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Procedure for validation of a functional model of a central heating system

Jing Wu[a,d,*], Laibin Zhang[a], Sten Bay Jørgensen[b], Niels Jensen[c], Xinxin Zhang[d] and Morten Lind[d]

[a]College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing
Beijing, 102249, China
[b]Department of Chemical and Biochemical Engineering, Technical University of Denmark(DTU)
Lyngby, 2800, Denmark
[c]Safepark Consultancy, Kannikestræde 14,
Slangerup, 3550, Denmark
[d]Department of Electrical Engineering, Technical University of Denmark(DTU)
Lyngby, 2800, Denmark
[*] Corressponding Author

***Abstract*— Functional models are increasingly being used in industries, such as oil and gas, for decision making problems. However, the results obtained from the models that decision makers rely on are dependent on whether the model of the system is suitable for the specified purpose. Hence, it is desirable to check the consistency and suitableness before the model is applied in problem solving. Consequently the questions of model verification and validation need to be addressed on a functional modeling background to develop a systematic methodology on a scientific basis to lead to a practically applicable procedure.**

The Multilevel Flow Modeling (MFM) methodology is adopted in the paper as a formalized qualitative functional modeling methodology for dynamic process systems. A procedure for a functional model validation is proposed. A simple engineering system, i.e. a central heating system is presented to illustrate the proposed functional model validation procedure.

Keywords- Multilevel Flow Modeling; Model verification and validation; oil and gas industry; fault diagnosis

I. INTRODUCTION

Functional models are increasingly used in, e.g. oil and gas industries for decision making purposes. However, the results obtained from the models that decision makers rely on depend on whether the model of the system is suitable for a specified purpose. The intended use of the model determines the necessary degree of sophistication required to make the model purposeful. It is believed [1] that the relationship between the real world and the model is impenetrable or non-transparent, the truth of the model is usefulness guided according to the chosen criterion. Hence, it is necessary to check the consistency and suitableness before a model is applied in decision making problems.

The questions of model verification and validation come up to access the accuracy and reliability of Functional models. Model verification is the procedure of determining whether an implementation accurately represents the developer's conceptual description of the model [2]. A conceptual process model is defined as a hypothesis for how a system or process operates [3] or as a model that is based on the understanding of a system and its behavior. Conceptual description (model) is the conceptualization from the observation of the involved phenomena. This idea can be expressed qualitatively as a functional model which serves as a means which the model development team employ to represent the real world possibly conveyed by semantics. The conceptual model may be used for building knowledge-based systems. In functional modeling the objective of the conceptual model is to convey the fundamental principles and functionalities of the system with the intended application. Hence functional model validation is a procedure of determining the extent to which a model constitutes a suitable representation of the real world system from the perspective for the intended use of the model. A practical functional model validation procedure is to assess whether the model is in sufficient agreement with observed data, prior knowledge and its intended use. As argued by Popper [4], a model cannot be determined to be valid; it can only be invalidated by experimental observations. Thus, a validation procedure results in gaining confidence in a model by repeated attempts to invalidate it. In this paper model verification is assumed to be handled by the modeling test bench, e.g. as a syntax check which may be performed immediately during each step of the model building.

Multilevel Flow Modeling (MFM) is adopted in the paper as a formalized method for causal and consequence reasoning on an abstract function-oriented representation of a process system. MFM is selected for demonstrating the model validation of process simulation due to its powerful expression ability [5] and a set of reference rules [6-7] which are applicable to validate the MFM model. Some MFM model verification issues has been addressed in Lind [8] and Zhang [9], i.e. to partly formulate the MFM syntax and implement these in the MFM Editor [10], a tool for acquisition of MFM models.

As argued by Kleindorfer et al., [11] it is not possible to unravel the sources of the main controversial discussions concerning model validation without understanding the paradoxes in the philosophy of science that are hidden in the debate: What is truth and how to prove truth. Therefore, it is our intent to approach validation at two levels (1) a scientific level, and (2) a practical level. A procedure for a functional model validation is proposed. The procedure is demonstrated by using a simple engineering system- a central heating system as an example.

II. A SCIENTIFIC BASIS FOR A FUNCTIONAL MODEL VALIDATION

A functional model in system engineering provides a structured representation of the functionality of the modeled system for an intended application purpose. [12]A functional model is developed from a functional modeling perspective which focuses on describing the purposes and functional organization of the specific possibly dynamic process. [5]Specifically, a functional model consists of sets of goals, function structures with interrelations and functional elements coupled by causal relations. Model validation is a procedure to compare the behavior of a model with that of the real world. If the predicted behavior of the model sufficiently well follows the behavior of the real world in a certain specified circumstance, then the model is considered to be a (not in-) validated model for the specified purpose. However, the question of objective vs. subjective existence of the real world is relevant for model validation. For example, whether a sunny weather can be judged good or bad depends on the intended action in the weather. : E.g. when taking a sun bath on a beach, then sunny weather is good. According to the distinction between ontological objectivity and subjectivity, and the distinction between epistemic objectivity and subjectivity in Searle [13], the sunny weather itself is ontologically objective. The value judgment of the sunny weather as acknowledged here is epistemically objective, as an agreement among the sunbathers. A subjective statement cannot be invalidated due to its dependence on personal feelings, experience or attitude. Besides this, another related question is what is meant with sufficiently well in the specified circumstance. Obviously, one can always strengthen the accuracy requirement of the model following. Therefore, a model validation in reality can only be carried out as a model in-validation, i.e. to determine within which range of application a model represents the real world behavior with the required accuracy for the intended application. As claimed by Popper [4], a theory can only be falsified.

When it comes to the question of validation of a functional model, first it is concerned with whether the validation of assignment of functions is objective or subjective. As discussed above, a subjective statement cannot be invalidated (objectively). For example, the statement "the function of a cup is to contain an amount of water" is not decided based on the intrinsic features of the cup, i.e., the physical material of a cup, instead, it is based on the intentional relative features, or the user related features of a cup. One could also claim that the function of a cup is the same as a paperweight in terms of one of the intrinsic feature of a cup, i.e., the weight of a cup. Therefore, it can be deduced that the validation of functions neither is objective nor subjective, instead, it is inter-subjective. The involved judgment criteria for validation of functions is chosen based on the ontological objective feature or the intrinsic feature of an object, as well as on the intentional relative or epistemic objective feature of an object. Notice that validation of elements of an MFM model and the proposed corresponding validation procedure of an MFM model in this paper are all based on the fundamental deduction statement of philosophy of model validation as claimed here. Therefore, it is claimed that the work on MFM model validation [14] is insufficient, since it only investigates the validation of casual relations between functions. It has nothing to do with the validation of the top level of intentional relative features of functions. The point stressed here is the philosophically oriented compass to guide us to accomplish the task of validation of a functional model.

Another point is that the causality detection method [14]: the modified cross correlation technique is inadequate and insufficient for validation of the causality between events. Correlation does not imply causation since a correlation between two variables does not necessarily imply that one causes the other [15]. A further point is that the assumption of the causality is also necessary to be considered which is against the basic argument of Friedman's essay [16] that the unrealism of a theory's assumptions should not matter; what matters are the predictions made by the theory. In reality, a typical theory is always presented together with a set of assumptions: If assumptions A and theory T hold, Then C follows. Now, if C is not observed, it is not always clear whether it is because of a wrong theory or invalid assumptions. It may thus be possible to save the theory by stating that the assumptions were violated. [17] However, in some cases, whether the assumption is logically valid or not is not so important. Because the assumption of causality could have been correct, although the logic behind the assumption could still have been flawed. A good evidence of such statement is the early atomic theory proposed by Bohr [18], based on contradictory assumptions to construct fairly convincing models of atoms. Therefore, in this paper, we hold the standpoint that assumptions of causality matter, however we will not make efforts to invalidate assumptions.

The purpose of the above discussion is to illustrate the possible benefit of applying science to develop a procedure for model validation. Based on these scientific arguments, the following section proceeds to model validation at a practical level.

The principal steps in practical a functional model (in-) validation proposed in this paper are:

1. Representing the system by functional modeling in agreement with the modeling purpose or application domain;

2. Designing validation experiments: actuating the actuator function in a function structure, causal reasoning for the changed state of the actuator function in the function structure;

3. Carrying out the validation experiments for each function structure iteratively;

4. Introducing the corresponding changes of input in real system and getting output to (in-) validate the functional model

These steps may be carried out in a top down or bottom up procedure.

III. HOW TO VALIDATE A FUNCTIONAL MODEL

A. Validation elements of an MFM model

An MFM model is an abstract function-oriented representation of process system. The elements of a functional model constitute representation of the intentions, the process functionality and their causal relations. The intention represents the ultimate application purpose or objective, i.e. the aim or goal. Goal achievement may be challenged by threats. The process system functionality is represented by interrelated flow structures which each include causally related flow elements. The interrelations between flow structures display their interdependencies. Finally means-end relations display the dependency relations between functions and the goal and subgoal specification. Means-ends analysis [19] or synthesis in a design environment aims at developing or synthesizing a process description of the path that leads to a desired goal. The general paradigm is: Given a blueprint of designed system purpose, to find a corresponding recipe of realizing the purpose[20]. When the above concepts are considered in a means-ends framework, the concepts may be categorized into five knowledge types from top down (ends to means) as shown in Table 1. To illustrate the five knowledge types, an MFM model of a central heating system [8] is presented to give examples of each knowledge type shown in Table 1.

The first knowledge type is called the intentional or the goal and purpose knowledge. The concepts of purpose, goal, objective and threat belong to this type. A purpose is an abstract description or characterization of any of a large number of situations. A goal, the final purpose is a concrete description or characterization of single situation at a point in time. One can have the goal to achieve a specific purpose. Also, the goal can be decomposed into subgoals. For example, during winter, it may be cold in a house. The purpose to keep us warm in the house can be achieved in different ways, such as turning on the radiator of a central heating system or turning on an air conditioner in heat mode. The goal can be set to maintain room temperature at 20°C. This objective is defined as the desired (intended) situation, in contrast, a threat which may challenge goal achievement may lead to an undesired situation. In this case, to maintain the temperature at 20°C is our desirable situation or our objective. If the temperature falls below 20°C, a threat may have disturbed the system. Such a threat could be increased cooling of the house due to colder outside weather. A threat in medicine may be what is called side-effect of a drug if that is harmful to health. An MFM model represents the modeled system as a man-made purposeful system, i.e. an artifact. Validation of the top level of an MFM model, the intentional level may be developed from perturbing intersubjective knowledge as it is known in the social sciences.

The second type of knowledge, see table 1 type 4, is associated with system functional knowledge. The system functions are assigned to achieve the decomposed goals or sub goals. In engineering, a function is interpreted as a specific process, action or task that a system is able to perform. [21] Thus the validation of system functions is dependent on the knowledge. Polanyi [22] regards knowledge as an active comprehension of the things known, an action that requires skill or personal knowledge. Personal knowledge is an intellectual commitment that is a fusion of personal participation and objective knowing. Besides knowledge, such system functions are facts such as that all knowledge shared by engineers is agreed upon in the community. These for these two interwoven principles, namely as machine-like functions and ‘regulation’ functions, then machine-like functions are ideally defined by precise operational principles, while the correctness of a regulative achievement can be expressed only in gestalt-like terms. Thus, validation of system functions also includes the tasks derived from the above two aspects. MFM models represent system functions knowledge in a set of mass, energy and control flow structures at several levels

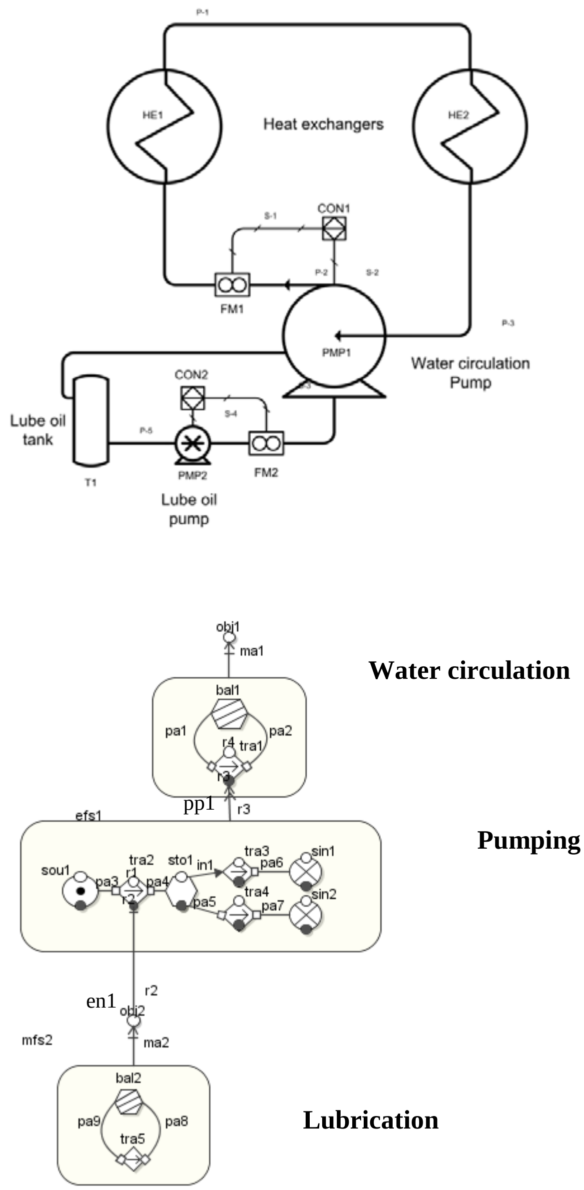

Fig. 1 MFM model of heat transfer system [8]

of abstraction. Therefore validation of MFM models encompasses a procedure for validating these flow structures (i.e. mfs 1, mfs 2 and efs 1 in Figure1) based on the system functions knowledge and e.g. on designed experiments.

The third type of knowledge, see table 1 type 3, regarding validation of a functional model is to validate the relations between means and ends. Means-ends relations are displayed in three layers vertically: goals and functions relations (i.e.ma1 and ma2 in Figure 1), functions and functions structures relations (i.e.pp1 in Figure 1), functions and physical structures relations (i.e. en1(r2) in Figure 1).

TABLE I. VALIDATION OF A FUNCTIONAL MODEL IS BASED ON KNOWLEDGE TYPES

Types	Knowledge categories		Examples
5	Intentional knowledge: The ultimate purpose or goal and subgoals		obj1: the desired flow of water circulation
			obj2: the desired lubrication for pump
4	System functionality knowledge		mfs1: water circulation flow
			efs1:Electrical energy transformed into mechanical energy for pump working properly
			mfs2:Lubrication flow for pump working properly
3	Means-ends relations	Goals and function relations	ma1: maintain the flow of water circulation
			ma2: maintain the lubrication for pump
		Function and function structure relations	pp1: the mechanical energy of pump is to produce the moving of the water
		Function and physical structure relations	en1(r2): The lubrication of pump (tra5) is to enable the pump (r2) working properly
2	Causal state dependency relations		in1: the energy stored in pump influences the conversion of kinetic energy of pump
			pa5: the energy stored in pump does not influence the conversion of friction loss of pump
1	Structural knowledge		r2:pump as an agent role

Goals and functions relations can be interpreted as the answer to the question of “How to utilize the functionality to achieve the goals”. Functional structures are made up of functional elements to represent an activity. Functions and functional structure relations can be seen as logic relations between action phrases or action sequences. Functional and physical structure relations can be interpreted as the answer to the question of “What to be utilized to realize the function”. Means-ends relations represented in MFM are of six types: Produce (pr), Maintain (ma), Destroy (de), Suppress (su), Mediate (me), Producer-Product (pp). Also, to improve the semantics of MFM, roles are regarded as the representation of relations between functional and physical structures. For example, agent and object are representative roles types, which also can be seen as structural entities in a process in terms of objectives. In the water circuit of the central heating system, the circulation pump is intended to maintain the circulation of water with the objective of maintaining the heat energy transport in the system. Here, the pump is the agent. Such relations can be associated to the third layer means-ends relations which are defined on the basis of agent and object roles of actions in the MFM (e.g. the pp relation and the me relation).

The fourth type of knowledge in Table 1, for validation of a functional model concerns the state dependency relations (i.e. in1 and pa 5 in Figure 1). In an MFM model, state dependency relations represent relations between functions inside a flow structure, i.e., causal relation between two functions. The assumption behind casual reasoning between functions is that the functions are available i.e. that the physical components realizing the functions are available and properly configured so that they can be used to implement the required functions. Causality is the relation between an event (cause) and a second event (effect), so it is relative to events rather than statistical variables. Causality itself may be deterministic or probabilistic. For example, one could easily hypothesize that one factor (i.e. bad air quality) causes one effect (i.e. increase in risk of getting lung cancer). Therefore, the validation of causal relationship faces the question of how to demonstrate that such a causal relationship, in fact, exists. In this paper this is done simply through a suitably designed experiment which imposes a specified change in the upstream variable and records the downstream result of the change. In this way, the causal relationship between functions in a flow structure can be assessed directly.

The fifth knowledge type in Table 1, for validation of a functional model is related with the structural knowledge (e.g. r2 in Figure 1). Structural knowledge is at the bottom level of a functional model. The validation of structural knowledge also has to deal with two questions. The first is whether there exists a structure to realize the function or not. Secondly, can the structure indeed realize the required function? In general, to validate such a bottom level of a functional model, the additional reliability and performance data of the pertinent component needs to be considered.

The following section, the validation procedure for an MFM model is presented.

B. Validation procedure for an MFM model

Validation of an MFM model for an artefact (i.e. a technical system) is here proposed as a task of performing a number of experiments using the model and testing, whether the experimental results are in agreement with knowledge, as depicted in Figure 2. The first step is to specify the modeling purpose, i.e. the intended use of the model. Therefore, the modeling purpose is divided into two categories: internal and external modeling purpose. Internal modeling purpose is meant to inquire whether the MFM model preserves the behaviors and characteristics of real system that we are interested in. External modeling purpose is meant to inquire into whether the applicable domain provides a sufficient representation for the intended purpose. This paper only deals with the first modeling purpose category. To verify the representation of our conceptual description of the real system, the MFM model is investigated as the second step, however this verification is assumed to be handled by the MFM syntax, i.e. the modeling environment. The third step, to validate the MFM model functionalities, a number of validation experiments should be designed to validate each of the above discussed elements of MFM model. The experiments are implemented by iteratively for $i < N$. Until $i=N$, if the qualitative result derived from the MFM model follows the behavior of real system, then the MFM model is not invalidated which means the validation procedure ends. In contrast, if the MFM model is invalidated and since it is here assumed that the MFM model correctly reflects the purpose specified, and then only two decision options are displayed. The two decision options are: either modify the model or modify the experimental design. A consequence of the first of these options would be a modification of the MFM model. Which route to select depends upon how the test failed.

There are three available sources for validation of an MFM model: Interviews, operational procedures, or a validated quantitative simulator. In this paper it is assumed for simplicity that a validated quantitative simulator exists which correctly represents the real system phenomena. Because a functional model is a conceptual model and explicitly represents the tacit knowledge behind the model usage; the scope of a functional model is broader than that of a quantitative mathematical model. Thus in some cases, a validated quantitative simulator is an insufficient source to validate an MFM model. This will reflected in one experiment in section 4. Therefore, interviews and operational procedure are the other two important sources to complement a validated quantitative simulator, because these two sources implicitly contain some of the tacit knowledge behind a functional model.

If a validated quantitative simulator is chosen to be used as a source to validate an MFM model, then the criteria for accepted discrepancy between behaviors of an MFM model and a validated quantitative simulator is related to two considerations: the difference in granularity and suitable applicable range between a qualitative and a quantitative model. When designing validation experiments it is important to consider the difference in granularity between a qualitative and a quantitative model. The disturbance to be applied has to be sufficiently large to inflict a discernible change in the qualitative model states. Such a change can appear rather large in the quantitative model. On the other hand, a quantitative model has limited range of application. When the designed experiment is out of the applicable range, it is unable to carry out such experiment in a quantitative simulator. Therefore validation of a functional model depends both on validation of the reasoning capability of the functional model for “small” changes in a quantitative simulator and on determining the validity range for these predictions as indicated by the limits determined from large(-r) disturbances in the quantitative simulator.

The following section presents a MFM representative aspect of model validation for a central heating system, where a quantitative simulator rather than the system proper is available for testing purposes.

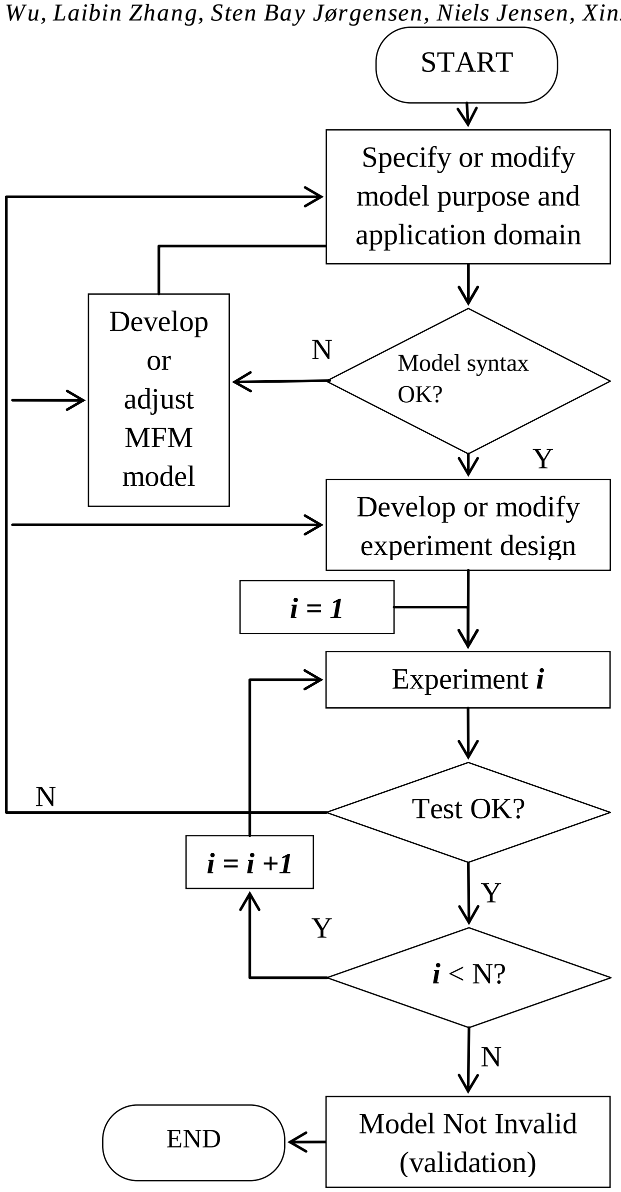

Fig. 2 Validation procedure for an MFM model

IV. DEMONSTRATING EXAMPLE FOR A FUNCTIONAL VALIDATION PROCEDURE

The example process shown in Figure 3[23] where the water circuit of the central heating system has been extended. The boiler loop is the distribution circuit for heat delivery. The boiler loop for a hot water system is a closed system, meaning that all water that leaves the boiler to the radiators eventually returns to the boiler. This loop has a supply and a return pipe to and from the boiler. On the return side, there is a circulation pump to keep the water moving. On the supply side, there is a flow control valve and an expansion tank to take care of the volume expansion of the water as the temperature increases. The modeling purpose is to maintain the temperature of a house at 20°C under varying outdoor temperature condition.

A. MFM model

To develop a MFM model of the central heating system, the operational principle of the water boiler central heating system needs to be captured in order to represent the system functionality and intended application purpose. As shown in the schematic of the central heating system in Figure 3, the operating principle is as follows: first, the system and water chamber of the expansion tank is filled with cold water driven by circulation pump and by the water supply subsystem. Then the cold water is heated by the boiler resulting in a density decrease, at the same time, driven by the denser return water from the radiator, the hot water is going up along the water main flowing into the radiator to form a water circuit. The mechanical energy of the water circulation pump functions to overcome the resistance of the system to formulate a forced circulation. When the system temperature increases, the water volume expands and the pressure of the pipe network increases as well. Part of the water will be squeezed along the expansion pipe into the water chamber of expansion tank to maintain the pressure of pipe network. In contrast, when the system temperature is decreasing, the water volume decreases as well, and the water in the expansion tank will be released into the pipe network. If the water level reaches beyond the upper limit safety limit value of the expansion tank, the excess water will be discharged through the overflow pipe of the expansion tank. When the water level is lower than the lower safety limit value of the expansion tank, then supply water will be added into the system to stabilize the system pressure. The function of the expansion tank and its overflow pipe is to prevent overpressure in the central heating system.

From a control engineer's point of view the room air temperature is defined as the process output or measured variable that has to be controlled. And the input or manipulated variable is the heat supplied to the boiler, i.e. the fuel flow rate. Whereas the heat losses through ventilation, walls, doors and windows are disturbance variables, which influence how much heat input is needed.

Figure 3 presents a means-end analysis of the central heating system. The function of the supply water sub-system (means) is to transport water to the expansion tank, its subgoal (end) is to maintain water level in expansion tank within safe limits (lmin≤l≤lmax). The water in the boiler, the water flow control valve, the radiator and the circulation pump (means) form together a water circulation sub-system, whose function from mass flow perspective is to circulate water in order to

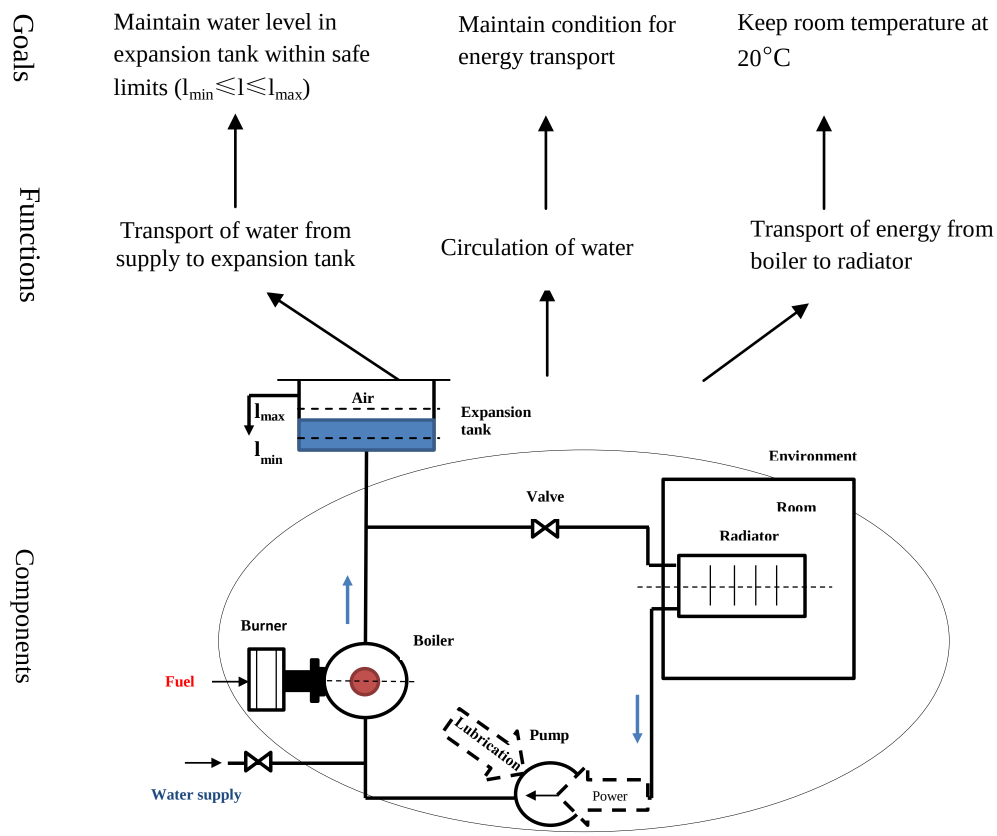

Fig. 3 Means-ends analysis of a central heating system

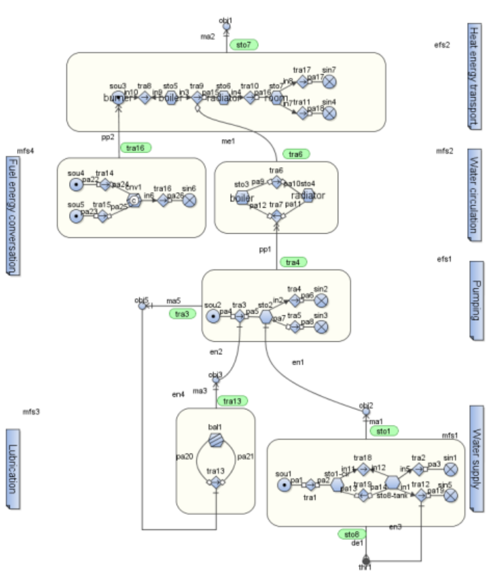

Fig.4 An MFM model of the central heating system

maintain the necessary condition for energy transport (end). However, from an energy flow perspective, the same means can fulfill the function of transport of energy from boiler to radiator to keep the room temperature at 20°C.

The modeling purpose is defined to maintain the temperature of a house at 20°C under varying outdoor temperature condition. To represent the modeling purpose, the MFM model (in Figure 2) is revised as follows. From a control perspective to encapsulate the actuating variables and disturbance (-s) to the system, as well as from fault diagnosis perspective, two mass flow structures (mfs 3 and mfs 4) are added, lubrication of the circulation pump and the fuel energy conversion in the burner from the mass perspective, respectively, and the heat losses through ventilation as a disturbance variable, walls and windows represented by tra 17 and sin7 are added as well as shown in Figure 4. The circulation lubrication system (mfs3) is a closed circuit inside the circulation pump. The so called circulation lubrication system ensures objective (obj3) i.e. continuous lubricant support and constant lubricant inflows as well as a lubricant return to enable proper operation of the circulation pump (tra13). In return, the objective (obj5) of maintaining the circulation pump work properly enables the lubricant inflow as well as a lubricant return. To introduce the manipulated variable (the heat to the boiler, i.e. the fuel flow) tra 14 is represented in mfs4. The fuel and the air (sou 5) are mixed and burned in the burner (cnv1), the conversion of chemical energy of fuel (tra16) producer-product (pp2) to the heat energy input (sou3). To explicitly explain the function of the expansion tank, the mass flow structure (msf1) is revised as shown in Figure 4. The storage sto 8 represents the water volume in expansion tank, to handle the threat (thr1) of overfilling the expansion tank, i.e. exceeding the lmax then the overflow pipe (tra12) enables excess water to flow out of the expansion tank.

The remaining part of the MFM model is illustrated in the following. The mass flow structure mfs1 at the bottom represents the water supply to the central heating system at the start-up time. The water source (sou1) is transported by pipe (tra1) and stored (sto1) in the water circulation loop of the central heating system and some water is also transported (tra2) and filled (sin1) into the expansion tank. The water stored in the water circulation loop provides and maintains the working pre-condition of the circulation pump. The next upper energy flow structure efs1 represents the energy conversion of the circulation pump. The source (sou2) represents electrical energy supply for the pump and the electrical energy is transported (tra3) and stored (sto2) in the pump. The transports tra4 and tra5 represent conversion of the energy into kinetic energy (sin2) and friction losses (sin3) in the pump. The electrical energy is transformed into kinetic energy (producer-product pp1) the return water stored in the radiator (sto4) pumping（tra7）into the boiler （sto3）. This water circulation is displayed in the mass flow structure (mfs2). The flow control valve controls the transportation flow rate（tra6）from boiler to radiator. And the tra 6 flow function mediates the heat energy transported (tra9) from the heat energy of water in boiler to the radiator in the top energy flow structure (efs2). Efs2 represents the heat energy transport in the central heating system. The heat energy source (sou3) generated in the burner of the boiler transported into (tra8) the water and stored （sto5） inside the boiler. Afterwards, the heat energy of water is transported (tra9) by pipe and stored (sto6) in the radiator and the heat is transported (tra10) and stored (sto7) in the room. The energy stored in room is to maintain the objective (obj1) of house temperature at 20°C.

According to the validation procedure for an MFM model presented in Section 3, validation experiments can be designed and carried out in a bottom up procedure. Below, 2 experiments are presented to illustrate two different validation aspects.

V. VALIDATION EXPERIMENTS

A. *Experiment 1- (in-) validate the MFM model against operation procedure*

To (in-) validate mass flow structure mfs 1 and the enable relation en1, associating actuator role with transport function (tra 1). Actuator role performs the commands it receives from a control agent attached with a function (source, sink, transport) to influence the state of the function. We assume that the state of transport function (tra1) is changed into high flow. By consequence reasoning in the MFM model, the consequence tree is generated as represented in Figure 5. There are 4 consequences: the state of water supply source (sou1) becomes low volume; the volume of circulation water increases (so1-cir, hivol) leading to that obj2 becomes false to be unable to provide and maintain the working pre-condition of the circulation pump; the water level in expansion tank increases (sin 5, hivol); and if the water level in expansion tank is higher than the lmax, to handle the threat (thr 1, higher than the safety limit) for enabling transport function (tra 2) to transport more flow of water through overflow pipe in expansion tank. This experiment can be implemented by operating water supply valve more than the normal stem position for start –up in the real system. The suggested change of the valve should be sufficiently large to be visible in the qualitative simulation model. Because start-up mode of a system is usually not in the applicable range of a quantitative simulator, so the result of the MFM model simulation can only be compared to the operational procedure for validation of the MFM model.

B. *Experiment 2-validate the MFM model against validated simulator*

To (in-)validate mass flow structure mfs 4, energy flow structure efs 2 and the producer-product relation pp2, the transport function (tra3) can be actuated into low flow and by consequence reasoning in MFM model, the consequence tree is generated and represented in Figure 6. The response behaviors of the MFM model are 3 consequences: the state of fuel source (sou 4) is high volume; the state of sink (sin6) of fuel energy is low volume; the heat energy absorbed in water (sou3) in burner is less, and consequently the heat energy dissipated from radiator into room (sto7) is low to result in objective 1 for maintaining temperature of room at 20°C to be threatened. Meanwhile, the heat dissipating to outdoor (sin 4) is less. In a validated quantitative simulator, this experiment can be implemented by setting fuel valve stem position less than the normal stem position. If the simulation is to be used to determine the validity range of a qualitative model, then suggested change of the valve should be sufficiently large to be visible in the qualitative simulation

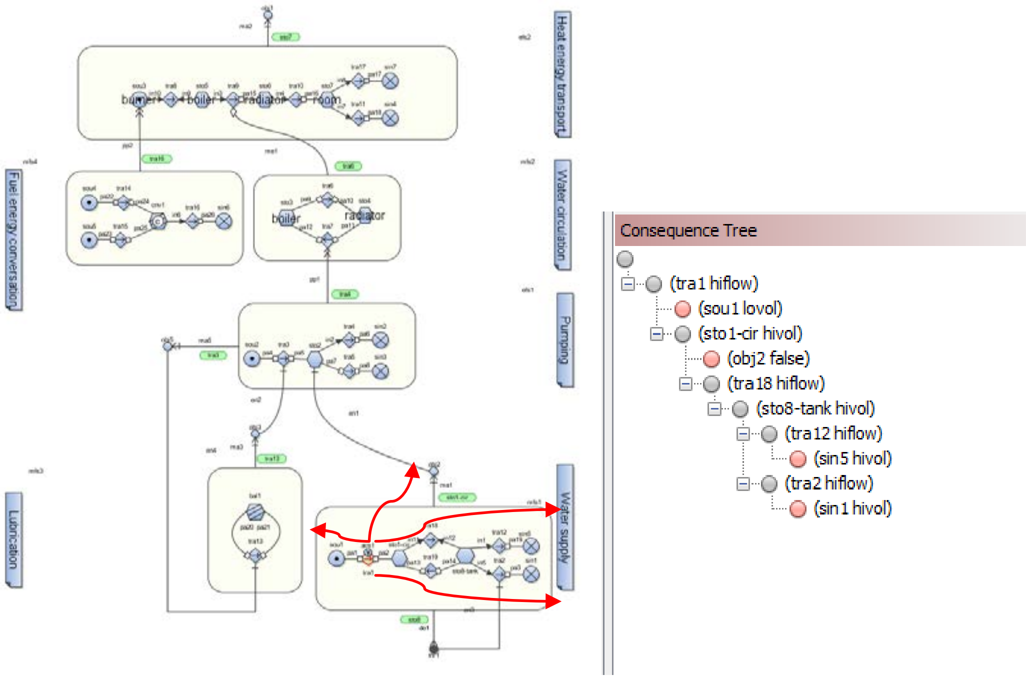

Fig. 5 Association actuator role [24] with transport function (tra 1) to changing the state of transport function (tra1) into high flow in left and the consequence reasoning represented in consequence tree in right

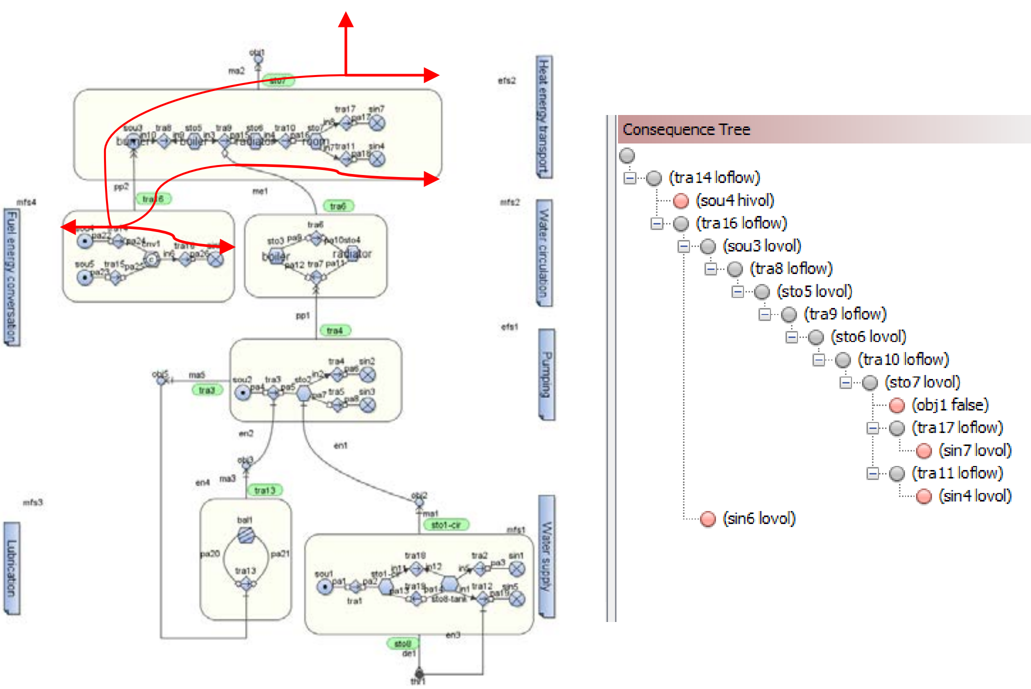

Fig. 6 Actuating transport function (tra 14) to changing the state of transport function (tra14) into low flow in left and the consequence reasoning represented in consequence tree in right

model. Getting the quantitative behavior for small changes the system should be used to validate the reasoning of an MFM model. As discussed the criteria for acceptance of discrepancy between a functional model and a validated simulator, the mass flow structure mfs 4, energy flow structure efs 2 and the producer-product relation pp2 can be validated.

VI. CONCLUSIONS

Qualitative process knowledge is increasingly used in various process industrial domains for HAZOP and failure analysis [25-26]. Consequently assessment of the validity of and the validity range for qualitative models represents an important scientific challenge. The paper assigns verification to the model syntax check in model development. Thus this issue can be entirely handled by the model implementation software. Based upon the functional modeling paradigm a two layered procedure for validating functional models is proposed. The key principles of the validation procedure are demonstrated on a central heating system for a house which is modeled using MFM. The causal reasoning system behind MFM is shown to be essential for demonstrating the validation procedure.

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