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A CROSS-PARADIGM SIMULATION FRAMEWORK FOR COMPLEX LOGISTICS SYSTEMS

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ABSTRACT

As hybrid simulation development context is a new topic with limited available applications and data, and thus still mistrusts most researches, this work proposes a methodology to combine discrete event simulation (DES) and System Dynamics (SD) paradigms on a logistics background. On the basis of knowledge induced from literature, a generic conceptual framework for hybrid simulation has been developed. The proposed framework is demonstrated using an explanatory case study comprising an user transportation mode choice. The methodology is able to create an feedback dynamic between both paradigms, ensuring advantage to hybrid methodology modeling, that is able to combine and extract the benefits from both paradigms.

1 INTRODUCTION

Hybridism is a crescent standard for developing simulation models, and is focus of many academic publications. Numerous authors in the simulation field state the need for development of hybrid simulation methodologies (Lee et al. 2004; Levin and Levin 2003), in order to surpass the DES and SD individual limitations. .

In proposing hybrid simulation methodologies, authors foresee an surviving tactic to overcome the constantly increasing demands of the business system, that demand decision makers to know more, faster and more diversified to take decisions. Being a proficient operations decision-maker is not enough anymore if your system is immerged in a complex net of social, political and environmental aspects. Decisions need to be taken considering and combining motioned above aspects and their significances and consequences. Bearing that in mind, this works proposes the development of a hybrid DES and SD approach to test the possibility and effectiveness of an hybrid methodology to expand the system spectrum comprehension, simultaneously evaluating complex logistics system operational aspects and decision-process, with alternate feedback

2 LITERATURE REVIEW – HYBRID SIMULATION

The call for efforts aiming at overcoming DES and SD individual limitations is well known in literature (Moyano and Macal 2016; Eldabi et al. 2016, Mustafee el at. 2015, Lee et al. 2004; Levin and Levin 2003). In particular, the DES and SD paradigms, as argued by Robinson (2005), Rabelo et al. (2005) and Helal and Rabelo (2004), are paradigms that offer complementarities to each other, providing the suitable environment to develop new paradigms of simulation, able to meet the requirements of the modern, integrated and dynamic global business system.

Morecroft and Robinson (2005), when developing two similar models in parallel to compare the behavior of SD and DES modelers conclude that the paradigms should not be seen as opposing, but as complementary. The conclusion is supported by the statement of Renshaw (1991) that both paradigms approaches have important roles to play in the analysis of any system.

Also, the work of Greasley (2005) represents a production facility using a DES model, and although the DES paradigm has been able to effectively investigate aspects of the operating-productive design of the system, it became clear that other factors also influence directly the performance of the system. In that case, one can mention the work practices of the sales department, which assessment was outside the scope of the DES model. Thus, the author adopts a complementary approach (SD) to represent the "missing" elements of the system. As a final conclusion, the author emphasizes the main advantage achieved with the construction of a multi-paradigm model: it was possible to expand the model in order to incorporate the behavior of decision-makers (sales force) and therefore provide a more detailed and precise behavior of the whole system.

Helal (2008) discusses the construction of hybrid dynamic-discrete simulation models for manufacturing processes and proposes a hybrid simulation approach for integrating production and planning systems of a factory. This approach maintains the integrity of the two traditional paradigms of simulation (DES and SD), and is able to capture the dynamics of the industry production system, while recognizing "soft" aspects of the production schedule.

Hybridism is thus a crescent standard for developing simulation models, focus of a number of academic publications. The idea to combine different simulation paradigms into a common environment helps to make complex simulation architectures easily handled and to profit from the advantages of different modeling approaches (Djanatliev 2012).

2.1 Review of the Application of Hybrid Simulation in Logistics

In the field of logistics modeling and simulation, the DES has always been the forefront employed paradigm, mainly driven by the confluence of its main characteristics with the characteristics of logistics systems in general. As Brito et al. (2011) explored, the DES has potentialities (related to its practical and technical aspects) that make it more suitable for detailed analysis of specific and well-defined systems, alike logistics systems are usually represented in simulation environments.

However, the first author to criticize this "traditional" approach to the simulation of logistics systems is Forrester (1968). He considers that the implementation of DES alone cannot completely solve the logistical problems of companies that depend on the proper modeling of the interaction between the system's logistics flows (material, order information), but also depend on understanding and implementing adequate control of these flows and of the relationship between its elements. Even if the first call for hybrid models was made by Forrester (1968), the literature review reveals that the applicability of hybrid simulation methodology and the extension of its research field are still limited. In the field of logistics systems planning, only few studies were found (Wolstenholme et al. 1982; Abbas and Bell 1994; Poles and Cheong 1999; Munitic et al. 2003), revealing a gap in this kind of application.

In the works of Wolstenholme et al. (1982) and Poles and Cheong (1999) manufacturing processes are simulated using the SD paradigm. The results initially obtained were unsatisfactory. A statistical study of the manufacturing production processes revealed significant randomness in most of the practical production procedures. The authors then chose to insert discrete event modules coupled to the existing SD model, to explicitly inject the randomness on the system representation.

Abbas and Bell (1994) work with the definition of the complex relationships between the multi-dimensional elements that compose a transportation system. The objective is to confirm that an accurate definition of these relations, through the SD paradigm, is capable to provide suitable answers to considerations and test policies over the system. However the authors have to deal with situations where the applicability of SD struggles (the randomness inherent in transport systems - travel times, processes, etc., the spatial and physical dimension and the necessity of obtaining numerically accurate answers), opening space for the discussion related to the increment of the model with other simulation paradigms. The author considers the DES paradigm as the first option to overcome such difficulties. It is noteworthy that the author classifies the SD approach as valid for the modeling the problem. Thus, the incorporation of the DES paradigm, according to the author, is an increment to the validity of the model.

The mentioned papers work on the integration between paradigms SD and DES under the following logic: while physical flows, activities, processes, arrivals, etc. - usually stochastic processes - are modeled by the DES paradigm, "soft" aspects (information feedback loops, causal relationships between variables, flows relationships, etc.) are incorporated into the model through the SD paradigm, building the insight specter of the model and its limits of operation. This is the basic integrative methodology formulated by the reviewed authors when developing hybrid simulation models, an approach that asseverates the unique characteristics of each paradigm - their particularly suitable behavior for specific situations. It makes clear the potential benefits of a simultaneous application of DES and SD, applied each to the a particular extension of the model that it represents more efficiently. The scope of application of each paradigm, based on its fundamental concepts, is described in the next session.

2.2 SD and DES paradigms contributions analysis

Based on the previous considerations, one can admit that the proper evaluation of the potential of applicability of a particular paradigm should be based on two aspects: (1) the effectiveness and efficiency and (2) the usefulness of the model built based on any given paradigm.

The issue of the effectiveness and efficiency of the SD and DES models has been already discussed in this work and in Brito et al (2011), and the final conclusion is that both paradigms are able, within their own limitations and difficulties, to properly represent complex logistics systems.

The work of Munitic et al. (2003) reports the barrier in the scientific community related to the use of logistics systems simulation models built based on the SD paradigm, making explicit the first barrier to the SD usefulness measurement. The main reported points regarding the "inability of representation" of SD models are: operational procedures of the system; randomness of the processes; control of arrivals intervals of ships, trains and trucks; financial considerations and system costs; behavior of inventory levels; representation of the timeline of the model; accuracy of the numerical results.

In fact, the points raised are connected to the considerations mentioned by Brito el at. (2011) about the limitations of the contribution of the SD towards logistic systems simulation. Even though the points mentioned do not affect directly the effectiveness of a logistics system model, they indirectly reflect on the level of confidence in the methodology, creating a "mental model" of SD paradigm usefulness deterioration, hard to be dismissed. As stated earlier, this situation is still scarcely addressed in the academic-scientific world, creating an environment of distrust between communities using DES and SD, of one paradigm over another.

Taking into account all considered aspects related to potential of DES and SD paradigms, opportunities, weaknesses and limitations of their contributions to the simulation of logistic systems, historical and practical aspects of application of the two paradigms, the final conclusion regarding the possible contribution of each of the two methods is that they should be applied in accordance with the following statements:

- The DES paradigm should serve as basis for the "physical modeling" of logistics systems: the efficient representation of the "hard" elements of a system (times, distances, rates of operation, events, etc..) is essential for the maintenance of utility model. Although the SD is able to play this role, its fundamental characteristics result in limitations and difficulties that tend to diminish the level of reliability in the model, further undermining its usefulness.
- As a result, to the SD paradigm remains the no less important role of element of expansion of the basis-model, incorporating elements and behaviors difficult to quantify through the DES paradigm, delivering a "strategic modeling" of the system, and serving as an element of analysis of policies, behaviors, relationships among "soft" variables, information flows, etc.

Thus, SD models should serve as support to DES models, which must command the basic structure of the representation of complex logistics system. The proposal of building hybrid model incorporating DES as the basis- paradigm and SD as an extender- paradigm, allows the expansion of the spectrum of comprehension of the behavior of the system under study, by adding new components to the model. The next stage of the work is to formalize the conclusions and proposals made so far by proposing the construction of a hybrid model simulation of a given logistics system.

3 BUILDING A HYBRID SIMULATION MODEL

Considering the previous sections recommendations, a practical procedures flowchart of the theoretical and practical steps in the process of a hybrid simulation model building are presented in **Error! Reference source not found.**. It's expected that this flowchart is particularly more suitable for logistics applications.

The flowchart is divided into two major parts: theory and practice. The theoretical prelude, which corresponds to the top of the flowchart, has been unfold throughout this (Section 2) and an previous study (Brito et al. 2011), supporting the description of the paradigms and evaluation of their potential of contribution to the construction of a hybrid model.

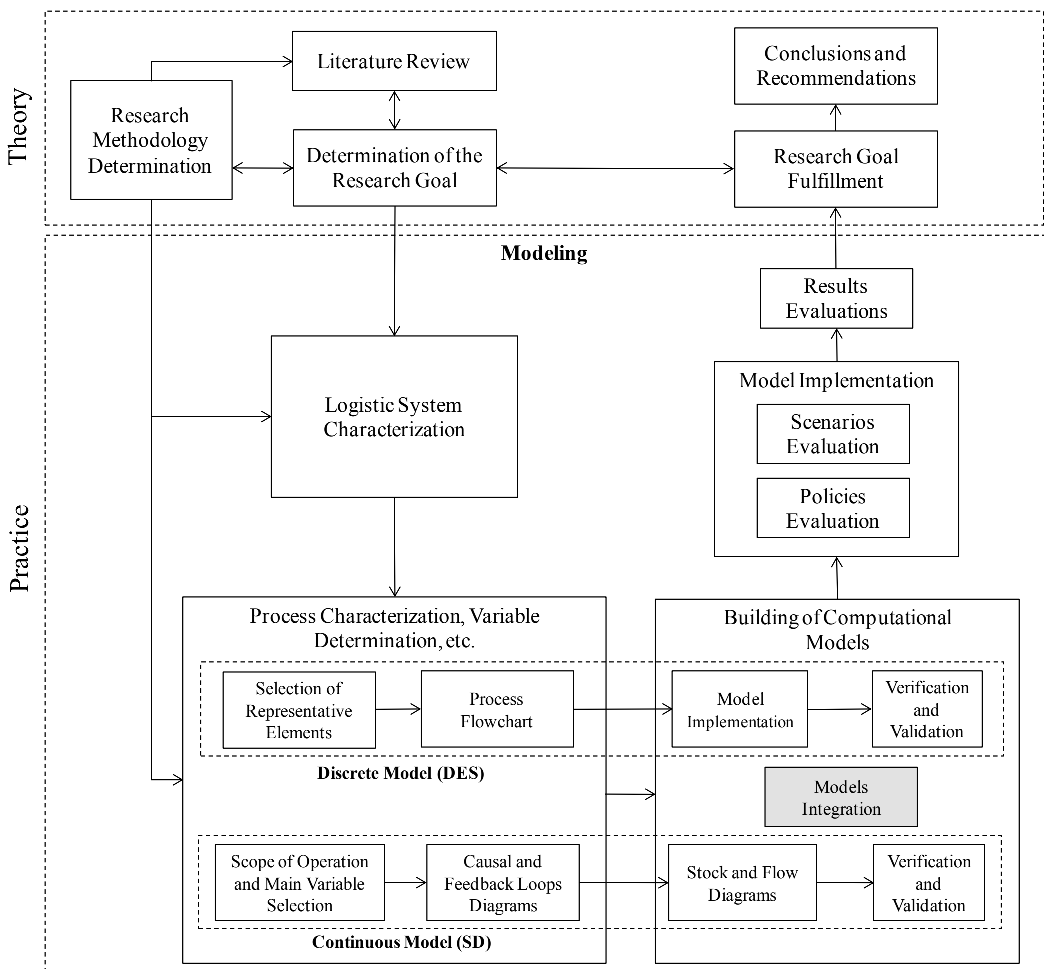

Figure 1 - Flowchart of the theoretical and practical steps in the process of a hybrid simulation model building (based on Loureiro 2009).

The practical procedure, which corresponds to the bottom of the flowchart, is presented departing from the characterization of a given proposed logistics system, including its description and ultimate goals of modeling. The sequence of practical procedures corresponds to the characterization of the DES model (basis of the hybrid representation), followed by the selection of representative elements, construction of the process flowchart, model implementation and verification and validation processes, simultaneously with the characterization of the SD model, which involves the determination of its scope of operation, building of causal and feedback loops, building of stock and flow diagrams and verification and validation processes. A crucial step refers to the integration process between the two models.

4 A CASE STUDY

This works proposes the development of a hybrid DES and SD model to test the possibility and efficacy of the proposed methodology to evaluate complex logistics system and simultaneously expand the system spectrum comprehension possibility. In that sense, the model was developed using

In the current section we describe the modeling approach using the commercial simulation tool AnyLogic 7 for realization purposes. As described by Heath et al. (2011) this software package has the power to combine multi-paradigm models in one common environment.

The developed model corresponds to the dynamics of passenger crossing between two cities, connected by a bay. This model uses parameterized data and simplified condition of the City A-City B crossing (in Brazil). The City A-City B passenger crossing can be accomplished in three ways: via waterway (using ferries), or road - through a bridge that connects the two cities, using public (bus) or private transportation (auto). City A is bay-crossing demand generator pole. A considerable portion of the population of City B crosses the by every day for several reasons (work, school, leisure, shopping).

The purpose of the model is to represent the three available crossing transportation modes operation and the behavior of the every-day passengers transportation mode choice. The physical modeling of the transportation modes operations - involving the physical distances, travel times and randomness and service processes, is handled by DES, and behavioral modeling of passengers - representation of the general policy decision-making, based on elements such as service level and price of transportation mode alternatives, is handled by SD. The proposal is thus aligned with the paper's methodological conclusions and previous recommendations. For the sake of brevity of the paper, this model will represented only one-way traffic (City B-City A), which is considered the most critical because it implies higher demand peaks.

4.1 DES Modeling

As stated before, the DES modeling is related with the "hard" (physical) aspects of the system, dealing with parameters such as distances, times, number or resources, and others. The transportation operational processes represented are stated below. For the sake of brevity, the DES model of the bus operational processes (Figure 2) will be the only represented.

- Ferry: the operation of the ferries fleet occurs on stations located on both sides of the bay. The ferry fleet operates uninterruptedly. The functional structure of the waterway terminal is simple: the passenger who arrives must go to the ticket booth and wait on the queue until the arrival of the next ferry. If space is available, passengers can board and cross the bay. Otherwise, passenger must wait for the next ferry. Ferry operation cycle is divided is 5 phases: docking, disembark, boarding, undocking and navigation. To dock, ferries must wait for available berths. After unloading passengers, boarding starts. If the ferry reaches maximum capacity, it receives permission to leave. If not, ferries must wait until a maximum waiting time, and only then is allowed to leave.
- Bus: the operation of the bus fleet is identical to the ferry fleet operational process and for the sake of brevity will be suppressed.

- Car: the car fleet operational process is individualized, and thus distinguished. A single origin and destination point was considered for cars travels (the cities centroids). From the cities centroids, travels are generated in both directions of flow. The travel between the centroids is done through a tolled bridge.

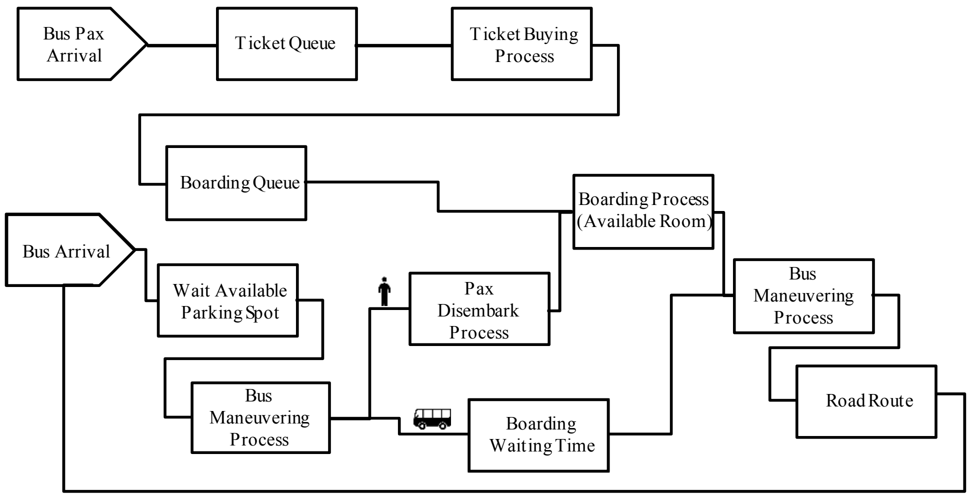

Figure 2 - Bus DES operational model.

4.1 SD Modeling

The logic of the continuous model is related with the capture of the behavioral dynamic of the crossing passengers transportation mode's choice. The SD model was developed based on the "Bass Diffusion" model, created by Bass (1969) to explain the adoption of new products based on the relationships between users and non-users.

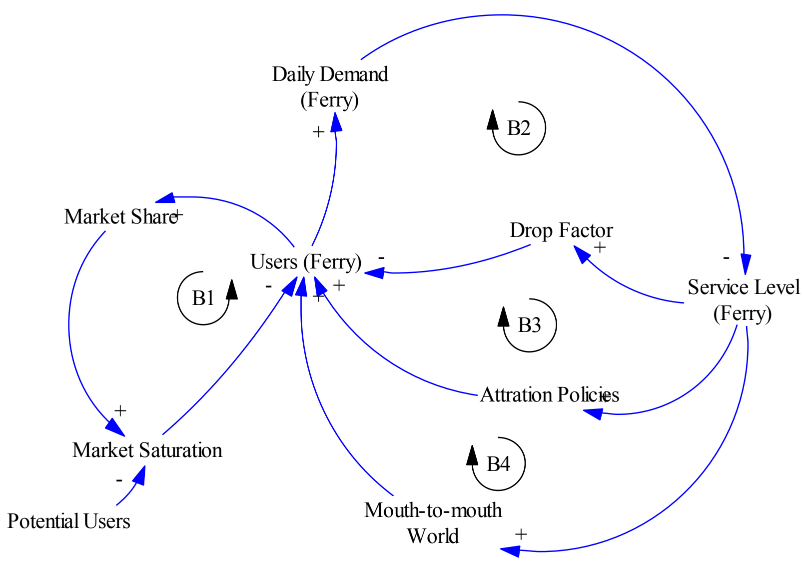

Figure 3 - Causal diagram of SD model of behavioral dynamic of passengers transportation mode choice, based on word-of-mouth concept.

The choice of transportation mode by passengers (ferry , bus or car) is assumed to be fully rational and is determined based on three parameter values: travel time, comfort level, and price, compiled into a single index of service level. Based on the comparison of this index, the passenger chooses the transportation mode with best satisfaction payback. The causal diagram of the decision model is presented in Figure 3.

Figure 3 presents only the ferry transportation mode option. The other modes have an identical causal loop diagram and thus will be omitted. The diagram represents the following relationships:

- The *Number of Transportation mode Users* (that will be presented as a level on the stock and flow diagram), represents the *Daily Demand* of the transportation mode, and is directly influenced (all else equal, if X increases (or decreases) the Y increases (or decreases) above (or below) what I would have been (AEE)) by the *Attraction Policies* and the *World-of-Mouth*;
- The *Attraction Policies* represent the incentives of public policies;
- The *World-of-Mouth* represents the interaction and contact between different transportation mode users, that share experience on their travels performance;
- Both are directly influenced (AEE) by the transportation mode current *Service Level*;
- Also, the *Service Level* inversely affects (AEE) the *Drop Factor*, which is the factor that represent the percentage of users changing behavior, leaving the current transportation mode option and choosing to use a different transportation mode. This relationship is represented in **Error! Reference source not found.**.
- The loop (B1) represents a balancing loop of the transportation mode utilization, that limits the transportation mode utilization infinity expansion;
- The *Number of Transportation mode Users* affects directly the transportation mode *Market Share,* and consequently causes *Market Saturation*, which is a global measure that indicates the total market current "occupation";
- The *Market Saturation* is related with the *Number of Transportation mode Users* once it affects the users model choosing behavior.

All those relationships are ruled by non-linear behavior that, due length restriction won't be presented in the current work. The causal loop diagram in Figure 3 gives birth to the a stock and flow diagram presented in **Error! Reference source not found.** (next page). The differential equations of the model won't be further formally described as they are not part of the main scope of this work.

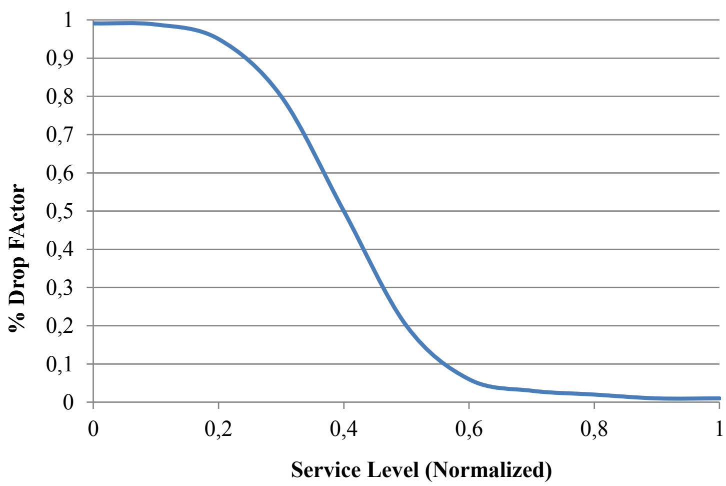

Figure 4 - Service level x drop factor relationship (proposed by the author).

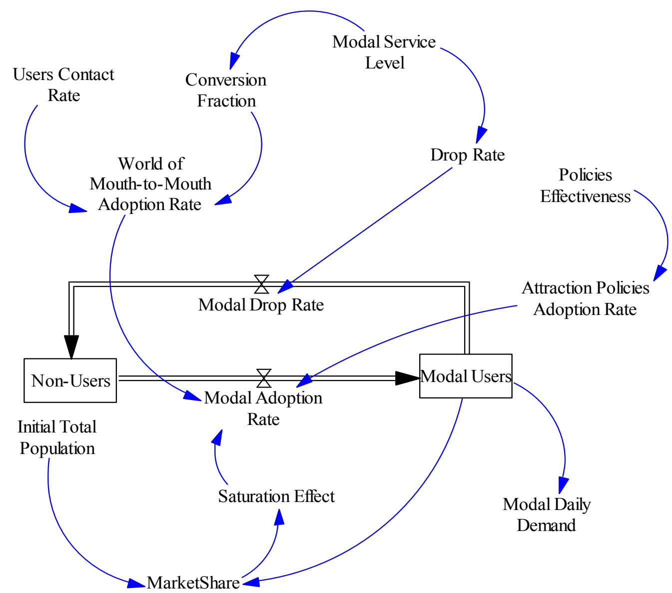

Figure 5 – Stock and flow diagram of behavioral dynamic of passengers transportation mode choice.

4.2 Integration between the DES and SD models

The methodology combination purpose is to create an application environment that is able to expand the model scope and contribution potential. A key element in this methodology is thus the integration between the SD and the DES models. To integrate the models, a user's satisfaction function evaluation methodology is proposed considering the following variables:

- Total Travel Time: extracted from the DES model results, all operational and waiting times are considered.
- Comfort Level: also extracted from DES model results, is determined by the average level of utilization rate of the different transportation modes.
- Cost: variable associated to the total usage cost of each transportation mode.

The calculations of the above variables are obtained directly from the performance evaluation of the DES model and are then transmitted to the SD model, which inputs calculates the service level of each transportation mode.

The flow of the integration between the SD and DES models also occurs reversely. The SD model generates a value for the daily demand of each transportation mode (equal to the value of the stock "Users"). This value, converted into a arrivals distribution rate is used as input for the DES model.

5 HYBRID MODEL APPLICATION AND RESULTS

The parameterization of the initial values of the basic variables of the DES and the SD models is the first step of the model application. Those initial variables are presented in Table 1. To illustrate the model application, an evaluation of the effects of a ticket price policy is presented. The initial baseline values of the ticket prices of the model is :

- Bus Ticket Price: $ 2.50
- Ferry Ticket Price : $ 2.50

In this scenario, the number of auto users remains, during all simulation run, higher than the number of ferry and bus users. This scenario is illustrated in Figure 6 (next page). This basic scenario indicates a trend toward users preference for individual over public transportation modes.

Figure 6 also reveals that there is a direct link between the service level and the growth or decline of total users of each transportation mode. The service level, the way it is proposed in this work, represents a comparison element between the operation efficiency of each transportation. So it does not reflect an absolute measure, but a relative measure among mode choices. Based on that, the user will decide to how to cross the bay. If the service level offered by modal is relatively higher compared to other, the trend is that the number of users grow (the opposite statement also holds true).

Table 1- DES and SD model's variables.

DES Model
· Routes
· Distances
· Average Speeds
· Transportation Infrastructures
· Tickets Booths
· Toll Booths
· Average Service Times
· Available Platform Spots
· Fleet Size
· Operational Times
· Entering Maneuver
· Exit Maneuver
· Maximum Waiting Time
· Capacities
· Maximum Transportation Modes Capacity
· Ratio Pax/Auto
· Users Costs
· Ticket Price
· Toll Price
· Gas Price

SD Model
· Initial Number of Users
· Total Population
· Contact Rate
· Conversion Fraction
· Policies Effectiveness

Unquestionably, a number of physical parameters of model might be evaluated to understand this behavior based on a detailed comprehension study of the performance of the system. However, the suggested intervention contemplates exclusively a new price policy for mass transportation, everything else constant. The new values of the ticket prices of the model are :

- Bus Ticket Price: $ 1.50
- Ferry Ticket Price : $ 2.00

In this new scenario (illustrated in Figure 7 – next page) the number of auto users remains during most of the simulation run, higher than the number of ferry and bus users. The number of ferry users however rises and remains close to the number of auto users (during some periods, it is even higher). This result indicates that a pure price policy application isn't enough to surpass the users preference for individual over public transportation modes. Probably the other factors of users decision making considered in this model (the comfort level and travel time) tend strongly to benefit the auto choice.

Based on that, further policies maybe proposed, such as an infrastructure investment policy - aiming at reducing travel and waiting times, or a combination of both.

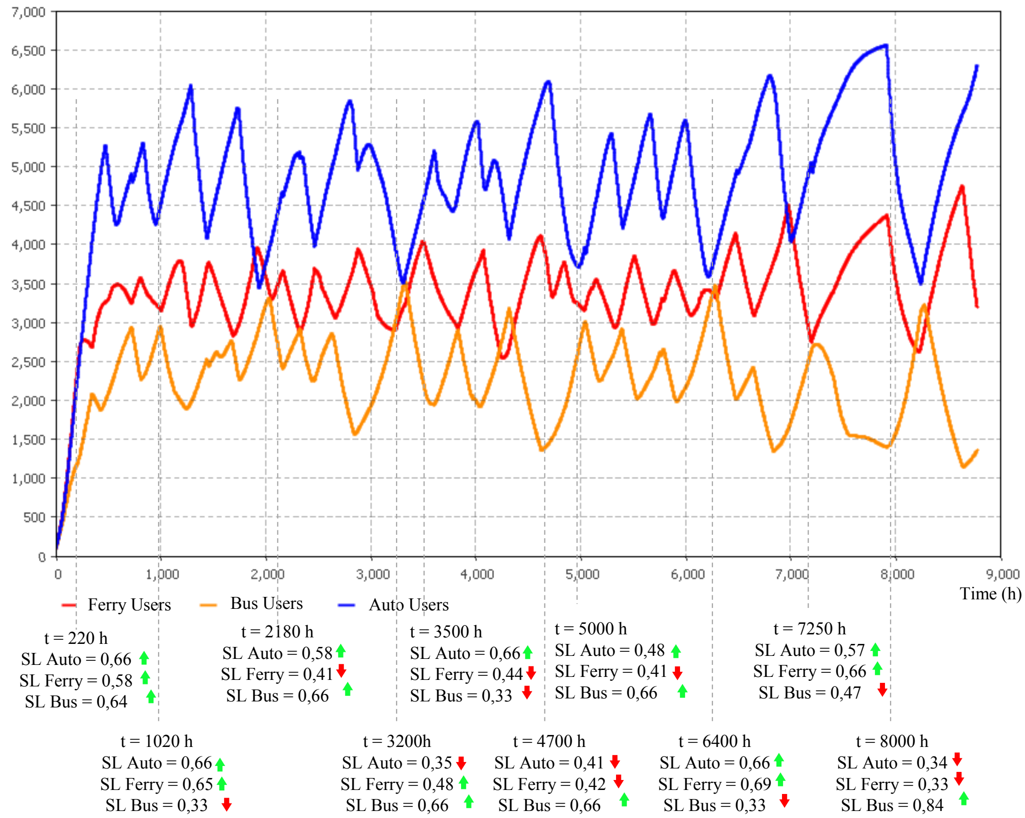

Figure 6 – Number of users of each transportation mode – basic scenario averages.

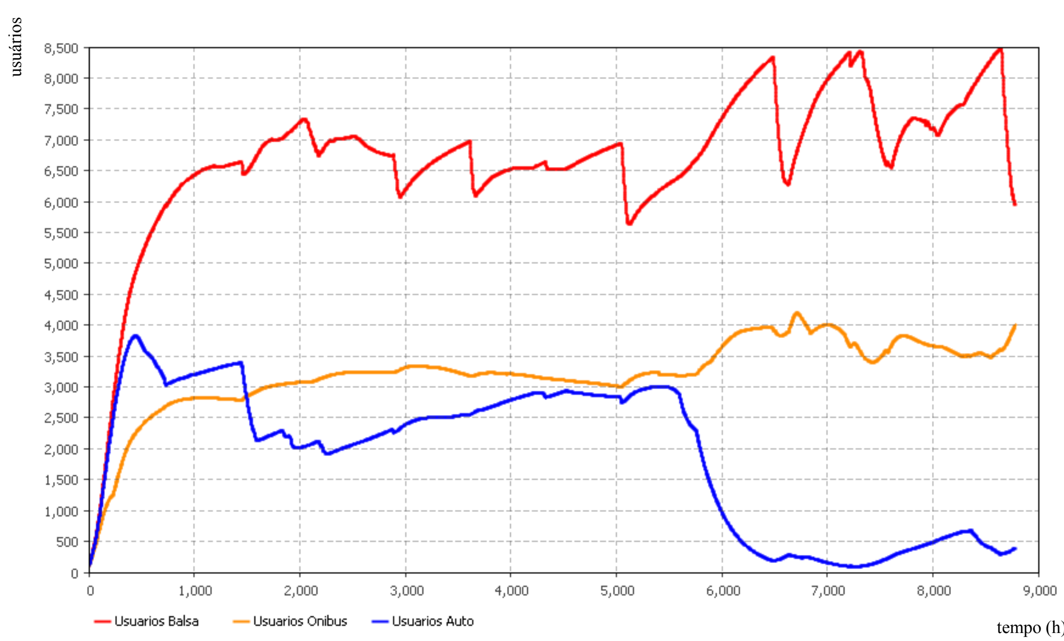

Figure 7 – Number of users of each transportation mode – new price policy scenario.

6 CONCLUSION AND RECOMMENDATIONS

This work concludes that an effective contribution approach between paradigms is possible. It is not the possibility of working with both paradigms simultaneously, but the process of assuring an effective exchange of information between paradigms that ensures advantage of an hybrid simulation methodology against discrete or continuous simulation alone. All previous works in literature state the need for development of hybrid simulation methodologies but with no effort on assuring this information trading.

In the model developed, the DES should be responsible to handle the physical aspects of the system such as travel distances, times, resources allocation, resources sizing, and other, and it output is a function of the user satisfaction level. On the other hand, the SD model should be responsible to handle all the policy aspects of the system, such as the users choice, interaction between users and the market behavior, and its output is the daily demand of the different transportation modes. The DES output serves as input to the SD model and vice-versa.

The basic scenario evaluated reveals a trend toward users preference for individual over public transportation modes. Based on that result, and aiming at testing if the model would answer to a different policy determination, the work conducted an sensitivity analysis of one the users decision variables – the travel price. The objective was to test if the determination of an public transportation incentive policy via public transportation price reduction would be effective in changing the individual transportation preference panorama.

The results suggest that the policy is able to approximate the number of individual transportation mode and the number of ferry users, but not able to overcome the users preference for individual over public transportation modes. Based on that successful application, this work concludes that the proposal of application potential investigation of the hybrid simulation methodology is fulfilled. Other studies and sensibility analysis might be carried to test either interferences on decision policies or new physical configuration of the system such as: infrastructure expansion and modernization, toll price raise, fleet expansion, etc. or any combination.

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