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A socio-technical Systems Approach to Managing Material Flow in the Indonesian Fertiliser Industry

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Abstract. The Indonesian fertiliser industry is a significant contributor to the national economy. Given the need to distribute its products to customers on the 17,000 islands making up the Indonesian archipelago, capacity and availability of ports are major factors in managing fertiliser product lifecycles. Improving the management of material flow in ports results in more efficient loading and unloading of ships which is critical to ensuring the effective operation of the Indonesian fertiliser industry's supply network. However, managing the flow of material around a port is a complex process, affected by a range of socio-technical factors. This paper proposes a conceptual model of supply network processes and their relationships to infrastructures such as ports based on a socio-technical systems analysis of material flow in the fertiliser industry supply network system. Supply network processes in the fertiliser industry are a special case because the overall structure of each network is determined by government regulations. Results from an application of the model to explore how changes to a port is operated affect material flow are reported. These results were used to inform the development of an agent based simulation model to support decision makers in investigating the effects of their decisions in considering the impact of potential management interventions on the flow of materials within the port. The conceptual and simulation models are illustrated using a case study taken from a port in the Indonesian fertiliser industry.

Keywords: material flow, socio-technical system, agent based simulation modelling, Indonesian fertiliser industry

1 Introduction

Balancing infrastructure availability is a substantial issue when managing industrial product lifecycles. Benefits will not be accrued from the excess if the availability of the infrastructure is over and above that required. On the other hand, if there is inadequate key infrastructure availability, this can cause delays in operation or even failure in process[1]. Considering the role of infrastructure in supply networks is essential to developing decision-making tools that result in more resilient supply networks. In global product distribution systems such as the Indonesian fertiliser industry, physical infrastructure, such as ports are important as these affect the supply network's performance. Inefficiencies in loading or unloading of material in ports cause negative which have a detrimental impact through the product lifecycle, from production process to consumer satisfaction [2]. For this reason, port availability needs to be managed in order to maintain continuity and increase performance of key supply networks processes such as logistics operations and manufacturing. This paper argues that the effectiveness of material flow in ports is critical in life cycle management processes. This paper proposes a conceptual model and an agent-based simulation modelling approach that was used to introduce people movement and interaction in scenarios of technology and infrastructure changes. A case study from the Indonesian fertiliser industry was used to specify and evaluate the model.

The paper begins with a review of literature on socio-technical systems in decision-making design. The methodology used in this research is explained in Section 3. Section 4 describes the case study and an application of agent based simulation modelling using the framework to the case study. Finally, Section 5 discusses the key outcomes of the research.

2 Socio-technical Systems in Decision Making Design

Parallel consideration of social and technical issues is needed in system design to deliver optimal whole system performance including people, processes and technology [3]. The idea of socio-technical systems was designed in response to theoretical and practical problems of working conditions in industry. The concept of the socio-technical system was established to focus on interrelationship between humans and machines in order to increase efficiency by considering the technical and the social conditions of work [4]. Challenger and Clegg [5] propose a socio-technical frameworks that identifies six components in an organization, namely: goals, people, culture, process and procedures, buildings and infrastructure, and technologies.

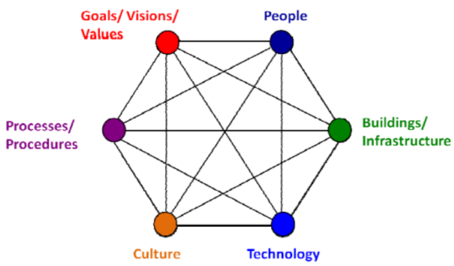

Fig. 1. A socio-technical system framework, Challenger and Clegg (2011)

In recent years, socio-technical systems approaches have been applied to a range of complex systems. However, complex socio-technical systems are difficult to analyse. Stanton and Bessell [6] developes Cognitive Work Analysis that offers an integrated way of analyzing complex systems in multiple interpretations. The effects of knowledge sharing, training, team coordination and human interactions have been an interesting focus of research into the socio-technical approach. Siemieniuch and

Sinclair [7] propose the socio-technical approach as an effective way to entrain information communication technology as global drivers. In human interdisciplinary interaction, McGowan et al [8] suggest that socio-technical approaches might be critical need in interaction of humans and organization in interdisciplinary systems.
This paper presents a new application of the socio-technical system approach by applying it to a material flow system in the context of broader supply network system. Identification of key elements in the material flow system used the six perspectives Challenger and Clegg framework:
a. Goal: to ensure the efficient flow of material through the port;
b. Procedure: standard operating procedures for material flow;
c. People: people in material flow;
d. Culture: administrative and production management process cycles;
e. Infrastructure: finished product warehouse and port loading area
f. Technology: trucks as facilities for product distribution
The result of the conceptual model in this paper is expected to assist decision makers to determine the number and combination of elements in order to measure loading time of products and measure berth occupancy ratio in the port.

2.1 Agent Based Modelling in Supporting the Decision Making Process

Agent based simulation has been applied in studies which consider the effect of human roles and behaviour on system performance and decision-making. For example, Siebers et al. [9] report an application of agent based simulation on assessing the effect of human resources management practices on customer satisfaction through observing changes in customer behaviour in a service-oriented organization. Crowder et al. [10] proposes an agent based modelling framework to facilitate the decision making process in managing the impacts of team composition and working process in product development.
In this paper an agent based simulation approach was used to help to visualise material flow management and determine the influence of variable changes in the material flow system of the port on the duration of the loading process and percentage of berth occupancy ratio.

3 Methodology

A case study analysis methodology was used to observe material flow in the supply networks systems [16]. The Indonesian fertiliser industry was chosen as the case study due to the contribution of the industry to the Indonesian economy and the complexity of material flow in supply networks such as this that are influenced by government regulation. This study focused on a port that is owned by the Indonesian fertiliser industry. Most of the processes in the distribution of raw materials and products on the system supply network are dependent on material flow through the port. For this reason, if problems occur in the process of material flow at this port, the performance of the entire supply network is affected. Data collection was carried out in the Indonesian fertiliser using semi-structured questionaires. The participants were key people who had tasks and responsibilities in material flow and supply network management.

This research used the Enterprise Engineering Framework [13] to contextualize the different aspects of the research.
The conceptual framework is summarised in Figure 1 and described here:

1. Define the purpose
The first step was to define the purpose of building tools or prototypes based on problems that exist in the system. IDEF3 Process Capture Method [14] is used in this paper to visualise the process and product flow in the fertiliser industry.

2. Define the agency
The second step was to define the system or department of research focus: for this paper this was a fertiliser industry supply network, especially the departments involved in the flow of fertiliser material, ie: the Sales Department, and Risk Assessment Department and the Ports Department.

3. Define the outcome of product or service
The third step was to define outcomes that would be generated to resolve the existing problems in the system. An outcome reported in this paper is a prototype simulation model that is expected to help the decision maker in optimizing the process flow of material through the supply networks.

4. Develop the tools or prototype
The fourth step was to determine how to make the outcome or prototype in step 3. This paper applies agent-based model software to build models of material flow analysis.

5. Applying the tools to the case study
The case study is represented using simulation model by using historical data on material flow system in the fertiliser industry supply network.

4 Case Study: The Indonesian Fertiliser Industry

This section describes the implementation of the conceptual framework in section 3 into the case study.

1. Define the purpose
As the focus of this research is on the influence of socio-technical changes, this study applies the IDEF-3 method to visualise product and process flows in order to better understand decision makers' perspectives. It can be seen from Figure 2 that raw material from suppliers is processed in three stages of chemical processing. Quality control activities are applied at the end of the process, before fertiliser is packed and distributed. Meanwhile, risk assessment is implemented in activities in the departments. Brainstorming with participants concluded that the greatest risk in the product life cycle was the process of distributing of the products from warehouses to loading process on ship in the port area. Material flow from the trucks to the ships is often delayed; this affects the berth occupancy ratio (measured as percentage) at the port. Currently the fertiliser industry has set a target of berth occupancy ratio at 70%. If the percentage of berth occupancy ratio is more than set target, this will cause loss to the company because the company has to pay larger demurrage costs.

Table 1. Conceptual frameworks for managing material flow in supply networks

	Define	Develop	Deploy
Purpose	How to manage material flow in the supply networks 1 To visualise product and process flows by using IDEF3		
Agency	The supply networks 2 To analyse the coordination between sales department, port departments and risk assessment department and to identify the biggest risk in material flow	To build conceptual and simulation modelling for managing material flow 4 To apply system dynamic and Agent based modelling	
Products and Services	Information availability for decision making process 3 To build prototype of simulation model for optimising material flow		How should the model be used for decision making? 5 To implement the model by using historical data from the fertiliser industry

2. Define the agency

The fertiliser industry distributes products to consumers (farmers) based on government policy. The amount of fertiliser demand, delivery schedules, buffer stock and the amount of fertiliser to be shipped are dependent on government regulations that have been established in the earlier years. Thus, the industry applies a special delivery schedule that has been established by the Sales Departments; they are The Sales Department Region I which distributed fertiliser to Java and Bali islands; and The Sales Department Region II which distributed fertiliser to the other islands (ie: Kalimantan, Sumatra, Sulawesi, Nusa Tenggara and Papua) product . This condition causes the supply network management in the fertiliser industry to be different from other industries that use lead-time in delivery scheduling. A further-result of brainstorming with participants indicated that the greatest problem in material flow was maintaining operators' performance in the unloading process of product from trucks into ships in the port area.

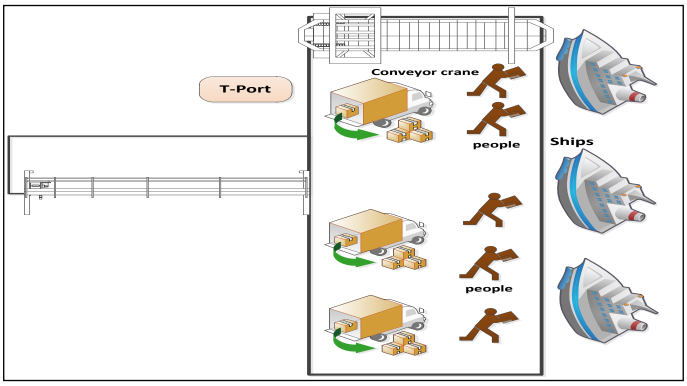

Figure 3 Material flow in the Fertiliser Industry port

3. Define the outcome of product or service

By applying a socio-technical systems approach and the enterprise engineering framework, the research assist participants to determine the optimum value of variables in the supply network system to measure the loading time and the berth occupancy ratio. An agent based simulation modelling was to be applied in this study.

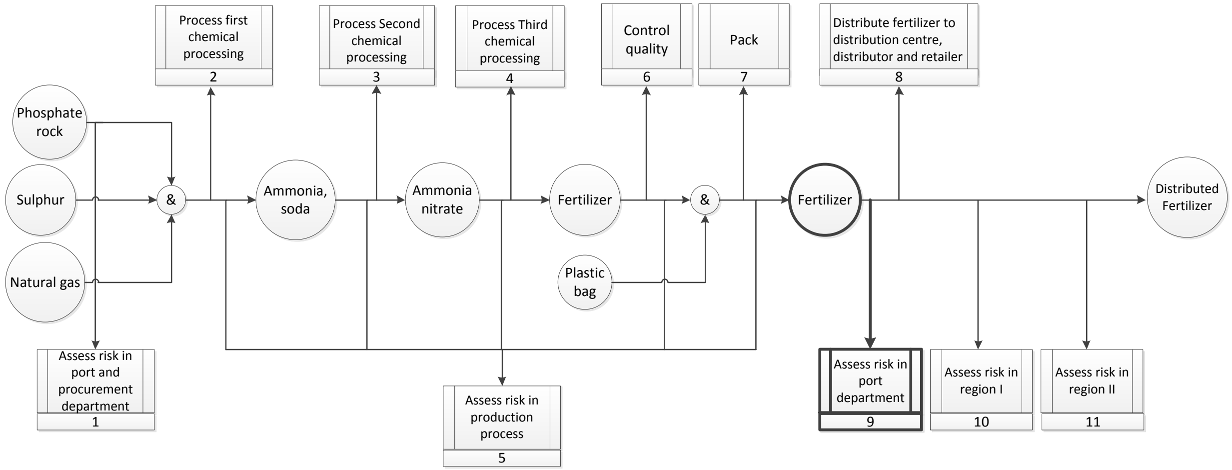

Fig. 2. IDEF3 the fertiliser product and process flow and the focus of this paper was in process 9

4. Develop the tools or prototype

The product-handling operators are important agents in the material flow of the supply network. Therefore, their movements in processing loading or unloading were analysed. This research designed the agent based modelling by using Netlogo 5.0.4 to visualise operators' movement in handling the product from the trucks to the ships in the port.

5. Applying the tools to the case study

Historical data from the fertiliser industry was used as input to the simulation model. Table 2 shows input variable names and values used in the agent-based model and Figure 3 shows a dynamic modeller of variables.

Table 2 Variables and code of the agent based model

Code / slider	Value
Number-of-trucks	represent number of truck used, scale: 0 to 1000 (units)
Number-of-operators	represent number of people scale: 0 to 100 (person)
Number-of-stocks	represent number of products distributed, scale: 0 to 100000 (tons)
Number-of-ships	represent number of ships docked in the port, scale: 0 to 50 (units)
Number-of-warehouses	represent number of warehouses used, scale: 0 to 5 (units)
Number-of-departments	represent number of departments, scale: 0 to 30 (units)
Number-of-board_directors	represent number of decision makers, scale: 0 to 3 (person)

Flow of processes on system modeller was arranged based on flow of information and reporting procedure on the material flow process in the case study. A process was represented by a variable. For instance, administration time represents the process of reporting and recording the amount of products that will be distributed from warehouses to the trucks. This model assumed that the administration time was 24 hours. This variable was inserted as an input in length of reporting process in reporting cycle. The Model assists decision makers to visualize flow of information and material on the system by analysing the calculation of time on each variable.

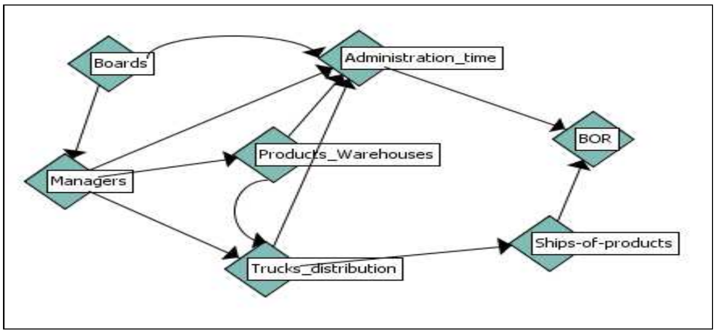

Fig. 3. Material flow system cycle: administration and report process of material flow

Figure 4 shows the interface of the agent based model developed for material flow optimization. Sliders at the interface of the model can be changed as the user desires. For example: the number of operators can be changed from zero to fifty or more. Sliders on the interface are used to set the values of the input variables. For example: the number of operator can be changed from zero to fifty or more. The graph shows result of running simulation model for loading time, number of operators, length of administration time, and of the berth occupancy ratio against an x-axis that represents time using Netlogo ticks. Face validation [15] was used to validate the conceptual and the simulation models. In the validation activities, people in the system were asked to review the model. In addition, the researcher conducted experiments using scenarios that change variables in simulation modelling. An experiment was carried out to investigate the influence of variables changing to the loading time and the berth occupancy ratio.

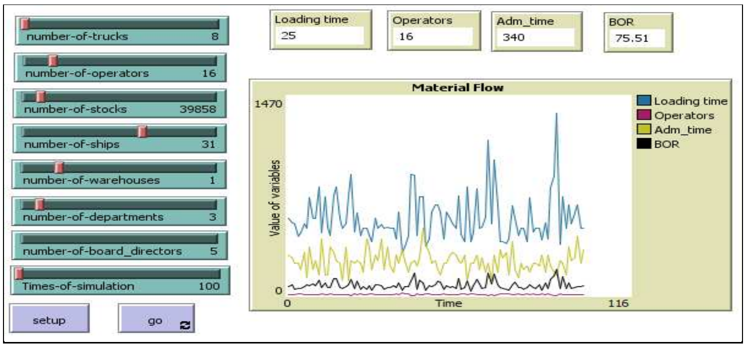

Fig. 4. The interface of simulation model

The output of the simulation model in Table 3 shows the number of operators, the length of material flow process and the percentage of berth occupancy ratio in five scenarios. Decision makers can use the output to determine the standard time of the loading process in order to achieve targets for the berth occupancy ratios. For instance, scenario one describes the berth occupancy ratio at 98.76%. The percentage will be occurred if decision makers employ fifteen operators in material flow and decide to use five trucks to transport fertiliser from three warehouses in the fertiliser industry to the port. As a result, administration time is 260 minutes and loading time is 531.60 minutes. On the other hand, in the second scenario, the berth occupancy ratio at 72.55% could be achieved if the material flow used 20 operators, 7 trucks and distributed fertiliser from one warehouses with administration process in 200 minutes. By using those variables, loading time in port would be in 401.05 minutes. This two scenarios show that the decision makers should add number of operators in order to decrease the berth occupancy ratio. However, as a further result of simulation model, scenario five shows a different significant effect of variable changes on the berth occupancy ratio. The berth occupancy ratio was declined from 98.76% in scenario one to 80.50% in the scenario five. This percentage can be accomplished by employing 15 people and using six trucks and the decision makers should transport the fertiliser from two warehouses in order to minimize administration time and result in the same length of loading time with scenario one. Thus, scenario five is the best scenario to obtain the optimum value of variables and minimise the berth occupancy ratio. The results of the scenarios were used to inform the decision-makers in investigating the effects of their decisions in considering the impact of potential variable changes on the flow of materials within the port and achieve optimum percentage of berth occupancy ratio.

Table 3. The output of simulation model in five scenarios

Fertiliser	Trucks	Ware-houses	Depart-ments	Board Directors	Loading Time	Opera-tors	Adm-time	BOR
39696	5	3	3	2	531.60	15	260	98.76
40065	7	1	1	1	401.05	20	200	72.55
39747	10	4	6	1	664.42	12	420	94.20
40032	6	2	1	1	499.85	16	200	80.64
39999	6	2	1	2	531.15	15	220	80.50

5 Conclusions

Managing material flow by applying socio-technical perspectives has initiated a new opportunity for research in product life cycle management. This paper presents a conceptual framework that considers human and technical factors in order to assist decision makers in managing material flow. An Indonesian fertiliser industry supply networks has been presented as a case study to apply the conceptual framework. Result from the case study analysis indicated that an inappropriate loading process in the material handling flow reduced the effectiveness of the loading process at the port. This tardiness resulted in a significant impact on the berth occupancy ratio of the port and delays in supply networks flow. An agent based simulation model was used to visualise and evaluate the material flow system based on the real data from the case study. The output of the simulation model showed the effect of variables in the material flow system on berth occupancy ratio of the port. The model can assist decision makers to optimize variables in the material flow system in order to reduce loading time and determine the percentage of berth occupancy ratio of the port. The standard time for the loading process, as the output of the simulation model can be used as information to determine and reduce target of loading time and number of operators to accomplish the material flow process. In addition, this model aids decision makers in assessing and predicting material flow performance in their supply networks by changing the value of variables in the simulation model.

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