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APPLICATION OF SUBTRACT AND OPERATE METHOD FOR DEVELOPING FUNCTION ENERGY STRUCTURES OF PRODUCTS AND SYSTEMS - A RULE-GUIDED APPROACH

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Abstract

The relation between functionality and energy efficiency of products and systems is examined. An extended configuration of Function Structure scheme is proposed and named as Function Energy Structure (FES). (FES) represents in a qualitative, yet detailed manner, the actual functions performed by the components (assemblies, subassemblies or parts) of a product and depicts the energy type(s) used and the energy transformations and losses that take place. (FES) indicates also the components used for the embodiment of each separate function. In (FES), the represented functions are in general form-independent. However, some functions may be related to certain components if the latter embody the product's working principle. For the formulation of (FES), a Subtract and Operate approach is used that locates product functions. These functions are then transferred to a proper Function Structure form, where all necessary material and energy notations are added. The whole process is rule-guided and for that reason sets of proper rules are introduced. A case study of a traction elevator serves as a reference example and contributes to better perceiving and understanding of the proposed method.

Keywords: Design Methods, Ecodesign, Functional Modelling, Energy Efficiency, Reverse Engineering

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1 INTRODUCTION

The globally increasing population and the upgrading of average wealth lead to the increase of energy consumption. Design and production of energy-efficient products and systems have become one of the major fields that concentrate the international scientific effort.

A thorough investigation of the current design practices reveals the fact that the majority of the scientific work focuses on the optimization of several factors that are related to the operational efficiency of the different subsystems of products, (e.g. the energy efficiency factor of an electric motor in a conveyer). However, the energy consumption of a system is strongly affected by the relation between the *product functionality and performance* and the *requirements posed by either the user(s) and/or the embedded technology*. For example, in the field of conveying equipment, the operation of an apron conveyer with a capacity of 1.5 (tn/hr) requires more energy than for a reduced capacity 0.8 (tn/hr), given that both machines operate with the same overall efficiency factor. In the same example, the use of an apron conveyer designed for a rated capacity of 1.5 (tn/hr) in order to cover a capacity of 0.8 (tn/hr) would be obviously less energy-inefficient due to a number of easy to understand reasons. On the other hand, the adaptation of design approaches that aim to unconditional reduction of energy consumption may lead - under certain circumstances - to poor functionality. Therefore, the conclusion is that all design processes that aim to optimizing a system for energy consumption should always take into account the basic aforementioned relation and should, by no means, sacrifice its performance.

In the framework of the hierarchical relationships among functions of a system and as far as energy efficiency is concerned, there is the issue of *selection* of the *appropriate subfunctions* that support the implementation of higher functions. For example, how better do the subfunctions of a traction elevator perform the main function "*transport passenger*" when compared with those of a hydraulic one? In that point, it is obvious that a method that could comparatively analyze the functions of alternative design configurations with respect of energy efficiency would be significantly useful.

According to the literature (Eggert, 2005, Otto and Wood, 2001, Pahl et al., 2007, Ulman, 1992), Function Structures (FS) are complete and well established tools for performing product function analysis. In its conventional version, however, a (FS) can depict the energy types used by product functions, but it does not provide adequate information about the relation between product functionality and energy efficiency. The reason for this is that, in a (FS), the energy flow is represented in a quite abstract form with poor or no any further information about the energy losses of each function and the energy bound within the limits of an assembly (e.g. the kinetic energy bound by a rotating component). Additionally, (FS) does not offer the ability to depict parts and /or assemblies that may be actually used in a product and consequently, it is impossible to represent and examine the auxiliary subfunctions performed by them and may contribute significantly to the overall energy consumption. Actual Function Structure (AFS) (Otto and Wood, 2001) is considered as more accurate for representing functional analysis of existent products, but it is characterized by two drawbacks considering the relationship between functionality and energy consumption. The first is that there is not any reference to the assemblies and/or parts that contribute to each function, even thought the functions are gathered usually from Subtract and Operate Procedure (SOP) (Otto and Wood, 2001). The second drawback is that it represents energy flow in the same abstract way as (FS).

The work done by Markos and Dentsoras (2014) may provide an answer to the aforementioned problem. In their study, authors use and evolve (FS) in order to depict within form and part-independent functions, the parts and assemblies as well as all energy types and conversions pertaining to the system under consideration. A systematic procedure separates the functions that are prerequisite for the product overall function (basic functions) from the auxiliary ones. A systematic procedure identifies the *Design Variables* (DVs) (Eggert, 2005*) that refer to those basic functions, in order these to participate in optimization process which aims to obtaining a minimal for energy consumption under the constraints set by the previously mentioned relationship between functionality/performance and requirements*.

In the present paper, the previous work is evolved and the Function-Energy Structure (FES) is introduced. The scope of (FES) is the detailed, yet qualitative, representation of: a. the functions performed by product components (assemblies, subassemblies, parts), b. the energy types and c. all energy transformations and losses related to that functions. Perceived within the context of a reverse engineering aspect, (FES) not only depicts the form-independent functions that constitute the overall product function as it happens in previous work of Markos and Dentsoras, but it also contains the specific subfunctions that are performed because of the existence of specific components that are chosen for the implementation of the product working principle. For example in a traction elevator, the existence of a counterweight is prerequisite for the implementation of its working principle, thus the function "*suspend counterweight*" should be contained in (FES). This is important because the representation of product subassemblies/parts with their functions and their energy usage is of critical importance for the evaluation of the product overall functionality towards its total energy consumption. What is obligatory for the development of (FES) is that the part-based functions must remain *geometry-independent*.

The product functions in (FES) are generated by applying systematically the (SOP) method. The implementation of (SOP) as well as the transition from (SOP) to (FES) is guided by sets of rules, as it is shown in the next chapter, proposed for the first time in the present paper. In the analysis that follows, the case of a typical traction elevator is adopted as a reference example that helps understanding the action of rule sets and the formation of the (FES).

2 PRODUCT FUNCTION – ENERGY STRUCTURES: FORMULATION, POSSIBILITIES AND CASE STUDY

2.1 From Subtract and Operate Technique to Function-Energy Structures

For the development of (FES), a roadmap is proposed that consists of two (2) main parts. The first focuses on the appropriate implementation of the (SOP) to provide the list of functions that will form the (FES); the second part focuses on the transfer of functions from the list of (SOP) to the form of (FES) and to its enrichment with notations that refer to the use, conversions and losses of energy. Table (1) contains the results from the implementation of (SOP) to the traction elevator with 2:1 roping and geared motor (Chartered Institution of Building Services Engineers (CIBSE), 2005, Dentsoras, 2009, Janovsky, 2004, Makris, 2000, Strakosh, 1998), while figure (1) represents the developed (FES) for the same system.

2.1.1 Rules for the implementation of (SOP)

For performing effectively (SOP), the following rules should be followed:

- If possible, the declaration of functions in (SOP) list should comply with the context of overall machine function (Keuneke and Allemang, 1989), yet not make reference to forms. There may be exceptions if functions refer to subassemblies or parts necessary for the implementation of the product working principle, e.g. "*apply tension to ropes*". On the other hand, the functions should strictly remain geometry-independent, e.g. there should not be any function dependency on whether the car frame deflector sheaves are assembled on the top of the frame or underneath it.
- The functions gathered for every subassembly/part (see table 1) should always be decomposed as deep as possible so that finally basic functions are reached. For example, the removal of counterweight affects the function of passenger suspension, but the basic function that should be stated is the application of tension to ropes here that leads to that suspension.
- The functions for every subassembly/part should always be decomposed with respect to the desired level of decomposition. For example, motor function "converts electricity to rotational energy" that is affected by motor removal should not be further decomposed to functions of motor assemblies or parts such as the windings or motor shaft, because the motor is usually purchased by elevator constructors as an integral unit with predefined technical specifications.
- The actions of users/customers should be noted as desirable functions performed by the product. For example in elevator case, passenger registers a call to a control panel, but in (SOP) list it should be written that the machine "Receives call".
- In case when subassemblies and/or parts are coupled in order to perform common functions, all these functions should be registered for every related subassembly and/or part.
- There are some cases where the operation of a product is difficult or impossible when subassembly/part is removed. Moreover, this may occur also after the subtraction of other assemblies of the product. For all these cases, there is always the danger the affected functions - collected after the application of (SOP) for these assemblies/parts - to be rather common and of

higher order and not basic. For example, the subtraction of both the car frame and the drive sheave affects the function of vertical translation of passengers. However, car frame and drive sheave perform different functions and (SOP) should focus on them. To deal with that problem, Otto and Wood (2001) suggest that the effects of subassembly/part removal (see table 1) should be examined within the assembly the subassembly belongs to. However, the problem that may arise in that way is that some critical functions performed through interactions between assemblies may not be depicted. For example, if the subtraction of car frame is examined only within suspension-guiding assembly, its affection to car suspension would not be noted, as the latter belongs to another assembly.

In order to overcome the above problem and in order for (SOP) to provide a complete function list to be used for the formulation of (FES), the following step procedure is proposed:

- Step 1. First, the effects of the removal of a subassembly/part within the assembly it belongs to are examined.
- Step 2. Next, the effects are examined for the subassemblies/parts of other assemblies directly attached to the subassembly/part being removed (e.g. the effects of car frame removal to car) or for the handled materials, signals and energy types provided to the system from the environment (e.g. supply of electricity). The functions resulting from the present step depict the functional interactions between assemblies and are noted in italics in table 1.
- Step 3. Furthermore, a thorough examination must be performed for the effects caused by the removal of a subassembly/part to subassemblies/parts belonging to other assemblies not structurally connected to it, which, however, present a direct relationship in terms of energy and signal exchange. For example, if the car is removed from the system, then the tension to ropes is not applied. The functions resulting from the present step, depict also the functional interactions between assemblies and are noted in italics in table 1.
- Step 4. Finally, the effects that occur due to the removal of a subassembly/part to the directly handled materials, signals and energy types provided to the system from the environment (e.g. supply of electricity) are examined. The functions resulting from the present step are noted in bold in the fourth column of table 1.

- If an assembly is not desirable to be functionally analysed in (FES), then only its overall function can be noted in (SOP) (e.g. the function "*protect passenger*" for the "*safety devices*" assembly).

2.1.2 Rules for the formulation of (FES)

The functions derived from the implementation of (SOP) are used to form (FES). For this transition and for the adequate representation of energy use and transformation among functions, the following rules are proposed:

- The formulation of (FES) for each assembly is a prerequisite for the formulation of product (FES). Every assembly (FES) should be so formulated that it could provide the possibility all functions of its assemblies/parts to be merged into a box that reflects the form-independent overall function of the assembly. This merge obeys to the principle of preservation for the flows of all functions of the contained subassemblies/parts. The procedure for the development of each assembly (FES) starts as soon as all assembly's functions derived from (SOP) are collected and placed appropriately to form a structure of a logical function sequence.
- If there are common functions between subassemblies/parts directly interconnected, whether these belong to the same assembly or to different ones, these functions are merged in common boxes and all the assemblies/parts that perform the common function are noted as material inputs. An example of that is the common box with the function "convert rotational to translational energy" that has the drive sheave and the ropes as material flows (see figure 1).
- Functions for supporting materials should not be drawn if they are self-evident, unless they are underlined by customer requirements as necessary product functions, such as the function "*suspend passenger*". If supporting functions have to be contained in a (FES) then the weights that are supported and the corresponding reaction forces that are generated should be noted qualitatively without any reference to their actual magnitude.
- Higher order functions can be omitted when more descriptive and relative subfunctions are revealed during (SOP). Consider the motor assembly and the affected function in (SOP) that

refers to gearbox: "*transmit rotational energy*". This can be omitted from (FES) because it can be covered by the subfunctions "*regulate torque*" and "*regulate angular velocity*".

- Two or more functions, performed by the same assembly, can be contained into a larger box with dashed lines that represents the overall function of the assembly (e.g. the functions "*regulate torque*" and "*regulate angular velocity*" into the dashed box that refers to gearbox). This is useful when the assembly is not necessary to be analyzed in great detail.
- A function that refers to application of force or to transmission of signal/energy can be given by a flow and not by a box (e.g. the transmission of electricity in cabling and wiring).
- Functions such as "*import passenger*" that do not belong in (SOP) list, but their presence in a function structure enhances the functionality of the product being analyzed and makes the (FES) more readable, must be always added
- If there are one or more functions (for example, B and C) that are prerequisite for the performance of another function (for example, A) and are expressed by the same verb expression as the latter but present different flows, then they can be all merged to a black box that represents function (A) and flows represented by the sum of the flows of all merged functions. For example consider in figure (1) the function "*suspend passenger*" into which the prerequisite functions "*suspend car fame deflector sheave*", "*suspend car frame*" and "*suspend car*" have been merged.
- In a cycle of product operation, a set of functions may be performed more than once. For reasons of simplicity, this set is drawn in the structure only once and a specific function box that represents this set is added. This kind of box contains repeated functions, it is proposed for the first time and is drawn with dashed line. For the case of traction elevator system (see figure 1), the set of functions enclosed into the box of function *f13* "*stop & stabilize passenger*" provide suspension and stability to passenger and are fully developed on the left side of (FES)
- The desirable characteristics that are not actually performed by functions, but are obtained by applying constraints or by certain selections, are drawn as "wishes" (Otto and Wood, 2001) (see function *f53* "*separate car frame and counterweight paths*" in figure 1)
- Material flows should denote every material that is necessary for the performing of a function, or it is affected by the function. For example, consider material flows in function "*constrain car frame path*" that consist of: a. the guides of the car frame because they are necessary for the performing of the function, b. the car frame because it is guided directly by the guides and c. the ropes, car frame deflector sheaves, car, car door and passenger that are affected by the function and move in a constrained path.
- The materials that are used within the limits of the product, should be denoted with flow loops.
- Effort analogies in energy flows should contain every force that generates/ affects a function or is generated by a function, as well as every energy type before and after function performing. Every notation in energy flows should be detailed, yet qualitative, without any magnitude reference. The latter can be deduced after the examination of the parameters that affect it (for example the magnitude of the translational energy transmitted in function f11 is affected, among others, from the mass of ropes).
- Flow analogies (linear speed etc.), that refer to materials whose energy state changes after function performing, should be denoted clearly in function energy flows.
- The degree of energy flow information detail in every function can vary, depending on the desirable detail in energy consumption analysis and the desirable easiness of comprehension. For example, in figure 1, for the energy flow in function "*regulate motor electricity*" the general symbol (e) is used instead of voltage (V) or amperage (I), since the further analysis of the inverter is not necessary.
- For every material (x) noted in an input material flow of a function, whose energy state changes after the function, the symbols (M[x]) and (I[x]) should be added in material flow for underlying that the mass and mass moment of inertia of material (x) affect the consumed energy.
- Energy losses of assemblies have to be denoted as autonomous flows and for that, the dash-dot flow lines are introduced. The denoted losses can be given in general if the assembly they correspond to is not decomposed, or they can be given with any desirable level of detail, but without any reference to their magnitude.
- In functions that convert and regulate energy flows, there may be certain materials whose energy state changes and the so produced amount of energy does not belong to the same energy type

developed by the function (energy term definitions pertaining to function structure theory are adopted here). In that case, the energy so produced can be considered as a loss. As an example, consider the function "*convert rotational energy to translational*" where the drive sheave develops rotational kinetic energy, while the outcome of the function is translational kinetic energy. The sheave's rotational kinetic energy is bound, and therefore, it is considered as a loss and not as energy efficiently used for the conversion of kinetic energy to translational.

- Friction forces should be denoted clearly and should be considered as losses that produce heat.
- In cases of energy type notations, additional information about crucial parameters that affect their magnitude such as heights and static pressures for potential energy, or speeds for kinetic energy etc. should be given.
- In order to describe efficiently the energy flows and conversions by or within the product, appropriate functions may be added such as "*Store Potential Energy (PE)*".

2.2 Advantages from the use of Function-Energy Structures

(FES) brings the design of energy efficient products from the level of just optimizing the efficiency factors in several assemblies/subassemblies to the level of *evaluating the functionality of the product/assembly by considering additionally the energy needed for the obtainment of this functionality*. The designers can start from that basis when they reversely engineer a product and decide whether a function consumes a lot of energy considering its importance. Also, it can be analysed how basic and/or higher level functions can be performed in an energy-efficient way or if a new function could be added and - in that case - which would be the required energy. Finally, the energy usage with respect to the outcome of the product functions can be examined. For example, which would be the energy usage for transporting the mass of passengers to a certain elevation height (from h1 to h3 in figure 1) and with a certain speed?

(FES) can also provide the parameters that affect energy consumption during the phase of parametric design and which can be categorized as design variables (DVs) and problem definition parameters (PDPs) (Eggert, 2005). For example, consider that (FES) is used by engineers in elevator constructing industry in order to design an energy efficient elevator system for a building. It is assumed that the masses of the system components (car frames etc.) are already known. The masses referring to elevator components in material flows ((M[cfr]) in figure 1 etc.) become (PDPs), while other information provided in energy flows such as speed (v) are considered as (DVs).

(FES) can reveal whether there are auxiliary functions that require additional energy consumption without being necessary for the preservation of the machine's functionality. For example, in the present case study of a 2:1 traction elevator with geared motor, (FES) helps designers to realize that there are actually four functions (f51, the sets of subfunctions f2-f3, f7-f8 and f9-f10) that are performed for the regulation of passenger elevation speed . These functions increase energy losses and affect the overall energy efficiency of the elevator. From these four functions and by considering the modern technology accomplishments in VVVF drives and electric motors, only f51 ("*regulate motor electricity*") should be preserved and an elevator with 1:1 roping and gearless motor should be designed if better energy efficiency is the design goal.

Another advantage of (FES) is that it offers to designers the ability to inspect graphically the amount, the use and the masses of the components that perform product functions. They can locate the components whose masses affect significantly the overall energy consumption and, thereby, they could be candidates for redesign for weight reduction. Also, they can examine the possibilities for preserving the same functionality with fewer or more integrated components (a car that works also as a car frame guided directly by guides?)

Next, (FES) is a tool for comparing - in terms of energy and material usage - of different embodiments with or without the same working principle. For the example under consideration, it could be examined which would be the advantages/disadvantages from the implementation of a different working principle such as the use of hydraulic pressure. It could be also examined which would be the new subfunctions that constitute the overall function and which would be the energy behaviour of the new subassemblies.

Finally, (FES) starting from the theoretical basis of (FS) can be implemented with every available functional database (Hirtz et al., 2002, Bonaccorsi and Fantoni, 2007).

Table 1. Implementation of (SOP) to a 2:1 geared traction elevator

Assembly	Subtracted subassemblies/parts	Effect of removal	Affected functions
Motor assembly	Motor **(mt)**	Electrical energy is not converted to rotational kinetic energy.	Convert electrical energy to rotational energy. Support gearbox.
	Motor brake **(mtbr)**	The drive sheave can be rotated unwillingly.	Brake drive sheave.
	Reducer gear box **(gbx)**	Motor torque and angular velocity are not regulated. Rotational kinetic energy is not transmitted.	Transmit rotational energy. Regulate torque. Regulate angular velocity. Support drive sheave.
	Drive sheave **(dsv)**	Ropes are not supported. Energy is not transmitted from motor to hoisting ropes. Rotational motion is not converted to translational.	*Transmit energy.* *Convert rotational to translational energy.* *Support ropes.*
Suspension/ guiding assembly	Ropes **(rp)**	Car frame, deflector sheaves and counterweight will fall down. Rotational motion of traction sheave is not converted to translational. Power is not transmitted to deflector sheaves.	Suspend car frame deflector sheaves and counterweight deflector sheave. *Convert rotational to translational energy.* Transmit energy.
	Car frame **(cfr)**	Car is not suspended. Ropes lose their tension and the remaining suspended masses will fall down. Ropes lose their tension and power cannot be transmitted from drive sheave to ropes. Transl. energy is not transmitted to car.	*Suspend car.* Apply tension to ropes. *Transmit translational energy to car.*
	Car frame guides **(gui)**	Car frame and car deflector sheaves are not stable into the hoistway. Car frame may swing into the hoistway when they are translated and therefore they may hit on the hoistway walls, or to the counterweight.	Stabilize car frame. Constrain car frame path. Separate car frame and counterweight paths.
	Counterweight **(cwt)**	Ropes lose their tension and the remaining suspended masses will fall down. Ropes lose their tension and power cannot be transmitted from drive sheave to ropes.	Apply tension to ropes.
	Counterweight guides **(cgui)**	Counterweight is not stable into the hoistway. Counterweight may swing into the hoistway when it moves and therefore it may hit on the hoistway walls, or to the car frame.	Stabilize counterweight. Constrain counterweight path. Separate car frame and counterweight paths.
	Car frame deflector sheaves **(csv)**	Ropes lose their tension and the remaining suspended masses will fall down. Ropes lose their tension and power cannot be transmitted from drive sheave to ropes. Car frame speed and hoisting force are not regulated. Trans. ener. is not transmitted to car frame.	Suspend car frame. Apply tension to ropes. Regulate speed. Regulate hoisting force. Transmit translational energy to car frame.
	Counterweight deflector sheave **(cwsv)**	Ropes lose their tension and the remaining suspended masses will fall down. Ropes lose their tension and power cannot be transmitted from drive sheave to ropes. Counterweight speed and hoisting force are not regulated. Translational energy is not transmitted to counterweight.	Suspend counterweight. Apply tension to ropes. Regulate speed. Regulate hoisting force. Transmit translational energy to counterweight.
Car assembly	Car **(cr)**	Passenger will fall down into the hoistway. Passenger cannot be protected from other equipment and from hoistway walls. Passsenger movements are not constrained into the hoistway. Transmit translational energy to passenger. Car door is not suspended. Translational energy is not transmitted to car door. Ropes lose their tension and the remaining suspended masses will fall down. Ropes lose their tension and power cannot be transmitted from drive sheave to ropes.	**Receive passenger.** **Insulate passenger.** **Suspend passenger.** **Transmit translational energy to passenger.** **Constrain passenger.** *Suspend car door.* *Transmit translational energy to car door.* *Apply tension to ropes.*
	Lighting system **(lgts)**	There are no lights into the car.	Provide light.

	Ventilation system **(avs)**		There is no air ventilation into the car.	Provide air.
	Car mounts **(cmou)**		Vibrations are sensible.	Dissipate vibrations.
Door assembly	Car door **(cdr)**	Panels **(cdrp)**	Passengers into the car are not protected from getting injured by their contact with the hoistway walls. Additional tension is not applied to ropes.	**Insulate passenger.** **Inhibit exit.** **Provide entrance.** **Provide exit.** *Apply tension to ropes.*
		Hangers **(cdrh)**	Car door panels are not supported. Additional tension is not applied to ropes.	Support panels. Support operation hardware. Constrain panels' path. *Apply tension to ropes.*
		Operation hardware (motor, pulleys controller, passenger detection device etc) **(cdrhw)**	Car door panels cannot be translated (door cannot open or close). Translational energy cannot be transmitted to hoistway door operation hardware. Passenger cannot be detected	Regulate electricity. Convert electricity to transl. energy. Transmit translational energy. **Provide entrance.** **Sense passenger.** *Apply tension to ropes.*
	Hoist. door **(hdr)**	Panels (hdrp)	Passengers are not protected from falling down into the hoistway.	**Inhibit entrance.** **Provide entrance.** **Provide exit.**
		Jabs **(hdrf)**	Passengers' members are not protected from injuries when they are inserted through slopes into the hoistway.	**Inhibit human members insertion.**
		Hangers **(hdrh)**	Hoistway door panels are not supported.	Support panels/jabs. Constrain panels' path.
		Operation hardware (pulleys etc) **(hdrhw)**	Hoistway door panels cannot be translated (door cannot open or close).	Transmit translational energy. **Provide entrance.**
Control assembly	Controller **(cnt)**		Electricity cannot be supplied to the system. Electricity for various circuits cannot be regulated. The elevator cannot start or stop. The elevator cannot change its speed (the frequency, voltage and amperage of supplied electricity to the motor are not regulated in VVVF drives). The landing and car calls from passengers cannot be received. Signals from electrical safety circuits and safety devices cannot be received and recognized. Sequence of elevator landings cannot be scheduled. (processing of calls). Passengers into the car and at landings are not informed for the location of the car.	**Supply electricity.** Regulate electricity. *Actuate motor.* *Stop motor.* *Regulate motor electricity.* Calculate landings. **Receive signal from car call.** **Receive signal from landing call.** Sent signal to displays for elevator location. Check safety circuits and devices.
	Car control panel **(ccpn)**		Passenger cannot give calls into the car. Passenger cannot be informed for the location of the car.	**Receive call.** Display elevator location &direction.
	Landing control panels **(lcpn)**		Passenger cannot give calls at the landings. Passenger cannot be informed for the location of the car.	**Receive call.** Display elevator location & direction.
	Cabling and wiring **(cbwr)**		Electricity cannot be transmitted within the components of control assembly.	Transmit electricity.
	Hoistway sensors **(hsns)**		The location of the elevator into the hoistway cannot be received and sent to controller.	Receive signal for elevator location.
Safety devices **(sfdv)**	Load measurement device on car (loadm) Electrical safety circuits (ecsf) Overspeed governor-safety gear (vgsf) Car buffer (bsf) Counterweight buffer (cbsf) Travel limit hoistway switches (tlhsw)		Passengers are not protected from injuries.	**Protect passenger.**

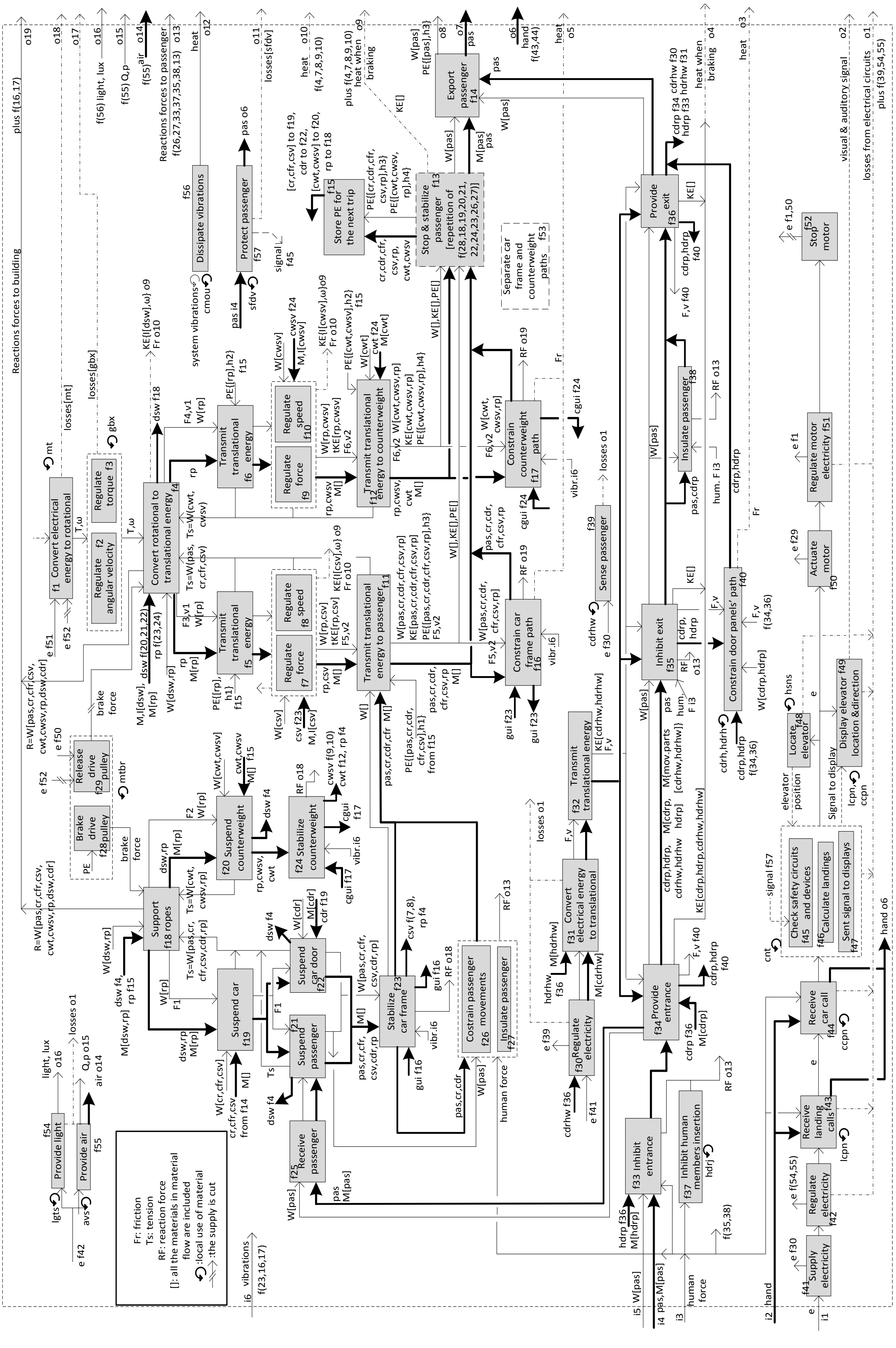

Figure 1. Function Energy Structure (FES) for a 2:1 geared traction elevator.

3 CONCLUSION

In the present work, the problem of examining the energy consumption of electromechanical products regarding their functionality is considered. Within the context of a reverse engineering approach, an extension of function structure methodology is proposed that represents in a qualitative, yet detailed manner, the actual functions that are performed by product components (assemblies, subassemblies or parts) and the type(s) of energy used for these functions. (FES) depicts also all energy transformations and losses and indicates - for every function - the components that are used for its embodiment. In (FES), functions should be in general form-independent. However, there might be, among them, functions that refer to components that embody the product's working principle. A mandatory condition is that component-based functions should remain geometry-independent.

To configure (FES), (SOP) is applied that identifies the functions performed by the product and transfers them to a function structure form, where appropriate material and energy notations are added. The extraction of functions in (SOP) and the configuration of (FES) are guided by corresponding sets of rules which are generic and provide a systematic framework that support the present approach.

The application of the proposed method for the study of a typical traction elevator reveals its usefulness. A graphical tool is provided to the designers for examining - in a qualitative way: a. the energy and material usage for performing functions for the system under consideration, b. the possibility of preserving and/or enhancing functionality with reduced energy consumption and c. the opportunities for better embodiment(s) of working principles regarding energy efficiency. By using (FES), designers can gather information to formulate - in the following phase of parametric design - the design variables and problem definition parameters that are connected to energy consumption.

Finally, it should be mentioned that while this method is proposed as a Reverse Engineering tool, it could be also useful for deign of new products. To be more specific, different embodiments in the stage of configuration design could be tested in a qualitative manner for their energy behaviour. Also, the simultaneous representation of product functionality and energy behaviour of a product may be useful for the extraction of solution evaluation parameters (Eggert, 2005) that correlate functional performance and energy efficiency. This point is currently under investigation.

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