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Development of the conceptual model of energy and utility management in textile processing: A soft systems approach

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ABSTRACT

This paper aims to use soft systems methodology (SSM) to identify management support system opportunities for managing energy and utility usage in textile manufacturing processes. It presents an approach based on SSM to analyze the complex situation of developing an effective energy and utility management support system (EUMSS). This involves the identification of the scope of the system and user requirements, conceptual modeling of complex problem situations, identification of actors and decision processes, and information-needs modeling. The current study pioneers the examination of the application of SSM to the development of a novel EUMSS and contributes to the body of information systems knowledge in the context of EUMSS design. There appears to be limited academic research in the field of energy and utility system development and, in particular, in the area of EUMSS design, and none in the area of the application of SSM to EUMSS design. In addition, the modeling process could be beneficial if EUMSS design ideas could be widely shared and discussed. The identified scope and system requirements can serve as a guideline for designing and developing an effective EUMSS for textile processing.

1. Introduction

Global warming is an alarming problem, which everyone should be concerned about. One of the most effective measures to reduce global warming is to reduce the emission of greenhouse gases (Ubeda et al., 2011). The manufacturing industry is one of the major sources of greenhouse gas emissions, and reduction of greenhouse gas emission in manufacturing facilities is a topic that has interested researchers in recent decades. Apart from developing different technologies to filter or convert greenhouse gases before being emitted from the factory, controlling and reducing inefficient or unnecessary energy and utility consumption is also helpful to reduce greenhouse gases. Reduction in usage of energy and utility can help organizations save costs and become more competitive. Therefore, effective energy and utility management is a key factor in enhancing the competitive advantages of organizations and to promote green and sustainable practices.

The textile industry is both energy intensive and highly polluting (Rock and Angel, 2007). In 2004, the global textile industry consumed 50.2 million tonnes of oil equivalent (MToe), which is equal to 1.9% of total industrial energy use, whereas industrial energy use increased by 61% between 1971 and 2004, with the average annual growth pegged at 1.2% (IEA, 2007). Moreover, global carbon dioxide (CO_2) emissions from all industries amounted to 9.7 gigatonnes in 2004 and accounted for 36% of total global CO_2 emissions (IEA, 2007). If we assume the textile industry's CO_2 emissions is proportional to its energy use, then in 2004 the textile industry's CO_2 emissions amounted to 0.18 gigatonnes. In 2009, global textile and clothing exports amounted to US$527 billion and comprised 4.3% of world merchandise exports (WTO, 2010). Therefore, the textiles and garment industries constitute a significant component of the global industry sector and is a significant contributor to global warming—from the manufacturing process to the distribution and transportation of products to stores and customers. Energy efficiency is crucial for the survival of small-scale industries, including the textile industry (Nagesha, 2005); hence, ways to reduce energy input without compromising product quality are being continuously researched. Measuring and monitoring the use of energy and utility resources in textile manufacturing processes are necessary to reduce energy losses and to recover lost energy, which are of great importance to companies for cutting cost and supporting sustainable development. There is a need for an energy and utility management support system (EUMSS) that can systematically collect energy and utility information from

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applications and provide data and information for analysis is essential in textile manufacturing processes.

The term management support system (MSS) was defined by Scott-Morton (1984) as the use of information technologies to support management. MSS can be broadly divided into three categories: data support systems, decision support systems, and executive information support systems. An energy and utility management support system in a textile manufacturing context can be used to systematically collect energy and utility information from applications and provide data and information for use in textile manufacturing processes. A well-designed energy and utility MSS captures information necessary to measure and monitor energy and utility performance.

To analyze the complex situation of finding ways to develop an energy and utility management support system in textile processing, we acquired the contextual requirements and developed a conceptual model using soft systems methodology (SSM) (Checkland, 1981; Mingers and Taylor, 1992). The situation is complex because different stakeholders may have their own perspectives, values, and beliefs on what constitutes the problems and how to address them. The different facets that are viewed as problematic are likely interrelated. Changing one facet may have an incidental effect on other facets. It is, therefore, important to develop a holistic understanding of the interrelationships between the various facets of the problematical situation. Moreover, the subjectivity of different stakeholders requires that researchers explore the perceptions of individual stakeholders to accurately define the issues and direction of future change.

SSM is suitable for the development process of EUMSS. SSM is employed in this study to analyze the current situation of the problem and develop a conceptual model for EUMSS in textile processing. The analysis is based on the results of the interviews with practitioners in four textile companies. As the result of the study, the functional and non-functional requirements of an effective energy and utility management system in textile processing are described.

In this paper, a literature review is provided in Section 2. The methodology employed is described in Section 3. After describing the current situation of the problem in Section 4, the conceptual model of the energy and utility management in textile process is developed in Section 5. In Section 6, system requirements for EMUSS for textile processing are presented. Section 7 concludes with theoretical and managerial implications.

2. Literature review

Literature related to energy and utility management in the textile industry is not very rich. This may be due to the fact that the textile industry is not a major energy consumer compared with the largest industrial consumers of energy, such as chemicals, metal refinery, cement and pulp, and paper (EIA, 2010). Most studies in energy and utility management in the textile process tend to focus on the introduction of energy-saving measures and technologies, as well as the potential benefits and energy savings obtained after implementing the measures and technologies suggested in the studies. The literature presented by United Nations Industrial Development Organization (UNIDO) (1992) provides a step-by-step description of the implementation of energy conservation measures in the production process. In the report of EPA (1997), some measures and technologies to reduce energy and utility use in the textile production process have been introduced. Tang and Mohanty (1996) showed that the combination of electricity and thermal energy cogeneration with a post-combustion heat recovery system in a textile factory is most efficient. Abdel-Dayem and Mohamad (2001) conducted a case study to explore the feasibility of using solar energy in the textile industry. Palanichamy et al. (2001) conducted an energy conservation project in a textile company. They showed that substantial energy savings become readily achievable by taking action about problems found during an energy audit in production-related and production-supporting facilities. Hall (2002), through the installation of a real-time computer monitored water management system in three textile plants in Alabama, reported savings on water, sewage, chemical, and electricity costs. Ozturk (2004) presented several energy conservation measures for using energy efficiently, identifying losses, and reducing such losses in factories. In their study, Palanichamy and Sundar (2005) shared the experiences of adopting conservation measures in the textile industry, such as equipment operational changes, building structural modifications, and changes in machinery accessories. They also showed the reduction in energy and the estimated annual reduction of greenhouse gases. Muneer et al. (2006) reported that the installation of a finned type built-in storage solar water heater in a dyeing factory is the most optimum choice in terms of energy saving. Kocabas et al. (2009) presented the results of the application of best available techniques (BAT) measures, which are essential for reducing water and energy consumption in the textile production process. Pulat et al. (2009) described a case study in a textile factory, wherein waste-heat recovery system was applied with water-to-water shell and tube heat exchanger to utilize residual heat generated from the dyeing process; the results showed substantial electrical energy consumption drop. Palamutcu (2010) investigated energy consumption of cotton textile processing and documented that actual electricity consumption per unit textile is higher than the estimated amount. Additionally, Palamutcu noted that plant managements' knowledge and awareness of energy management practices are not up to the desired level. Hong et al. (2010) reported that the energy savings made by 303 textile firms that implemented an energy-saving plan amounted to a significant amount of energy savings and reduced CO_2 emission through savings in production and production-support systems. Such results suggested that the energy declaration system implemented by the Taiwan government is effective in helping energy users in the textile industry find ways to conserve energy. Furthermore, none of the research approaches cater to the high-level aspects of EMUSS design, such as user requirements, conceptual modeling of complex energy and utility management situations, identification of actors, and decision method for the textile process. To the best of our knowledge, there are no studies that analyze or examine the approaches to managing energy and utility consumption using SSM, as well as the application of SSM to identify energy-saving opportunities in the textile processes.

3. Methodology

Soft systems methodology will be applied to diagnose and to aid in the understanding of complex organization problems, as well as the energy and utility usage and management. Results can then be used for the development of an EUMSS in textile processing. SSM has been used in many fields of applications (Macadam et al., 1990; Kasimin and Yusoff, 1996; Taylor et al., 2007; Sørensen and Bochtis, 2010). SSM was developed by Checkland et al. in the 1970s. It is an organized way of tackling complicated situations in the real world based on systems thinking (Wilson, 2001), and is described in a seven-stage model (Checkland, 1984; Fig. 1), as follows:

1) unstructured problem situation;
2) expressed problem situation;

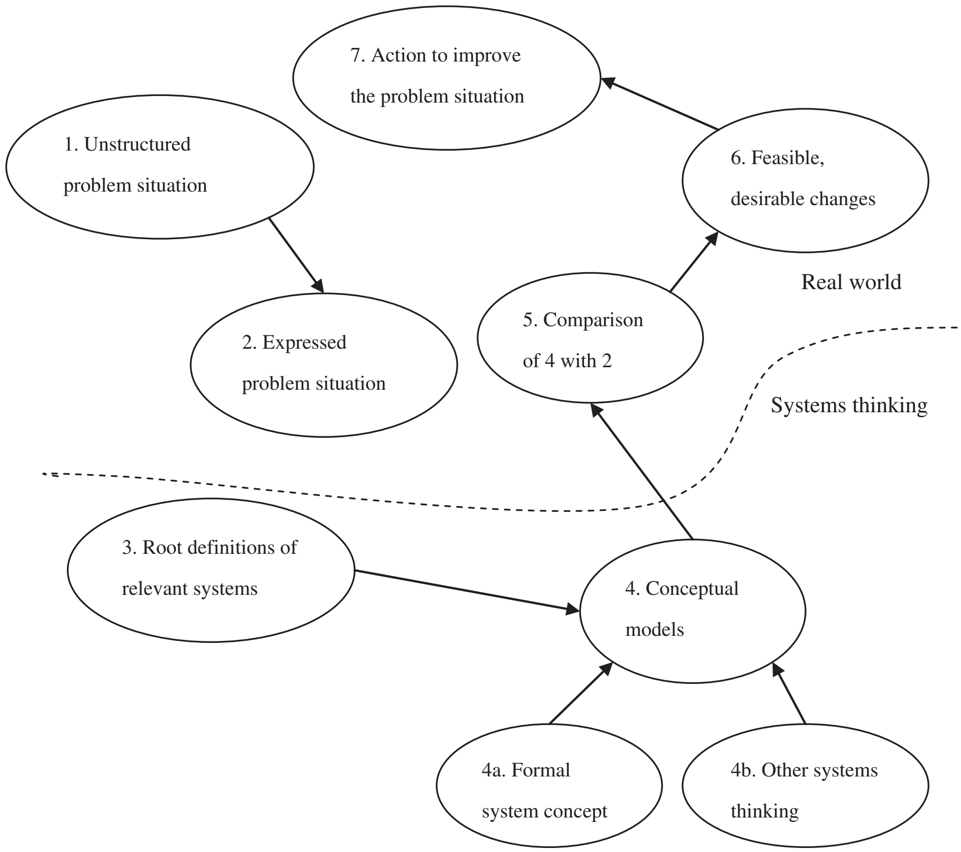

Fig. 1. SSM seven-stage model (Checkland, 1984).

3) root definitions of relevant systems;
4) making and testing conceptual models;
5) comparing conceptual models with reality;
6) feasible and desirable changes; and
7) action to improve the problem situation.

In this study, SSM is used to analyze complex and soft systems situations to develop an effective EUMSS in textile processing.

3.1. Stages 1 and 2: the problem situation (unstructured and expressed)

The problem situation is understood, and all the relevant information and relationships are identified. Then, a detailed description of the problem situation, expressed as a "rich picture," is developed. The rich picture is a picture of the situation, including the organizational entities of interest, relationships among them, roles of apparent significance, issues, areas of conflict, and so on (Wilson, 2001). There is no formal technique or classic form to present the rich picture; it is usually visually presented as an ordinance survey map, mind map, etc.

3.2. Stage 3: root definitions of relevant systems

In this stage, "root definitions," which are the essence (root) of the relevant systems, are defined. The root definition is a concise, tightly constructed description of a human activity system (Checkland, 1984). A well-formulated root definition explicitly generates each of the elements of CATWOE, a mnemonic concept representing the terms:

Customer (C)—people affected by the system, either victim or beneficiary.
Actor (A)—people participating in the system.
Transformation (T)—input–output conversion or the process carried out by the system.
Weltanschauung (W)—world view.
Ownership (O)—people having the power to decide whether the system is useful.
Environmental constraints (E)—external factors that constrain the transformation.

CATWOE provides a mechanism or checklist for testing the root definitions, as well as ensuring that the words chosen are as precise as possible and that they represent the best choice for the meaning they capture (Wilson, 2001). The root definition is a short paragraph or a long sentence containing all necessary information to describe the system. A completely general root definition embodying CATWOE might take the following form (Checkland, 1984):

> A (…O…)-owned system, which, under the following environmental constraints: (…E…), transforms this input (…) into this output (…) by means of the following major activities among others: (… … …), the transformation being carried out by these actors: (…A…) and directly affecting the following beneficiaries and/or victims (…C…). The world-image, which makes this transformation meaningful, contains at least the following elements: (…W…).

3.3. Stage 4: conceptual models

At stage 4, a model of the activity system needed to achieve the transformation described in the root definition is made (Checkland, 1984). A conceptual model is a systemic account of the human activity system, built on the basis of the root definition of the system, usually in the form of a structured set of verbs in the imperative mood (Checkland, 1984). The model contains the minimum necessary activities for the system and represents the relationships between activities. For details of the technique and examples of conceptual models, see the reference provided by Checkland (1984). As illustrated in Fig. 1, the model building is fed by stages 4a and 4b. The formal system concept, stage 4a, is the use of a general model of any human activity system that can be used to check that the models built are not fundamentally deficient. Stage 4b, other systems thinking, consists of modifying or transforming the model, if desired, into any other form that may be considered suitable in a particular problem (Checkland, 1984).

3.4. Stage 5: comparison of the conceptual model with the real world

In this stage, activities in the conceptual model are identified. The conceptual model is then compared with the real world to find out possible changes in the real world. Checkland suggested four ways of achieving this comparison (Checkland, 1999):

1) Unstructured discussions;
2) Structured questioning of the model using a matrix approach;
3) Scenario or dynamic modeling; and
4) Trying to model the real world using the same structure as the conceptual model.

In short, we investigate the conceptual model and the basis of the model (i.e., CATWOE and the root definitions), and check what actually occurs in the real world. We then identify what is present and what is missing; what are similar and what are not.

3.5. Stage 6: feasible, desirable changes

After the comparison, the differences between the model and the real world generate possible actions and changes that could be introduced in the problem situation. The changes should be discussed with interested parties, and should be arguably desirable and culturally feasible in terms of the people involved, prevailing attitudes, shared experiences, and prejudices (Checkland, 1984).

3.6. Stage 7: action to improve the problem situation

After the feasible and desirable changes are defined in stage 6, actions are taken to implement these changes. The purpose of the changes is to improve the problem situation. Therefore, the problem situation is modified and becomes a new problem situation. This shows that the process is cyclical.

For the current study, plant visits were made in some selected textile manufacturing companies that represent the versatile nature of the industry. Documents related to current energy and utility management were collected prior to plant visits to better understand the present practice. Practitioners in the textile industry will be interviewed about the current situation of energy and utility management in textile processing. The current situation will be expressed in a rich picture (stages 1 and 2), and the root definition will be defined using the CATWOE mnemonic based on the rich picture (stage 3). Afterwards, a conceptual model will be developed for the energy and utility management in the textile process (stage 4). The activities from the model are then identified, and the current practice for undertaking these activities and their information requirements are determined

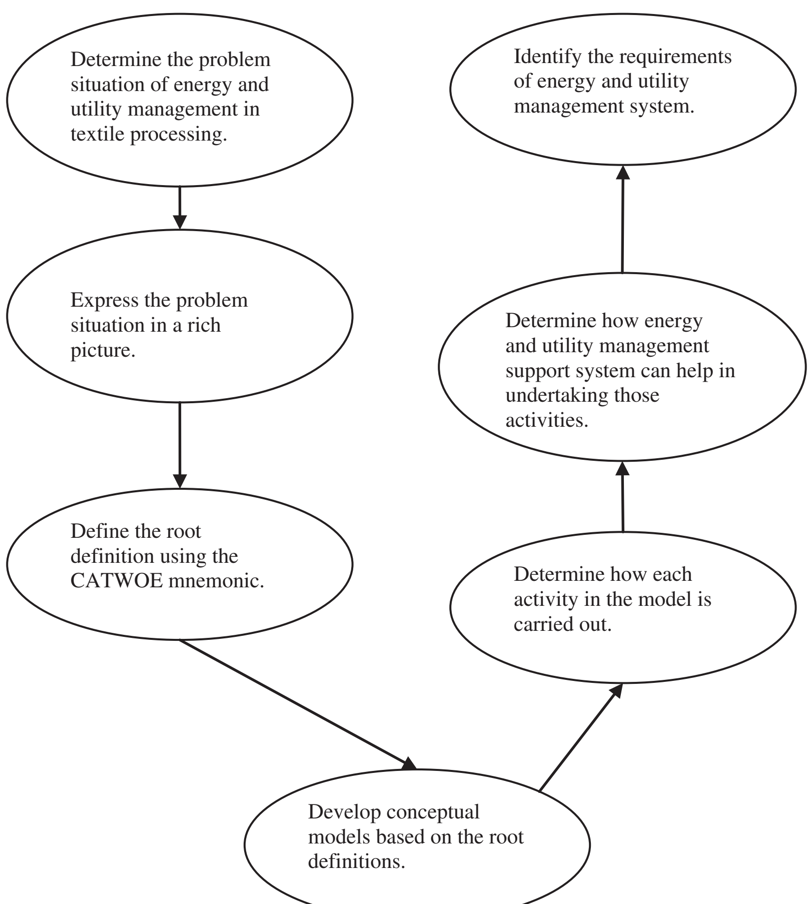

Fig. 2. Process for developing EUMSS requirement through SSM.

(stage 5). Based on the opinions of the textile practitioners, who were interviewed, the energy and utility management support system's contribution will be discussed (stage 6). By analyzing the above information, we develop the requirements of an EUMSS for textile processing, which can help address the problem (stage 7). Fig. 2 shows the process for developing EUMSS for textile processing requirements through SSM.

4. Understanding the problem situation

To understand the current situation of energy and utility management in textile processing, the researchers first visited the manufacturing plants of the four selected sponsoring textile manufacturing companies of this project, and collected documents related to energy and utilization management, including policy statement, operation manuals, and relevant reports, and briefly discussed with various staff regarding energy and utility consumption management. Interviews were subsequently conducted in these four textile manufacturing companies. Brief backgrounds of the companies are shown in Table 1. Interviews were conducted with executives (see Table 2), who were important actors in, familiar with, or responsible for this EUMSS project. The interviews lasted about 2–3 h. The four companies are invited to participate because they are sponsors; furthermore, producing different types of products in the textile and garment industries may ascertain whether the manufacture of different product types by various companies converged on a similar set of facts in energy and utility usage.

In addition, all four companies have manufacturing facilities in the People's Republic of China (PRC); hence, they need to comply with similar requirements or registrations. We believe that integrating the information and data provided by these companies can create an overall picture of the current situation and the problems encountered in energy and utility management. During each interview, a semi-structured questionnaire was distributed, which was prepared based on the researchers' plant visit and collected documents. The questionnaire covered production and operation processes, machinery, resource usage, resource data capturing and reporting, and information technology adaptation. The questions were designed to be as open as possible so as not to restrict the interviewees to one of a number of possible answers. The following are some sample questions:

- What energy utilization and process data can be captured from the machine? How are the data recorded, and how often are they recorded? How much time is required for recording a set of data? How easy/difficult is it to access the data?
- Will knowing the actual data in real time have an effect on the control of energy consumption of the machines, and thus increase efficiency?
- What are your requirements for and objectives in managing energy and utility? What information does your factory expect the system to provide?
- What benefits does your company want to obtain from EUMSS?

Adequate level of trust between the interviewer and interviewee is a critical factor for a successful interview, because it can be difficult for an interviewee to disclose sensitive information to a stranger (Webb et al., 2000). Our interviews were conducted in a friendly atmosphere and the interviewee had enough trust with the interviewer such that no sensitive and confidential information

Table 1
Brief background of the four companies.

Company	Size	No. of Staff	Brief background of the company
Company A	Large	16,200	It is a listed company in Hong Kong with production facilities in PRC, Sri Lanka, and Indonesia. It produces knitted fabric (including cotton spinning, knitting, dyeing, printing, and finishing) and garments.
Company B	Large	Over 10,000	It is a listed company in Hong Kong, which produces silk products, woven fashion, and knitting. It has spinning, weaving, printing and dyeing, finishing and garment factories located in Guangdong and Zhejiang, PRC.
Company C	Medium	Around 2700	Its factory stands on a land of 250 acreages in Guangdong Province, containing buildings with a floor space of 150,000 square meters. Its products include corduroy, spandex twill, tabby fabric, cocoon satin, dobby, etc. The company integrates weaving, dyeing and printing, garment manufacturing and washing industries.
Company D	Medium	2800	The garment manufacturer has factories in Hong Kong and PRC. It carries out all the production processes, from cutting and sewing to washing and finishing, using the vertical setup.

Table 2
Highlight of the findings from interviews with the companies.

Interviewee	Excerpts from the interview survey
Interviewee A (Senior Engineer of Company A)	We always want to make decisions, such as choosing which brand of dyeing machine is more effective, to find the actual cost of each order. However, there is always lack of data or lack of effective ways to capture data.
Interviewee B (Operations Executive of Company A)	Some machines are equipped with electronic meters and data capturing devices; however, the supplier of the machines would always ask for high prices to provide the interface of electronically obtaining data output. There is also no single system that can handle the integration with different kinds of interfaces and data sources.
Interviewee C (MIS Director of Company B)	There is always a lack of well-designed analysis reports regarding energy and utility management that can be easily understood by management. Therefore, this report should be one of the major elements of energy and utility management system.
Interviewee D (Operations Executive of Company C)	Although we want to, we cannot frequently capture energy and utility consumption data. To us, this is a time-consuming procedure because it requires the designated staff to walk around the factory and some meters at the location are not easy to reach. In our case, three workers take 1–3 h to record the meter readings each day.
Interviewee E (Factory Director of Company C)	Recently, more clients have requested energy consumption data for each piece of goods in order to calculate the carbon footprint. New government policies and international standards also urge the need to regularly provide detailed energy and utility consumption information.
Interviewee F (Factory Director of Company D)	That the system can help determine team or worker performance by analyzing the amount of energy and utility wasted or used for rework is good. We can also have an accurate and quantitative indicator for staff appraisal or award system.

related to the company were divulged inadvertently. The information collected in interviews enabled us to understand and examine the current problem. In addition to personal interviews, the project investigators followed up with email and telephone calls to obtain background information, clarifications, and points not covered during the interviews. The interviews were audio-recorded and transcribed. We considered each interview as one unit of analysis. Two researchers read through the transcripts several times to obtain a sense of the overall picture, discussing ideas with each other and noting emerging patterns from the interview data. Qualitative content analysis was conducted (Graneheim and Lundaman, 2004) in order to categorize and consolidate the data for text retrieval. The two researchers decided to sort the data into two main content areas: current energy management situation and improvement demand. The two researchers then applied the coding process to break down, identify the concepts to sub-categorize the data under the two main categories by grouping similar incidences, claims, and discursive words independent of each other (Corbin and Strauss, 2008). Each researcher further refined the data to bring together patterns, consistencies, and categories and then proceeded to create themes from these. Each researcher then revisited the transcripts to check whether any idea was missed out or if there were inconsistencies that had to be rectified. The individual records of the main category and sub-categories were discussed and compared between the two researchers. Any difference between the existing system featuring inadequacies and the new system's functionalities were noticed. A process of self-reflection and discussion between the two researchers resulted in agreement as to the problems in the existing practice and features required by a new system. In case the two researchers disagreed on a particular issue, a senior researcher stepped in the discussion to help the two resolve the disagreement. An analysis of relevant documents collected during the plant visit was conducted to supplement the interview findings. Preliminary results of our content analysis were discussed with the interviewees to ensure that we accurately recorded their words and ideas, and minor changes were made where necessary. Table 2 highlights some of the findings from the interviews with the companies.

4.1. Rich picture

From the results of our study, energy and utility management in textile process is basically equivalent to a monthly cost analysis against the overall throughput of the factory. Identifying any opportunity for saving energy or improving the effectiveness of energy usage is difficult. After the qualitative content analysis, we prepared a comprehensive picture to organize the information collected during the interviews. By drawing such a picture, the researchers were required to think deeply about the problems and understand them well in order to present an accurate image of the situation being analyzed. The drawing process made us aware of what we needed to find out more and helped us clarify contradictions in the preliminary conclusions drawn before. We tried to capture the flow of information among stakeholders, as well as their interrelationships and concerns in the rich picture. After completing the drawing, this was shown to our interviewees, and we made changes based on further discussion with them. Drawing a rich picture is an iterative process of understanding and refining our understanding of the situation. It helped us record, analyze, and communicate significant concerns of stakeholders after the interview process. Fig. 3 depicts the rich picture, which illustrates how energy and utility management in textile process is currently performed.

4.2. Problems in energy and utility management in textile process

At the current situation, if the company wishes to implement energy and utility management, it encounters several problems.

4.2.1. Energy and utility consumption data are time-consuming to capture

Meters are usually installed at locations that cannot be easily reached; therefore, workers may need to exert effort to capture the readings. In addition, a certain amount of time is required for workers to walk around the whole factory to check all the meters. After recording the meter readings, workers need to enter the data into the computer system.

4.2.2. Energy and utility consumption data are insufficient for monitoring and analysis

Resource usage data is usually recorded by workers once or twice a day. The data collected are only a snapshot per day or per half a day. Many work orders are processed every day in the factories. Therefore, the data collected are insufficient to monitor and analyze the resource usage per work order or for each machine.

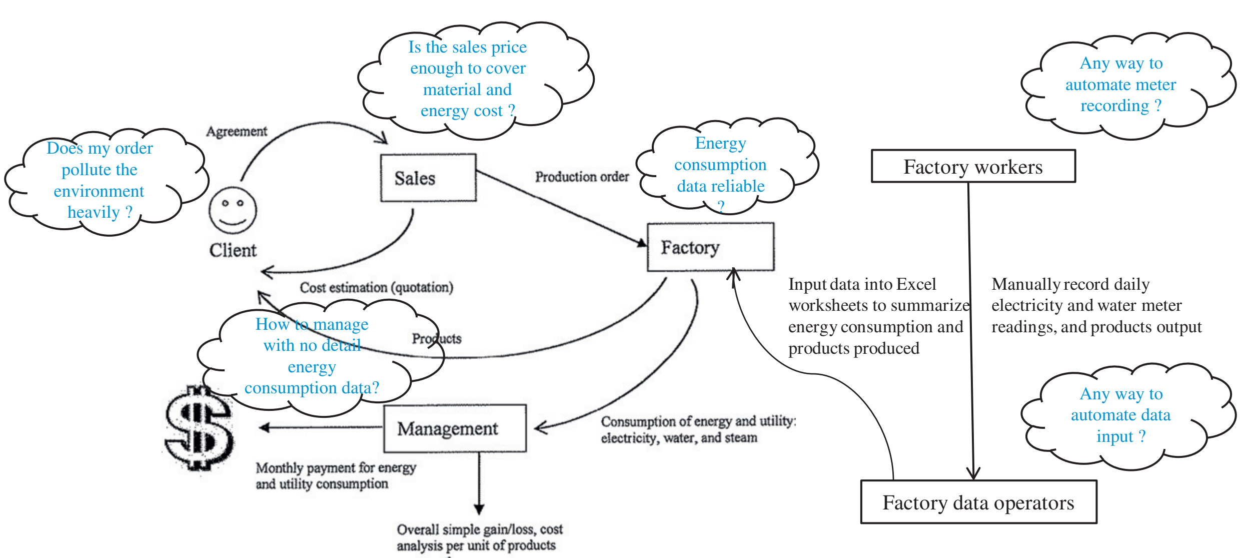

Fig. 3. Rich picture illustrating current energy and utility management in textile process.

4.2.3. Energy and utility consumption data are not accurate

In the sample companies, production and resource usage data are recorded by workers and entered into their ERP by office staff, based on the data written by operators on job sheets/daily reports. Therefore, there may be a risk of mistakes in data entry and in handwritten data.

4.2.4. Energy and utility consumption data are not timely

The data recorded by workers are usually entered into computer systems. However, there is a time delay between data recording and system data entry. Therefore, the data in the system are not timely. The resource usage of a day or half a day is only represented by the snapshot data per day or per half a day. There is no real-time resource usage data in the system. The only way to monitor real-time status and resource usage of each work order is to go into the mills and search for the batch of fabric. However, this is inefficient and inconvenient.

4.2.5. Energy and utility consumption data are not continuous

Resource data collection is performed by human beings; however, delegating a worker to stand beside each machine to monitor and record the resource usage is not feasible. Currently, there is no tool or equipment to enable continuous resource usage data record for each machine.

4.2.6. Energy and utility consumption data cannot be integrated

Currently, there is no way to integrate the resource usage data from different kinds or brands of machines or meters. There is no digital data output of the internal or external meters. Some machines may provide digital output of the internal meter readings; however, they may have different output interfaces, which may make integration complicated and costly. Moreover, there is no tool or equipment available to integrate the resource usage data captured from different machines or meters in a single database.

5. Developing a conceptual model of energy and utility management for textile processing

After understanding and structuring the current problem situation, the root definitions are then built and the conceptual model is developed based on the root definitions.

5.1. CATWOE

According to the rich picture identified in the previous stage, root definitions are constructed in the form of the elements of CATWOE, as shown in Table 3.

Based on the CATWOE elements identified above, an inclusive root definition is defined as an energy and utility management support system to capture and convert energy and utility consumption data into structured and organized analysis reports to find opportunity for energy and utility conservation, where energy and utility consumption data are easily and continuously captured and can be used to improve the quality of decisions made in finding opportunity for energy and utility conservation, within defined constraints.

5.2. Conceptual models

The conceptual model describes the activities associated with energy and utility management in textile process based on the root definitions (Fig. 4).

To allow the management to find the opportunity to save, the system should analyze different data to measure production cost and production efficiency. For example, production efficiency, which indicates the resource cost per unit goods, can be compared among different machines, different groups of workers, or under different weather. The management can identify the machines that are inefficient to see if repair or replacement is needed. Data captured for analysis include energy and utility consumption data (i.e., meter readings; production output data, such as the amount of goods produced by the machine; and activity data, such as processing time of the machine, name of operators; and so on).

According to SSM, a comparison of the conceptual model with the real world (stage 5) is made after defining the conceptual model (stage 4). Activities in the conceptual model and ways to perform these activities are compared and identified, as shown in Table 4. Four sponsoring textile manufacturing companies of this project were invited for the interviews. A brief background of the companies and some excerpts from the interview are given in Tables 1 and 2, respectively. Interviews were conducted with executives, who were important actors in, familiar with, or responsible for the EUMSS project. Qualitative content analysis was conducted to identify the existing system inadequacies and the required new system's functionalities. The results of our content analysis were discussed with the interviewees to ensure our findings related to current energy and utility management and action in order to improve the situation through an accurate recording of their words and ideas. Afterward, the energy and utility management support systems that can contribute to carrying out those activities were determined, and then listed in the third column of Table 4. These activities are the possible actions and changes that the proposed system could implement that can improve the energy and utility management (SSM stage 6).

6. System requirements for EMUSS for textile processing

At SSM stage 7, the feasible and desirable changes defined in stage 6 will be converted into actions. One of the deliverables for EUMSS is considered as the realization of the changes. A system designed and developed based on the system requirements will be an effective EUMSS. By analyzing the information in Table 4, the functional and non-functional requirements for an effective EUMSS in textile manufacturing process are derived and described in this section.

Table 3
CATWOE for an energy and utility management system.

Customer (C)	The one managing and controlling the cost of production and operation of the manufacturing facility (e.g., production managers).
Actor (A)	The one operating in the manufacturing facility (e.g., the operations manager or other operators).
Transformation (T)	The transformation of energy and utility consumption data into structured and organized analysis reports to support and find opportunity for energy and utility conservation.
Weltanschauung (W)	The energy and utility consumption data are easily and continuously captured and can be used to improve the quality of decision made in finding opportunity for energy and utility conservation.
Ownership (O)	The one managing and controlling the cost of production and operation of the manufacturing facility (e.g., production managers).
Environment (E)	The harsh physical environment in the factory, the reliability, and the data capture technologies used.

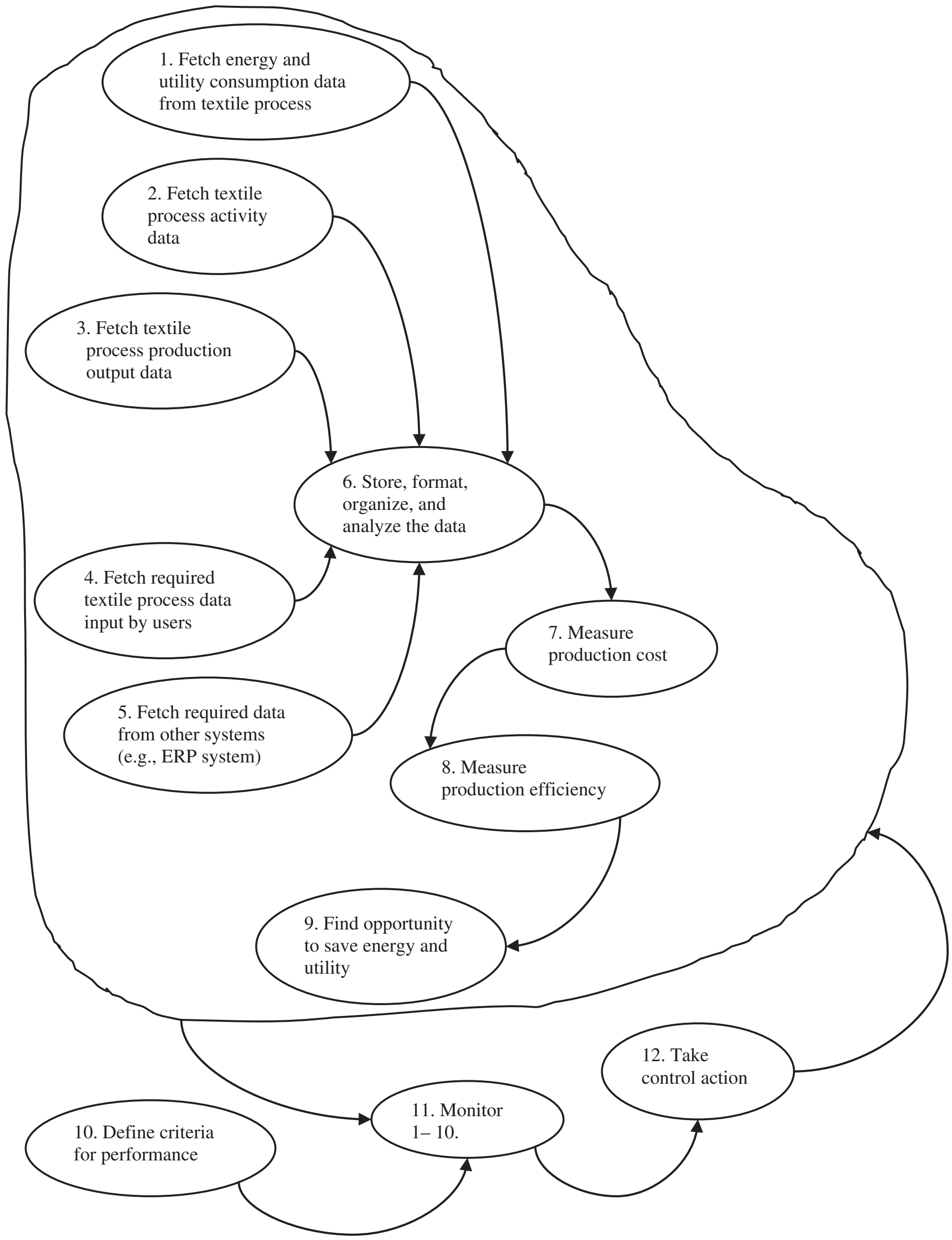

Fig. 4. Conceptual model of energy and utility management in textile process.

6.1. *Functional requirements*

The functional requirements are mainly based on activities in the conceptual model of energy and utility management in textile manufacturing process described in Table 3. The functional requirements are illustrated in the form of use case (Fig. 5), which presents a graphical overview of the functionality provided by the EMUSS.

1) *Define workflow*. The workflow of the work order can be defined in the system, such that the planned procedures to process the items under the work order are specified.
2) *Capture activity data*. At each procedure in the production process, real-time data, including procedure start and end time, operator ID, work center ID, or product ID, can be accurately captured in activity log database. Resource usage and output can be retrieved for the time buckets of the activity from work center log database.
3) *Enter output data manually*. In addition to automatically capturing the output of work center, the system allows users to input the output data for the batch of fabric at each work center. For example, the weight of the whole batch of fabric after each process requires recording; therefore, before check-out, the operator can key in the weight of the fabric after weighing it.
4) *Associate unique identifier with items*. Unique identifiers, such as radio frequency identification (RFID) tags and barcode labels can be associated with operator ID, production order ID, and operation ID to allow automatic capture at the shop floor. This allows the system to track the worker or section responsible for the item to be produced, as well as the specific work center and production step.

Table 4
Comparison of activities in the conceptual model.

Activity	Current practice	Contribution of EUMSS
Fetch energy and utility consumption data from textile process	Energy and utility consumption data (i.e., reading of meters measuring water and electricity consumption) are recorded daily (once or twice per day). The worker usually writes down the meter readings at the beginning and/or at the end of the working day.	Provide and support automatic, continuous, and accurate device and method by leveraging radio frequency (RF) technology, sensor network, and pattern recognition method to capture energy and utility consumption data.
Fetch textile process activity data	Workers usually write down their names and start and end time of the process.	Provide and support automatic and accurate device and method to capture activity data involved in the whole textile manufacturing process.
Fetch textile process production output data	The volume or length of material processed in each procedure is written down by the workers.	Provide and support automatic and accurate devices and methods to capture the textile production output data.
Fetch required textile process data input by users	If any data needs to be recorded, it is written down by the workers.	Provide and support automatic and accurate device and method to let workers key in the required data into the system.
Fetch required data from other systems (e.g., enterprise resource planning (ERP) systems)	Workers can check data, such as detailed information of the work order, in the ERP system after logging-in the system.	Provide interface and method to import data from other systems, such as ERP systems.
Store, format, organize, and analyze the data	Data recorded by workers is usually entered into a Microsoft Excel spreadsheet.	Provide a method to automatically collect data from different sources. Provide a structured, secure, and centralized database for storing all the data.
Measure production cost	Only the production cost of the whole factory per day/week/month can be estimated.	Provide a simple, fast, and accurate way to calculate production cost in different dimensions. Production cost can be calculated per time unit (day, week, month, or any time period), per work order, per sale order, and so on.
Measure production efficiency	Only the production efficiency of the whole factory per day/week/month can be estimated.	Provide a simple, fast, and accurate way to calculate production efficiency in different dimensions. Production efficiency can be calculated per different time unit (day, week, month, or any time period), per machine, per group of workers, and so on.
Find opportunity to save energy and utility	The management has difficulty finding the opportunity to save energy and utility because there is insufficient data.	Provide more information to support management to find opportunity. For example, the efficiency of different machines can be compared to decide which one uses less energy and utility for the same amount of products.

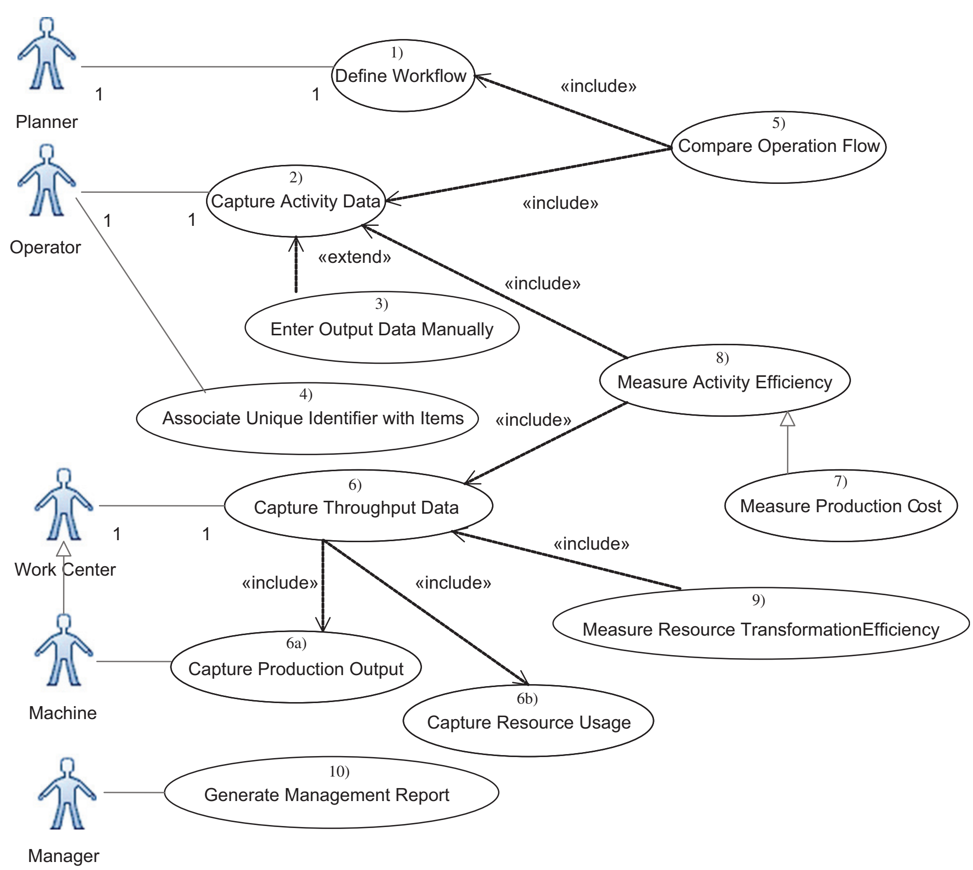

Fig. 5. The use case of energy and utility management support system for textile processing.

5) *Compare operation flow*. As activity based data are captured at machine level, even without a predefined production workflow, operation flow can be detected by fabric pass between different machines. Flows can be compared within the defined workflow to detect rework or inefficient step.
6) *Capture throughput data*. The amount of material and resource consumed and produced real-time are automatically obtained and the record is stored in the work center log database. The level of detail and accuracy depends on the meter installed on the specific levels of the work center. A work center can be considered a single machine or group of machines.
7) *Measure production cost*. Detailed level of activity and work center throughput, such as material, labor, overhead, pre- and post-operation, rework operation, and abnormal operation consumption information are tracked to provide real-time insight of the current activities in each work order.
8) *Measure activity efficiency*. Calculate the amount of resource used against the amount of products using the captured activity and throughput data. The efficiency can be compared among different machines, different groups of workers, and others.
9) *Measure resource transformation efficiency*. A resource can be transformed into another resource medium, such as heavy oil to stream. Such transformation is recorded real-time to measure efficiency and convert actual cost for transformation.
10) *Generate management report*. Generate simple management monitoring report, such as statistics of the production data (e.g., duration of each procedure), or any other reports for calculating the key product index (KPI) using production data.

6.2. Non-functional requirements

The non-functional requirements are derived based on the general physical environment, IT adoption, and practice in textile manufacturing process.

1) *Synchronize data to server in real-time*. Data, such as activity data and resource usage data can be synchronized to the server in real-time mode.
2) *Wireless sensor network.* Usually, there is no local area network (LAN) fully implemented in mills (Ngai et al., 2010). Only offices or limited areas can access the LAN. Wiring the new network is costly and may adversely affect the infrastructure of the mill. Therefore, the system required to synchronize real-time data to the server should only make use of existing limited LAN access points and avoid any implementation of new networks. Alternatively, the data should be communicated to the server through wireless sensor network, which can resist the noise in the factory environment and which does not require any wiring.
3) *Support multiple types of meters.* There are different types of meters already installed in mills; however, most of them do not have digital interface to a computer system. Installing a new digital output-enabled meter is costly and not feasible for mills that are already in operation. Therefore, the system will provide a data recognition device using pattern recognition technology to transfer meter data back to the system.
4) *Flexible production control.* Multiple production route paths can be defined and multi-operation can be assigned to a work center. The system allows additional ad hoc operation for flexibility to adopt all kinds of textile and garment manufacturing processes.
5) *Interface with existing enterprise resourcing planning* (*ERP*) *system.* Data related to the fabric and work orders in ERP can be exported into a data file, allowing the proposed system to access and avoid double data entry. In contrast, captured production data may be uploaded to a file, which can then be accessed by the ERP to retrieve real-time production data.
6) *Simple and user friendly.* As operators in the factory are not advanced users of IT, providing a simple and user-friendly interface for them would be more effective. This can also encourage users to easily accept the system.
7) *Minimum impact on the existing operation.* After implementing the system, the daily operations should be minimally affected. With the help of the system, operations should be smooth and easily accepted by operators.
8) *No extra data entry*. There should be no extra large volume data entry before the system can be used.

SSM applications for the development of an innovative EUMSS are investigated. Our analysis above was motivated by the question: How can we model the real world to better facilitate our designing, developing, and using more valuable EUMSS? Overall, SSM provides EUMSS designers with a structured and rich definition of a real world for the development of EUMSS, and allows all those involved in the EUMSS development project to contribute to the design process. The conceptual model developed by SMM can provide major planning activities and show how these activities are related to each other in the textile process in energy and utility management.

7. Conclusion

Industrial processes for textile require abundant energy and utility (e.g., water) resources. The scarcity of natural resources and their rising costs are forcing industries and governments all over the world to more efficiently use energy and water. This study has demonstrated the potential benefit of using SSM as a system analysis methodology aimed at developing systems to diagnose and analyze complex problem situations and to conceptualize energy and utility management support systems for textile manufacturing process. A holistic view and scope of the management support system has been presented together with the system constraints. In this study, the conceptual model has been developed from rich picture and root definitions. Based on the conceptual model, we have derived the functional and non-functional requirements of an effective EUMSS. These system requirements can be considered as a guideline to the practitioners for developing effective EUMMS. Several managerial implications are derived from this study:

1) *Improved quality of decisions.* With real-time and accurate data, reports generated from the proposed system can support management to make the decision of energy saving in a better manner, such that opportunities to save are more easily identified. For example, after analyzing the production efficiency of the machines for the same product, the management can easily identify the machines that are performing badly and that are in need of repair or replacement.
2) *Quick and prompt reaction*. The data provided by the proposed system are in real-time; therefore, the management can instantly react to any inefficient energy and utility usage and abnormality in the production process. This can help in the timely prevention of waste of energy and utility.
3) *More accurate pricing.* The data of the proposed conceptual model is useful for energy and utility saving and for determining the pricing of the company. The proposed system allows management to calculate the average energy and utility cost for producing a specific product, more accurately estimate the price of the product in future orders, and ensure that the company does not suffer due to underestimated price.

The current study contributes to the body of information systems knowledge in the context of EUMSS design. To the best of our knowledge, academic research in the field of EUMSS development is limited, particularly in the area of EUMSS design; furthermore, no studies exist on the application of SSM to EUMSS design. SSM has provided an approach to develop the high-level design of an EUMSS. For future studies, we will design and develop the proposed EUMSS according to the functional and non-functional requirements described in the current study.

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