Hybrid Approach to Reliability and Functional Analysis of Discrete Transport System

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Abstract. This paper describes a novel approach of combining Monte Carlo simulation and neural nets. This hybrid approach is applied to model discrete transportation systems, with the accurate but computationally expensive Monte Carlo simulation used to train a neural net. Once trained the neural net can efficiently, but less accurately provide functional analysis and reliability predictions. No restriction on the system structure and on a kind of distribution is the main advantage of the proposed approach. The results of reliability and functional analysis can be used as a basis for economic aspects discussion related to the discrete transport system. The presented decision problem is practically essential for defining an organization of vehicle maintenance.

1 Introduction

Modern transportation systems often have a complex network of connections. From the reliability point of view [2] the systems are characterized by a very complex structure. The main issue of reliability considerations is to model the influence of these faults at a satisfactory level of detail. This analysis can only be done if there is a formal model of the transport logistics, i.e. there are deterministic or probabilistic rules on how the transport is redirected in every possible combination of connection faults and congestion. The classical models used for reliability analysis are mainly based on Markov or Semi-Markov processes [2] which are idealized and it is hard to reconcile them with practice. The typical structures with reliability focused analysis are not complicated and use very strict assumptions related to the life or repair time and random variables distributions of the analysed system elements. The proposed solution is to use a time event simulation with Monte Carlo analysis [1], [5] to train a neural net. Once trained, the neural net can efficiently provide functional analysis and reliability predictions. One advantage of this approach it supports the computation of any point wise parameters. However, it also supports estimating the distributions of times when the system assumes a particular state or set of states.

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2 Discrete Transport System Model

The basic entities of the system are as follows: store-houses of tradesperson, roads, vehicles, trans-shipping points and store-houses of addressee and the commodities transported. An example system is shown in Fig. 1. The commodities are taken from store-houses of tradesperson and transported by vehicles to trans-shipping points. Other vehicles transport commodities from trans-shipping points to next trans-shipping points or to final store-houses of addressees. Moreover, in time of transportation vehicles dedicated to commodities could fail and then they are repaired. In general, a system does not need to be equipped with any trans-shipping points. However, all system configurations need at least: one store-house of tradesperson, one road, single vehicle and one store-house of addressee [6], [7].

2.1 Commodities

The media transported in the system are called commodities. Different commodities are characterized by common attributes which can be used for their mutual comparison. The presented analysis uses the capacity (volume) of commodities as such attribute. The following assumptions related to the commodities are taken: it is possible to transport n different kinds of commodities in the system and each kind of commodity is measured by its capacity.

2.2 Roads

A road is an ordered pair of system elements. The first element must be a store-house of tradesperson or trans-shipping point, the second element must be a trans-shipping point or store-house of addressee. Moreover, each road is described by following parameters: length, the number of vehicle maintenance crews (at a given time only one vehicle could be maintained by a single crew) and the number of vehicles moving on the road. The number of maintain crews ought to be understand as the number of vehicles which can be on a single road maintained simultaneously.

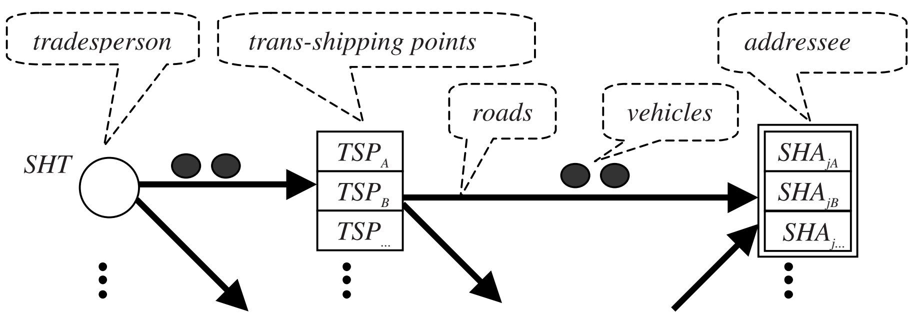

Fig. 1. Exemplar model of discrete transport system

2.3 Vehicles

A single vehicle transports commodities from the start to end point of a single road, after which the empty vehicle returns and the whole cycle is repeated. Our vehicle model makes the following assumptions. Each vehicle can transport only one kind of commodity at a time. Vehicles are universal – are able to transport different kinds of commodity. Moreover, the vehicle is described by following parameters: capacity, mean speed of journey (both when hauling the commodity and when empty), journey time (described by its distribution parameters), time to vehicle failure (also described an distribution), time of vehicle maintenance (described by distribution). The choice of distribution for the random variables is flexible provided that we know both a method and the parameters needed to generate random numbers with that distribution.

2.4 Store-Houses of Tradesperson

The store-house of tradesperson is the source of commodities. It can be only a start point of the road. Each store-house of tradesperson is an infinity source of single kind of commodity.

2.5 Trans-shipping Points

The trans-shipping point can be used as a start or end point of a single road. This is a transition part of the system which is able to store the commodity. The trans-shipping point is described by following parameters: global capacity C, initial state described by capacity vector of commodities stored when the system observation begins, delivery matrix $\boldsymbol{D}$. This matrix defines which road is chosen when each kind of commodity leaves the shipping point (1 means that a given commodity is delivered to a given road). On contradictory to previously described systems ([6], [7], [8]) in this case a commodity could be routed to more then one road (direction). The dimensions of the delivery matrix are: number of commodities x number of output roads.

Input algorithm:

only one vehicle can be unloaded at a time, if the vehicle can be unloaded the commodity is stored in trans-shipping point, if not – the vehicle is waiting in the input queue, there is only one input queue serviced by FIFO algorithm.

Output algorithm:

only one vehicle can be loaded at a time, if the vehicle can be loaded, i.e. the proper commodity is presented in trans-shipping point, (a commodity which could be routed to a given road), the state of trans-shipping is reduced, if not – the vehicle is waiting in the output queue; each output road has its own FIFO queue.

2.6 Store-House of Addressee

The store-house of addressee can be used only as the end point of a single road. The main task of this component of the system is to store the commodity as long as the medium is spent by recipient. The store-house of addressee is described by following parameters: global capacity *C*, initial state described as for the trans-shipping point, function or rule which describes how each kind of commodity is spent by recipients. Input algorithm is exactly the same as for trans-shipping point. Output algorithm can be described as: stochastic process, continuous deterministic or discrete deterministic one. The model assumes that the capacity of the commodity can not be less than zero, “no commodity state” – is generated when there is a lack of required kind of commodity (marked as τ on Fig. 2).

3 System Structure

The simulation program generates a description of all changes in the system during simulation (with all events). It is a base for calculation of any functional and reliability measures. The most valuable results of statistical analysis are: time percentage when the vehicle is present in each state, time percentage when the store-house of addressee is present in each state, mean time when the store-house of addressee is empty - this way we can say if “no commodity state” is prolonged or only momentary (Fig. 2.). We also propose a quantile calculation of time when the store-house of addressee is empty. This is the answer if “no commodity state” situation sometimes lasts significantly longer than the mean time of empty store-house. Moreover, it is possible to observe the influence of changes related to single parameter or a set of parameters – vehicle repair time for example – for other system characteristics – as vehicle utilization level, or commodity accessible in store-houses. The calculated reliability and functional measures could be a base of developing economic measures [8]. Such layered approach allows a high level, economic analysis of the system. It is necessary to check different variants of maintenance organization and to choose the less expensive among them if the reliability criteria are satisfied. It could be done by subsequent Monte-Carlo analysis and calculation of the required economic or functional measures for a set of analyzed parameters.

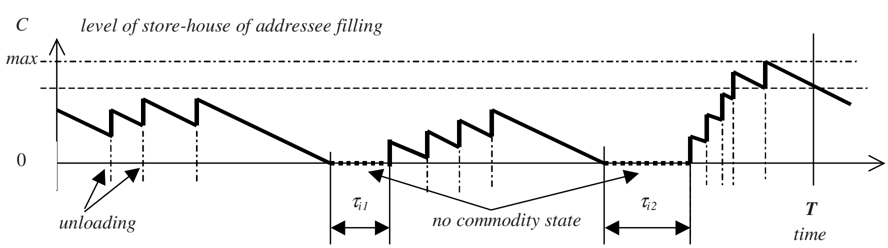

Fig. 2. Single store-house of addressee filling in time-period *T*

The system model described in previous sections is a subject of computer simulation. A special software package for simulation of the discrete transport system has been developed. The transport system is described in specially designed script language (with syntax similar to XML) [4]. It is an input for simulator programme (written in C++) performing Monte-Carlo simulation [1], [5].

Monte Carlo simulation has an advantage in that it does not constrain the system structure or kinds of distributions used [4]. However, it requires proper data pre-processing, enough time to realize the calculations and efficient calculation engine.

4 Hybrid Approach

The problem of speeding up functional and reliability analysis of discrete transport system we propose to solve by hybrid system using simulation and neural nets. In many tasks, i.e. in decision systems, there is a need to give an answer in a short time. However Monte-Carlo simulation requires quite a lot of time to realize calculation for a given set of system parameters. To solve this problem we have proposed a use of artificial neural networks [9]. The use of neural network is motivated by its universal approximation capability [3]. Knowing that most of output system parameters are continues we can expect that neural network can approximate any unknown function based on a set of examples. The time needed to get an output from learnt neural network is very short. Solution generated by net seems to be satisfactory [9], because we do not need very precise results - time is the most important attribute of the solution. The neural network ought to substitute the simulation process. As it is presented in Fig. 3 the neural net module is added to developed simulation software. The aim of this module is to generate an answer how to select the best system parameters (i.e. the maintenance agreements - the average time of vehicle repair) based on the achieved system functional parameters (i.e. the average time of "no commodity" in the storehouse of addressee).

The process of data analysis will be as follows:

1. set the input parameters for model of discrete transport system;
2. give a range of analyzed free parameter (parameters);
3. perform initial Monte-Carlo analysis for a few parameters from a given range - calculate all required functional and reliability parameters;
4. build a neural network classification tool:
   - use multilayer perceptron;
   - the input to the network are analyzed free parameters;
   - the outputs are functional and reliability measures;
5. build the answer about the maintenance agreement based on the output of the neural network and the proper economic measures;
6. communicate with a user:
   - play with functional and reliability data, goto 4.

   If more accurate analysis of economic parameter in a function of free parameter is required goto 3 – perform more Monte-Carlo analysis.

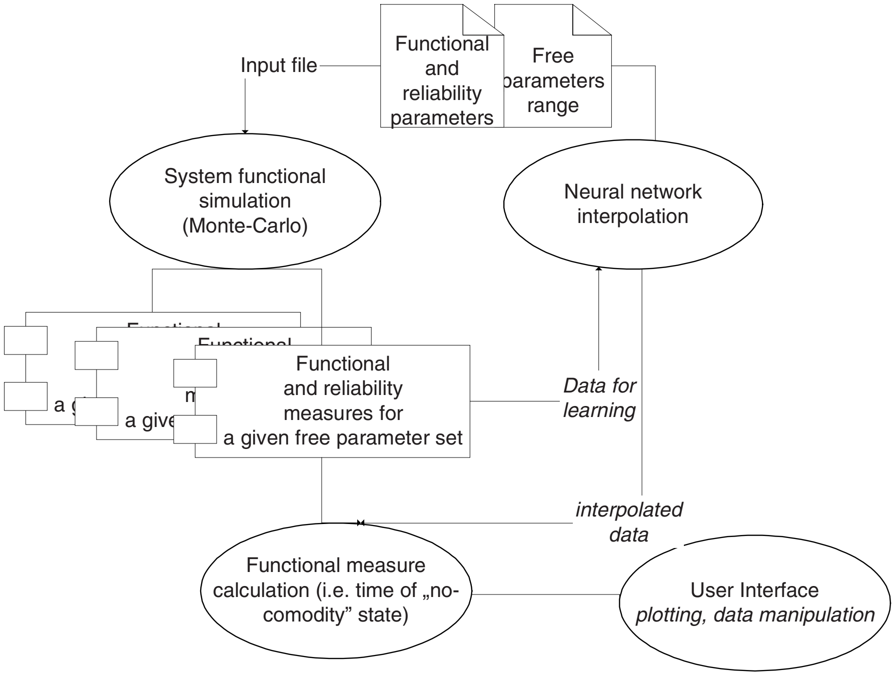

Fig. 3. Hybrid system overview

5 Case Study

To show possibilities of the proposed model and developed software we have analyzed an exemplar transport network presented on Fig. 4. The network consists of two store-houses of tradesperson (each one producing its own commodity, marked as A and B), one trans-shipping point (with one storehouse for both commodities) and two store-houses of addressee (each one with one storehouse). The commodities are spent by each recipient. The process is continuous deterministic as presented on Fig. 2, the amount of consumption in time unit is marked by u with subscripts corresponding to store-houses of addressee and commodity id. It's exemplar values are presented in Fig. 4. Having lengths of the roads (see Fig. 4), the amount of commodity consumption in time unit for each store-house of addressee, the capacity of each vehicle (15), vehicle speed (50 and 75 in empty return journey) the number of vehicles for each road could be easy calculated. We have take into account some redundancy [8] due to the fact of car failure (we assumed that the time between failures is 2000 time units) what results in following number of vehicles: road one n_1=40, road two n_2=12, road three n_3=18(A)+6(B)=24 and road four n_4=16(A)+8(B)=24. The analysis time T was equal to 20000.

We have analyzed maintains and service level agreement (SLA) dependency. From one side the transport network operator has to fulfill some service level agreement, i.e. have to deliver commodity in such way that a "no commodity state" is lower then a given stated level. Therefore the analyzed functional measure was a summary time of "no commodity state" during the analyzed time period. It could be only done if a proper maintenance agreement is signed. Therefore the argument of analyzed dependency was a average time of repair of vehicles. We assumed that we have four separated maintenance agreement, one for each for each road (roads 1 and 2 with one maintains crew, and 3 and 4 with two maintains crews). Also the exponential distribution of repair time was assumed. Therefore, we have four free parameters with values spanning from 1 to 1200. The system was simulated in 1500 points. For each repair time values set the simulation was repeated 25 times to allow to get some information of summary time of "no commodity" distribution. Two measures were calculated: average time of summary of "no commodity state" and its 4% quantile (i.e. the value of summary "no commodity" time that with probability 96% could be not higher).

The achieved date from simulation was divided randomly into two sets: learning and testing. We have used the multilayer perceptron architecture with 4 input neurons which correspond to repair time for each road, 10 hidden layer neurons and 2 output neurons.

The number of neurons in the hidden layer was chosen experimentally. Such network produced best results and higher numbers did not give any improvement. The tan-sigmoid was used as a transfer function in hidden layer and log-sigmoid output layer. Besides that, the output values have been weighted due to the fact the log-sigmoid has values between 0 and 1. The network presented above was trained using the Levenberg-Marquardt algorithm [3].

The achieved results, the mean of absolute value of difference between network results (multiplied by time range: 20 000) and results from simulation, for testing data set is 364 time units and 397 respectively for average time of summary of "no commodity state" and its 4% quantile. It is in range of 1-2% of analyzed transport system time. We have also tested the simulation answer stability, i.e. the difference between two different runs of simulation (25 of them each time) for both functional measures (average time of summary of "no commodity state" and its 5% quantile) is 387 time units in average.

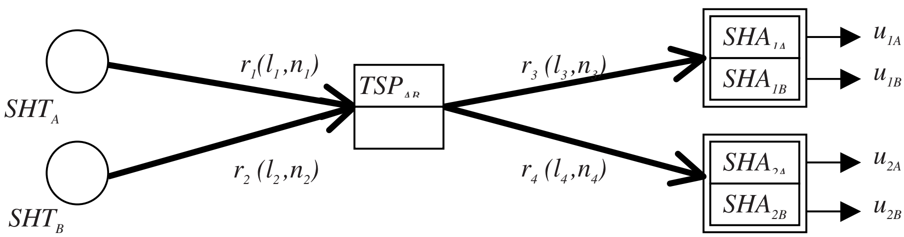

Fig. 4. Structure of case study discrete time system
(parameters: l_1=120, l_2=90, l_3=90, l_4=120, u_{1A}=60, u_{1B}=20, u_{2A}=40, u_{2B}=20)

6 Conclusion

Results of functional and reliability analysis of exemplar discrete transport system are very promising. Time necessary for whole neural network training is less (in average 4 times) then time necessary for a single training vector preparation (run of 25 simulations for a single set of free parameters). An error related to the network answer - when the already trained network is tested by the input data which are not used during training - is in the range of disperse related to results of simulation. Of course there is an important aspect of avoiding over fitting or under training by neural network. At this stage of work it was done manually by observing the global error in function of training epochs and stopping training when the curve stops to decrease.

The other interesting aspect of presented approach is the scalability projections. Increasing the number of modeled vehicles or system elements increases the Monte Carlo simulation time significantly. In case of training time of neural network (classification time is negligible) increasing a number of simulated entities has not direct influence. However, if one wants to analyze more sophisticated relation between input parameters and output measures, i.e. increases the number of input parameters, it results in an increase of input neurons, therefore needs a larger number of training data and results in a longer training time. Future work is planned on checking the extrapolation features of the neural network. We are going to analyze the answer of the network for input data with range outside the training set.

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