Utility-Cost Model for Discrete Event Logistics Systems Simulation

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Abstract – A study on simulation fidelity, utility and cost is conducted to address simulation quality issues in Discrete Event Logistics System (DELS) context. First, a simulation lifecycle management (SLM) framework is constructed. Secondly, the concept of fidelity is brought into the framework. Then, simulation fidelity, utility and cost are divided into multi-dimensions each according to DELS simulation features. Finally, a dimension decomposition based relationship analysis between Fidelity-Utility and Fidelity-Cost is presented. A Utility-Fidelity mapping method is used to map simulation objective into fidelity requirement (FR). Fidelity design (FD) is strictly based on this FR, and simulation design is in turn based on FD. Finally, a Utility-Cost management model is presented to show how well a simulation implementation is done. The SLM framework is effective in guiding the simulation to achieve reasonable balance between utility and cost, which falls into the cost-effective equilibrium zone in the Utility-Cost management model.

Keywords - Cost, DELS, fidelity, simulation, utility

I. INTRODUCTION

Despite the wide use of discrete event simulation (DES) in Discrete Event Logistics Systems (DELS) planning and design[1][2], the issues about the quality of simulation application are left unstudied. In a way, the quality of a simulation study can be evaluated by simulation utility (SU) it achieves and simulation cost (SC) it spends[3]. The lack of understanding about SU and SC leads to two kinds of consequences: insufficient SU and unnecessary high SC. Insufficient SU, in turn, usually results in large errors or even invalid simulations, and/or inefficiency in simulation modeling. This is why a study on Utility-Cost (U-C for short) equilibrium is valuable.

Fidelity (F) is the main drive of SU and SC. In general, the higher the fidelity, the higher the SU, and inevitably the higher the SC[4][5]; thought this is not always the case due to the nonlinear relationships between F-SU (F-U for short) and F-SC (F-C for short). In this paper, the relationships between F-U and F-C are explored in DELS context, and a U-C model is built to address DELS simulation quality problems.

II. METHODOLOGY

A. Framework and perspective

For simulation quality, the lifecycle management of simulation is of great importance. A framework of simulation lifecycle management is given in Fig. 1. It includes four stages: simulation preparation, simulation implementation, simulation design, and simulation quality management. How the simulation is prepared and designed largely decides the quality of a simulation study.

B. Concepts and dimensions

1) Fidelity and its dimensions

Generally, fidelity tells how well the simulation system represents the object system[6][7]. The concept of fidelity is recognized as early as 1960’s. It was studied in the following half century, but still remains as a nebulous term used by simulation community. It could be the model itself, the behavior of the model or the simulation execution results[8][9]. In this sense, simulation fidelity is divided into experiment fidelity and model fidelity. Experiment fidelity tells how the simulation experiment scheme is designed to achieve the simulation objectives, while the model fidelity tells how well the model represents the object system. A simulation system with high model fidelity is capable to serve a simulation analysis with low experiment fidelity, though this is not economical, but a model with low model fidelity could not serve a simulation analysis with high experiment fidelity[10].

Theoretically, model fidelity is defined as the ratio between the simulation world and the object real world (existing or imagined reality)[11]. See formula (1).

\[ Fidelity = \frac{M_f}{M_e} \]  

(1)

Where \(M_f\) is the simulation model and \(M_e\) is the reference model abstracted from the understood reality.

Simulation application in DELS domain is different from training field[12][13]. There is no hardware and/or man in the loop. The object system is usually a compound
future system integrated by a set of queuing, inventory, transport network and other kind of systems. Usually, the purpose of simulation is to understand, analyze, evaluate and/or optimize the system. Based on the features of DELS simulation, fidelity is divided into the following dimensions as shown in Fig.2.

2) Simulation utility and its dimensions

Simulation utility is a blur and elusive concept, like fidelity itself. In a narrow sense, SU indicates how well a simulation implementation works for the given simulation objective pre-determined from a default viewpoint of the user. But a broader view of SU means more. In this study, the SU is divided into the follow dimensions shown in Fig.3. The relationships between different dimensions are complex. Some of the dimensions are correlated with others, while others could be regarded as independent elements. For example, the reusability is positively correlated with timeliness, while the interoperability is rather independent.

3) Simulation cost and its dimensions

Simulation cost, as a concept, is much clear than SU. The resources used and the amount of time and manpower spent in simulation are the actual cost, which is usually measured in monetary value. A simulation is always expected to be cost-effective[14].

But when considering quantitatively cost evaluation, SC issue becomes much more complicated. It is difficult to measure SC in terms of monetary value based on time and manpower spent because of the random and uncertain factors, such as intelligence, experience and skills. Objective measures are needed. In DELS context, investments for hardware, such as computers and software, are easy to be evaluated. The time and manpower cost in DELS simulation is spent in the simulation activities. In this sense, the essential activities in modeling and simulation (M&S) are the objective cost of the simulation.

Each of these M&S activities contains two parts: time to “know how” and the time to “do it”. The two parts are usually disproportionate. The first part could be much greater than the second part. And the time for “know how” could be largely reduced by certain methods, skills and experiences.

Here, SC is divided in the dimensions shown in Fig.4. The dimensions are correlated. For example, if the computer has a higher configuration, the time to run the simulation could be reduced.

C. Relationship analysis and mapping

1) Relationship between F-U

Basically, the relationship between F-U is classified into three types: positive, negative and random correlation. See Fig.5. The complexity of the F-U relationship comes from two aspects. First, the model fidelity dimensions are not strictly independent. For example, the logic dimension is related to structural dimension. Second, the relationship between fidelity dimensions and utility dimensions is not clear.