SIMULATION-BASED ANALYSIS OF THE BULLWHIP EFFECT UNDER DIFFERENT INFORMATION SHARING STRATEGIES

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KEYWORDS

Bullwhip effect, Supply chain simulation, Information sharing strategies, Inventory control policies.

ABSTRACT

This paper describes the impact of two different information sharing strategies – decentralized and centralized information – combined with two inventory control policies – min-max and stock-to-demand inventory control – on the bullwhip effect. To investigate and measure this impact, simulation models are developed using the Arena 5.0 software package for a four-stage supply chain, consisting of a single retailer, wholesaler, distributor and manufacturer. The experiments with the developed models are described and the results are analyzed.

INTRODUCTION

Inventory control plays an important role in supply chain management. It is concerned with how much and when to order from the supplier. The first policy that will be used in the simulation models presented in this paper is min-max inventory control. It is a variant of the classical reorder point model. The main concept of this policy is that the inventory level is continuously monitored and as soon as the inventory level drops below the reorder point a replenishment order will be triggered. The second policy, stock-to-demand inventory control, is a variant of the periodic review model. The inventory level will be reviewed at predetermined time intervals. At this review times, an order will be placed to get the inventory back up to a target level.

In order to determine the parameters of the inventory control policy, one needs to forecast demand. The amount of information available for a company in the supply chain will determine the accuracy of the forecast of mean demand and of the forecast of the standard deviation of demand. According to Simchi-Levi et al. 2000, each stage in the supply chain forecasts demand based on the orders it gets from the downstream stage in the decentralized information sharing strategy. By downstream we mean in the direction of the end customer. In the centralized information sharing strategy, all stages have access to data about actual end customer demand and can base the forecast of demand on the actual end customer demand data, instead of on the orders from the downstream stage. We will compare the different strategies from the point of view of the bullwhip effect.

The bullwhip effect is an important observation in supply chains and suggests that the demand variability increases as one moves up a supply chain, towards the manufacturer or supplier of raw materials.

In the second section, the background, the importance of the bullwhip effect as research topic will be demonstrated. The section 3 on conceptual models will treat the logical and mathematical formulation of the model. The section 4 on model logic in Arena is about the features specific for the Arena implementation. The experiments and their results are described in section 5.

BACKGROUND

As markets tend to be more and more customer-oriented, the uncertainty connected with end customer demand and its consequences in the supply chain have become an important subject for research. The bullwhip effect is caused by this uncertainty, and several researchers have identified causes to this effect and have tried to propose methods to minimize it.

Chen et al. 1998 and Lee and Padmanabhan 1997 have discussed the main causes of the bullwhip effect. In this paper, we will try to reduce the bullwhip effect using information sharing strategies (centralized information) and breaking order batches (changing the frequency of reordering using two inventory control policies).

Due to the uncertainty and complexity inherent in a supply chain and in inventory control systems, simulation was found a suitable tool to analyze the bullwhip effect (Banks and Malave 1984). Especially the combination of the high-level simulation tool Arena and the procedural programming language Visual Basic for Applications (VBA), proved its usefulness to simulate the systems presented in this paper. The model logic can be represented comprehensibly in Arena, while the more complex calculation algorithms can be programmed in VBA.

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CONCEPTUAL MODELS

The combination of two information sharing strategies and two inventory control policies results in four models. The four-stage supply chain used in these models, can be seen in Figure 1, where the solid lines represent the models with a centralized information structure; the striped lines are specific for the models with a decentralized information structure. This figure illustrates that in the decentralized information structure, the demand forecast is based on the orders a stage gets from the downstream stage. In the models with centralized information structure, the demand forecast is based on the actual end customer demand.

This demand forecast will be calculated as the moving average of the demand during the last ten periods. The same observations will be used for estimation of the standard deviation of demand.

In the min-max inventory control policy, a replenishment order will be placed as soon as the inventory level drops below the reorder point. The order size is the difference between a target level, and the effective inventory level. It is important to remark that replenishment triggering will be based on the effective inventory level, which is the quantity on hand plus the quantity on order minus the unshipped backorders to customers or the quantity allocated to production.

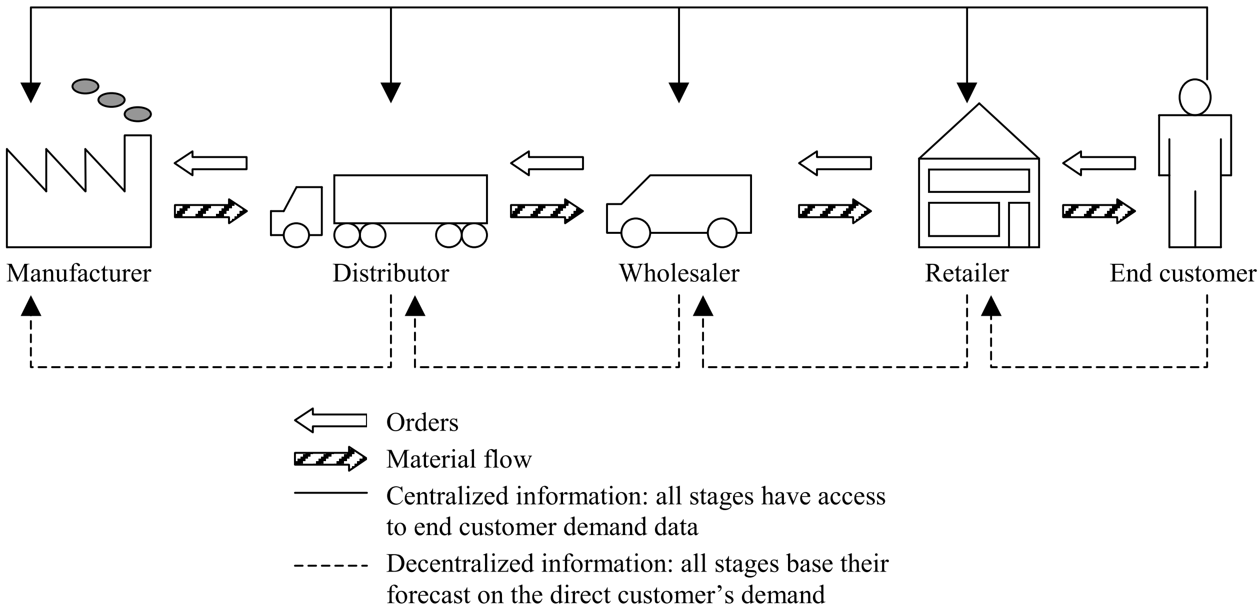

Figure 1: Conceptual Model

Based on Ballou 1999, the reorder point (ROP) and target level can be calculated as:

$$ROP = d * LT + Z * \sigma_d * \sqrt{LT}$$

$$Target = ROP + EOQ$$

where

$EOQ = \sqrt{\dfrac{2 * d * OrderCost}{HoldingCost}}$ – economic order quantity;

d – the forecast of average weekly demand;

LT – the lead time;

Z – the safety stock factor, based on a defined in-stock probability during the lead time;

σ_d – estimation of the standard deviation of the weekly demand.

The target level is calculated as the reorder point plus the economic order quantity (EOQ), where OrderCost is the fixed cost for placing an order and HoldingCost is the cost to hold an item in stock during one week.

Under the stock-to-demand inventory control policy, stages will place orders with their suppliers in accordance with a predetermined review period. The order size is the difference between the target level and the effective inventory level at the review time. According to Ballou 1999, the target level can be calculated as:

$$Target = d * (LT + T_r + T_{ss})$$

where

T_r – the review period;

T_{ss} – the safety time.

This safety time represents the safety stock, and is expressed as a number of weeks of average demand. Its value is a managerial decision.

SIMULATION MODELS IN ARENA

The general structure of the Arena models is identical for all four models. However, the calculation of the demand forecast and the inventory, as well as the reordering trigger is different for different models, as was indicated in the previous section.

Certain model parameters had to be chosen. End customer demands arrive with fixed time-intervals of one week. Their size is variable and is derived from a normal distribution with mean = 100 and standard deviation = 30. A constant lead time of 2 weeks will be assumed. No order processing delay is taken into account, so all demand events are treated immediately by the upstream stage. We also will assume no capacity constraints for the manufacturer. The estimation of average demand and of standard deviation of demand will be based on demand data from the ten previous weeks.

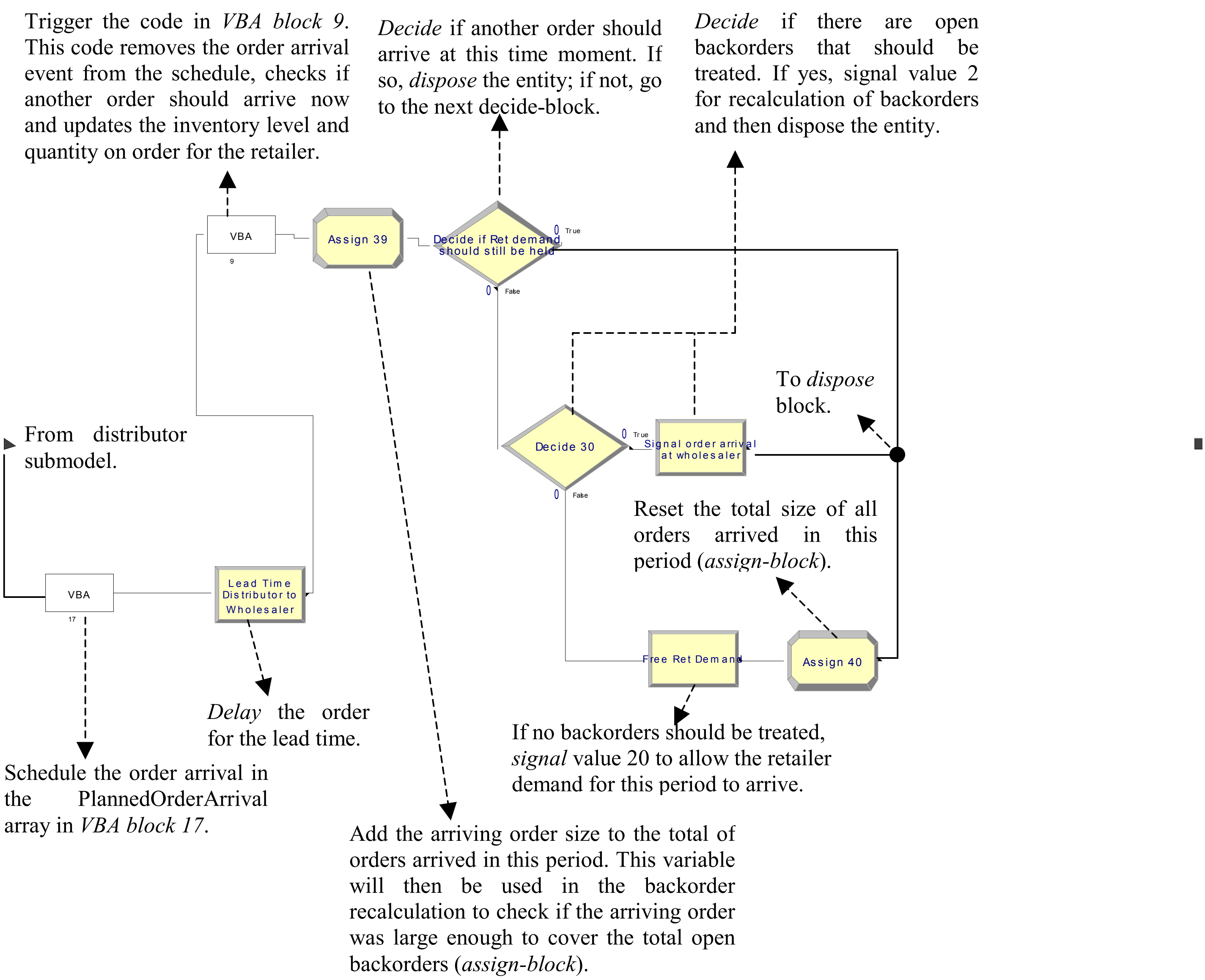

Figure 2: Submodel of Order Shipment to Wholesaler

If several events are scheduled to occur at a certain stage at the same simulation time, there is a fixed order in which the events should be processed:

1. order or backorder arrival from upstream stage (stock replenishment).
2. fulfilling of backorders (only if an order has arrived)
3. new demand fulfilling.

As Arena's simulation engine didn't always process the events in this order (Kelton et al. 2002); a procedure had to be developed to guarantee that events are processed in the mentioned order. Wait and Signal blocks formed the basis of the implementation of this procedure in Arena. Implementation in Arena of an order shipment procedure from the distributor to the wholesaler is shown in Figure 2.

Another important choice to be made concerned stockouts. In these models, stockouts will not lead to lost sales, but to backorders. We thus assume that we have loyal customers. The calculation of backorders was modeled in detail. An example of the backordering procedure implementation for the wholesaler in Arena can be seen in Figure 3.

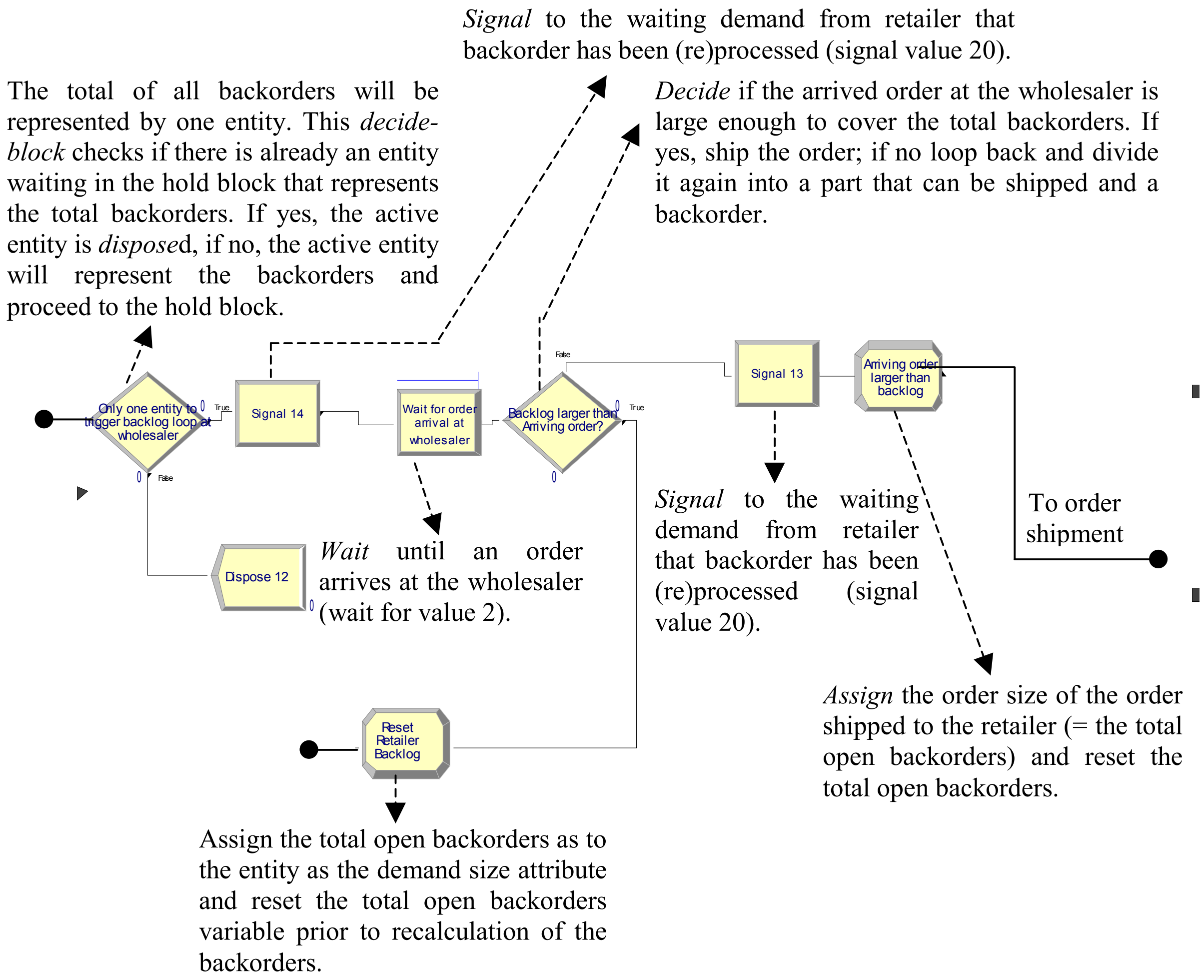

Figure 3: Wholesaler Submodel: Backordering Procedure

RESULTS

It is important that the simulation results are independent from the empty-and-idle initial state. In addition, there is no predetermined starting and finishing point for a simulation run of the system under study. Therefore the simulation study conducted is a non-terminating system study. After the determination of the warm-up period, all models were run for ten replications, each replication lasting for 10,000 weeks.

As measures of performance for these experiments, the standard deviations of demand between stages, the service levels at all stages, and a measure for the bullwhip effect over the entire supply chain will be calculated.

The standard deviations of demand between stages identify if the bullwhip effect is present. If this is the case, a measure for the bullwhip effect over the entire supply chain is determined.

The measure of the bullwhip effect over the entire supply chain for the i-th replication can be calculated as

$$\Delta_i = \frac{\sum_{s=1}^{5} \left(\sigma_{s,i} - \overline{\sigma}_i\right)^2}{4}$$

where

$\overline{\sigma}_i = \frac{\sum_{s=1}^{5} \sigma_{s,i}}{5}$ - the arithmetic average of the standard deviations of demand between stages and $\sigma_{s,i}$ – the standard deviation of demand between stage s-1 and s.

Here stage s=0 is the end customer and stage s=5 represents the manufacturer's production facility, while stage s=4 is the manufacturer's stock point.

This measure takes into account differences in standard deviation of demand between stages; these differences give an indication of the seriousness of the bullwhip effect.

The results of the simulation runs are represented in Tables 1, 2 and 3. The standard deviations of demand are also shown in Figure 4.

Table 1: Standard Deviations of Demand between Stages over all Replications

Standard deviation of demand				
Stage	Decentralized information		Centralized information	
	Min-max	Stock-to-demand	Min-max	Stock-to-demand
End customer demand	29,911	29,891	29,911	29,911
Retailer demand	202,100	46,571	202,100	46,591
Wholesaler demand	259,003	73,661	230,603	63,191
Distributor demand	332,513	109,502	245,603	78,061
Manufacturer demand	428,314	150,203	254,301	91,241

Table 2: Overall Measure of the Bullwhip Effect for each Replication

Overall measure bullwhip effect				
Replication	Decentralized information		Centralized information	
	Min-max	Stock-to-demand	Min-max	Stock-to-demand
1	22423,7	2351,2	8557,1	600,7
2	22108,7	2332,9	8713,4	595,8
3	23086,1	2364,3	8569,4	591,0
4	22385,2	2432,3	8687,8	602,9
5	22157,7	2392,7	8674,6	594,2
6	21676,9	2362,1	8634,5	581,2
7	22650,1	2335,2	8697,9	599,8
8	22691,9	2393,5	8750,1	595,9
9	21961,6	2333,9	8647,7	596,7
10	22421,3	2322,9	8618,3	595,4

Table 3: Service Levels for all Stages over all Replications

Service levels				
	Decentralized information		Centralized information	
	Min-max	Stock-to-demand	Min-max	Stock-to-demand
Retailer	0,999	1	0,999	1
Wholesaler	1	0,999	0,938	1
Distributor	0,992	0,973	0,911	0,999
Manufacturer	0,962	0,915	0,9	0,993

CONCLUSION

A first important conclusion to be drawn from the experiments is that in all four alternatives, the bullwhip effect is present. This means that we cannot eliminate the bullwhip effect by sharing end customer demand information, not even when we order every week. Under both inventory control policies, the models with centralized information structure give better results. The models using a stock-to-demand inventory control reveal better results than the models with min-max inventory control from the point of view of the bullwhip effect. This is mainly due to the choice of the review period, which was chosen as one week, leading to more frequent reordering and thus less batching of orders.

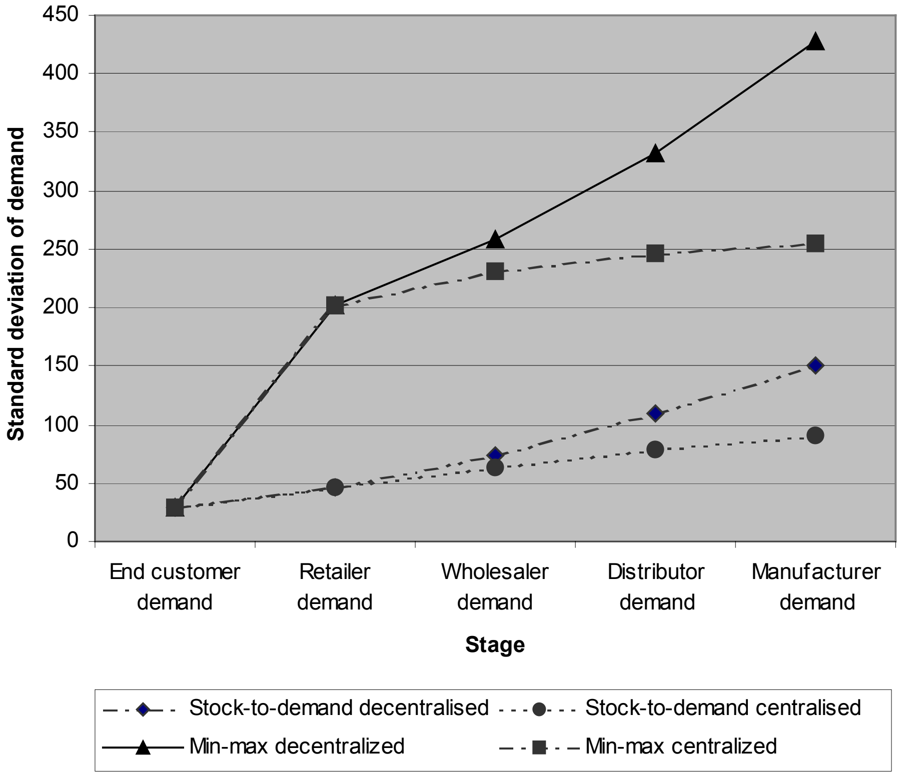

Figure 4: Standard Deviations of Demand between Stages

We can say that the model with centralized information structure and stock-to-demand inventory control gave the best results.

An important remark to the conclusions drawn above, is that no cost consideration was taken into account.

An important disadvantage of the measure of the bullwhip effect over the entire supply chain is that it does not take into account whether this difference is positive or negative. Further research will be aimed at the elimination of this disadvantage.

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BIOGRAPHY

YURI MERKURYEV is Habilitated Doctor of Engineering, Professor of the Institute of Information technology at Riga Technical University, Head of the Department of Modelling and Simulation. His professional interests include a methodology and practical implementation of discrete-event simulation, supply chain modelling and management, and education in the areas of modelling, simulation and logistics management. He is Programme Director of the curriculum "Industrial Logistics Management" at Riga Technical University. Prof Merkuryev has wide experiences in performing research and educational projects in the simulation area, at both national and European levels. He regularly participates in organising international conferences in the simulation area. For instance, he is Track Co-Chair for "Simulation in Logistics, Traffic and Transport" at the annual European Simulation Symposium. Prof. Merkuryev has about 180 scientific publications, including 2 books. He is a Board member of the European Council of the Society for Computer Simulation International, President of the Latvian Simulation Society, and Board member of the Latvian Transport Development and Education Association.