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Identification and Modelling for input/output system representation of supply chains

PhD theses

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Tartalomjegyzék

1. Preliminaries

During the long history of logistical systems the most crucial task is the proper identification of complex processes and their representation. The reason for this is first of all the change in structure of conveying systems as well as their complexity has been continuously changed and it changes nowadays, too. At the beginning the primary application areas of logistics have been determined by military related logistics. In the XIX. Century the logistics played crucial role during in Napoleonic wars, had significant impact on their positive as well as negative outcome. The same is true for the 2nd WW especially for pacific war events. The NAVY has had strong influence on evolution of the logistical science from the mid of the last century. The technological evolution of the agriculture in the XX. Century has brought many of the problems related to distribution of chemical fertilizers and other protecting chemicals. The centralization of industrial productions has significantly increased the importance of optimization related to plant deployment as well as the selection of optimal routes for distribution of products being in strong relation to building up the infrastructure.

Logistical processes play crucial role in many systems where the resources as well as tasks related to them are to be organized or scheduled in order to increase the throughput of the system, thus the rate of servicing demands. In order to increase the throughput of a loading system, delays caused by its certain subsystems are to be minimized.

Supply chains as a specific category in logistics might be represented as a network of nodes representing facilities that perform some actions related first of all to manufacturing, transportation and distribution of products. Depending on the participant of the supply chain such a network may consist of many interconnected nodes, with specific characteristics. Thus, the behaviour of a complex supply chain may depend on many factors. The topology of the network may change as well especially when a facility becomes unable to fulfil its function due to some reasons.

The authors, for example deal with so called integrated supply chain optimization problems where the locations of facilities, customer allocations, etc. are considered as well when facilities are subject to disruption risks. [1-5]

In order to identify these factors as well as their impact on the whole chain, modelling and identification of the system has to be performed. As in many fields also in logistics modelling and identification approaches play significant role especially when accurate models of complex logistical processes (LP) have to be designed. Authors in consider queuing models to compute the response time for the delivery of items. Proper supply chain models may be helpful to predict various features related to the modelled system, such as the response time or in case of supply chains the delivery cycle time, customer order path (related to time spent in different channels), etc. In addition a good model may be helpful also to identify critical nodes in the chain and help to improve its reliable by changing the topology of the supply chain network. [6-8]

In case when the inner structure of the system is unknown (for instance the concrete service strategy and other internal mechanisms) the modelling and identification can be performed only based on the available measurement input-output data, which means only black box like modelling and identification methods are utilized. In the literature many models (as for instance scheduling, transportation planning, flow-shop sequencing problem) related to logistic systems are based on the fuzzy set and fuzzy control theory statistics or their combination.

Many times it is difficult to find a proper mathematical model in form of differential equations which would suitable approximate the behaviour of the observed logistical process even if the identification of the system is considered locally. However subspace identification techniques combined with tensor product transformation seem to be promising to model complex logistical processes based on input-output data. In this case there is no need for an explicit model parametrization, which is a rather complicated matter for multi-output linear systems. [9]

Depending on the knowledge about the modelled system a broad range of solutions can be utilized. Since complex logistical systems are non-linear MIMO (multiple-input and multiple-output) systems and are influenced by many parameters their modelling is not a trivial task. Many methods have been proposed to deal with multi-input, multi-output systems in the literature. Perhaps the most popular tool in this topic is the linear parameter varying (LPV) structure by which non-linear systems can be modelled and controlled on the basis of linear control theories. Furthermore, the most recent results of the numerical algebra, such as the higher order singular value decomposition and the related tensor product transformation (making connection between LPV models and higher order tensors) offer promising tools to bridge heuristic and analytic approaches. In such a joint framework besides analytic description of the system the expert knowledge can be considered, as well. This may further improve the effectiveness and extend the applicability of the related methods.

2. Objective

The aim of this research is to elaborate heuristic and analytic approaches or methods based on their combination to model and identify the behaviour of logistical systems (especially that of loading systems representing a specific topic in logistical systems). In addition the aim was also to adapt the methods and approaches of the classical system theory in order be able to model logistical systems, as well.

In strong connection to the above aims the primary step during this work was to study and investigate various architectures of loading systems (with special attention to queuing based architectures). In addition I would like emphasize the importance of the investigation and research on how logistical systems, especially loading systems can be modelled and identified on the basis of classical system theory as well as to analyse the efficiency of these methods. Similarly, the investigation of the joint applicability of heuristic and analytic approach on loading systems represents stand for a distinguished task during this research. As another important consideration during the research, I would like to emphasize the black box like techniques (based on input-output pairs) which are going to be investigated in relation to modelling and identification of loading systems, as well. Here besides heuristic approaches I would like to emphasize the importance of subspace based identification techniques which will be especially considered during this work. The aim is to show how efficiently subspace based identification techniques can be applied in the field of logistics to identify state space models of loading systems. Here we are planning to model the local behaviour of the logistical system by linear deterministic state-space models and identify them on subspace basis by using input-output data obtained by the elaborated simulation models. The elaboration of these models plays also an important task during this investigation. The overall behaviour of the system can be modelled by mixing the locally identified linear deterministic models. We would like also to show what techniques can be applied to blend these models efficiently. First of all we would like to study and investigate blending techniques coming from the field of fuzzy theory as well as the so called higher order singular value decomposition which stands form a modern and well applicable tool of the multivariate algebra. In strong connection to this topic another aim is to show how neural networks considered as local models can be blended by the mentioned approaches. As already mentioned, the importance of input-output data is crucial, thus the elaboration of simulation models of loading systems (in Matlab Simulink framework) to collect such data plays significant role, as well. With the help of such simulation models the efficiency of the identification can be evaluated for different types of loading systems.

3. Methodology

I have shown that logistic systems can efficiently be modelled by applying analytic and heuristic techniques jointly. The joint application of analytic and heuristic techniques to describe logistical systems -- first of all including loading systems -- is based on HOSVD (Higher Order Singular Value Decomposition) and Takagi-Sugeno approaches [10]. With the proposed approach nonlinearities in logistical systems can be approximated by simpler linear models. Here the main aim of investigations was to show theoretically that such hybrid techniques are applicable also in case of modelling logistical systems.

In strong relation to this I have elaborated new methods on subspace identification basis to enable to investigate the strength of relations being present between certain parameters of logistical systems. I have shown that there is a strong correlation between the approximation accuracy of the identified model and the modelled the parameters.

I have also shown that logistical systems can be modelled, represented and identified by subspace identification techniques. The elaborated models are well applicable also in case of loading as well as queuing systems. For system identification I have utilized input-output data generated by simulated loading systems in Matlab Simulink framework. Since the identified model appears in the form of deterministic linear time invariant (LTI) state space model, tensor product transformation based modelling approaches and all the related reduction techniques can be directly applied.

Based on fuzzy logic and neural networks I have elaborated new models to describe the internals of logistical processes especially of loading systems. I have proposed a new method to blend neural networks of the same structure on higher order singular value decomposition basis. The reduction techniques applied in case of state-space models can be adopted to neural based models.

4. Theses

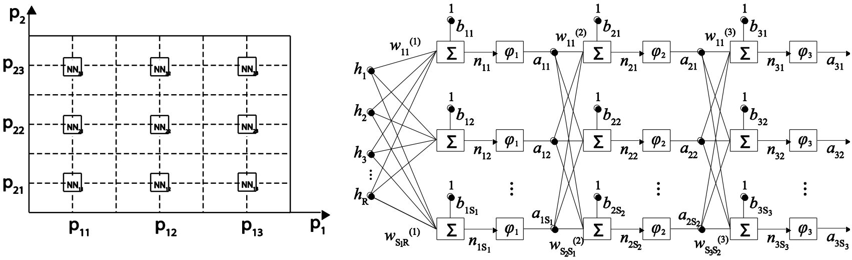
Theses 1.: I have shown and verified by simulation that logistic systems can be modelled (represented) using subspace identification techniques. The elaborated models are suitable both in case of loading as well as queuing systems. For system identification I have used input-output data generated by simulated loading systems in Matlab-Simulink framework.

1.1: I have elaborated new methods based on subspace identification to enable the study the nature and strength of relations between certain parameters of logistic systems. I have shown that there is strong correlation between the approximation accuracy of the identified model and the modelled parameters. Correlation analysis techniques can also be directly applied to the collected time series data. [S1][S2]

1.2: I have identified queuing type (loading) systems in form of linear deterministic models. Data used for identification have been generated by simulated loading systems. The internal mechanisms have been designed to contain various factors with connections of different strength between them. This structure provided the opportunity to perform the necessary investigations. [S1][S2]

1.3: The above approach can be applied both in case of linear stochastic or nonlinear models. Nonlinear dynamic models describing logistic systems can be approximated by blending linear time invariant models on tensor product basis. The mentioned LTI models are defined and identified over the vertexes of a hyper-rectangular grid in the parameter space. I have shown that these techniques can efficiently be applied to modelling logistic systems, as well. [S1][S2]

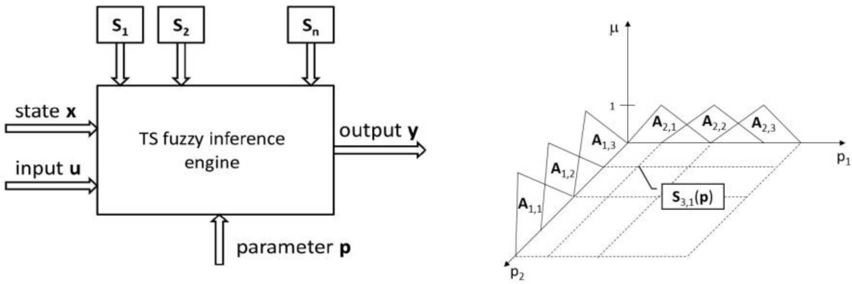
Theses 2.: I have elaborated new models based on fuzzy logic and neural networks to describe the internals of logistic processes, especially of loading systems. I have shown that classic and heuristic modelling techniques (or their combinations) can be applied in case of logistic systems, as well. I have proposed a new method to blend neural networks of the same structure on higher order singular value decomposition basis. For the blending I have adopted the aforementioned HOSVD based approach to multi-layer perceptron networks having the same internal structure. Here the basis functions are obtained through the HOSVD of the tensor composed of weight matrices of the corresponding layers in the network. The reduction techniques applied in case of state-space models can also be adopted to the neural network based models. [S4][S5][S6]



(a) (b)

1. figure: (a) Example of a two dimensional parameter space, with identified neural networks as local model at equidistant parameter values. (b) The architecture of local neural network models

Theses 3.: I have shown that logistic systems can efficiently be modelled using joint analytic and heuristic techniques. The combined application of analytic and heuristic techniques for the description logistical systems (including loading systems) is based on HOSVD and Takagi--Sugeno approaches. With the proposed approach nonlinearities in logistic systems can be approximated by simpler linear models. Here the main aim of investigations was to show theoretically that such hybrid techniques are applicable for modelling logistic systems. [S3][S6]



2. figure: The Fuzzy inference engine and illustration of the approach in two parameter case

$$\mathbf{S}(\mathbf{p}) = \sum_j \mu_j(\mathbf{p}) S_j, \ \sum_j \mu_j(\mathbf{p}) = 1, \ 0 \le \mu_j(\mathbf{p}) \le 1$$

$$\mathbf{x}(k+1) = \mathbf{A}(\mathbf{p})\mathbf{x}(k) + \mathbf{B}(\mathbf{p})\mathbf{u}(k),$$

$$\mathbf{y}(k) = \mathbf{C}(\mathbf{p})\mathbf{x}(k) + \mathbf{D}(\mathbf{p})\mathbf{u}(k),$$

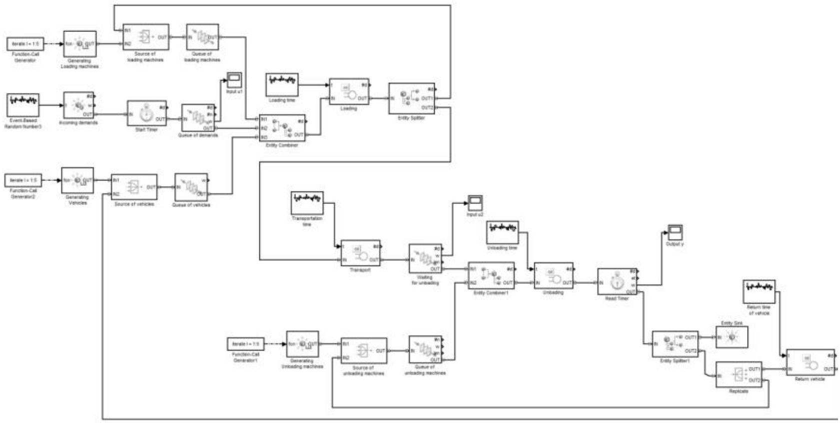
$$\mathbf{S}(\mathbf{p}) = \begin{pmatrix} \mathbf{A}(\mathbf{p}) & \mathbf{B}(\mathbf{p}) \\ \mathbf{C}(\mathbf{p}) & \mathbf{D}(\mathbf{p}) \end{pmatrix},$$

where **x** state vector, **u**: input vector, **y**: output vector, **p**: parameter vector.

Theses 4.: I have shown and verified, that the behaviour of simpler logistic systems can efficiently be approximated by deterministic linear state-space models.

4.1: By this investigation I have pointed out that complex nonlinear logistical systems can be approximated by HOSVD or fuzzy based blending of linear deterministic state-space models. I have shown that the basic concept of linearization applied here lies in the identification and blending of LTI vertex models in the parameter space. [S1][S2][S3]

4.2: The above results can serve as a starting point of further research in various topics concerning the modelling of loading systems. They also form a good foundation for the investigation of loading systems with various architectures using joint analytic and heuristic techniques. In close relation to this, analyzing the approximation error of reduction techniques in case of simulated as well as real logistical systems stand for an important consideration, as well.



3. figure: The architecture of the system used to generate simulated data pairs

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