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INTERDISCIPLINARY MODELING FOR LOGISTICS DESIGN

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ABSTRACT

In this paper a conceptual model is defined that can be used for the innovative design of logistic systems. The model is constructed by using the systems approach in a formal and fundamental way. It turns out that the model complies with the 'hard systems approach', positioned in a trajectory according the 'soft systems approach'. By this the model is an interdisciplinary tool that serves as a common frame of reference and decision making platform for the different disciplines involved. It enables unambiguous communication. Conceptual modeling of each separate discipline including their different monodisciplinary goals, is reflected by this single model.
The model also serves as a facility to save design conditions and decisions for future innovations. The model forms the basis to build "shared memory".

INTRODUCTION

One of the recurring problems in any large scale design project is the relation between the multidisciplinary design and the mainly monodisciplinary participants. For example the complaints about information systems that do not live up to the expectations keep pace with the growth of automation. Machines (whether automated or not) often don't deliver the performance as was promised during the design phase. The performance of a system in reality differs significantly from the simulation results during the design project. Such a mismatch between the intentions of the decision makers and the perceptions of the simulation experts can only be explained by assuming a communication problem

Nowadays all disciplines use some kind of a 'system' concept to deal with complex problems. For example organization science considers organizations as combined *social, technical and economical* *systems*; Logistics emphasizes an integrated approach to deal with an *operational* *system*; Information technology developed several approaches for the design of *information* *systems*. They all construct conceptual models to formulate problems and find solutions. However there are significant differences between conceptual modeling of each discipline. The conceptual information model of a system is quite different compared to a conceptual logistic model of the same system. Apparently conceptual modeling is part of the discipline itself.

These differences in system perceptions can be avoided by considering conceptual modeling a generic interdisciplinary activity rather than a multidisciplinary activity. The term "interdisciplinary" denotes cooperation with a common goal (and by this a common perception of the system). This goal is and stays the starting point for all activities during the design project and project management serves this goal. An interdisciplinary approach generates discipline specific concepts starting from a single system concept, a multidisciplinary approach generates a system concept starting from discipline specific concepts.

During the last half of the 20th century the systems approach emerged as an interdisciplinary approach to study "systems". It opens the way to a generic conceptual way of modeling logistic systems, thereby avoiding the jargon and specifics of separate disciplines. In this article the systems concept will be elaborated the other way around. Starting with a general concept, a conceptual model for logistic systems will be derived until the level, where single disciplines have to become specific.

A SYSTEMS APPROACH FOR LOGISTIC SYSTEMS

The systems approach evolved as a generic interdisciplinary approach during the last decades to investigate and describe "systems", not only by studying the elements but by emphasizing the relations between the elements. The systems approach supports decision making by formulating problems 'in terms of systems'. A system is defined as a: "set of elements that can be distinguished from the entire reality, dependent on the objective of the researcher. These elements are mutually related and (eventually) related with other elements in the entire reality" [in 't Veld, 2002].

In literature systems approaches are classified in different ways (see a/o Whitmore [1998], [Wigal, 2001], [Daellenbach, 2002] and [Williams, 2002]). The classifications range from dividing systems approaches according the researcher's subjective or objective system perception to dividing systems approaches according the system's complexity level. All these classifications show that the theoretical development of the systems approach mainly took place in what is called the 'General Systems Theory' (GST) and in Cybernetics.

Applications of the systems approach are divided into three categories: 'hard' systems approach, 'soft' systems approach and 'critical' systems approach ([Flood & Jackson, 1992]).

Hard systems approaches consider a system logically based and capable of unbiased description. They are characterized by the modeling of purposive systems in order to optimize a performance or required objective. The basic assumption, whether or not implicitly, is that the problem is stated right and unambiguous. Typically hard systems approaches are Operations research, systems analysis, software development, database design and systems engineering.

The soft systems approaches consider a system a subjective perception: dependent on the observer the same system is presented in different ways. The observer himself may also be part of the system and may have his own objectives besides the system's objective. Soft systems approaches therefore are mainly aimed at the understanding and the formulation of these so-called ill-defined problems and address the "what" question instead of the "how" question.

The critical systems approach emerged in the 1980's and "sits somewhat uncomfortably in the overlap between sociology, organization theory, systems thinking and by extension management science" [Daellenbach, 2002]. This approach looks at the methods developed by hard and soft systems approaches from the perspective of existing social structures and aims to define the conditions for their applicability. The contribution will result in a better definition of preconditions for problem statements and the period of validity of solutions.

The hard systems approach is in fact part of the soft systems approach. Once the stakeholders reach agreement on the problem statement (a consensus on subjective perceptions), methods of the hard systems approach can be used to solve the problem. Recapitulated briefly, the soft systems approach aims to state the right problem and the hard systems approach aims to solve the problem right.

The design process of a logistic system requires a soft systems approach to deal with different perceptions. The design process starts with a so-called ill-defined problem. The first steps of the process must lead to an agreement on the objectives and conditions. By then it is called a well-defined problem. Using a hard systems approach only, would pass over the proper objective definition and will lead to:

- *accepting system boundaries as given*. For example looking at the effect of economic lot sizes, if one does not take the environment of the total supply chain into account, the savings may be smaller than the extra costs [Christopher, 1998].
- *Considering elements as being naturally defined*. If one regards an organization as a system, often the existing departments are regarded as the elements. But the departments are the result of design processes in the past. By doing so, the assumptions and starting points of these earlier design processes are implicitly imported into the new design process with its new objectives and in a changed environment.

Now the problem is to find a system concept in a hard systems approach, which can be generally applied within the design process of a logistic system, taking the soft systems approach into account, and which can form a more or less lasting framework for specification and review of logistic systems.

Such a system concept will be called a ***conceptual system model***. Only a small number of such conceptual models has been defined. Checkland [1981] positions the use of these models in his Soft Systems Methodology (SSM), the most widely used and accepted soft systems approach. SSM is shown in the figure 1 below.
The methodology consists of 7 steps. The first step is the recognition of an unstructured problem situation. Initially 'rich pictures' are made to describe and discuss the problem. Rich pictures are combinations of text and pictures expressing the situation in terms of the researcher and problem owner. Rich pictures use draughts of elements, structures, processes and environment. In step 3 the rich pictures are analyzed and 'root definitions' are defined by abstraction. Relevant systems are

distinguished in which activities are formulated. A number of activities is declared absolutely necessary for the system and these are the root definitions. A correct root definition satisfies the so-called CATWOE principle. It states explicitly the Customers, the Actors of the activity, the Transformation performed by the activity, the World view (Weltanschauung) of the activity, the Owners and the accepted preconditions from the Environment. The root definitions are used to construct conceptual models in step 4. In the next step these models are compared with reality as described by the rich pictures. The comparison leads to the identification of feasible and realizable changes. These changes determine the actions required to improve or solve the problem situation.

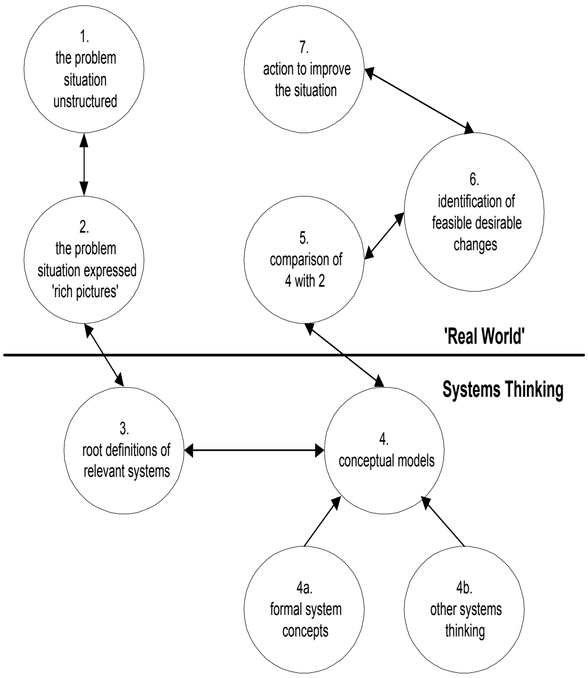

Figure 1. The Soft Systems Approach

One of the main shortcomings of SSM is that the objectives of the activities are missing in the CATWOE principle; the very same objective, which was found to be the expression of subjective ‘perception’. To apply the hard systems approach in the conceptual models the objectives must be preserved by defining the elements as ‘functions’ rather than as ‘activities’ or ‘tasks’. This leaves only a few models to be considered for constructing a conceptual model of a logistic system:

- the Formal System Model of Macauley (1996)
- the Viable System Model of Stafford Beer
- the Steady State Model of in ‘t Veld
- the Control Paradigm model of De Leeuw.

The Formal System Model (FSM) of Macauley (figure 2) represents a Human Activity System and to be a “formal” system there must be:

- some mission
- some measure of performance
- a decision making process
- mutual interaction between the elements
- a wider system or environment

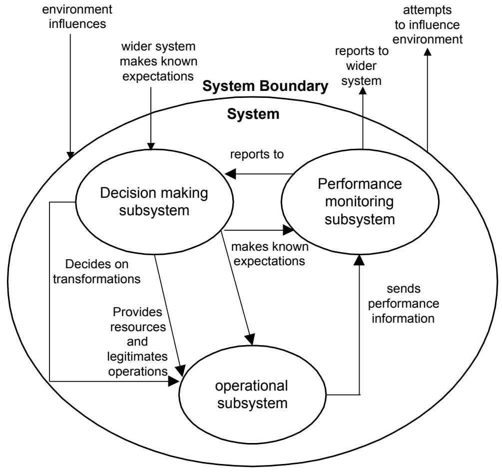

Figure 2. Formal System Model [Macauley, 1996]

- decision making resources
- stability or an ability to recover.

The Viable System Model (VSM) of Stafford Beer [1985] is shown in figure 3 and consists of functions to be present in any viable system.

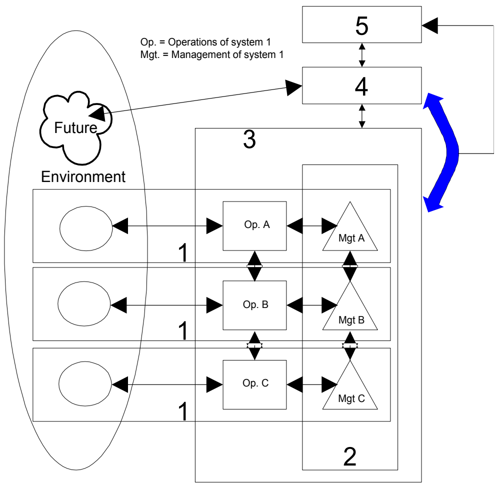

Figure 3. Viable System Model

Viable systems all have the same pattern of functions. This pattern should not be considered an organization structure but a function structure. Beer distinguishes five functional groups. He calls them systems, because each functional group is a viable system on its own. The systems are:

1. System 1: Implementation consisting of execution, operational management and environment
2. System 2: Coordination of operational systems

3. System 3: Internal control. This system preserves the purpose of the organization, “here-and-now”.
4. System 4: Intelligence deals with the future environment: “there- and-then”. It makes propositions to adapt the purpose.
5. System 5: Strategy and Policy. This system is responsible for the direction of the whole system.

In ‘t Veld [2002] defines two separate models: The steady state model for repetitive processes and the innovation model for innovation process. The steady state model is (simplified) shown in figure 4.

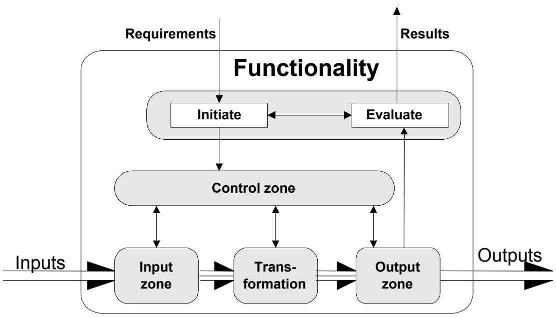

Fig. 4. The steady state model [Veeke,Ottjes, 2000]

The steady state model consists of a structured set of functions, expressing which contribution is repeatedly delivered to the environment in a controlled way but not how this contribution is achieved in a concrete way. The set of functions is itself a function again, which makes the model recursive. The model contains:

1. A transformation function, by which input is transformed into a desired output.
2. An input zone to identify, qualify and quantify the input flow.
3. The output zone analogously qualifies, quantifies and identifies the outputs to be delivered to the environment.
4. The control zone corrects disturbances in input, throughput and output by means of feedback, feed forward and repair of deficiencies. The actions of the control zone are directed towards these standard values.
5. The initiation - evaluation zone delivers the standard values for the control zone with respect to the facets quality, quantity and lead time; it is the translation of the requirements entering the function from a higher echelon, into manageable rules and standard values for these facets.

In ’t Veld distinguishes subsystems and aspect systems: a subsystem includes a subset of the elements, but all relations, an aspect system includes all elements, but only a subset of the relations. An aspect system covers a particular flow of elements. The steady state model is a model for one single aspect where the elements are functions. Examples of an aspect system are the product flow, the job flow, the resource flow and the data flow. Several aspect models are required to completely model a system.

The control paradigm (figure 5) of de Leeuw [1982] consists of a controlled system and a controller. Both the controlled system and the controller interact with the environment. De Leeuw describes a number of conditions for the control to be effective:

1. There must be an objective.
2. The controller must have a model of the controlled system to predict the effect of control actions. During the process of control this model can be refined.
3. The controller needs information about the environment and the state of the controlled system.
4. The controller needs sufficient possibilities to control.
5. The controller must have sufficient capacity for information processing at its disposal.

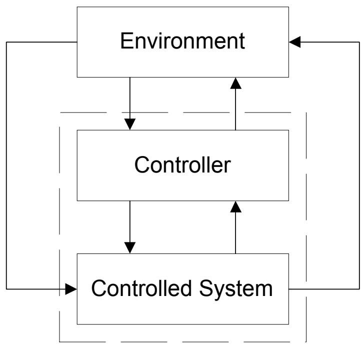

Fig. 5. The control paradigm [de Leeuw, 1982]

Control actions can be executed both directly (internal control) and indirectly through the environment (external control).
For both types of control de Leeuw distinguishes:

1. Routine control: actions within the scope of the current model of the controlled system.
2. Adaptive control: actions, which change the structure of the controlled system.

Strategic control: actions, which result in a change of the objective of the controller.

All conceptual models are related to open purposive systems and can therefore be applied to logistic systems. VSM and the control paradigm distinguish explicitly:

- functions to maintain a stated objective (objective keeping)
- functions to adapt to a new objective (objective adaptation).

So therefore a logic distinction will be made between:

- a logistic system being an open system with objective keeping facilities
- a design process being an open system that creates a logistic system on behalf of a desired objective adaptation.

The hard systems approach concentrates on the logistic system with a stated objective, a soft systems approach emphaiszes the design process where concurrent (or even conflicting) objectives arise as a consequence of different perceptions.

Common characteristics of the conceptual models

- they are empty with respect to resources and tools
- All elements are systems again
- Every system fulfills a function in its environment by satisfying a need
- All models clearly distinguish control (decision making) functions and operational functions. It's a "paradigm" indeed.

Only the steady state model defines the border between system and environment to be a boundary zone containing functions to fit the flow elements for transformation or delivery by the system. Furthermore the steady state model represents the required functionality for one single aspect of the system. The design of a multidisciplinary product requires several steady state models, one for each aspect. Each aspect will be reflected by a single flow of elements. Finally, the steady state model is the only model where "something is produced". It not only shows the function structure but it also includes the process by which input elements are transformed into output elements. This gives a strong connection to the usual way of process thinking in logistics.

As a conclusion a conceptual model of an objective keeping system (logistic system) has to meet the following conditions:

- The system fulfills a function to satisfy a need of the environment and is by this purposive.
- The elements of a system are systems again
- Each system consists of a control subsystem and an operational subsystem
- The model distinguishes aspects, being subsets of the relations. More than one aspect can be modeled by including more product flows.

The system will be the same as the function it fulfills from now on. The elements will therefore be functions also. A function description must be determined by means of abstraction from the physical reality. It is not important "how" something is done, but "what" and "why". This offers two adavantages:

- it stimulates to be creative and to radically change the way of realization in a structured way.
- The basic assumptions and choices made during the design process stay clear and accessible for future design projects. This construction of "memory" prevents the ïnvention of the wheel"once again and excludes the implicit assumption of superseded conditions.

THE "PROPER" MODEL OF A LOGISTIC SYSTEMS

The logistic system is a subsystem of the organization as a whole; it contains a subset of the elements, but includes all the relations. Approaching logistics from the viewpoint of the primary function three aspects will be included in the conceptual model. First of all the "product" as a flow of elements to be transformed. To make a product "resources" (people and means) are required. To be able to use them, they must enter the system and they will leave the system as used resources. The third aspect is the flow of orders; without customer orders no products will flow and no resources are needed. Orders are transformed into handled orders.
In the conceptual model the processes are shown in a structure including control functions. Control in this sense consists of initiation, evaluation, feed back, feed forward and repair f deficiencies.The whole system function delivers some kind of performance and therefore the model is called PROcess PERformance model or "PROPER"-model.
At the highest level of aggregation the PROPER model is represented by the figure below.

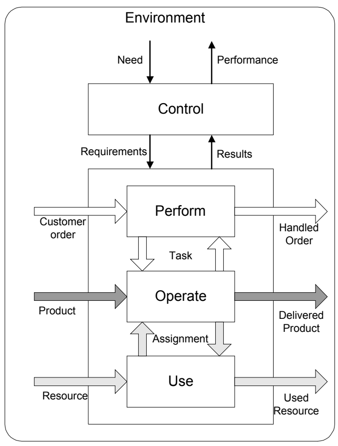

Figure 6. The PROPER model of a logistic system

Performance will be expressed in terms of productivity, effectiveness and efficiency.
These criteria are used during real operation of the system, but also during the design of a system to evaluate design alternatives. The properties are used for three different purposes [in 't Veld, 2002]:

1. strategic: to select between alternative resources. In this case the criteria are expressed in terms of "results in view" and "expected efforts".
2. tactical: to determine the best way to use selected resources. This best way is reflected by "standard results" and "standard efforts".
3. operational: to determine the operational performance. Now the "real results" and "real efforts are clear and compared to the standard values defined at the tactical level.

THE PROPER MODEL AND LOGISTIC PRACTICE

During the last decade material management and physical distribution are integrated in "supply chain management". In terms of the systems approach integration means extending the systems boundary and considering the whole as a system to be controlled again.
At the end of the nineties the Supply Chain Council (SCC) developed a so-called reference model for this integrated approach of logistics: the Supply Chain Operations Reference Model [SCC, 2002]. This model supports the evaluation and improvement of the performance of the supply chain, organization wide. It emerged from the combination of Business Process Reengineering (BPR), benchmarking and process measurement. SCOR contains:

- All customer interactions starting from order entry up to paid invoice (see order flow in figure 6)
- All material transactions (see product flow in figure 6)
- All market interactions, starting with the determination of aggregated need up to the execution of each separate order (see control in figure 6).

The model describes four levels of supply-chain management:

- Level 1 contains five elementary management processes: Plan, Source, Make, Deliver en Return; The objectives of the supply-chain are formulated at this level.
- At level 2 the five processes are described more precisely by means of three process categories: 'Planning', 'Execution' and 'Enable'. The basic idea is that each of these three categories can be distinguished in each of the processes. The execution category of Source, Make and Deliver is further divided into 'Make-To-Stock', 'Make-To-Order' and 'Engineer-To-Order' types. In this way a complete scheme of 26 possible process categories is created. Any company is able to configure its existing and desired supply chain with this scheme.
- Level 3 shows, which information (and software) is needed to determine feasible objectives for the improved supply-chain.
- Finally level 4 addresses the implementation. Level 4 changes are unique, so specific elements are not defined; only guidelines and best-practices are described.

SCOR is a reference model: contrary to a conceptual model it classifies all logistics activities; it aims to improve rather than to innovate. All existing configurations can be modeled, currently non-existing solutions cannot as it turns out from the most recent addition of 'return'.

Plan, source, make, deliver and return are management processes and are part of a control function. To decide to which control function they belong, a short explanation of each is given below.
<u>Plan:</u> is demand and supply planning and management. It balances resources with requirements and establishes/communicates plans for the whole supply chain. It manages business rules and supply chain performance.
<u>Source</u>: takes care of the supply of stocked, make-to-order, and engineer-to-order products. It schedules deliveries, receives, verifies and transfers products, it manages inventories, capital assets, incoming products, supplier networks, import/export requirements, and supplier agreements.
<u>Make:</u> concerns the execution of make-to-stock, make-to-order, and engineer-to-order production. It schedules production activities, manages in-process products (WIP) , performance, equipment and facilities.
<u>Deliver:</u> covers order, warehouse, transportation, and installation management for stocked, make-to-order, and engineer-to-order products. It includes all order management steps from processing customer inquiries and quotes to routing shipments and selecting carriers. It also includes all warehouse management from receiving and picking products to load and ship products.
<u>Return</u>: is the return of raw materials (to supplier) and receipt of returns of finished goods (from customer), including defective products, and excess products.

Comparing these descriptions with the functions and aspects of the PROPER model of figure 6 shows that:

- There is no strict distinction between aspects in SCOR. Source, make and deliver in particular contain parts of each aspect; to put it differently, each aspect contains a source, a make and a deliver process.
- The control of the product flow is split up between make and deliver. Make takes care of stocks-in-process, while deliver emphasizes warehousing at receipt and shipping.
- Plan contains both the long-term planning and balancing and the daily coordination of the flows.
- Return represents a complete product flow. In terms of the PROPER model it is a subsystem within the product aspect.

Each flow oriented control system again must be coordinated with the other aspects by a control function at the next higher echelon.

Including the basic processes source, make and deliver finally leads to the PROPER model for each aspect of a logistic system as shown in figure 7.

Literature on logistics usually distinguish purchase logistics, production logistics and physical distribution. These areas can be mapped one-to-one to the Source, Make and Deliver functions of figure 7. It is remarkable to see that the field of logistics is divided into functional areas instead of flow oriented areas. Terms like order logistics, product logistics or resource logistics are not encountered in logistic concepts.

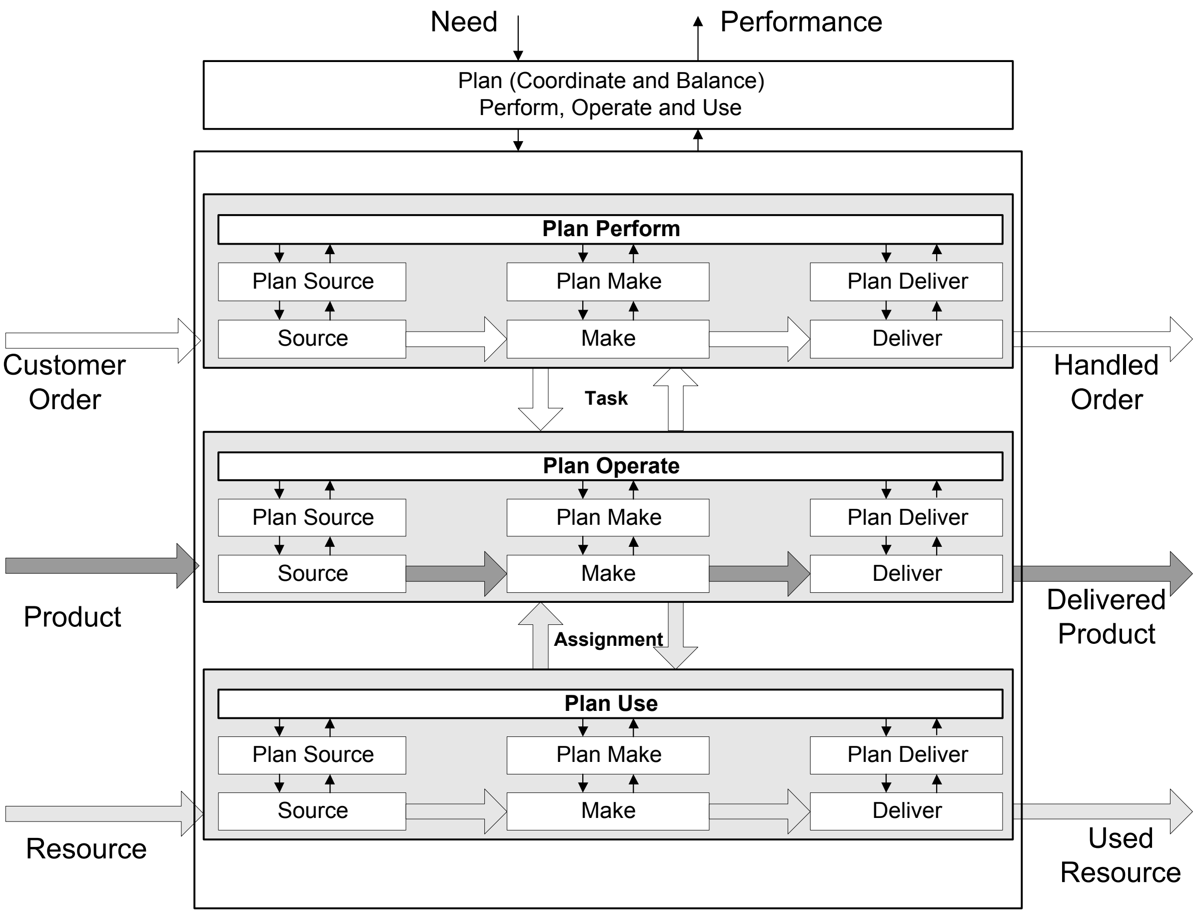

Figure 7. Common functions in the PROPER model

As argued before the distinction between aspects is important, because they reflect disciplinary backgrounds and perceptions. It must be clear whether decision-making concerns the order flow, the product flow or the resource flow, in order to enable correct objective settings. Each flow is controlled by its own control system coordinating the source, make and deliver control functions.

CONCLUSIONS AND FUTURE RESEARCH

In this paper the conceptual interdisciplinary PROPER model has been defined that can be used by all disciplines involved for the design of a logistic system. The model is a common frame of reference to support communication and decision making by different monodisciplinary approaches. The model is also used to record conditions,

decision and assumptions that lead to the final design.
The model is primarily used to better fit the expectations on the performance of a design with the performance in reality. Using the model will not automatically lead to better designs, although a correct expectation may lead to reconsider decisions in an early stage of the design project.
The model has first been used at the start of the large design project FAMAS.MV2 to study the future land extension for container handling in the Rotterdam port area (Veeke, Ottjes, 2002). At this moment it is being used as a starting point for a planned research project to construct a virtual industrial system at the Delft University of Technology, where several research groups will be involved e.g. organization, technology, logistics and information technology.
Meanwhile the model has been extended with a so-called ‘process description language’ to extend communication on the conceptual model to the time-dependent behavior of the system (see Ottjes, Veeke, 2002). In this way a connection is established to the field of simulation and is the validation of simulation modeling supported for situations where no real system exists yet. A correct connection requires a pure process interaction approach by the simulation platform. An example of such an approach is found in TOMAS (Tool for Object oriented Modeling And Simulation) that can be found at the web site www.tomasweb.com.

Finally the conclusion is drawn that the field of logistics is rather function oriented than flow oriented. Further research is required to investigate if a flow oriented approach is able to enhance the logistic achievements.

REFERENCES

Beer S., 1985, “*Diagnosing the system for organisations*”, John Wiley and Sons Ltd., Chichester, England
Checkland, P., 1981, “*Systems Thinking, Systems Practice*”, John Wiley & Sons Ltd, New York, ISBN 0 471 27911 0
Christopher, M., 1998, “*Logistics and supply Chain management. Strategies for reducing costs and improving services*”, London, FT Prentice Hall
Daellenbach, H.G., 2002,”*Hard OR, Soft OR, Problem Structuring Methods, Critical Systems Thinking:A Primer* “, report University of Canterbury, Christchurch, New Zealand.
Flood, Robert L., Jackson, Michael C., 1992, “*Critical Systems Thinking*”, John Wiley & Sons, Chichester, England, ISBN 0-471-93098-9
de Leeuw, A.C.J., 1982, *“Organisaties: management, analyse, ontwerp en verandering”,* Assen, Van Gorcum.
Macaulay L. A., 1996, “*Requirements Engineering*”, Springer-Verlag London Ltd.
Ottjes J.A., Veeke H.P.M., “*Prototyping in Process Oriented Modeling and Simulation”,* Proceedings of the 16th European Simulation Multiconference (ESM 2002), June 2002. Darmstadt [SCS]. ISBN 90-77039-07-4
SCC, 2002, The Supply Chain Council website: www.supply-chain.org
Veld, J. in ‘t, 2002, “*Analyse van organisatieproblemen, een toepassing van denken in systemen en processen*”, Stenfert Kroese, ISBN 90-207-3065-7
Veeke, H.P.M., Ottjes J.A., 2000, “*Objective Oriented Modeling*”, Proceedings of Industrial Systems 2000 (IS 2000), Wollongong, Australia, The International Computer Science Convention ICSC.
Veeke H.P.M., Ottjes J.A.,”*A Generic Simulation Model for Systems of Container Terminals*”**,** Proceedings of the 16th European Simulation Multiconference (ESM 2002), June 2002. Darmstadt [SCS]. ISBN 90-77039-07-4
Whitmore, R., 1998, “*Systems Applications in the Theory and Practice of Resource Development: A Review of the Literature*”, Department of Resource Development, Michigan State University, Occasional Paper RDOP-98-1.
Wigal, C.M., 2002, “Utilizing Systems Thinking to Improve Problem Solving Practices”, technical paper ASEE SE section Annual Conference, Florida
Williams, B., 2002, “Evaluation and Systems Thinking”, work in progress on website ‘users.actrix.co.nz/bobwill’