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OBJECTIVE Oriented Modelling

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SUMMARY

A modelling approach is described, that is generally applicable for organizational, technical and information system design. The basic element of the approach is a so called ‘objective’. An objective is defined as a structured set of functions around a transformation function. The set provides a goal keeping environment for any transformation process. Combined with a well defined zooming mechanism the design can focus in from global view to any detail level.
It is shown that the approach is a common basis for concurrent design of organization, equipment and information. To make the approach concrete, the design process of a new container terminal is used as a global example.

1. INTRODUCTION

The design or redesign of a production or transportation system is a multidisciplinary (and often interdisciplinary) task. To achieve the best results a common and well-defined “language” is needed, which can be understood by all disciplines involved. Systems theory (or systems approach) can be considered as such a language; however, if applied informally it often leads to misunderstandings between the practitioners of different disciplines and if applied formally (i.e. mathematically defined) it becomes a specialization understood by only a few people. Above that (and maybe because of that) one sees in practice different design methods for each discipline involved. Studying these methods shows that they heave a lot of resemblance and start to really differ in the final design stages.

This paper shows an approach in which systems theory is used to support the design process from the very start for all disciplines involved. The approach is called ‘objective oriented modelling’ (OOM). In this paper OOM is applied to the design of the organizational, technical and information aspect of a production / transportation system, but is in general not restricted to these aspects. The method will be explained with an example of the design of an automated container terminal.
At the end of this paper some remarks will be made on the use of simulation during this kind of design processes.

2. OBJECTIVES

As can be seen from the title, the main element of OOM is called an ‘OBJECTIVE’. An objective is defined as *a goal including its goal-keeping environment*. By using objectives, each designer is automatically forced to think in terms of *‘why’* and *not* in terms of *‘how’*. Thinking in terms of objectives makes it possible to postpone the physical or technical implementation as long as possible. This provides two advantages:

1. Postponing technical choices enables the developers to reach a real optimum. Fixing the technology to be used at an early stage implicitly restricts the further design of the system.
2. Objectives can be combined in numerous ways. The choice of combinations can now be founded on considerations about the desired results and acceptable costs.

Objectives possess the following qualities [in ‘t Veld 1998]:

a. A set of *transformation functions*, to attain the objective.A transformation function performs the real action (cut, paint, transport etc.). How this will be done has not yet been defined. For example, a transport-transformation can be carried out by truck, train, boat, conveyor or pipes.

b. An *input zone*, containing functions to guarantee the acceptance of only the correct input.
Typical functions in this zone are coding, filter and buffer functions.

c. An *output zone*, containing functions to guarantee the delivery of only the correct output. This zone contains the same functions as the input zone.

d. A *control zone*, with functions for feedback and feed-forward (cybernetics).
To keep the transformation functions directed towards the objective, a mechanism is needed to react in cases of disturbance. If the mechanism reacts to the cause of disturbance, it is called feed-forward; if it reacts to the result of a disturbance it is called feedback.

e. A *steering zone*, with functions to guide the above mentioned functions (a. to d.) and to evaluate their long-term correct functioning.

All these qualities are combined in figure 1.

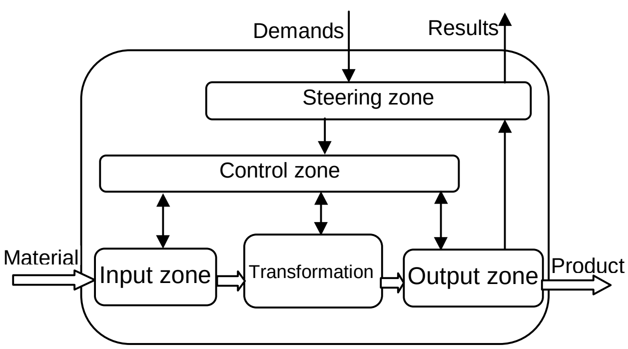

Fig. 1. The Objective model

The combination of functions into one objective offers:

- *goalkeeping properties*
The desired external demands are received in the steering zone, that translates this into internal requirements for each function. Whenever the desired external result changes or the result is not achieved these values will be evaluated and eventually reset by the steering zone. Results are reported to the environment, also if the demands are not feasible at all.
- *zooming facilities*
This translation in the steering zone allows all other functions of the model to be considered as objectives again. And that enables 'zooming in' to see more detailed objectives.
- *general applicability for recurring processes*
We will apply it to construct an organization, equipment and information system, that will perform a recurring process.
The transformation functions transform input materials to products. Materials and products can be anything, from concrete (raw materials, parts, components, jobs) to abstract (data, knowledge) elements.

For each kind of flow separate models can be derived. So the model with a material flow will differ from the model with a job flow. Practice shows that for each of the disciplines mentioned (organization, engineering and information technology) a different set of flows is used. If each discipline starts with its own set of flows (defined as an *aspect*) as being a complete description of requirements, suboptimalization can easily be the unwanted result.
The next paragraphs will explain the use of OOM in a project to design a (partly) automated container terminal [see also Veeke and Ottjes 1999]. Starting point is (and will always be) the "*primary objective*".

3. THE PRIMARY OBJECTIVE

In this example the primary objective is to transfer containers between different transporting modalities. We first concentrate on the container flow and our goal is to gain insight in the transformation functions needed. One of these transformation functions will be elaborated further for each of the aspects involved.
The highest level objective is shown in figure 2.

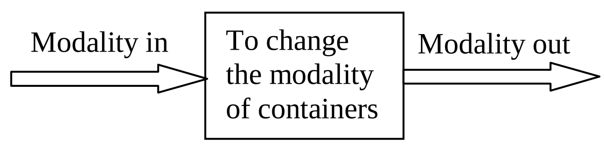

Fig. 2. Primary objective of a container terminal

We can complete this model in the way of figure 1. The transformation function is 'to transfer containers' (it's a good habit to emphasize the functional approach by using full verbs). From the environment, results are required in terms of the number of container transfers per year, schemes of ship/train arrivals including expected loads, accepted maximum berth times etc. Based on these data a steering zone derives required quay length, storage space and loading/unloading capacities. These data will be used internally, but don't say anything yet about equipment to be used or storage structures. Remember also, that data once derived during the design phase, must be evaluated on a regular basis during real time operation.
Each 'modality in' and each 'modality out' is allowed. Modalities vary from multicontainer ships to single container trucks. We will always need to be able to work on a single container level. For reasons of clarity however we restrict the model now to seasided operations, so only looking at containers arriving and

leaving by ship.
Describing the input zone a ship is 'coded' by its identification , travel number and specified load. A ship is then allocated to a quay position and stays in the model as being a buffer of containers. In the output zone the ship remains in a similar buffer before it is decoded (by means of required paper work and load descriptions) and leaves the system.
Feedforward and feedback are mainly concerned with using the flexibility in the use of the quay region and capacities to achieve the accepted berth times. Fig. 3 now shows this objective model.

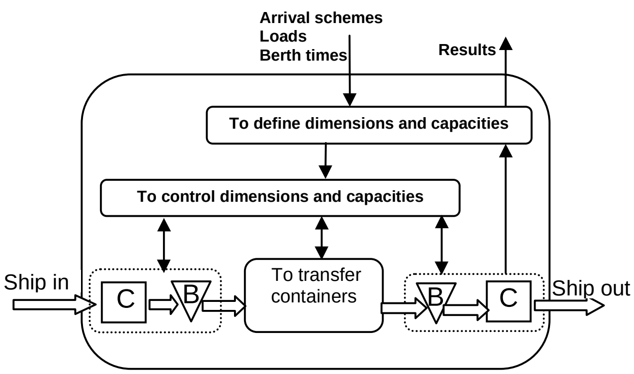

Fig. 3. Primary objective of container terminal

Global simulation models are often used to support the definition function in the steering zone [see for example van der Ham 1999].

Now zooming in on the transformation function we will always see at every container terminal 6 transformation functions, independent of area arrangement and equipment used (see fig. 4).

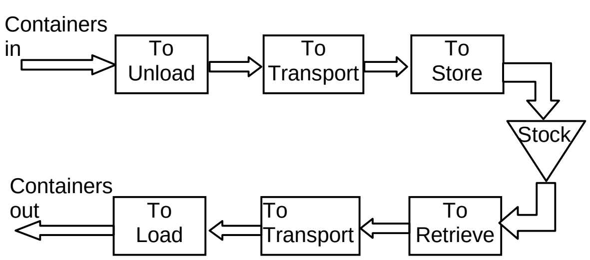

Fig. 4. First level transformations at seaside

First we must 'unload' a (set of) container(s), then 'transport' it and 'store it' in a stock (normally this is called the stack); then we must 'retrieve it', 'transport' again and finally 'load' the container.
For each of these transformations we can make an objective model with the primary objective as the environment. But first some essential multi-disciplinary decisions must be made here. Having more than one transformation on a single level of detail the question arises how to combine these (Remember: every decision made here reduces the degrees of freedom in the next steps).
We can perform each transformation with different equipment or combine transformations to be executed with more or less universal machines. The scale of operations plays a significant role here. On small terminals universal equipment can be found. In case of very large terminals area dimensions and high operation loads lead to equipment that performs only one of these functions. Questions on this type of *differentiation* are mainly concerned with organizational complexity and technical feasibility in terms of results versus costs.
Extreme differentiation leads to simple, though high quality technology. It also leads to complex organizational control, because with each change of equipment added, a new transfer function is introduced. Transfer functions automatically lead to synchronization problems and/or buffering costs.

Another way of combination can be found in the flow elements themselves. Do we want to transfer all types of containers by each type of equipment, or will we introduce specialized equipment for different types of containers? This *specialization* issue is traditionally approached from the efficiency viewpoint and therefor lots of efforts have been done in the field of technological feasibility. The more element types can be handled by one type of equipment, the lower capacity costs will be.
From an organizational point of view however, it is well known that specialization leads to decreased control complexity (often a hidden costs factor). As a result -depending on flow dimensions- specialization can be very profitable on balance. Above that one should realize that specialized hardware is a form of *static* specialization; a specialized organization however can be very *dynamic* (in this case for example universal transport equipment could temporarily be specialized to operations on one ship).

At each level of detail new choices for differentiation and specialization can be made. If we decide to differentiate at the level of fig. 4 then we can still decide –after zooming in- to specialize inside the transport function.

Depending on the structures decided on, data flows are structured also. It can easily happen, that organizational differentiation doesn't coincide with technical differentiation. In each case however the elementary functions are being performed and provide a basis to combine or split data flows accordingly.

The next paragraphs will explain the objective oriented approach further for each of the aspects mentioned.

4. ORGANIZATION DESIGN

Types of objective oriented modelling have already been used extensively in organization design. From systems theory to bussiness process redesign, they all refer to some kind of process or function approach. The strength of the model of par. 2 however is found in its generality and consequent distinguishment between function types (transformaton, control,steering etc). Returning to our example, decisions must be made for differentiation or specialization. In this case area and ship dimensions (both horizontal and vertical) make it necessary to differentiate all functions (our example concerns a terminal for about 500000 container moves (annual basis) and ships up to 5000 TEU (twenty feet equivalent units). There's no technical difference however between loading and unloading, so these operations can be combined for each equipment. To cut down personnel costs the project decides to investigate automatization of transport and stack functions(by means of Automatic Guided Vehicles: AGV's, and Automatic Stacking Cranes: ASC's). This leads to fig. 5.

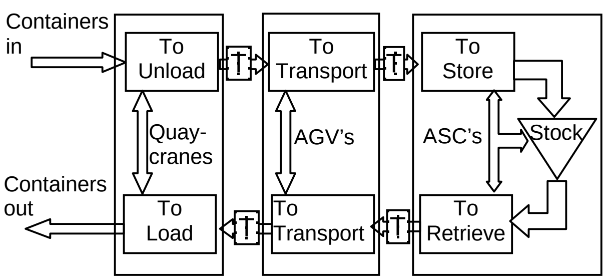

Fig. 5. Function combinations at seaside

As a consequence of the differentiation transfer functions are included now.

Until now we have seen the next management levels (we define "management" as the combination of steering and control functions):

- terminal level; mainly concerned with the management of operations related to modalities (ships, trains, trucks).
- Seaside and landside level; fig. 5 shows the seaside level, landside is analogous extending to the right side of the stack area. Management here is mainly concerned with the container flows through the different functions.
- Function level; in fig. 5 we see three management functions: for the quaycrane system, the AGV system and the ASC system.
- Equipment level; each piece of equipment needs its own management function. A quaycrane is manned equipment and the cranedriver will perform a great deal of this management function. AGV's and ASC's are automated equipment so the management function must be made explicit here and becomes part of the technical design.

Based on this partition of functions the organization structure can be completed. There's one problem left. To assign competences and responsibilities in a right way, the transfer functions must be elaborated further; which system is responsible for the right transfer of containers and gets the competences to influence the operations of other systems? By means of simulation the organizational (or logistical) aspect of this question can be investigated. On the other hand the question has vast technological consequences and to show this we will zoom in on the technical design of AGV's.

5. MACHINE/EQUIPMENT DESIGN

Numerous models have been developed to describe the design *process* [de Roode 1999,p 9-41]. Above that he distinguishes three general types of *product* models: problem definition models, concept models and evaluation models [De Roode 1999,p. 56]. Problem definition models focus on the requirements, boundaries and required functions, where concept models contain information about the concepts that solve the problem. Evaluation models finally show to what extent a concept solves the problem. As can be concluded from par. 3 objective oriented modelling is an approach to describe the required functions and combine them into the best (goal supporting) way (differentiation, specialization). As such, objective oriented modelling must be considered as a combination of a problem definition model and a concept model.

Generally spoken all design projects deal with functions and processes, starting with decomposition followed by composition [Erens and Verhulst 1995]. Our objective oriented model gives strong support to the decomposition phase, not only by defining the functions but also by distinguishing again function *types*. Objective oriented modelling is therefor a general prescription for function decomposition.

Most design models start with 3 types of input: materials, energy and signals. As can be seen from fig. 1 signals are already sorted in the control and steering zone. Unless the primary function is the transformation of signals, we only need to add the energy flow to our model. We now will illustrate the approach in the design of an Automatic Guided Vehicle (AGV).

Two alternatives must be considered:

- AGV's with lifting capabilities. This means that AGV's will in fact perform the transfer functions (and so simplify the synchronization with quaycranes and ASC's).
- AGV's without lifting capabilities. Now quaycranes and ASC's must perform the transfer functions (and synchronization becomes a complex item).

The synchronization problem must be solved at an organizational level. We are now concerned with the technical aspect. The two alternatives (with or without lifting) are represented in figures 6 and 7.

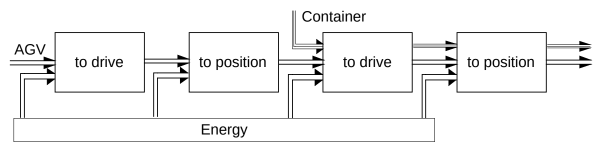

Fig. 6. AGV functions without lifting

An AGV as transport equipment is added to all functions that it should perform. Functions now are reordered to the sequence of operations from the AGV's point of view. So a complete cycle for an AGV is 'to drive' to a receiving position, 'to position' as accurately as needed, wait for a container and then 'to drive' to a delivery position and 'to position' again, and finally wait for removal of the container. Because all functions need some kind of energy, the energy flow is added to each black box. There's however no statement yet about the kind of energy used.
What happens if we add lifting capabilities to the AGV's?

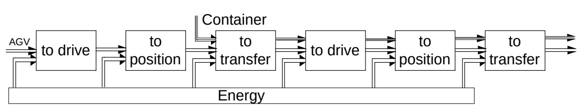

Fig. 7. AGV functions with lifting capabilities

Main difference with figure 6 is that the transfer functions 'to transfer' become part of the AGV design. How the transfer will be done is still open. A lifting mechanism or frame based containers are still some possibilities.
Again differentiation and specialization questions arise. In case of differentiation, functions are combined into function modules (p.e. the transfer functions are combined into one 'transfer module'). In case of specialization variants will appear at modular or even vehicle level. For example one could decide to design separate AGV's for 20" containers only and others for 40" containers only.
These design alternatives are completely analogous to the alternatives considered in organizational design (a module can be considered as a department, a variant as a product group). But each monodisciplinary decision has consequences for other disciplines. It is clear that two kinds of AGV's do have consequences for the organizational logistics. *But apparently, objective oriented modelling offers a common language and approach for the organizational and technological aspect, so communication remains possible at each level.*
Special consideration is needed for the required energy flows. Zooming in, more details become clear on the energy flows. After that these flows can be combined (again by differentiation and specialization) and the best type of energy can be chosen. Combining flows in this case is a purely technical matter, the choice of energy type however is not. For example choosing diesel fuel as energy type for the driving functions, refuelling will be needed and this may interrupt the operational progress.
Now let's zoom in to the first driving function and present them in the objective oriented way. This leads to figure 8.

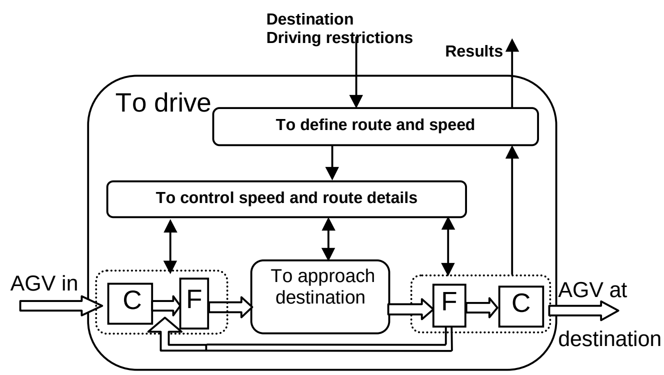

Fig. 8. Objective model of 'to drive'.

'To drive' has the goal to approach and finally reach the destination. To be able to do that we need at least a destination and eventually driving limitations (possible routes, maximum speed allowance or requested arrival time). Based on these data we need to fill in the route details (passing points and trajectory speed), by means of a steering function. To start and perform the route properly we need a control function, which monitors the progress and adapts speed and direction according to the steering data. A coding function can be added to input zone to identify the AGV and route combination. Also a filter can be added, to check the AGV's status etc. The filter in the output zone is meant to check the finish of reaching the destination, while decoding can be added to add the data needed to continue with the next function 'to position'. Zooming in further we could reach a detailed level of AGV design.
For our purpose we focus now on the data handling aspect. Because at the level of fig. 8 it is already clear, that the steering, control, coding and filter functions

are mainly data handling functions. Organizing the functions we can decide to add these functions locally to each AGV or centralize them in one information system. Each choice will influence the organization and information system concept and depends on the knowledge on control systems available. In the next paragraph we will investigate the use of the so far derived models in information system design.

6. INFORMATION SYSTEM DESIGN

From the organizational point of view, the primary flow consists of containers and we differentiated the defined functions to organizational units as Seaside, Storage and Landside (the last two were not covered explicitly). The technical point of view adds equipment as flowing elements and differentiates to equipment subsystems as Quaycrane (QC) system, AGV system, ASC system and Straddle Carrier (SC) system (for Landside modalities).
Normally data flows support the execution and control of all these differentiations. But how do we structure the data flows? Especially when structures of the two approaches are not equal?

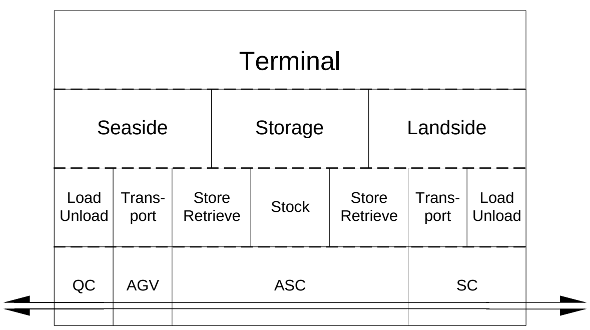

Fig. 9. Organizational and technical structure

In fig. 9 we recognize the elements worked out as objective models for the Terminal, the Seaside and the AGV. Between the technical structure (lower level) and the organizational structure (second level) we see the elementary functions for changing modalities. Differentiating them led to one ASC system for 'store and retrieve' and 'stock'. From the figure it becomes clear that the ASC system however supports all three organizational units. How does this influence the data structure?
To answer this question, we first must distinguish between [in 't Veld 1993]:

- data for the transformations themselves
- data to manage the transformation
- data to assess the state of the system

The first category of data is directly connected to the flow of elements. Many of these data even accompany the flowing elements physically. All the data do flow through the same functions as described in the models. We can represent this easily by changing the "material" flows to "data on material" flows. Usually the best representation of "data on material" is the "job". No container is moved without a "job". A ship arriving represents in this case a batch of jobs to be done. An AGV moving a container is added to the job's data at the moment the container is received and this can in fact be modelled as a coding function etc. In the author's opinion it is best to structure the information according to the primary functions performed by the equipment subsystems.

The second category of data we have already met in fig. 3. To manage the transformations we need steering and control data. Because these data are always needed for keeping the goal of each function, we will encounter these data in each elementary function or combination of functions. So 'Seaside' will need this data, but also the 'ASC system'. Because these data are all derived from the primary objective, the relation between these data must be reflected in the information structure. Starting from the execution level itself, the data must be interpreted according to the functions involved and then again be reordered according to the departmental or personnel structure. An example of this structring is given in fig. 10 for the information needed to evaluate the transformations.

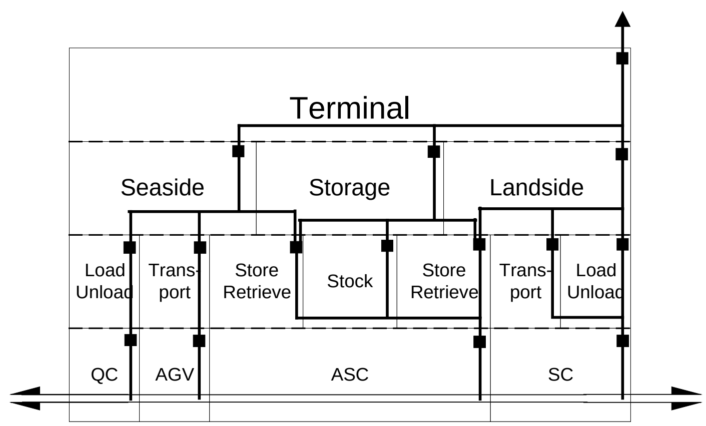

Fig. 10. Structure of evaluation data

Each black box represents an evaluation function. For example the evaluation data for the ASC system must provide data to the 'store and retrieve' and the 'stock' functions. But each of these functions must provide the data for 'Seaside', 'Storage' and 'Landside' departments. The same relations but in reversed order hold for the steering data.
In practice we often encounter situations where completely separate information systems are being

used at the different levels. ERP systems mainly operate at the departmental levels, while tailor made or specialized systems support the technical levels. In our view the link between these systems can be found by the level representing the elementary functions involved.

Finally, data must be available to assess the state of the system. Mostly this concerns the actual state of equipment, personnel and space. Are they still adequate to reach the goals requested etc.? For this category of data the same structuring considerations hold as for the second category above, because they are part of the steering zone. The difference is the long term character of the data. The relationships must be clear in the datastructures to prevent unnecessary or double actions. For example based on AGV evaluation one could decide to upgrade the AGV's during maintenance; based on the same data however, but now from the 'Seaside' evaluation, one could decide at the same time to add more AGV's to the system. To prevent this kind of situations it is not only necessary to report results, but also measures taken to guarantee future results.

7. CONCLUSIONS AND DEVELOPMENTS.

In this paper 'objective oriented modelling' is introduced as an objective and well-defined method to design organizational, technical and information structures. This way of modelling offers a common reasoning base by which communication between the different disciplines is preserved, and by which the quality of decision making can be improved.
The method is currently being used in graduate assignments by students of the university. It will also be used in extensive design projects starting this autumn.
Parallel to that the development of a software tool is started to support the model building. This tool recognizes all the functions of an objective and supports the zooming quality. However further formalization of the definitions is still necessary. We hope to be able to show the first version of this tool at the conference.
To support the modelling with simulation a process oriented simulation tool TOMAS has already been developed. By TOMAS it will be possible to translate a function descriptions of an objective oriented model directly into corresponding process descriptions and simulate the behaviour of the system. This translation can be applied at every level of modelling.
TOMAS can be found at http://www.tomasweb.com.

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