing conducted for CIMS included testing the usability aspects of modules in the system including chemical management module, user request and acquisition module, procurement module and alarm technology. The results indicated that the majority of CIMS users found the usability of all the modules at satisfactory level.

The integration of request and acquisition module in the system for users made the process of obtaining chemical product effortless. The findings are in line with the development of the Chemtracker system [37] that allowed for

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interaction between end-users and lab personnel. The interaction aspect of end-users and administrator is rarely highlighted in previous studies [1][7][31][36][38][39]. The focus of these studies was more on chemical stock management and storage.

Innovation in chemical demand systems grow in line with the development of web-based technology. The web based CIMS prototype in this study provided an advantage over its previously developed stand-alone counterparts such as ChemSW CISPro by Cournoyer [3] and another system by Tipton et al [39]. While the approach is not novel as Gibbs [37] and Rapppaport [40] also have developed web-based chemical inventory systems, the CIMS system in this study, further utilized its web-based nature to facilitate interaction between users and system management. Overall, the results showed that most users were satisfied with the developed module in the developed web-based inventory system.

3.2 Notification System and Alarm Technology

Based on literature review and the conducted ethnographic study, the researchers have found that the main issue of chemicals management in an academic research center is the control and monitoring of stock level. The study adapted Periodic Ordering and Ordering Point Method as described earlier [11]. These two methods are implemented as an economic strategy for an organization to ensure the stability of stock at all time. However, with this approach, there exists the need to constantly monitor the quantity of stock manually. In this study, the researchers have developed a more flexible stock control method in which the minimum stock quantity is predefined and can be changed according to the usage pattern of each chemical. The alarm notifications in the web-based system enabled the objectives of stock control to be achieved.

Usability Testing Results of Alarm Technology and Notification System

Applying stock ordering methods suggested by Kagami et al [11] helped researcher to develop a stock control module in CIMS. This study improved this existing stock control concept by integrating an alarm technology and notification system. In this study, the minimum level set for each product varies and determined based on user consumption pattern. Researcher also added a visual element in the alarm display for each chemical to indicate its quantity has reached the minimum level. The visual approach helps system administrator to be more sensitive to changes for each chemical stock quantity, therefore helping them to initiate the ordering process timely. In the CIMS system, the chemical stock information is automatically updated for every usage and stock ordering.

The test results on the application of alarm technology and notification system in the prototype received positive responses from all respondents. Stock control status usability testing results indicated that most users strongly agree that a  sign should be displayed on each chemical that has reached the minimum level. The stock control concept in this study can be found in many previous works [1][3][7][24][26][29][31][37]-[40].

3.3 Ethnographic Study

Every organization has its own unique behavioral and social patterns which influenced its work flow and process. An ethnographic study was conducted to understand these aspects, and further translated as the process to identify the chemical inventory management requirements and constraints. The ethnographic approach in information technology is not uncommon, as previously seen in similar studies [20][41]-[45]. Kaplan and Maxwell [16] highlighted the importance of this qualitative assessment to evaluate how users used a system in the real setting.

This study developed an ethnographic framework based on a previously developed framework. Spradley's [41] framework was used as a general guide for the ethnographic framework where the need to understand the daily routine of a field in order to identify various complex problems is addressed. Hartmann's [46] framework was then referred as it involved ethnographic action-research methods in system development. The combination of these two frameworks allowed for a dynamic and systematic information acquisition process which can be useful to information technology-based development. By understanding the environment and identifying the workflow problems and later solutions, a CIMS prototype was able to be developed and consequently tested via system implementation.

4. CONCLUSION

The contribution that this study has made is on its approach in integrating ethnographic methods to

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understand the social aspect of chemical management and the framework for CIMS which was tested via system implementation in real-world setting. The ethnographic study helped the researcher to identify and understand the work and process flow in order to translate the findings as requirements and constraints to develop a web-based chemical inventory system prototype. The inventory management systems prototype included modules such as chemical management module, request and acquisition module and procurement module for both end-users and administrators. The developed systems prototype also utilized alarm technology and notification system to alert the administrators when chemical stock has reached a predefined minimum level. The positive findings via system implementation affirmed the framework's soundness.

5. LIMITATIONS AND FURTHER RESEARCH

There are two limitations that need to be acknowledged and addressed regarding the present study. The first limitation concerns the ethnographic nature of this research project. The commitment phenomenon was studied within the context of information system development. The ethnographic-oriented research in this study enabled the researcher to acquire detail understanding of the management and procurement aspects of chemical products in order to implement an effective CIMS that fulfills the unique requirements of a specific organization, in this case an academic setting. The developed CIMS prototype was then tested in terms of the relevancy and comprehensiveness of the content, system usability and accessibility at the School of Chemical Science, FST UKM but not at other faculties, schools or departments of science and technology. The second limitation has to do with the extent in which the framework can be applied. At the moment, the developed system prototype is only limited to managing chemical products.

Further work from this study can include management of disposal chemical products and disposable material, along with additional modules to support online communication with vendors, vendors rating based on supplied history, and incorporating the usage of mobile technology. The CIMS's framework can also be applied to inventory management for other form of product. Further empirical evaluations, however, are needed to replicate the findings in different contexts and surroundings such as in industrial setting and governments departments/ institutions that conduct scientific testing, experiments and research.

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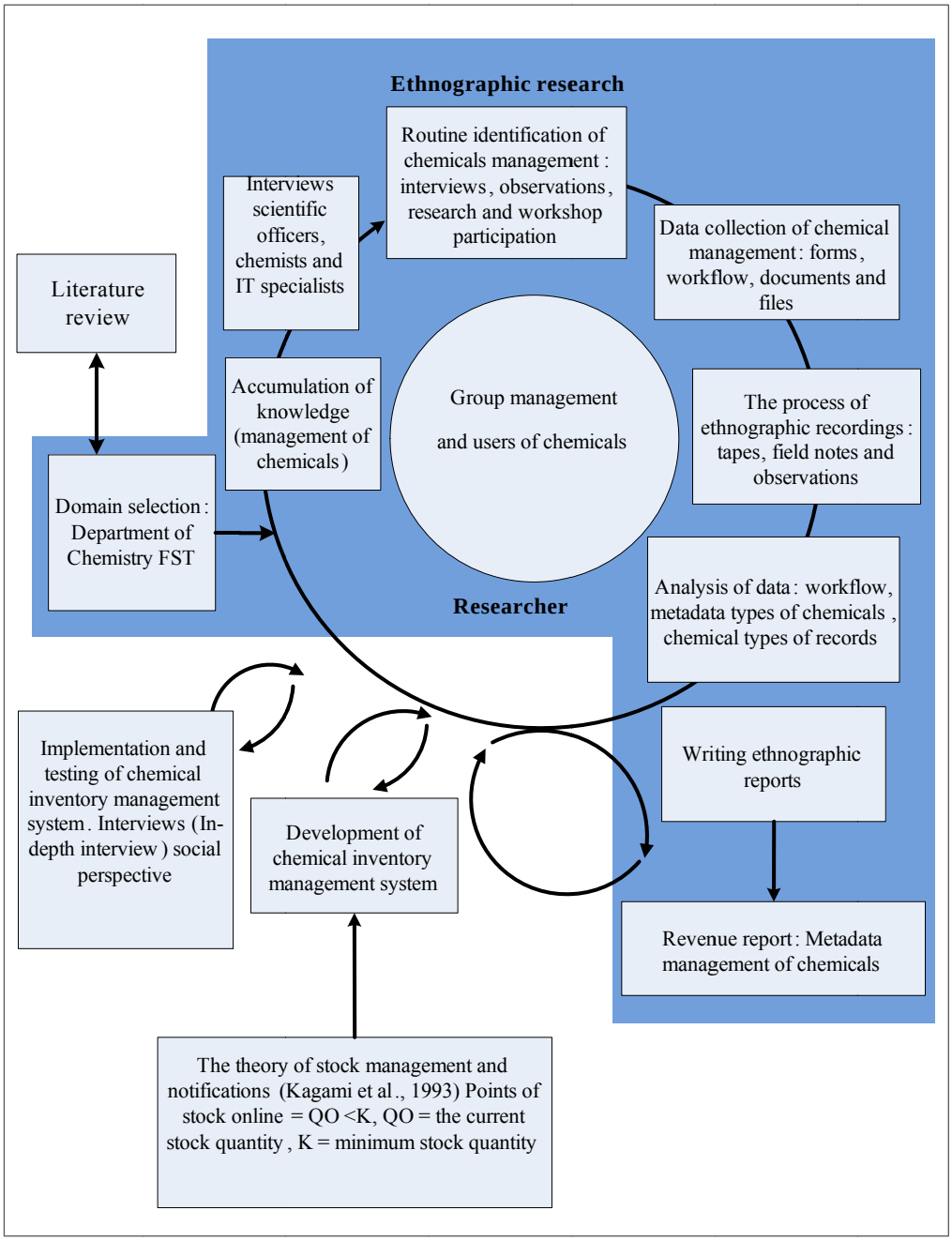

Figure 1: Framework For The Chemical Inventory Management System (Cims) Based On Ethnographic Research