Application of linguistic modelling to systems and product design

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Abstract: Design thinking is an integral part of problem solving which is an incessant activity in the living sphere for survival and achievement of ambitions, the alternative is extinction. There is a variety of problem solving or design methods usually pursued separately for systems and product in business, management, in engineering and fashion design otherwise the activity is carried out instinctively, it is innate. The aim of this paper is to introduce an integrated design thinking procedure which is supported by the 'new science of systems' in particular by linguistic modelling. Thus, design thinking has acquired a theoretical support with clearly different functions of the systems and component designers. Parts of 'science of systems' relevant to design thinking are described which serve as guidance for design activity. Problematic issues and expectations of those affected can be elucidated by managers, designers and individuals leading to emergence of a scheme intended to aid systemic thinking for solving problems and to detailed design of prototype models while admitting creativity and innovation.

Keywords: integrated design thinking; linguistic modelling; systems science; producers; users; product.

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Biographical notes: Janos Korn graduated in 1960 in Mechanical Engineering at Queen Mary College, University of London with a 2nd Class Honours Degree. After a few years in industry as a Development Engineer, he became a Lecturer, a position he retained until leaving Middlesex University in 1996. He was part time tutor at the Open University for 20 years. He obtained his MPhil and PhD degrees and was a member of the Institutions of Mechanical and Electrical Engineers. He published five books and 145 papers in professional journals and conferences. Research areas are: 'Network modelling of engineering systems' and 'New science of systems' inclusive of 'Linguistic modelling of scenarios'.

1 Introduction

Living things: plants, animals (including man as a biological entity) and man (as a social entity) find themselves in the natural, inanimate world on this planet which happens to possess the right physical properties for their continual existence and further development. Living things are engaged in activities to sustain themselves and their species by exchanging matter and energy with their 'environment' individually and in groups when they are organised into:

- a pasture of grass (emanating oxygen and absorbing minerals and compounds)
- a herd of buffalo (consuming the grass and emanating compounds)
- a pride of lions (hunting the buffalo and emanating waste products)
- a group of men (hunting a gazelle (which also eats grass) and emanating waste and artefacts).

In the latter two cases intense exchange of information must take place to cooperate for the achievement of a successful hunt. In general, if a plant runs out of water it dies, an animal seeks an alternative source but a man may use a drill or other appliance, a physical 'product', or 'medium with use' for searching for and locating water. Man also uses informatic 'products' or 'medium with meaningful symbols' to communicate h/her finding and in general to create the world of artificial in arts, sciences, technology and social functions (Simon, 1996; Korn, 2009).

Man or human beings although biologically fit into the picture just outlined, is an intensely social being. They not only exchange matter, energy, information, use and money with their particular environment and with companions as a matter of necessity but actively exploit the physical and social environments as an individual or member of a group for the:

> *Achievement of not merely* survival but of: convenience, satisfaction of ambitions and aspirations, achievement of power or influence, enforcement of will or ideas, improvement of physical and mental being (own and of others), self-glorification, emotive effects like love or anger, higher productivity, action for higher performance through new ideas and inventions and employment of organisations of men, plants, animals and machines. (exp. 1)

The impression of intense activity by living things as indicated by exp. 1 (expression) comes through which is fuelled by

a *Detecting* and identifying unsatisfactory or undesirable states of affairs as initial states (IS) of selected parts of the world called 'problematic issues' and 'needs' for change which is usually followed by *setting* envisaged, preferred, not yet existing states or envisaged *ideas* or expectations or final states (FS) which are agreed on after discussions between interested parties or stakeholders and are consistent with IS.

b *Acting* to transform an IS into a corresponding FS by a 'purposive scheme' exhibited by living things rather than waiting for 'chance' as appears to be the case in the natural world (Simon, 1996).

There is, thus, an intense activity of *problem solving* which in the living sphere is 'innate' and 'universal' (Korn, 2018). In other words, problem solving is as common in the living sphere as the action of gravity in the material sphere.

Accordingly, the mental process of 'problem solving' consists of two parts:

1. The perception, imagination or inspirational part to recognise a 'problematic issue' and 'need for change' such as 'need for carrying troops across muddy terrain pronounced by the commanding officer' followed by setting new 'ideas' to lead to resolution of the 'problematic issue' carried by a 'problem situation' or a scenario.

2. The methodical, inspirational and inventive part to create the apparatus which is intended to carry out the change implied by the first part. The apparatus is destined to bring about the resolution of the 'problematic issue' i.e., the conversion of the IS regarded as unsatisfactory into a 'consistent', final, satisfactory state, FS, satisfying a 'need' for the new 'idea' and subject to expectations by a living thing, if there is one that can be agreed on (Rittel and Webber, 1973). The apparatus for bringing about the FS is called the 'prototype model' which can be exposed to tests of experience and is seen as the result of problem solving or 'systems and product design thinking'. Its function is 'to change an existing situation into a preferred one' (Simon, 1996).

For example,

- there is a need recognised by an individual: 'infantry troops need to be carried over muddy terrain as required by the commanding officer'
- problematic issue: 'infantry troops are stationed at the edge of muddy terrain' (is of troops)
- satisfactory state: 'infantry troops are over the other side of muddy terrain' (FS of troops)
- prototype model: 'helicopters, tracked vehicles, elephants (including their drivers), legs of soldiers, etc'.

However, the activity of problem solving does not take place in vacuum, it is pursued towards the achievement of benefit or otherwise of living things in particular man called here 'user/utiliser' and summarised in exp. 1 and its part is played by the 'commanding officer' or any other stakeholder.

In other words, the 'problematic issue' with IS and its resolution or FS in the first part is carried by a living or inanimate object called 'object with problematic issue', OPI, in which the change of state is effected by the state of another object called 'product' in the second part. Matching the properties of the 'product' or any other object or idea to those of the 'problematic issue' is part of design thinking and is carried out by 'requirement engineering' (Bray, 2002). The term 'product' refers to any kind of object: concrete (motorcar, lava), abstract (seriousness of the child), symbolic (word, novel, painting). For example, 'the feet of the lady, size 36, are bare (problematic issue, IS) so there is a need for means to cover them so that they become covered (FS) when she walks around the house. A pair of woolly slippers of size 36 (product) may satisfy the requirements of the lady'. The resolution, or not, of a 'problematic issue' may result in satisfaction of a 'user/utiliser' played by the 'lady' in this example.

The actual creation of both parts involves the exercise of creativity and invention (de Bono, 1970) and it is proposed to support this by a structural or *systems theory* inclusive of linguistic modelling with the use of conventional science of physics at the level of individual components or agents as part of the structural entity. This leads to an integrated 'scientific enterprise' (Korn, 2018). In this context conventional science can perform specific tasks such as setting up and solving differential or algebraic equations, aiding decision making, providing knowledge of mental and material properties of individuals as wholes and so on.

1.1 Research problem and its proposed resolution

Current design methods although recognise the preceding description, are fragmented and appear to centre around topics like with diverse methods:

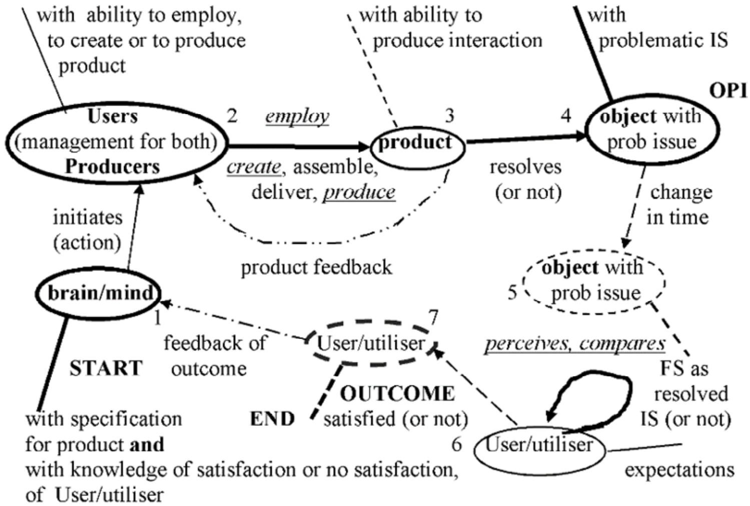
- Conventional engineering design engaged in determining the size, material and configuration of machine elements using topics from conventional science of physics supplemented by application of diagrams and sketches inclusive those for processes involved in making an end product (Jones, 1981; Pahl and Beitz, 1984; Cross, 1989; Hubka and Eder, 1996).
- Fashion design which is usually concerned with creating overall impressions usually as a result of inspiration, by drawings or sketches which lead to specifications of materials and manufacture.
- Project management which embraces the whole range of specialised areas like construction of any kind of buildings including tunnels, roads and railways, sale and delivery of goods, financial and accommodation services such as hotels and so on (Lock, 2007).
- Systems engineering without as yet clear agreement of its concerns due to lack of recognised systems theory (Hall, 1962; Boardman, 1990; Korn, 2018).
- Computer aided design and software development (Narayan, 2008).

The *intention* of this paper is to describe a comprehensive and methodical approach to design thinking linked to the formalism and method of ‘linguistic modelling’ which is part of systems theory (Korn, 2018). The approach is intended to supplement and to aid the innate ability of living things to solve problems in accordance with purposive activity. It can facilitate design activity currently practiced by laymen and professionals and its proposed use of linguistic modelling lends a theoretical support to ‘systems and product design thinking’ while allowing creativity and intuition to play their part.

2 Aspects of the systemic view relevant to design thinking

According to systems theory as suggested by current work of the author, the structural description or systemic view of any part of the world is pervasive, empirical, indivisible and hierarchical supplemented by qualitative and/or quantitative properties as selected by an investigator or designer which is the first general principle of systems (Korn, 2018). This implies a *single* domain or discipline and a *single* general linguistic model of the constituents of which have begun to emerge in the discussion in the previous section and is shown in Figure 1 and to which any particular case of a linguistic model of a scenario conforms.

Figure 1 Universal linguistic model of scenarios



The scheme in Figure 1 defines the structure and constituents of a scenario including those of the problem solving scheme with the 'prototype model' and is a less technical version of that suggested by the third general principle of systems (Korn, 2018). Effects of environments are included as modelling of a particular scenario unfolds. The scheme operates along the lines of 'problem solving' as described in the previous section and includes the interacting constituents for:

X utilising systems which 'employ' existing or newly invented 'products' such as a 'train *carriage* carrying passengers' or 'waiter laying the *table*'

Y producing systems which 'create' new products such as a *motorcar* or *newspaper*

Z inanimate systems such as 'spewing *lava* from an erupting volcano'.

The *problem solving procedure* in particular the scheme in Figure 1 operates along the following lines:

- 1a: there is a designer, a creative person or any individual in the course of every day life activities or a committee or any living thing called the 'systems engineer' who instinctively or by internal or external inspiration or intentional stimulus, identifies through h/her senses a part of the world designated as the 'Object with problematic issue, 4-5' or 'OPI, 4-5' carrying an unsatisfactory state of affairs (IS) seen as the 'problematic issue'.

  From the existence of an object or part of the world with 'problematic issue' it follows that there is another object called 'user/utiliser, 6-7' who expects the 'problematic issue' to be resolved to fit h/her 'expectation' which is also stipulated by the 'systems engineer'. Otherwise the scenario is incomplete, for there is: 'an 'identifier' of a 'problematic issue' to be resolved for the 'benefit, or not, of an individual' which can be the same living thing.

- 2a: Figure 1 can be read as follows: the 'brain/mind, 1' activates the 'management, users/producers, 2'. This component is either part of systems X. or Y. to employ or to create a 'product, 3' which happens by 'chance' in systems Z. In case of X. and Y. 'product, 3' is used to deliberately resolve the 'problematic issue' by transforming IS into a consistent FS which conforms, or not, to expectation of 'user/utiliser, 6-7'. 'Management, users/producers, 2', 'product, 3' and 'brain/mind, 1' together is called the *prototype model*.

The 'user/utiliser, 6-7' perceives FS and compares with 'expectations'. If FS is favourable then 'user/utiliser, 6-7' is satisfied which is checked by 'brain/mind, 1' and is the OUTCOME of the problem solving activity. If there is no satisfaction, the procedure is repeated in a modified form until satisfaction will have been achieved.

Thus, the function of 'product, 3' is to generate the 'interaction' that can accomplish the required change of state of 'OPI, 4-5' from IS to FS which may turn out to be the resolution of the 'problematic issue'.

In case of utilising systems X, we distinguish two cases:

1 'Product, 3' is employed by 'management, users, 2' after usually instinctive and creative selection or invention by 'systems engineer' to match 'OPI, 4-5' and is communicated to 'brain/mind, 1' which activates a 'management, users/producers, 2'both of which can be selected by the systems engineer.

   This means that all constituents in Figure 1 are known and a mathematical or linguistic model including that of the 'prototype' can be set up to investigate the occurrence of 'outcome' towards satisfaction of a 'user/utiliser, 6-7'. This process is called *instinctive design*.

2 'Product, 3' is employed by 'management, users/producers, 2' after a methodical and creative selection or invention by 'systems engineer' to match 'OPI, 4-5' including selection of 'management, users/producers, 2' and 'brain/mind, 1' so as to produce FS to match expectations of 'user/utiliser, 6-7'.

In this case, methodical use of linguistic modelling is proposed supplemented by mathematical models to determine the constituents and their interactions of the scheme in Figure 1 including the 'prototype model'. This process is called *methodical design* and is introduced in this paper.

In case of producing systems, Y, 'product, 3' is created by 'management, users/producers, 2' according to 'need' or 'market demand' or 'market research' or by 'instinctive and intelligent guessing'. The latter itself is set up according to the nature of 'product, 3'.

This is the case of *manufacturing* organisations the modelling of which is not considered here.

In case of inanimate systems, Z, 'product, 3' is produced by 'producers, 2' without 'management, users' by *chance*.

Since the scheme of Figure 1 is universal, linguistic modelling is applicable to this case as well (Korn, 2018) with aspects of a particular scenario investigated by 'conventional science of physics' (Korn, 2018).

We note that

1 Points 1a and 2a correspond to points a and b or 1 and 2 in the previous section but with more details.

2 In cases of X. and Y, activities take place in accordance with 'purpose' as described by the third general principle of systems (Korn, 2018) and in all cases, including systems Z., are directed towards the state of *equilibrium* (Korn, 2012, 2016).

3 The linguistic modelling of all activities in all cases belongs to the realm of activities of the 'systems engineer' which may not be the same individual. However, design of particular component is a matter for the 'component engineer' aided by 'linguistic networks' and the knowledge base of 'conventional science' (Korn, 2009, 2018).

4 In all cases particular instances represented by Figure 1 need to be developed into *symbolic structures* or models so as to lead to operational models.

2.1 Conditions of existence of symbolic structures

The first general principle of systems requires that a symbolic structure is to consist of the following constructs (Johnson-Laird, 1988 modified, Korn, 2018):

a elementary constituents which can evolve over centuries like the atomic view (Levene, 2010)

b a method for relating the results of conceptualised experience to elements of a symbolised domain and vice versa i.e., applying the language of model to chosen aspects of a part of the world

c rules for constructing a variety of 'complex structures' from elementary constituents within the domain.

We consider the constructs in more detail as far as relevant to the symbolic structure of linguistic modelling only.

2.1.1 Elementary constituents

Figure 1 is a symbolic structure which consists of elementary sentences of the 'subject – predicate' form of qualified and interacting noun phrases of 'initiating' and 'affected' objects (Burton, 1984; Korn, 2009) diagrammed by closed contours connected by directed lines. Qualifiers are designated by lines attached to contours. For example, 'The happy boy gave his toys to his friend'.

initiating (boy) -interaction (gave to) – affected (friend) object (happy) (his toys) object (his). (exp. 2)

2.1.2 Construction of domain from experience

By 'domain' we mean a field of study formed from elements arrived at by conceptualising experience through a sense organ by the brain/mind or assigning a symbol to a group of sense impressions to form a 'model' or a symbolic structure (Korn, 2018, 2019). Natural language is the 'primary model' for forming a 'story' or 'narrative' which is the first step in linguistic modelling. Natural language is comprehensible by all, experience is already conceptualised into 'words', it is then useful to use natural language as the basis for comprehension of other models. For example, there is a 'slowly revolving, blue, about 0.5 cm diameter, computer symbol' which is an element in a symbolised domain and can acquire the meaning ‘time delay’ by conceptualising the experience of ‘time delay’. Another example is provided by the notion of ‘force’ as an ‘element’ in the symbolised domain of mechanics of which the conceptualised experience ‘push’ is an instance.

Identification of terms in the story with general terms in the ‘universal linguistic model’ as shown in Figure 1 is required. In general, in Figure 1 the function of entities in contours are defined by their position in the diagram. For example, ‘product’ in contour 3 is defined as the entity which is created by the entity in contour 2 as the means to resolve the problematic issue carried by the entity in contour 4.

The terms in Figure 1 are expressed in ‘model language’, the terms in a ‘problematic situation’ are expressed in ‘story language’ and, in an application, the latter must fit, usually functionally, into the former or the latter is ‘contained’ in the former in constructing particular instances of the scheme in Figure 1 (Saeed, 1998). For example, the term ‘product’ (model language) can be identified as an ‘energy converter’ (story language) which can be made more concrete towards an ‘operational model’ when named as ‘electric motor’ or ‘candle’ (story language) which all fit the term ‘product’. ‘Shoe lace’ also fits ‘product’ but it does not fit ‘energy converter’, it functions as a ‘converter of an open shoe into a laced shoe’. The notion described can be summed up by:

A term in model language – a term in story language. (exp. 3)

2.1.3 Construction of complex structures from elementary constituents

Any part of the world is a ‘complex structure’ when seen to consist of more than one simpler structure. When we construct a structure we join objects such as the ones enclosed by contours in Figure 1 either by ‘relations’ (representing static state)or ‘interactions’ (representing dynamic state), both are designated by directed lines (Korn, 2018).

Joining is possible when there are two objects one emanating and the other accepting the same directing line. Emanation and acceptance are judged by the meaning of the terms, for example, the sentence ‘The boy shouts to the table: ‘come closer to me’ cannot form a complex structure because the meanings of the objects do not match. Network representation of complex, multidisciplinary structures is an example of this notion (Korn, 2012).

Remarks

1 Linguistic modelling of scenarios displays all three constructs:

   a elementary constituents are 1 and 2 place sentences (Korn, 2009)

   b model language of Figure 1 is based on natural language, story language is constructed from natural language so application of exp. 3 is a matter of matching the meaning of terms from each

   c complex structures are constructed from ‘elementary constituents’ through allowing an ‘interaction’ to emanate from one ‘object’ or ‘agent’ and accepted, or not, by another as stipulated by the story of a ‘problem situation’ or as demanded by the formalism of linguistic modelling (Korn, 2009).

2 Design thinking is possible for scenarios which exhibit the constructs a, b, and c because this kind of thinking is based on model language used in Figure 1. The

alternative is *speculative language* which is a symbolism for expressing thoughts and as such must consists of A., elementary constituents, as stipulated by the first general principle of systems (Korn, 2018, 2019).

3 The objective of constructing the scheme in Figure 1 is:

- To show an organised way of generating an *outcome*.
- To aid thinking by
  - a Bringing order into a confusing scenario by providing the means for assigning functional objects assumed to operate in an orderly manner to verbal expressions in a story as stipulated by exp. 3. Thus, facilitating problem solving.
  - b Explicitly including a beneficiary with expectations into the theoretical framework.

4 We demonstrate an application of construct b:

The narrative in 'story language': 'the country is separated from the rest of the land by a channel of sea of about 30 km. The government of the country is anxious to keep the people happy by enabling them to cross the channel by means other than ships so it instructed construction companies to look into the means of connecting the country with the rest of the land'. Hence,

- model language story language
- systems engineer – government of the country
- brain/mind, 1 – committee (not in the story and created by the government)
- OPI, 4-5 – the country separated from the rest of the land, with IS, the 'problematic issue'
- user/utiliser, 6-7 – people 'separated' by channel of sea
- product, 3 – having the capability of connecting the country to the rest of the land: tunnel or bridge or any other possibilities
- management/producers, 2 – a construction company.

Second example, the narrative in 'story language': 'in the mid-2000's, a large company selling consumer goods direct to the public, attempted to shift their brand to appeal to higher-income customers. In 2005 they started re-branding themselves by launching a high-fashion campaign in high fashion and lifestyle magazines. They also presented fashion shows in New York and opened an office in Manhattan's Fashion District. Shifting their unique brand would prove to be a 'one-shot operation' as it has not been done before, making it difficult to measure effectiveness and control risk. The result was that, by 2008, massive layoffs shut two divisions at its headquarters, a disaster'.

- model language story language
- systems engineer – members of a large company … attempted to …
- brain/mind, 1 – not stated
- OPI, 4-5 – a large company selling consumer goods direct to public (IS) to be rebranded (FS)

- user/utiliser, 6-7 – large company selling consumer goods direct to the public with expectation to enter into a ‘new market’
- product, 3 – launching a high-fashion campaign…. fashion shows….
- management/producers, 2 – not stated.

Which shows that the scheme in Figure 1 is incomplete and to embark on change is risky: customers, the ‘public’, are used to ‘the company selling consumer goods …’, now trying to enter into a ‘new market’. The penultimate sentence shows an attempt at reproducing the feedback link from object 7 to 1. The ultimate sentence implies the result of activity at object 7 and a need at iteration. We have a ‘problematic situation’ which appears to be a ‘wicked problem’ perhaps due to the difficulty in identifying terms in the story language with those in the model language, thus, arriving at the structure of Figure 1 (Rittel and Webber, 1973).

5 Figure 1 is a diagrammatic representation of the following systems:

a *Utilising systems* which are recognised by their use of ‘products’ which exists or can be invented for generating ‘interactions’ for changing the state of ‘OPI, 4-5’ without change of identity i.e., only properties that do not interfere with identity are allowed such as location, colour, dress, information and so on.

For example, ‘A traveller starting from h/her hotel, wants to be at the airport (‘brain/mind, 1’, ‘user/utiliser, 6-7’). He/she uses a taxi with driver (‘product, 3’, ‘management,users, 2’) for overcoming the distance between hotel and airport (‘OPI, 4-5’)’.

b *Producing systems* which are recognised by their activity of manufacturing, assembling and delivering ‘products’ and create the identity of a ‘product, 3’so as to become usable. Products are conjectures so as to fill an imaginary need for correcting an ‘OPI, 4-5’ to satisfy a ‘user/utiliser, 6-7’.

For example, ‘Fabricating and assembling a wooden chair (‘product, 3’) from pieces of timber’ or ‘Writing a book (‘product, 3’)’ or ‘Painting a portrait on a bare canvas (‘product, 3’)’ or ‘Assembling a motorcar (‘product, 3’)’ in which products are usually manufactured in accordance with expectations of a ‘market’.

In case of producing systems the state of the ‘product’ in Figure 1 needs to be divided into two parts:

- first part – manufacturing and/or assembling according to an *algorithm*
- second part – delivering to a situation at which the ‘product’ becomes capable of exerting interaction as in Figure 1.

The ‘user/utiliser, 6-7’ which creates the ‘market’ with changes of tastes and habits, is affected directly by ‘product, 3’ the appearance of which alters the market and individual and social habits. In Figure 1 there is no ‘OPI, 4-5’.

c *Trouble shooting* systems exist through perception of a ‘OPI, 4-5’ through ‘symptoms’ manifested by a breakdown (of a car), deficiency (of vitamins), disease (of heart) and ‘producers, 2’ like ‘restore fuel supply’, ‘supply of vitamins’ etc. are searched for to eliminate symptoms to satisfy ‘user/utiliser, 6-7’.

d *Inanimate systems* which are recognised by the presence of 'producers, 2' (with no management) producing affecting 'product, 3' possibly affecting a 'user/utiliser, 6-7'. For example, 'An erupting volcano in which molten lava ('product, 3') is produced by moving masses of earth ('producers, 2') according to *chance*. The lava then burns the surrounding countryside ('user/utiliser, 6-7')'.

The absence of 'OPI, 4-5' and 'management' as can be deduced from a narrative, shows which system, a, b, c, or d. the analyser, observer or designer is dealing with. All activities are directed to achieving a *state* of *equilibrium* (Korn, 2012).

The scheme in Figure 1 acts as the 'guide' in systems and product design thinking.

2.2 Elementary constituents in linguistic modelling

Scenarios described as 'stories' or 'narratives' in natural language, the primary model are converted from 'story language' into 'model language' of Figure 1, the problem solving scheme, which identifies the functional objects or agent in the scenario (Korn, 2019). The scheme of Figure 1 can be expanded into a reasoning structure by linguistic modelling in particular cases using *elementary constituents* (Korn, 2009, 2013, 2016, 2018).

Any structure, concrete, abstract or symbolic, perceived as a whole is constructed from 'elementary constituents' prevailing at the local level of *complexity* according to the first general principle of systems. Molecules, electrical networks, walls, a herd of cattle, a squad of soldiers are regarded as organised wholes of elementary constituents of atoms, network elements (Korn, 2012), bricks, cows, soldiers/officer respectively. Discovery of elementary constituents like 'air, fire, water and earth' or the periodic table of elements, has been a preoccupation of thinkers for a long time (Levene, 2010).

The elementary constituents of linguistic modelling at the first level of abstraction are 1 – and 2 – place sentences (Korn, 2009) which are reintroduced here because of introduction of 'decision making' as part of' driving properties' and interactions qualified by 'changes from IS to FS' as adverbial qualifiers which become part of acquired properties. They also serve as an introduction to linguistic modelling and the pattern to design procedure to be used here.

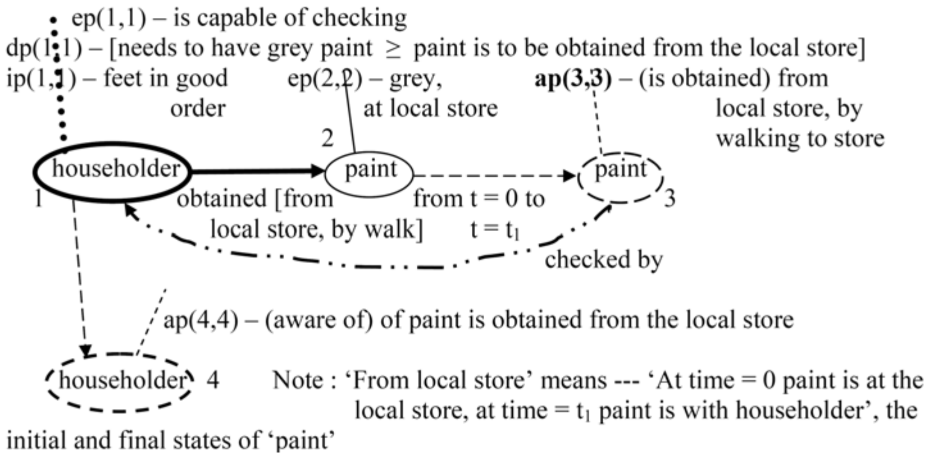
The 'semantic diagram' of a 2 – place sentence 'The householder needed grey paint which he obtained from the local store' is shown in Figure 2. With reference to Figure 2, action or simulation is initiated at time = 0 when the 'difference between the householder needs to have paint' and 'paint is to be obtained from the local store'.

Before constructing Figure 2 matching 'model to story language' is given by:

- model language story language
- brain/mind, 1 – householder (implicit: identifies 'problematic issue' – he has no
- paint and specifies kind of paint)
- OPI, 4-5 – householder (implicit: IS – he has no paint, FS – he has paint)
- user/utiliser, 6-7 – householder (implicit: expects to have paint as specified)
- product, 3 – (grey) paint
- management, users, 2 – householder obtained 'paint' (from local store)

which is a 'utilising system'.

Figure 2 Semantic diagram of a two – place sentence with decision



From Figure 2 the causal chain is 4, 1, 3, 2, 1 which starts at an object which no longer changes and proceeds against the arrows carried by dotted lines designating changes of state. Hence, the predicate logic statements without 'uncertainties' and 'graded adjectives' (Durkin, 1994; Korn, 2009) are

dp(1,1) – ip(1,1) → in(1,2, (adv(1,2))) where in(1,2,(adv(1,2)) is qualified by

in(1,2,(adv,1,2)) → ep(2,2) → ap(3,3) the initial conditions. (exp. 4)

ap(3,3) → in(3,1)

in(3,1) – ep(1,1) → ap(4,4)

in which the additional term 'ep(1,1)' is to express a property of the affected object 'householder' required by the formalism.

Exp. 4 is expressed in words as follows:

- *If* 'the householder needs to have paint' and 'paint is to be obtained from the local store' *and* 'the householder's feet are in good order' *then* 'householder obtained paint from the local store by walking to the store'.
- *If* 'the householder obtained paint from the local store by walking to the store' *and* 'the paint is grey' *then* 'paint is obtained from the local store by walking'.
- *If* 'paint is obtained from the local store by walking' *then* 'paint is obtained from the local store is checked by the householder'.
- *If* 'paint is obtained from the local store is checked by the householder' *and* 'householder is capable of checking' *then* 'householder is aware of paint is obtained from the local store'.

We note that successful accomplishment of 'paint is obtained from the local store (ap(3,3))' depends on the 'colour of the paint' which must be specified by the 'householder' in this case.

A ‘product’ can be expressed as a set of ‘ordered pairs’ each of which is created by change of state as part of an elementary constituent (Korn, 2009, 2016). The ordered pair at object 3 is

$n_{3,10}$ = (grey)paint(obtained(by walking))fromstore(local). (exp. 5)

which is represented as a ‘linguistic network’ in Figure 3.

Figure 3 Linguistic network of ordered pair

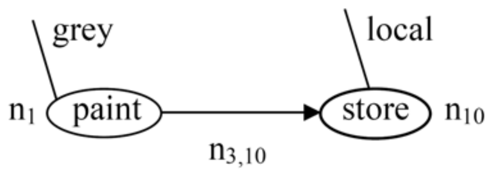
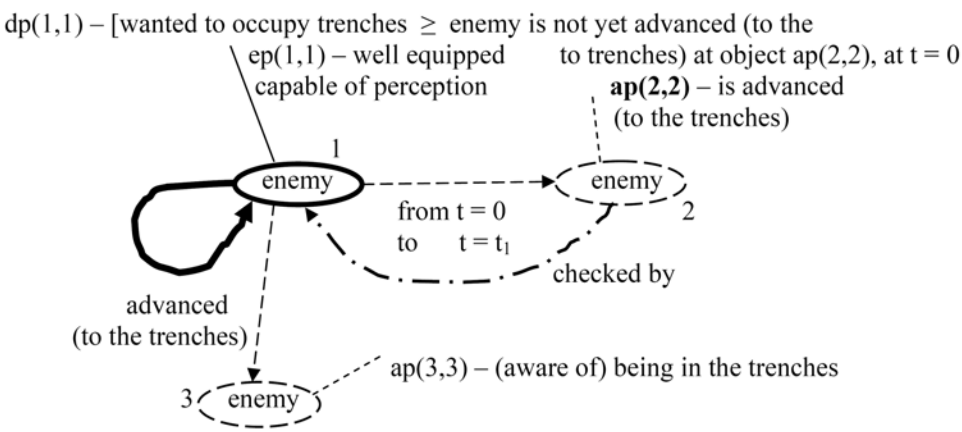


Figure 4 Semantic diagram of a one – place sentence with feedback



The second kind of elementary constituent is the 1 – place statement such as ‘The well equipped enemy wanted to occupy the trenches so it advanced towards them’. The semantic diagram is shown in Figure 4. The derivation of logic sequence is the same as for a 2 – place sentence, its verbal equivalent is given as follows:

- *If* ‘there is a difference between ‘the enemy wanted to occupy the trenches’ and ‘the enemy is advanced to the trenches’ *then* ‘the enemy advanced to the trenches’.
- *If* ‘the enemy advanced to the trenches’ *and* ‘the enemy is well equipped and capable of perception’ *then* ‘the enemy is advanced to the trenches’.
- *If* ‘the enemy is advanced to the trenches’ *then* ‘the (position of) enemy is checked by the enemy’.
- *If* ‘the (position of) enemy is checked by the enemy’ *then* ‘the enemy is aware of being in the trenches’.

3 Implementation of design thinking

From the discussion in the 'Introduction' we suggest that 'problem solving in the living sphere is as common as the action of gravity in the material sphere' because without this kind of continuous effort the alternative is extinction. The suggestion implies the existence of a 'single' domain of activities. If this is true then there is a 'single', unique modelling and problem solving method which uses the scheme in Figure 1. So far we have been discussing aspects of this method, now we intend to show its application in systems and product design thinking using linguistic modelling of scenarios.

Further to Figure 1, the 'aims of design thinking' as practiced by a 'systems engineer' is:

- First, based on a story or narrative, to identify an 'OPI, 4-5' i.e., the object or agent and its 'problematic issue', and the subsequent 'user/utiliser, 6-7' together with external influences and effects such as 'markets', 'environmental consequences' and so on,
- Second, to identify the constituents of the scheme in Figure 1 with their qualifiers and interactions which organises problem solving thinking along the lines of systems a, b, c or d in Section 2.1 which uses expression exp. 3.
- Third, to use the formalism of 'linguistic modelling' as introduced in Section 2.2 and in Korn (2009, 2018) towards development of design procedure leading to a *prototype model*.

3.1 Concepts involved in the design procedure

The following concepts are needed for the implementation of 'aims of design thinking' and of the scheme in Figure 1 into a design procedure (Korn, 2013, 2016):

3.1.1 Entailment relations (ER)

The activities described in a story and translated into model language as shown in Figure 1 proceed from object 1 towards outcome at object 7 which is an *analysis* type of problem.

Design thinking aims at reconstructing a story in terms of 'elementary constituents' realised by Cartesian products in static state and by predicate logic statements in dynamic state to form a 'reasoning scheme' so that 'outcomes' can be worked out or predicted (Korn, 2016, 2018). Design thinking proceeds:

- from properties of 'OPI, 4-5' which may be given in the 'story'
- working towards creating the qualifiers and interactions of 'product' 3', 'management, users, 2',and 'brain/mind, 1', the constituents of the 'prototype model'.

Once this is completed, can the 'brain/mind, 1' initiate action for:

- A utilisation system a or production system b to go ahead to 'testing the prototype model' for satisfaction of 'user/utiliser, 6-7'.

- A ‘utilisation or production system must form a coherent *whole*. For this to happen, the qualifiers of the constituents of the prototype model must *match* or fit the qualifiers of ‘OPI, 4-5’ and ‘user/utiliser, 6-7’ together with those of the constituents themselves. These must be selected, designed or invented so as to be capable of supplying the required qualifiers’.

To ensure the satisfaction of this *requirement*, the idea of ER is introduced as follows:

a there is a selected *group* of qualifiers carried by objects embedded in sentences

b there is a sentence or a phrase of commitment to fit, to match or to satisfy or to the contrary, fulfilment of which

c requires that there be *another group* of qualifiers carried by objects embedded in sentences which fit, match or satisfy those in point a.

ER expresses the ‘notion of entailment’ validity of which is judged through the ‘meaning of the terms’ involved and it relates the two groups, A. and C. (Saeed, 1998; Korn, 2013). For example, ‘The lady has just had her hair done and it is raining (a), she does not want her hairdo to be spoilt (b), requires or entails that she carries an umbrella or any other implement to protect her hair from rain (c)’.

3.1.2 Product selector matrix

In ER once the second group of qualifiers has been obtained, an object carrying these qualifiers needs to be selected. This can be helped by product selector matrix (PSM) which is constructed as shown in Figure 5.

Figure 5 Diagram of PSM

	second group of qualifiers			
	a.	b.	c.	and so on
objects carrying	1	0	0	
the qualifiers	1	0	0	
---	0	1	1	
---	1	1	1	

The 1’s and 0’ in Figure 5 are numerals indicating whether an object carries a particular qualifier or not. The object carrying the largest number of 1’s is selected.

3.1.3 Necessary relations (NR)

In general, in an elementary constituent X., we propose that there is a necessary relation between sentences:

1 Known =

The affected object property designated by the ‘solid line’ attached to the contour like objects 2 and 1 in Figures 2 and 4.

The outgoing interaction at the contour of a ‘changed object’ such as objects 3 and 2 in Figures 2 and 4.

2 To be found =

The acquired object property at the 'changed object' and the incoming interaction at the affected object in the same elementary constituent.

A relation between statements 1 and 2 is necessary to complete the elementary constituent X and it must exist because

a the 'changed object' must be in an appropriate state to produce the outgoing interaction

b the incoming interaction must exist so that a change of state can take place from affected object to 'changed object'.

The affected object property in '1 known' is found from the 'matching condition' using ER on the same property in the elementary constituent Y immediately connected to X and in front of X. The outgoing interaction is found from the change of state in Y.

In summary:

There is an ('object' with known affected object property) (known) which in order to produce an (outgoing interaction) (known) when undergoes a change of state, acquires an (acquired property as a past participle) (acquired property found).

The (past participle) (now known) defines the verb which designates the (incoming interaction) (found).

Exercise of NR ensures the continuity of a semantic diagram.

For example,

> Known = 'An interesting, fiction type 'book' (affected object with property)', 'sells in large quantities to the public (outgoing interaction)'.
>
> IMPLIES: that 'the 'book'(changed object)is stocked (acquired property = past participle)'.

From the past participle without qualifiers:

> The incoming interaction is = 'an object (not yet known) stocks interesting, fiction type books'.

Determination of adverbial qualifier of the incoming interaction using ER:

a book is stocked

b to store stocked books

c requires a warehouse [stocks in a warehouse (adverbial qualifier)].

3.2 Demonstration of design procedure

We demonstrate the procedure for systems and product design as the systems engineer would do it, by an example as follows.

Problem situation

The narrative of a scenario in 'story language': 'a housewife noticed that her valuable carpet, 3 m long, 1 m wide and made of thick material especially along the edges, was very dusty with dust engrained in places'. The narrative needs no linguistic analysis.

Identification of constituents of Figure 1 from the 'story'

From the description of the 'problem situation' or the 'story' we identify:

- model language story language
- brain/mind, 1 – housewife who also identified OPI
- OPI, 4-5 – carpet
- user/utiliser, 6-7 – housewife (expects carpet to be free from dust)

which is likely to lead to a 'utilising system'.

'Product, 3' and 'management, user, 2' are part of the 'prototype model' and are to be determined.

Identification of constituents and their properties

We know:

1 from the 'model language' we have the 'object with problematic issue' which is IS of OPI, 4 – carpet (with problematic issue) = carpet is very dusty (from story)

2 from the 'story' the affected object properties of 'OPI, 4' from Figure 1

epOPI(4,4) = Geometrical: 3 m long, 1 m wide

material:

a made of thick material especially along the edges

b dust is engrained in the carpet

marketing: valuable carpet.

First, we deduce:

1 Following the 'problem solving procedure' in 'Aspects of the systemic view relevant to design thinking' and Figure 1, there is a desired 'FS' of OPI

FS of OPI, 5 – carpet has an acquired property which is

apFS(5,5) = carpet (is freed from dust)

in which 'freed', is the *past participle* of the verb 'to free' which defines the incoming interaction.

2 Incoming interaction, in(3,4) = 'product frees carpet (IS = from very dusty to FS = free of dust)' in which the first part is a context free sentence and the second part is the IS and FS of OPI.

3 Using material property 2 in epOPI(4,4) which affects interaction and ER in Section 3.1, we determine the 'adverbial qualifier' of interaction, in(3,4):

a dust is engrained in the carpet

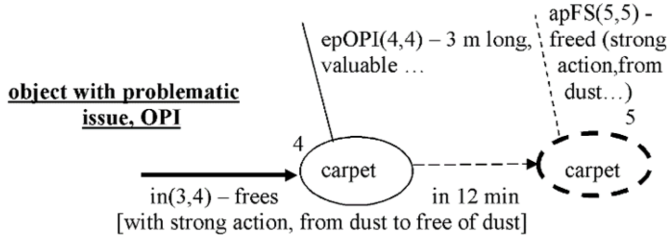
b to remove this kind of dust

c *requires* 'strong action'.

Accordingly, the interaction to be produced by 'product, 3' to affect 'OPI, 4-5' is in (3,4) – product frees carpet (with strong action, from very dusty to free of dust).

and the results so far are shown in Figure 6.

Figure 6 Sematic diagram of OPI and interaction



Second, we deduce

1 Determination of the affected object property, 'ep(10,10)' of 'product, 3' to match those of OPI

known: the affected object properties of'OPI, 4' which are:

epOPI(4,4) = Geometrical: 3 m long, 1 m wide

material: made of thick material especially along the edges

marketing: valuable carpet

and using ER we obtain:

a properties of 'object, 4' are epOPI(4,4) = valuable carpet, 3 m long, 1 m wide, made of thick material especially along the edges

b in order to free this kind of carpet from dust

c *requires* the affected object property of the product, ep(10,10) (the numeral 10 is an arbitrary designation of the 'not yet changed 'product'), to be

- *gentle* in action
- *capable* of coping with the size and thickness of material of the carpet.

2 Determination of the identity of 'product, 3'

A suitable product needs to be found that satisfies property:

ep(10,10) = a. gentle, b. capable

from existing stock or if none found one must be designed or invented. To select a product we can use the PSM as shown in Figure 7.

Figure 7 PSM for cleaning carpet

ALTERNATIVE PRODUCTS	a.	b.
using vacuum cleaner	0	1
washing the carpet with wet sponge	1	1
beating carpet with stick	0	0

In Figure 7 'Wet sponge' is selected for product because it has two 1's.

3 Determination of the acquired object property, ap(3,3),and incoming interaction to ‘product, 3’.

This is done by application of NR using known ‘affected object property’ and ‘outgoing interaction’ and seeking the missing ‘acquired property’ followed by ‘incoming interaction’. Accordingly,

Known = ‘The gentle, capable wet sponge (affected object properties)

Frees with strong action the carpet from dust (outgoing interaction)’

Implies: ‘that the wet sponge (changed object) in order ‘to free with strong action the carpet from dust’ is to be moved (past participle) in contact with the carpet’ in which the required past participle for ‘ap(3,3)’ ‘is moved’ with verb ‘to move’ which stands for the interaction from ‘management, user, 2’ or in(9,10) which is now known. We have found the new interaction by using the ‘necessary relation (NR)’ signalled by the term ‘implies’.

4 Determination of adverbial qualifier of incoming interaction, in(9,10), to ‘product, 3’ or ‘wet sponge’, from ‘man, user, 2’.

The interaction causing the change of state of ‘product, 3’ is known from the previous point, and it is:

in(9,10) – man, user, 2, moves the wet sponge (so as to be in contact with the carpet (FS))

and its adverbial qualifiers can be found from known affected object properties of ‘product, 3’, ep(10,10) and from the intuitively added property. Using ER:

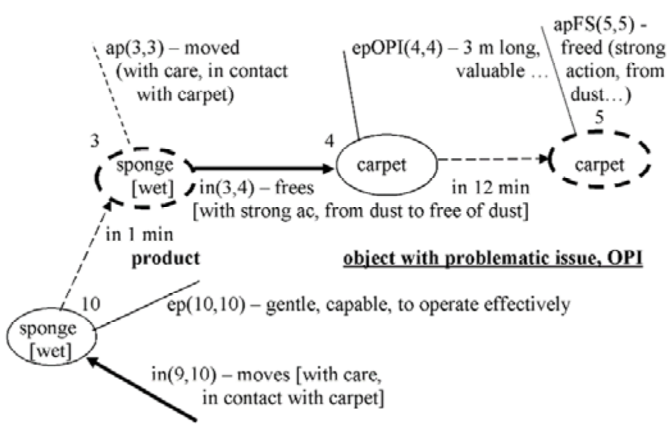
a the wet sponge is ‘gentle, capable and to operate effectively’

b to cater for these properties

c *requires* the ‘man, user, 2’ to move the wet sponge ‘with care and in contact with carpet’.

Accordingly, the interaction, in(9,10) – ‘man, user, 2’ moves wet sponge (with care, in contact with carpet).

Figure 8 Sematic diagram of ‘product’ and OPI



Results so far are shown in Figure 8.

Third, we deduce

1 Determination of the affected object properties of 'man, user, 2'.

We know the affected object properties of 'product, 3', ep(10,10) and from ER

a the wet sponge is 'gentle, capable and to operate effectively'

b to cater for these properties

c *requires* that 'man, user, 2', to be able to handle a wet sponge, needs skilled power (Korn, 2009) which is designated by ep(11,11).

2 Determination of the identity of 'man, users, 2'.

We know that the affected object property of the 'man, user, 2' is, 'ep(11,11) – a able to handle wet sponge, needs skilled power'. We construct the PSM in Figure 9 to find an object that is suitable to handle these properties.

Figure 9 PSM for management of cleaning

ALTERNATIVE MAN, USERS	a.
cleaning lady	1
cleaning man	0
robot	0

From Figure 9 the 'cleaning lady' is selected to act as 'man, users, 2' with affected object property, ep(11,11) – able to handle with skilled power.

3 Determination of the acquired property of and the incoming interaction to 'man, users, 2'.

This is done by application of NR using known affected object properties, 'ep(11,11)' and outgoing interaction, in(9,10) – moves (with care, in contact with carpet).

Known = 'the cleaning lady is able to handle with skilled power the wet sponge (affected object property)

Moves wet sponge (changed object) with care, in contact with the carpet'.

Implies: 'that the cleaning is with exerted force (past participle)' in which the required past participle of 'ap(9,9) is 'with exerted force' with verb 'to exert force' which stands for the interaction from 'cleaning lady' to 'cleaning lady', it is a 1 – place sentence.

4 Determination of adverbial qualifier of incoming interaction, in(11,11), to 'man, users, 2' or 'cleaning lady'.

The interaction causing the change of state of 'man, users, 2' or 'cleaning lady' is known, it is:

in(11,11) – man, user, 2, exerts force

Its adverbial qualifiers can be found from known affected object properties of 'man, users, 2' which is ep(11,11). Using ER:

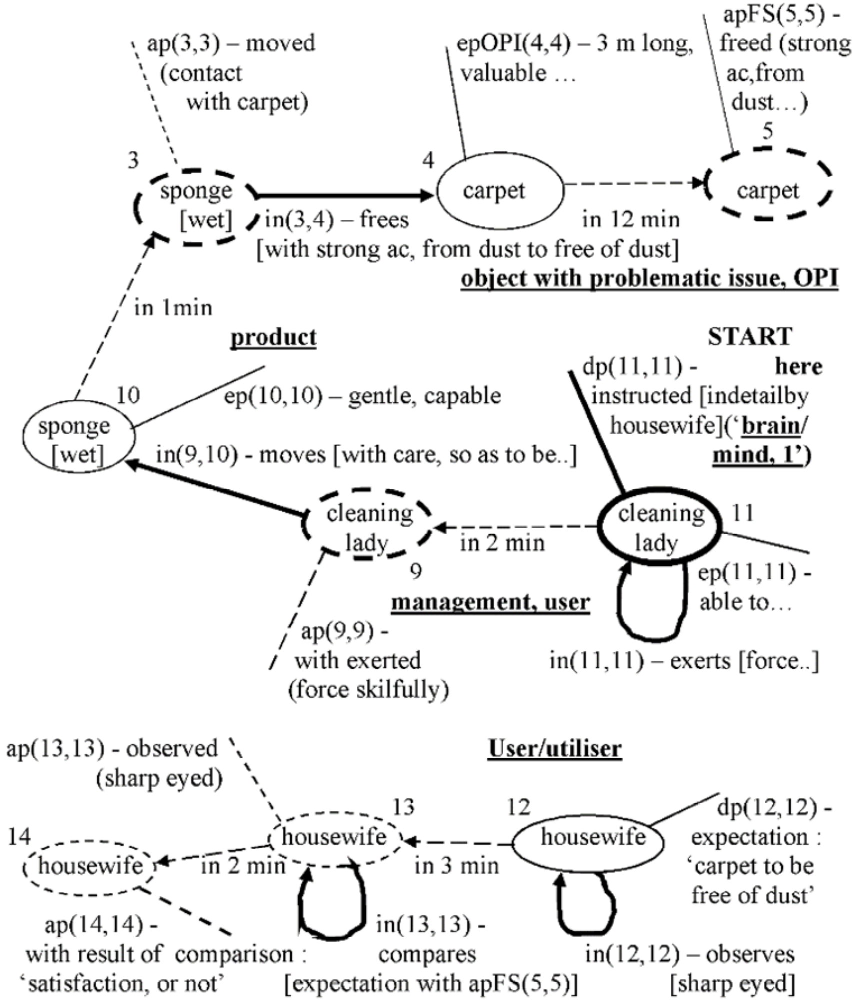
a the cleaning lady is ‘able to handle the wet sponge with skilled power’

b to cater for this property

c requires the cleaning lady to exert force ‘skilfully’.

Thus, the interaction, in(11,11) – ‘man, users, 2’ exerts force (skilfully) as shown in Figure 10.

Figure 10 Semantic diagram of ‘housewife-carpet’ scenario



We know,

According to the scheme in Figure 1 the ‘brain/mind, 1’ initiates (action) by ‘man, users, 2’. In this example, the ‘housewife’ functions as ‘brain/mind, 1’ as determined in ‘Identification of constituents of Figure 1 from the ‘story’, the ‘cleaning lady’ also performs as the ‘man, users, 2’.

This effect can be represented in the semantic diagram of Figure 10 by driving object property, ‘dp(11,11) – instructed by the housewife’ who observes the progress of cleaning the carpet, in(12,12) and compares, in(13,13) with ‘expectation’, dp(12,12), which leads to her state of mind of satisfaction or not, ap(14,14).

The designer now knows enough to interpret the initial semantic diagram in practical terms which includes the required prototype model as shown in Figure 10 and it is the formal representation of the ‘problematic situation’. Being in possession of the complete, initial design it is possible to modify, improve or add.

Remarks

We comment on design procedure outlined in Section 3.2 under the following points.

1. Only the semantic diagram in Figure 10 as the result of the design procedure is presented here due to lack of space and the need for peer review before more effort is invested in this work.

2. The procedure for systems and product design produces ‘one’ prototype model to deal with a ‘single’ property of an ‘object with problematic issue, OPI’. This is the general case because the procedure is specific and as such operates at ‘property’ level to lead to operational models. In case of more than one property each has to have its own procedure which are combined according to an ‘algorithm’.

3. The procedure identifies the objects or agents of the prototype model and their properties and interactions. This allows detailed design of components and their features to conform to those arrived at by the systems design procedure and to be carried out by the *component engineer*. We note the importance of the affected object properties, ep(..,..), of the product in originating other properties constituents.

4. The identified and agreed on ‘object with problematic issue, OPI’ and its properties which trigger the design procedure.

5. It is the properties of objects which propel the procedure. They can be given

   a. in the story which describes the problematic issue

   b. as demanded by the formalism of linguistic modelling

   c. by exercising creativity, inspiration or inventiveness.

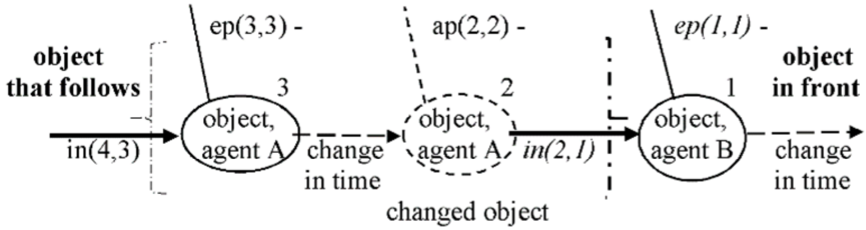
   Here in this introductory paper the ‘initiating object property, ip(..,..)’ has not been considered to avoid complications but this does not apply when software becomes available (Korn, 2009).

6. The design procedure consists of the repeated application of four steps as demonstrated by the example which in general terms is described as follows and is supported by the general semantic diagram of the relevant parts in Figure 11.

The design procedure is prompted by identification and agreement among interested parties of the ‘problematic issue’ and represented by the ‘affected object properties of ‘OPI, 4-5’ and its desired change of state.

With reference to the semantic diagram in Figure 11.

Figure 11 Semantic diagram of general design procedure



Step 1 Determination of affected object *property*, ep(3,3), of 'object/agent, 3'.

Given – ep(1,1) using ER, determine → ep(3,3).

Explanation – Properties of one object must match those in front of it in the following elementary constituent.

Step 2 Determination of the *identity* of 'object/agent, 3-2'.

Given – ep(3,3) using PSM, select/invent → 'object/agent, 3-2'.

Explanation – Finding the constituent that actually has the matching properties

Step 3 Determination of acquired *property*, ap(2,2), and incoming interaction, in(4,3).

Given – ep(3,3) and in(2,1) using NR, determine → ap(2,2) and derive the dynamic verb of in(4,3).

Explanation – there is an 'object/agent, 3-2' and an outgoing interaction 'in(2,1)' which by 'necessity' must be produced bychanged object with ap(2,2) described by past participle. This defines the incoming interaction 'in(4,3)'.

Step 4 Determination of adverbial qualifiers of incoming interaction, in(4,3).

Given – ep(3,3) using ER, deduce → adverbial qualifier.

Explanation – incoming interaction must match affected object property of 'object/agent, 3-2' otherwise it is unable to change its state.

4 Conclusions

4.1 Summary of research

An integrated design method to be practiced by systems engineers, designers or managers or individuals for systems and product design has been presented. The method uses aspects of the 'new science of systems' which gives it a theoretical guidance (Korn, 2018). The problem solving structure in Figure 1 enables determination of and to make explicit the functional constituents initially presented in a 'story' of a problem situation in natural language implicitly. This leads to application of linguistic modelling to determine properties and interactions of functional constituents from a reasoning structure starting with known characteristics of identified 'objects with problematic issue and expectations', 'OPI, 4-5' and 'user/utiliser, 6-7'. The whole effort is exerted to create a scheme called 'prototype model' which is to act so as to produce satisfaction of a 'user/utiliser' as shown in Figure 1.

The design procedure creates the initial design for a prototype model consisting of the 'product, 3', 'management, user, 2' and the 'first and second functions of 'brain/mind, 1''a part of Figure 1 of a 'utilising system'. This is done by initiating deduction of their identities and properties from the known identity and properties of 'OPI, 4-5'. The 'user/utiliser, 6-7' acts as the source of criterion of acceptability of operation of the prototype model by obviating the 'problematic issue' carried by 'OPI, 4-5' which is done by the interaction for changing the state of 'OPI, 4-5' as shown in Figure 1 and the example of 'carpet, housewife'.

4.2 Practical implications and possibilities, limitations and future research

Application of problem solving in particular design of systems and products is carried out incessantly in the living sphere the alternative is deterioration and extinction. The activities described in exp. 1 practiced by humans can only be executed by design thinking.

The method introduced in this paper is intended to guide this kind of thinking as shown in Figure 1 and to demonstrate the application of a theoretical approach to a largely unguided design thinking. Peer review is needed.

Design considerations for 'utilising systems' have been considered, those concerning 'producing systems' and 'trouble shooting' are left for other occasion. Semantic diagrams with 'prompting chains' need to be investigated. Linguistics and semantics of the kind of relationships generated by the concepts of ER and NR need to be looked at more closely. The contribution of creativity, inventiveness and intuitive thinking in the methodical reconstruction of a story needs investigation.

Here the design of a 'system' for dealing with change of a 'single' property has been considered. Complex problematic issues are seen to consist of single properties which are connected by an algorithm. The generality of the method outlined here and the systematic use which it provides presupposes the familiarity with linguistic modelling which is not widely available.

With reference to the scheme in Figure 1, design thinking integrates systems and product design by considering:

- First, the function of systems engineer or designer performed by professionals or any creature in the course of its everyday activities for survival or achievement of ambitions as referred to in exp. 1 is the recognition of a 'problem situation' and, if relevant, casting it into a 'story' in natural language and developing the formalism as described.
- Second, this is followed by the function of the 'component engineer' or designer who takes the identities, interactions and properties of components as found in the first point and design the details of each so as to satisfy the results of found above.
- Third, the universality of the systemic or structural view of parts of the world as suggested by the first general principle of systems (Korn, 2018) and the application of linguistic modelling as its symbolism, enables design thinking to be domain independent. In addition, the involvement of 'conventional science of physics' at object/agent or component level integrates 'systems thinking with conventional

science and design thinking into a 'scientific/creative enterprise' (Lewin, 1981; Korn, 2018).

The 'new science of systems' is rooted in accepted branches knowledge and its basis is in natural language. Linguistic modelling transforms a story in natural language into a hypothetical deductive and computable structure when software is available and the approach has been peer reviewed.

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