A Multi Simulation approach to develop Physical Internet.

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Abstract:
The Physical Internet (PI) concept has many different connotations at various levels of business, from the strategic point of view of the company, the horizontal collaboration with other companies, down to the operational integration of the processes. Complexity reduces the sense of control in the logistics operation. These intricate relationships of PI make logistics flows more complex, but the final result from a point of view of resources is a more efficient and environmentally friendly process. This paper describes how the use of different types of analytical models and simulation models could help to create trust and confidence around the PI concept. The simulations help to analyse business models, to evaluate the relationship between the main variables, to visualize the flows, to understand the dynamics of the processes and to evaluate numerically the impact of the new flows of products.

Keywords: *discrete event simulation, system dynamics, multi-agent simulation, multi-simulation.*

1 Introduction

Simulation is used in many different disciplines and application areas. In the domain of production and logistics, simulation is a well-accepted tool for the planification, evaluating and monitoring relevant processes. The relationships between stakeholders under PI concept is complex due to the considerable amount of interactions, high variety of products, different operations, many types of transport and different information systems. There are different simulation techniques useful to represent the product flow under the PI framework: System dynamics, Discrete event simulation and Multi-agent simulation.

System dynamics (SD) is an approach to understand the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delay. It is a method to enhance learning in complex systems to help us learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies Sterman (2004). It is a computer-aided approach for analysing and solving complex problems with a focus on policy analysis and design. Much of the strength of System Dynamics comes from its ability to be used in two related, but different ways Coyle (1996). On the one hand, it can be used qualitatively to portray the workings of a system as an aid to thinking and understanding. On the other, the diagram can be turned into a simulation model for quantitative simulation and optimization to support policy design.

Simulation is the imitation of the operation of a real-world process or system over time. Discrete event simulation (DES) works by modelling system state changes occurring at specific points in time, which are probabilistically determined by historical data. Simulation involves the generation of an artificial history of system and observation of that artificial to draw inferences concerning operating characteristics of the real system that is represented.

Multi-agent simulation (MAS) or Multi-agent-based modeling (MABS) is a branch of computer simulation where multiple intelligent agents, capable of independent action and interact within environments that are typically dynamic and unpredictable. This technology is well suited to model systems with heterogeneous, autonomous and pro-active actors, such as human-centred systems where a software system (software agent) does something often on behalf of a person. Multi-agent systems are designed to handle changing and dynamic business processes.

2 Framework description

This paper describes a framework to integrate different types of models and simulation techniques to build trust around the PI concept and to assess the concept under different scenarios. This framework has two levels to deal with the high complexity. The first level is the strategic level, as it is shown in Fig 1. It is a representation of the whole picture of the PI model, but with a reduced level of detail. Only the main factors are included. The flow of material and the flow of information is important at this level. Also the links between stakeholders and the time dependencies and delays in the processes. The best simulation technique to deal with this type of elements is system dynamics.

In system dynamics models the ratios are used to describe the flows and the process involved. This values, or ratios must correspond with the values in the real world. Thus it is important the connection between the strategic level and the operational level with a feedback mechanism to keep updated these values.

At the operational level, the level of detail required is higher, and additionally, the different models needs diverse analytical models and simulation techniques. In this level we can find various processes which are interconnected between them like the supply chain strategies, the transportation modes and routes, the handling operations at the distribution center or the behavior of the final customer. Depending on the sector additional elements could be added to this framework.

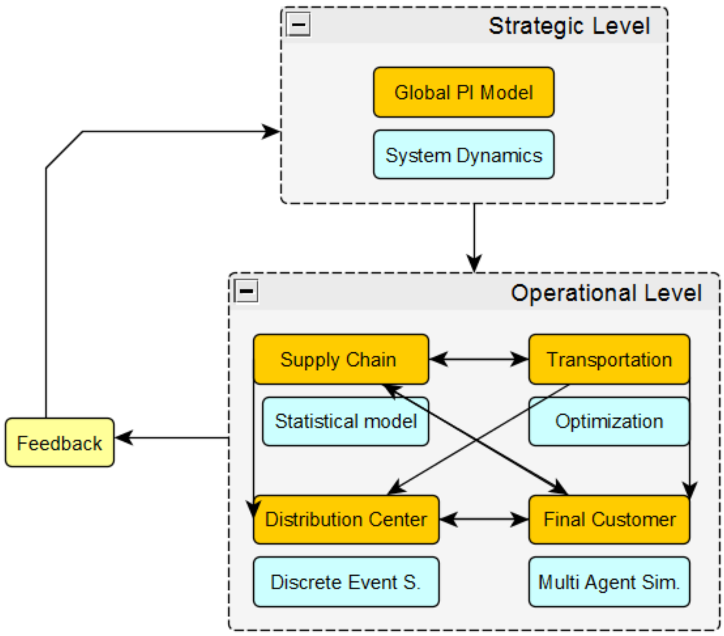

Figure 1: Multi-Model Physical Internet Framework

3 Simulation Models

In the following lines we show some examples of different models that can be used to represent the elements in a Physical Internet framework.

3.1 Global System Dynamics

The system dynamics (SD) method has proved to be particularly good at supporting a strategic point of view, in the sense of matching very closely the concerns of top-level decision-makers. By supporting the modelling of the forces underlying a system's evolution into the future.

System dynamic models allows to evaluate the representation of high level of the processes. Physical Internet flows are complex. SD technology allows to represent the dynamic through a stock and flow diagram. The diagram shows the relationship between the main variables that influence the dynamics of these flows and feedback from other point from the flow. With these models the user can easily evaluate the effect of small changes in the parameters on the global behavior of the system.

The flow in this model could represent, for example, the flow of products in different distribution channels, or the number clients in a certain region. The variables used in these models are related to objectives like service level objective, effect of delays in deliveries or price variations. Through this representation we can evaluate the impact changes in the behaviour. They can make the flow increase, decrease, or because of some decisions the behavior begins to oscillate.

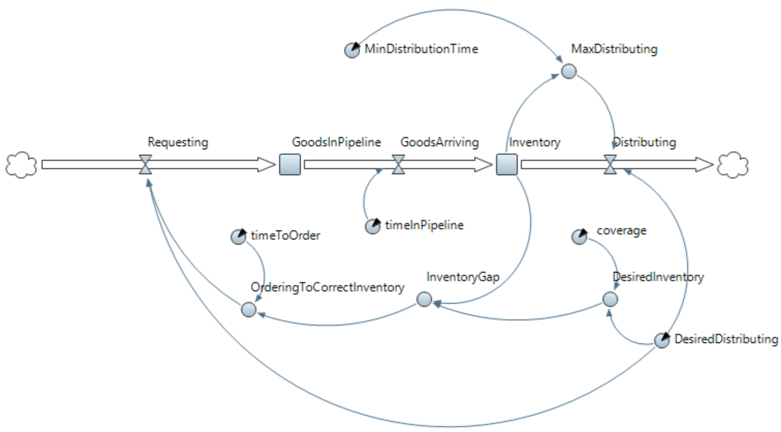

Figure 2: System dynamic supply chain representation

3.2 Supply Chain

Simulation and statistical models are often used to get a better distribution network design. One of the applications of supply chain simulation consists of an impact analysis of Vendor Managed Inventory. Production lot-sizing has a great impact on inventory, particularly under seasonal fluctuations of demand and constrained production capacity. Many companies adopt the MTO (Make To Stock) policy in which products are not built until a confirmed order for products is received by the manufacturer. Other companies maintain high levels of inventory (stock) to face periods of uncertain demand. However, a production schedule which does not adjust accurately the real demand may lead to overstocks for some products and stock-outs for other. Inventory sizing by product is especially important under uncertainty, when the inventory is necessary to guarantee a service level in a stochastic environment. One of the

integration practices that can contribute to reduce inventory in the supply chain is Vendor Managed Inventory (VMI). VMI programs allow for consumer demand information to be disseminated up the supply chain, thus mitigating upstream demand fluctuations due to the bullwhip effect Govindan (2015) and Kwangyeol (2013). Due to this demand anticipation, VMI may allow to reduce logistics and manufacturing costs, reduce overall leadtimes, improve service level and reduce transportation costs.
With a simulation model under a PI framework we compare the performance of VMI and MTO strategies in the two-echelon serial supply chain with finite production capacity Kwangyeol (2013). The purpose of using simulation is to provide a simplified environment into which a number of situations and ideas can be tested. From the simulation outputs, the effect of the strategies on manufacturing on-costs, inventory holding costs and transport costs will be quantified and discussed.

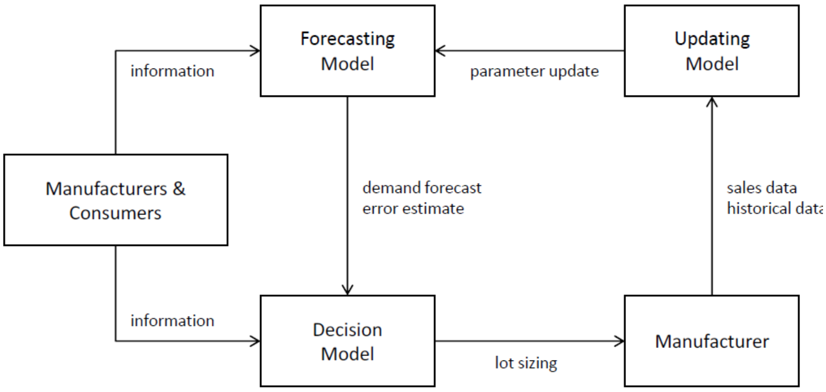

Figure 3: Information flow in a supply chain model

The model simulates the collaborative VMI, taking profit from the PI advantages, and traditional supply chain MTO strategy in a scenario which previously has been configured with the forecasted demand of the customer. During the rolling horizon, the designed network of supply chain makes replenishment orders to cover the forecasted demand with the objective of minimizing the total costs. Decisions made by each customer individually affect in the decisions taken in the assigned manufacturers in terms of inventory levels and quantity production. The simulation of the supply chain policies requires to previously forecast the demand for each day of the rolling horizon. Capturing the time-varying stochastic patterns within the replenishment policy is a key factor in order to ensure cost minimization.

3.3 Transport

Regarding the transport network, the main idea is to capture the main concepts of passenger transport and translate them into the freight distribution. Physical Internet should not only be fed by the network performance but also for other transport status. In the following example we propose a freight transport network similar to the carriage of passengers.
In a PI network the nodes represent the distribution centers, or warehouses, the starting and ending point of the movements. Between two nodes, there exists a set of connections, each one with a mode of transport (bus, train, car), and certain capacity (volume, number of seats, etc) and a set of frequencies. The set of frequencies may be represented as a weekly basis with their timetables.
When we have to design the optimal way to transport one order from an origin to an destination, as done in Royo (2016), as well as we do when searching for a passenger trip. In addition to this, the orders must be served inside the boundaries of their corresponding time windows, although the waiting time is allowed on certain defined occasions. As a general

rule, we always select the shortest path with the minimal cost, measure as a global function with money, time and quality service.
This is what we have done with the long distance simulation model: get inspired by the passenger decisions and deploy transport network to "route" orders. But here we face with a small but challenging issue: a passenger only thinks on her/himself. Nevertheless, the system deployed think on "all the passengers" (all the orders).
This research objective is to find the least distance to serve all the orders of the customers selecting the lowest way under different boundary conditions and constraints values.
The figure 4 shows an example of our long distance transport network: three warehouses and two connection. Each warehouse node is enriched with arrival or departure type and a date. This way, the future optimization algorithm does not have to consider this constraints during the execution time. Besides that, this approach let experts to enhance the warehouse with other valuable information, depending on the environment of the problem.

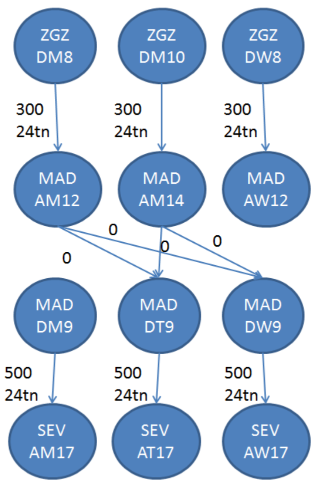

Figure 4: Transport Network representation

Virtual graph as a result of exploitation of the main network. As can be seen, the links between the virtual nodes represent real connections with a demand, date and travel time. The virtual graph can be used an input for the optimization algorithms as Dijkstra's Algorithm. This way, the system could find an optimal way from the order origin to the final destination just by adding a temporal virtual node and linking it with the corresponding departure.

3.4 Distribution Center

The simulation includes the physical model of the layout and the most important rules of dynamics behavior of the resources used in the facility.
In Chackelson (2013) we can find that the warehouse design has become important due to its impact on service to customers and total logistics costs. Order picking is the key activity of a warehouse and an appropriate design will directly affect its overall performance. The increasing complexity of warehouses means that the main operating strategies such as storage location assignment, batching and routing need to be considered simultaneously. A Design of Experiment (DOE) approach aided by Discrete Event Simulation could help to meet these new picking design process requirements. With the DOE the relationships between the main variables are obtained. This data could be used in other network simulation or in the Supply chain dynamics.

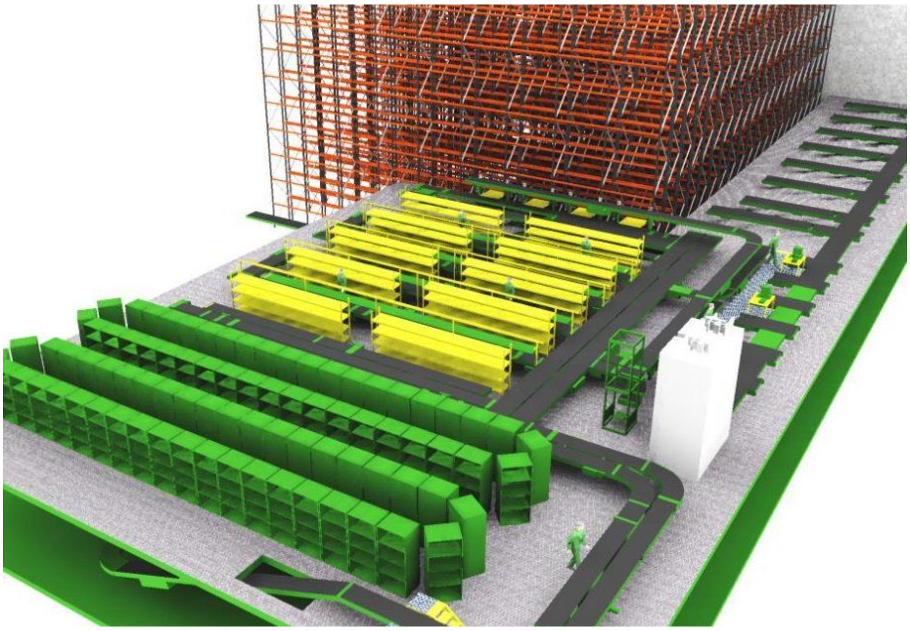

Figure 5: Discrete event simulation from a distribution center

Won and Olafsson (2005) have highlighted that although previous research traditionally focuses on improving system throughput (total picking time and effective use of equipment), the primary concern of customers is often fast delivery of their orders (order maturity time). Nevertheless, it is possible that some initiatives to improve one of these performance measures might impact negatively on other order from the PI framework. In this context, analysing performance evaluation trade-offs is an important task in order to align warehouse efficiency measures with PI customer requirements.
This type of simulation is very interesting to evaluate the performance from new handling strategies related with Physical Internet like handling operations related with PI-containers, cross-docking operations, multi-client picking strategies or consolidation process to increase the fill factor.

3.5 Customer behavior

Due to effects like the high level of globalization and short product launch cycle the behaviour of customer is not easy to anticipate. There is a need of new tools allowing to take the key element of such consumer-centric production systems, such as people and their behaviour, into account when trying to understand and predict the behaviour and performance of these systems. The behaviour of humans differs notably among people and therefore the heterogeneous and diverse nature of the actors needs to be taken into account during the service design and the processes to provide de services. At this point is where multiagent simulation systems and technologies play a key role.
A particular consumer-centric domain where people's behaviour has a huge impact in production systems and logistics services is Ecommerce. Ecommerce represent a revolution not only for retailers but also for Logistics Service Providers (LSPs) in terms of range of products, order fulfillment, delivery points, time windows restrictions or returns processing among others.
For this reason this paper proposes MAS as one of the key technologies that will help to assess, analyze and support the business decision process taking into account the buyers and end users behaviour and much more in a collaborative approach proposed by physical internet paradigm integrating the conduct and the performance of each stakeholder involved in the delivery of goods between producers and customers along the supply chain.

There are several logistics processes and activities that can benefit from MAS. From a tactical perspective, simulating and understanding buyers behaviour, their motivations and their habits can improve the predictive analysis and demand forecasting processes, that represent the starting point and the source of information for downstream processes. Once the forecast provides more accurate information companies can manage the uncertainty and enhance their planning processes regarding inventories, logistic-facilities such as warehouses or distribution centers, human resources or fleets of vehicles.
From an operational point of view the results and conclusions from these multi-agents simulation systems could help to take complementary decision at day or shift level such us: change cutoff times, production scheduling, order batching fulfillment, time windows restrictions, route calculation, deliveries and collection integration or vehicles assignment.

4 Conclusions

This paper describes a framework to evaluate different aspects of the Physical Internet framework to build trust among stakeholders and to assess the concept under different scenarios and conditions. It shows examples from the strategic point of view and from the operational point of view to help to identify the critical points and generate confidence for companies to be involved

The strategical level, deals with socio-economics aspects from the PI initiative. These models are mainly designed through the high-level relationships that exist between the business variables and the flows of goods and resources. The models at this level are evaluated under the technique of dynamic systems.

The operational level evaluates the process with a higher level detail. In this layer the processes are evaluated from the supply chain point of view, from the supplier to the final consumer (machines, conveyors, containers...). These models include information of products and, especially, on process attributes like process capacity, vehicle occupancy, travel times, productivity ratios, etc. In this level it is also important to consider the behavior of the agents involved in the supply network.

The combination of all this powerful simulation tools gives a complete vision from the complexity of PI flows. The feedback between this models helps the analyzer to take into account multiples input from different processes.

As final remark is important to mention the importance of involving different people, which are related to the decisions about Physical Internet flow, in the development and validation of the models, to create confidence, to evaluate the risks and to detect problems of integration in the early stages.

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