Adapting a causality model of technical systems to represent socio-technical systems: A Case study from the BoP

Jagtap, Santosh; Kandachar, Prabhu

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ADAPTING A CAUSALITY MODEL OF TECHNICAL SYSTEMS FOR SOCIO-TECHNICAL SYSTEMS: A CASE STUDY FROM THE BOP

Santosh Jagtap
Faculty of Industrial Design Engineering
Delft University of Technology
The Netherlands
S.N.Jagtap@tudelft.nl

Prabhu Kandachar
Faculty of Industrial Design Engineering
Delft University of Technology
The Netherlands
P.V.Kandachar@tudelft.nl

ABSTRACT

The base of the world economic pyramid, generally called the base of the pyramid (BoP), consists of four billion people with average daily income of four dollars. Over the past several years, the design and development of products and services for BoP markets has been investigated by several authors from different disciplines. While some authors suggest a systems approach to design and develop products and services for these markets, a little work has been carried out in this area. Specifically, no studies have been found in the reviewed literature that systematically explain how businesses bring about systemic changes in BoP markets. This study methodically explains how businesses bring about systemic changes in these markets through the design and development process. In order to explain these systemic changes, the study first describes the development of a causality-model for socio-technical systems by modifying a causality-model of technical systems. It then explains the developed causality model for the BoP. Lastly, it tests this model by an in-depth investigation of a case study from the BoP. The findings systematically explain the need of: gaining an in-depth understanding of the existing BoP system to bring about desired actions (e.g. gaining profits, satisfying under-served or un-met needs of BoP customers, etc.); including different stakeholders from the BoP in the design and development process; and appropriately modifying existing BoP system before deploying products and services. In addition, this study proposes some applications of the developed causality-model to support practitioners involved in designing, developing and assessing interventions (i.e. products and services) for BoP markets.

KEYWORDS

Base of the pyramid (BoP), causality, socio-technical systems, interventions

1. INTRODUCTION

The base of the world economic pyramid, generally called the base of the pyramid (BoP), consists of four billion people with average per day income of four dollars, and over a billion of these people earn less than one dollar a day. Most of these four billion people live in rural villages, urban slums, or shantytowns. Usually these people have little or no formal education. These people are hard to reach via the conventional means of communication and distribution channels. The quality and quantity of products and services available to these people is usually inferior [29]. Prahalad and Hart [29] state, “Low-income markets present a prodigious opportunity for the world’s wealthiest companies – to seek their fortunes and bring prosperity to the aspiring poor”.

Over the past several years, the design and development of products and services for the BoP has been investigated by several authors from different disciplines [21, 23, 26, 30, 35, 36]. Designing and developing products and services for BoP markets requires addressing issues in these markets, and these issues are varied. Jagtap and Kandachar [21] synthesized the literature on these issues in the BoP.

Their study found that the issues identified in the study conducted by the United Nations Development Programme (UNDP) [35] are comprehensive and include those identified in other relevant studies. These issues are about: how businesses can gain the information on BoP markets; under-developed regulatory frameworks; poor physical infrastructure; lack of knowledge and skills of BoP customers; and BoP customers' lack of or poor access to financial services.

In order to address these diverse issues, an integrated approach using knowledge from different disciplines such as technical sciences, social sciences and management sciences has been proposed by Kandachar and Halme [23]. This approach is in line with the systems approach. While some authors have highlighted the need and importance of systems approach in the BoP, much less work has been carried out in this area excepting the studies of Subrahmanyan and Gomez-Arias [33], Whitney and Kelkar [36], and Nielsen and Samia [27]. However, these studies focus on narrow areas of the BoP. For example, the work carried out by Subrahmanyan and Gomez-Arias [33] aims at developing integrated frameworks to explain consumption patterns of the BoP-people. Furthermore, there is to date no research in the BoP that aims at developing a generic framework for explaining causal phenomena of how businesses bring about systemic changes in the BoP through the design and development of products and services for these markets.

Systems approach has been investigated in areas other than the BoP. Some of the sectors in these areas are healthcare, economics, agriculture, energy, etc. [2, 7, 8, 13, 16, 25, 34]. However, these studies also do not focus on causal phenomena behind systemic changes. These abovementioned sectors and the BoP are socio-technical systems. In contrary, several authors have investigated causal phenomena in the case of a systems approach to technical systems or artifacts such as bicycle, aero-engine, telecommunications infrastructure, etc. The literature on the theory of technical systems is rich and can be used to explain the causality in a socio-technical system. It is therefore important to overcome the weaknesses and limitations of the reviewed literature on the BoP and on the systems approach regarding socio-technical systems.

The overall aim of this research is to develop an understanding of how businesses bring about systemic changes in BoP markets through the design and development process. This overall aim is divided into the following specific aims:

- to develop a framework to explain the causality in a socio-technical system;
- to contextualise this framework for the BoP;
- to validate or test this framework; and
- to develop suggestions, using this framework, to support practitioners involved in designing, developing and assessing products and services for BoP markets.

In this research, the above-mentioned framework turned out to be a model of causality.

This paper is structured as follows. Section 1 presented the background, motivation, and research aims. Section 2 presents the research methodology. Section 3 explains the developed causality model for socio-technical systems and for the BoP, and Section 4 explains the testing of this model. Some applications of the contextualised causality model to support practitioners are proposed in Section 5. Finally, Section 6 sets out the conclusions.

2. RESEARCH METHODOLOGY

In general, research approaches can be divided into the following two broader categories: (1) data-driven (i.e. inductive approach); and (2) theory-driven (i.e. deductive approach). In a data-driven approach, theoretical constructs are derived by analyzing the empirical data. In the case of a theory-driven approach, theoretical constructs are developed first, and these constructs are then tested using empirical data. Many researchers agree that in reality these two approaches do not exist in their 'pure' form [6].

The reviewed literature in the BoP-domain suggests that so far data-driven approach has been employed in this area. There is to date no research in the BoP that has used the theory-driven approach. In this research, we employ the theory-driven approach. There are three major steps in this research approach: (1) develop a causality model for socio-technical systems by adapting a model of causality found in the reviewed literature on technical systems, and contextualise this model for the BoP; and (2) test this contextualized model by using a case study drawn from the BoP.

2.1. Selection of the case study

United Nations Development Programme (UNDP) [35] led an initiative called 'Growing Inclusive Markets' (GIM). In this initiative, they analysed 50 BoP-cases from ten different sectors such as energy,

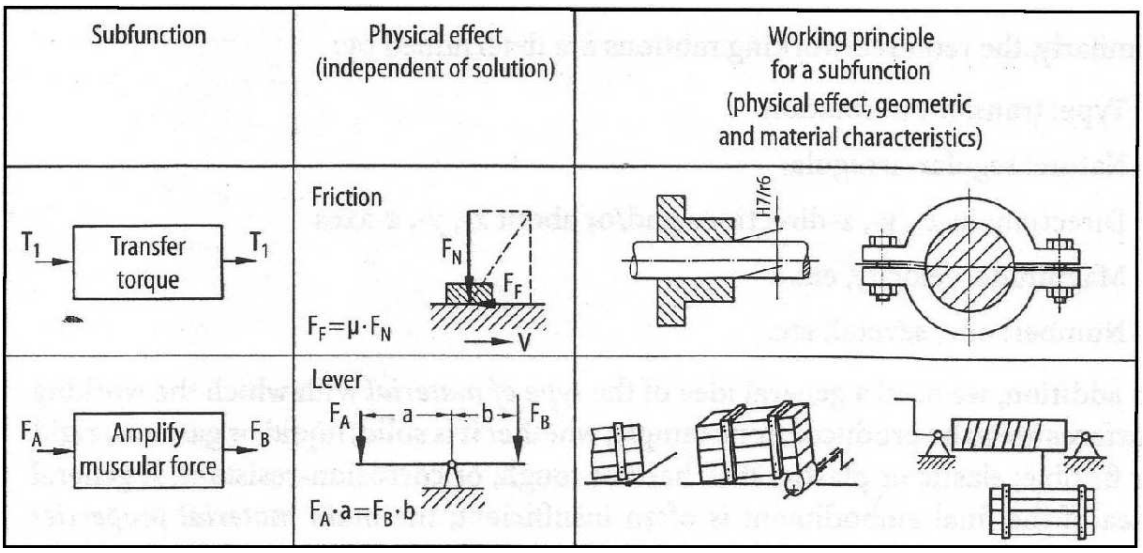

Figure 1 Achieving a sub-function using working principles that are developed from physical effects and geometric and material characteristics - adopted from [28].

healthcare, etc. and from different countries. In order to test the developed theory, we randomly selected one case from the UNDP-study.

3. DEVELOPMENT OF A CAUSALITY MODEL FOR SOCIO-TECHNICAL SYSTEMS

3.1. Causality in a technical system

A given function of a technical system is achieved by a physical process, which is realised by *physical effects* and the geometric and material characteristics of the system [28]. Figure 1 shows two examples adopted from Pahl and Beitz [28]. The quantitative relationships between the physical quantities allow the description of physical effects. Several physical effects may need to be combined to achieve a function. On the other hand, a given function might be achieved by one of several different physical effects (e.g. a force can be amplified by the lever effect, the hydraulic effect, the wedge effect, etc.).

Hubka [19] uses the terms *process structure* and *function structure* to explain and solve design problems. The process structure is a transformation between the input and output situations demanded by the problem. The function structure can be explained in terms of verbs allowing these processes to happen. Sembugamoorthy and Chandrasekaran [32] explain *function* as the intended response of a device to external or internal stimuli. *Behaviour* is an explanation of how such a response is produced, and is described by a causal chain of states. A state establishes state of some objects in the world. Chakrabarti [9] proposes *function* as "a relation (or relations) between at least two situations, describing the measurable responses of a device to measurable external stimuli". He proposes *form* as "one or several structural descriptions of a solution, and could be described by one or a set of situations". Bell [5] defines the term *structure* as "the physical composition of the device; its components and connections"; *behaviour* as "how a device works, what it does in terms of its internal properties"; *function* as "a device's behaviour expressed in terms of its purpose"; and *purpose* as "the need that the device is intended to fulfil". He states that the above concepts provide abstract description of the previous concept; for instance, function is abstraction of behaviour.

Pahl and Beitz [28] define *side effect* as "functionally undesired and unintended effect of a technical system on a human or on the environment". Chakrabarti and Johnson [10] discuss the issue for identifying side-effects in conceptual solutions. They define *side effects* as "effects whose outputs affect the intended operations of a system". In order to activate physical effects, the right 'inputs' and right 'contextual parameters' are necessary. The authors have provided an example – "activation of a piezoelectric effect requires stressing (input) of certain crystals (context)". Side-effects can be identified by noticing the inputs and contexts that are available in the situation in which a system works. From these inputs and contexts the possible physical effects that might get activated can

be identified. These side effects can be considered as *secondary effects* of Hubka's [19] model of the structure of technical processes.

There are multiple meanings and representations of function, form, design problems and solutions [9]. Chandrasekaran and Josephson [12] state, "there is also quite a bit of confusion between function and behavior in the literature". The SAPPhIRE model provides a rich causal explanation of a physical phenomenon and attempts "to reach a non-arbitrary degree of detail of behavioural explanation" [11]. The SAPPhIRE (*S*tate-*A*ction-*P*arts-physical *Ph*enomenon-*I*nputs-o*R*gan-physical *E*ffect) model explains the relationships between the following seven constructs:

- parts - "a set of physical components and interfaces constituting the system and its environment of interaction";
- state - "the attributes and values of attributes that define the properties of a given system at a given instant of time during its operation";
- organ - "the structural context necessary for a physical effect to be activated";
- physical effect - "the laws of nature governing change";
- input - "the energy, information or material requirements for a physical effect to be activated; interpretation of energy / material parameters of a change of state in the context of an organ";
- physical phenomenon - "a set of potential changes associated with a given physical effect for a given organ and inputs"; and
- action - "an abstract description or high level interpretation of a change of state, a changed state, or creation of an input".

Jagtap et al [22] modified Chakrabarti et al's [11] SAPPhIRE model by proposing an additional construct 'stimuli' and two additional relationships 'embody' and 'affect'. They defined the construct 'stimuli' as follows: "input context necessary for a physical effect to be activated in the presence of the relevant organs". Different aspects of an input (e.g. measure of input's attribute) and/or relationships between inputs create 'stimuli'. The developed model is called the 'Sym-SAPPhIRE' model of causality (see Figure 2). The Sym-SAPPhIRE model thus provides a rich causal explanation of an action.

The Sym-SAPPhIRE model can be useful in tackling the confusion created by the multiple meanings and representations of the various concepts such as function, behaviour, structure, etc. We believe that

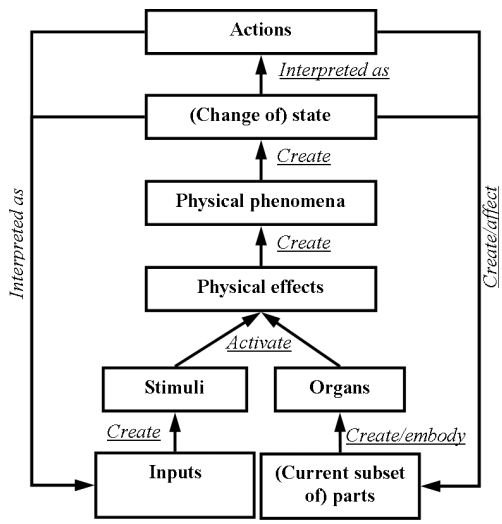

Figure 2 'Sym-SAPPhIRE' model of causality - Jagtap et al [22].

this model has integrated the concepts, namely function, behaviour, and structure. The constructs parts and organs explain the structure of a device, and the construct regarding the changes in states describe the behaviour of a device. Regarding the function of a device, Chakrabarti et al [11] state, "In our view, function is seen as specific, limited, intended aspects of the rich causal behaviour of artifacts embedded in and in conjunction with the environment in which it operates, and could be seen as:

- State change
- Attained, final state
- Inputs
- I/O *(input/output)* transformation
- Creation of the context for physical effects to appear, i.e., organs, etc".

The SAPPhIRE constructs for a system transmitting power through a shaft are as follows (see Figure 3):

- Parts: shaft forms a revolute pair with bearings;
- Organs: one degree-of-freedom of motion between the shaft and bearings, bearings fixed to a rigid support;
- Input: torque applied to the shaft;
- Physical Effect: Newtonian laws of motion;
- Physical phenomenon: rotation of the shaft;
- State: shaft in static state, and shaft in rotating state;
- Action: power is transmitted through the shaft.

Action is interpretation of a change of state, and depends on the interpreter. This above action (i.e. power is transmitted thorough the shaft) is interpretation of the change of state by the authors of this paper.

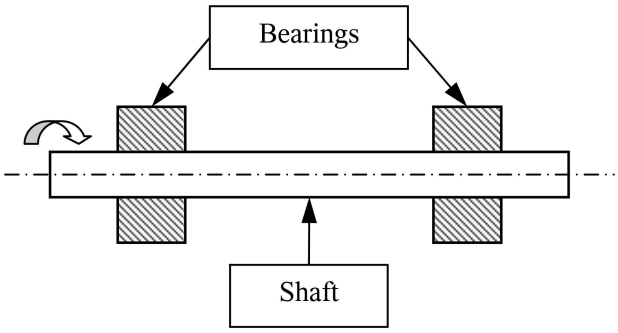

Figure 3 Transmission of power through a shaft.

3.2. Causality in a socio-technical system

Technical systems can be represented by using the Sym-SAPPhIRE model of causality because in these systems we know the organs, stimuli, and the physical effects that can get activated in the presence of these stimuli and organs. Furthermore, in the design of these technical systems, the information on these physical effects is useful. For example, a database of physical effects along with the stimuli and organs required to activate these physical effects can assist designers in selecting appropriate stimuli and organs to achieve desired functions. In a technical system, in addition to desired physical effects, some unanticipated physical affects can also get activated. By careful analysis of these systems, these unanticipated physical effects can be identified, and thereby unanticipated changes of state and actions can be noticed. These unanticipated actions are generally called side effects. For example, Jagtap et al [22] analyzed case studies involving deterioration of components from aero engines. They used the Sym-SAPPhIRE model of causality to analyse the data in those case studies. The deterioration mechanisms faced by the components are called side effects.

Solutions developed by businesses in the BoP include social and technical systems. The technical systems can include physical products or infrastructure such electricity network, telecommunications infrastructure, roads, etc. These physical products can be represented using the Sym-SAPPhIRE model of causality. The social systems do follow the laws of nature (i.e. physical effects); however, we do not know these laws for such systems. Therefore, we can not represent social systems using this model. In addition, we can not represent the relationships between the social and technical systems using this model. The lack of knowledge on the laws of nature in the case of social systems can be tackled by knowledge and judgment of stakeholders involved in designing and developing products and services. These experts can use their judgment and experience to estimate the response of a social system to some inputs.

To represent the causality in a socio-technical system, we simplify the Sym-SAPPhIRE model of causality as shown in Figure 4. We call this simplified model as the causality model for a socio-technical system (CMSTS). The system in this model consists of relevant elements in it such as people, technical systems (i.e. products), and operating procedures. This construct includes these different elements, relationships between these elements, and its environment of interaction. This is illustrated in the lower part of Figure 4. We have not explicitly included the constructs 'organs' and 'stimuli' of the Sym-SAPPhIRE model. To simplify, we consider the construct 'organ' to be implicitly included in the construct 'system', and the construct 'stimuli' in the construct 'inputs'. The inputs include material, en-

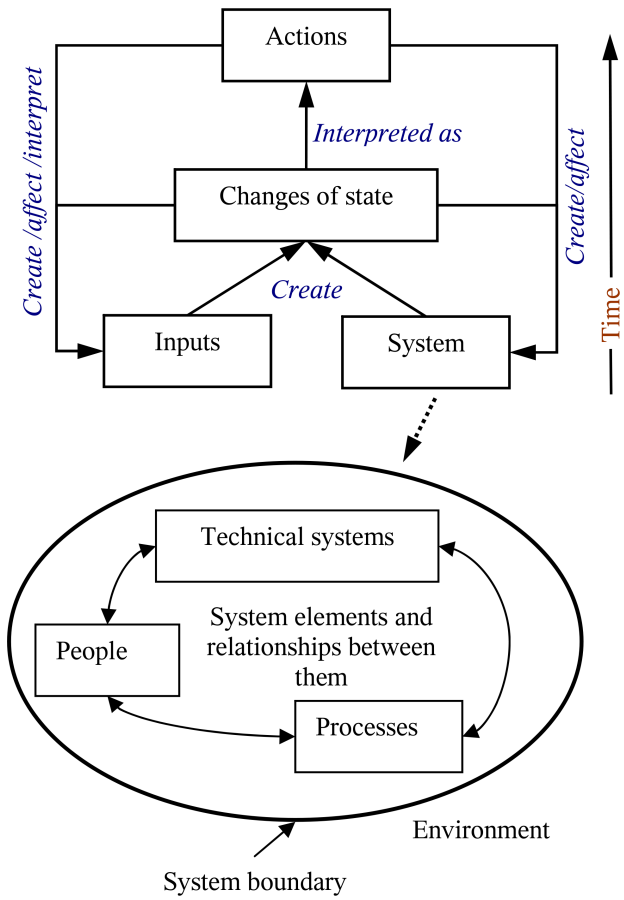

Figure 4 Causality model for a socio-technical system (CMSTS).

ergy, and information requirements to create some changes of state for a system. The changes of state are interpreted as actions, and therefore these actions are subjective in nature. These changes of state and actions can create or affect inputs and system. In addition, the changes of state and action can be interpreted as inputs for further changes of state. The causality model shown in Figure 4 also includes time dimension.

3.3. Contextualising the CMSTS for BoP

In the case of the BoP, businesses deploy their products and services to achieve some desired changes of state and thereby actions. These products and services act as an intervention. In the case of the BoP, *the inputs* in Figure 4 can be seen as an *intervention* and the *system* as a *BoP system*. This BoP system consists of different elements such as BoP customers, regulatory frameworks, available infrastructure (e.g. roads, electricity network, etc.), operating procedures, relationships between these elements, and the environment of interaction.

An intervention can be comprised of people, products, and processes. Businesses design this intervention in order to obtain desired actions such as gaining profits and satisfying under-served or un-met needs of BoP customers. The intervention and the existing BoP system activate some physical effects which in turn bring about some changes in state, which are interpreted as actions. The model in Figure 4 is at a broader-level. However, to bring about the desired actions, there can be a complex network of causal chains.

In order to achieve desired actions by employing an intervention in an existing system, it is crucial to understand the existing system. In the case of the BoP, an in-depth understanding of different elements in the BoP, relationships between them, and environment of interaction is crucial to design and develop an intervention, which can bring about desired actions. This understanding of the existing BoP system is input to the process of design and development of the intervention. This understanding can include different characteristics of the BoP stakeholders, existing state of the physical infrastructure, regulatory frameworks in the BoP, and relationships between them. In addition, this understanding can provide information on the issues in the existing system. In the case of a BoP system, these issues can be underdeveloped regulatory frameworks, poor physical infrastructure, lack of knowledge and skills of BoP customers, etc. The CMSTS is thus useful to explain the importance of gaining an in-depth understanding of an existing system in order to bring about desired actions by employing an intervention.

The changes of state or actions can create or affect system and inputs (see Figure 4). This suggests that in the case of a BoP system, the changes of state or actions can affect existing BoP system and intervention over time. Therefore, the same intervention may not result into the desired changes of state over some time period. This implies the need to periodically update the understanding of the BoP system and accordingly redesign the intervention to achieve desired changes of state and actions.

In the case of a socio-technical system, the lack of knowledge on physical effects puts an emphasis on identifying changes of state using stakeholders' knowledge, experience, and interpretation. As the desired actions are interpretations of changes of state by different stakeholders, it is important to include these stakeholders in the design process. Different stakeholders can have different interpretations of changes in states – that is – they can interpret different actions based on their knowledge and experience. For example, the BoP customers can interpret changes of state due to an intervention to identify whether or not the intervention would satisfy their needs or if they would accept the changes of state due to the intervention. Therefore, it is useful to include the stakeholders including BoP customers in the design of an intervention. This will also help to understand the existing BoP system as the stakeholders from this system can provide their insights and knowledge regarding that system.

Furthermore, the developed intervention can activate some unanticipated physical effects and thereby can create some unintended changes of state and actions. These unintended actions can be called side effects. In the case of a technical system, a database of physical effects along with required inputs and parts for the activation of these physical effects can help to identify side effects. However, in the case of a socio-technical system, a database of physical effects can not be built because of the lack of knowledge regarding physical effects in a social system. The knowledge and experience of different stakeholders can help to indentify these side effects.

Therefore, their involvement in the design and development of an intervention is useful in identifying side effects. In addition, different stakeholders

can have different interpretations of changes of state; therefore, it is likely to identify different actions for a given change of state. Some of these interpreted actions can be undesired for some stakeholders, and therefore these actions can be considered as side effects. In essence, different interpretations of changes of state are useful in identifying different desired and undesired (side effects) actions. As shown in Figure 4, a change of state or an action can be interpreted as inputs for a further action. Therefore, different stakeholders can identify different inputs by different interpretations of changes of state or actions. The identification of different inputs can help to identify further possible changes of state and actions which can be desired or undesired.

In the BoP, the process of designing and developing an intervention can affect or modify the existing system. This design and development process can be seen as 'inputs' as shown in Figure 5. We call these 'inputs' as 'Design and Development Process Inputs' (DDPI). This DDPI can change the existing BoP system before implementing the developed intervention. The DDPI can change the regulatory frameworks, physical infrastructure, etc. in the BoP. The DDPI is required when the final intervention can be employed after some changes in the existing system. As shown in Figure 5, the DDPI and the existing BoP system modify the existing system and produce the final intervention. The modified system and this intervention in turn bring about some desired actions such as gaining profits and satisfying needs of BoP customers.

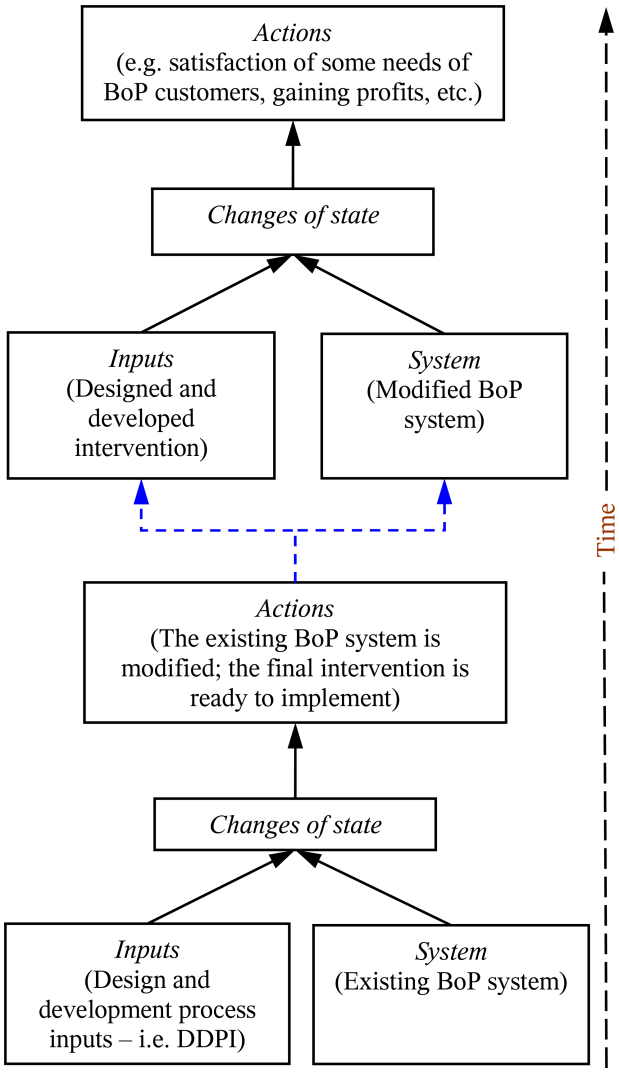

Figure 5 Modifying the existing BoP system prior to implementing the final intervention.

4. CASE STUDY

This section illustrates the CMSTS by using a case study. This case study presents information on a project where a company called Amanco designed and developed an irrigation system for low-income farmers from Latin America.

The unfair prices and commercial intermediaries caused low productivity in the agricultural output of small farmers from the BoP in Latin America. A company, Amanco, developed an integrated irrigation system for these farmers who produced lemons on their land. This system aimed at increasing productivity of the agricultural output and at increasing the efficiency of water use. In order to implement the developed system, the company collaborated with partners from the BoP. In addition, the company collaborated with partners providing micro-credit. The company first developed the system in Guatemala and then in Mexico. We illustrate our model (i.e. CMSTS for the BoP) by presenting information on the system developed in Mexico.

4.1. Existing BoP system

Amanco implemented the irrigation system in a community called La Testaruda in Mexico. The company first gathered information on this community. In order to gather the required information, the company selected a social entrepreneur, Arturo García, the director of the NGO called Sustainable Farmers Network (RASA, Red de Agricultores Sustentables). Ashoka, an international civil society organization which promotes social entrepreneurship worldwide helped Amnaco to select this social entrepreneur from RASA. RASA had experience of over 25 years

in rural projects. In addition, the trust and legitimacy of RASA among the community was useful in gaining the required information on the community (i.e. existing BoP system). The farmers in the community were using outdated irrigation methods due to the lack of capital, and they lacked the awareness of the importance of renewing the old lemon plants. The productivity of old lemon plants was poor. These farmers sold lemons in local markets or nearest cities without reaching larger wholesalers or supermarket chains.

In addition, the small farmers of the La Testaruda community felt neglected as the agriculture was not a priority for the government, and the distribution of public resources lacked a pro-poor approach. Prior to the Amanco's project, small farmers formed a cooperative, which lobbied and achieved transportation infrastructure and public lighting services in 2005. These small farmers were unable to afford the total cost of the new irrigation system, public subsidies were not reaching them, and they lacked the financial criteria and standards for getting the required capital for investing in the new irrigation system

In addition to the information on existing BoP system, other inputs were necessary in the design and development process. These inputs, for example, were experience and knowledge of the Ashoka and Amanco. Ashoka' experience in the field of social entrepreneurship helped Amanco. Amanco's experience and knowledge of designing irrigation systems was crucial in the design and development process.

4.2. DDPI

The design and development process started in 2005. 104 hectares of the La Testaruda community's land was selected for the project. In order to tackle the lack of coordination and weak social capital in this community, social gatherings were arranged among farmers and their families for collaborative activities (e.g. preparing roads for excavation).

Amanco carried out the hydraulic design and topographic mapping required for designing technical aspects of the new irrigation system. The company provided training to the technicians from the RASA for creating distribution channels, and for supporting and supervising the installation of the new irrigation system. The installation of the new irrigation system was the responsibility of small farmers. RASA was responsible for the promotion of the new irrigation system. The promotion was achieved through meetings and word-of-mouth strategy among small farmers. In addition, RASA created cooperatives of farmers in order to facilitate the promotion of the new irrigation system.

The development of financial model was carried out by Amanco and RASA. This model consisted 20% down payment by farmers in three installments, 30% microcredit, and 50% public subsidy. RASA facilitated access to financing channels and public subsidies.

The inputs to the design and development process thus were from the BoP system and the traditional non-BoP system. For example, the NGO, RASA, had experience in the BoP system, and Amanco had prior experience of traditional non-BoP markets. There were issues or conflicts at the interface between these partners from different systems. The lack of understanding of low-income markets required an exploratory and learning approach for Amanco to gain the market information. In addition, lack of competencies to enter low-income markets caused difficulties for the company. The company had no prior experience of working with an NGO. Amanco faced difficulties in convincing the small farmers about the benefits of the new irrigation system. Specifically, the company found it hard to convince small farmers, who had good access to water, of the potential benefits of the new irrigation system. These small farmers having good access to water experienced high inefficiencies. The company could convince only ten out of 52 small farmers from the La Testaruda community to renew their lemon plants. Although, the productivity of the old lemon plants was poor, the famers had an emotional value for these plants.

4.3. Intervention and the modified BoP system

The design and development process modified the existing system and created the final intervention, which is the new irrigation system. The modified BoP system resulted into coordination and increased social capital among small farmers of the La Testaruda community. Ten out of 52 farmers renewed their lemon plants by 2006. The trained NGO could support and supervise installation of the new irrigation system, and the financial model was available. The final intervention consisted of the new irrigation system. Three types of irrigation systems, namely drip irrigation, portable irrigation, and microsprinkling, were designed. The price of the irrigation system was in the range 2500 to 3000 US dollars per hectare.

4.4. Actions

The intervention and the modified BoP system created some changes of state and actions. These actions are as follows.

- Agricultural (i.e. lemon) output increased due to the new irrigation system and the replacement of old lemon plants.
- Estimates of the representatives of the Irrigation Unit suggest that the income of the small farmers would increase by at least three times.
- Labor cost and time required for irrigation reduced.
- About 60% savings in the consumption of water were achieved. In addition, the new irrigation system helped to mitigate the land erosion.

One of the farmers of the La Testaruda community interpreted the changes due to the new irrigation system as, "there is a renovated hope as we are starting to see the transformation".

5. IMPLICATIONS: SUPPORTING THE PRACTITIONERS

Sections 3 explained the CMSTS, and Section 4 explained its testing by using a case study from the BoP. This section presents some applications of the CMSTS to support practitioners involved in designing, developing and assessing interventions for BoP markets.

5.1. Use of the past and existing BoP-interventions

As mentioned in Section 2.1, United Nations Development Programme [35] led an initiative called 'Growing Inclusive Markets'. In this initiative, they analysed 50 BoP-cases from ten different sectors such as energy, healthcare, etc. and from different countries. Some part of this UNDP-study is reported by Gradl et al. [15]. For each of the 50 cases, the UNDP-study identified relevant issues considered by the business and the strategies used to address these issues. While this UNDP-study has identified issues in BoP markets and strategies used by businesses to address these issues, it has not developed a framework to structure the information on the 50 cases. The information on these 50 cases is stored a text format, and these cases are not represented using a causality framework.

The CMSTS is useful to structure the information on the past and existing BoP-cases. This can be achieved by using the constructs of the CMSTS (e.g. existing BoP system, DDPI, modified BoP system, final intervention, actions, etc.). The case study on Amanco's irrigation system in Mexico, described in Section 4, has illustrated how the constructs of the CMSTS can be used to structure the information on a BoP-case. Furthermore, the CMSTS allows a diagrammatic representation of information. The reviewed literature [1, 17, 24, 31] suggests that the diagrammatic representation of information during the early phases of a design process has the following advantages:

- it helps designers to comprehend problems;
- it improves the effectiveness and efficiency of early design, and facilitates human cognitive processes fostering innovation;
- information can be analysed at a faster rate than in a text format.

This implies that diagrammatic representation of information on the past and existing BoP-cases can help practitioners in designing a new intervention or in redesigning an existing intervention. The CMSTS helps to diagrammatically represent information. Figure 6 exemplifies the diagrammatic representation of the information on the Amanco's intervention regarding the irrigation system. This diagrammatic representation can help practitioners who are involved in: (1) designing a new irrigation system in BoP markets; or (2) redesigning an existing irrigation system. It is thus clear that the CMSTS is useful in structuring and representing information on BoP-cases, and a database of the past and existing BoP-cases can be developed using the CMSTS. Such a database can help practitioners to: (1) easily comprehend these BoP-cases; and (2) generate solutions for the problems they are tackling.

Information on interventions or cases similar to the one being designed can help practitioners to understand different issues relevant to their design task. Analogical thinking/reasoning can assist in identifying the similar interventions or cases. Ball et al [3] state "Analogical reasoning entails the use of 'source' information from a previous problem-solving episode as a means to facilitate attempts at solving a current, 'target' problem." Holyoak and Thagard [18] explain that "…analogical thinking involves establishing a mapping, or systematic set of correspondences, between the elements of the source and the target analog." The constructs of the CMSTS (e.g. actions, system, intervention, etc.) can be used to search for similar cases or interventions in the abovementioned database.

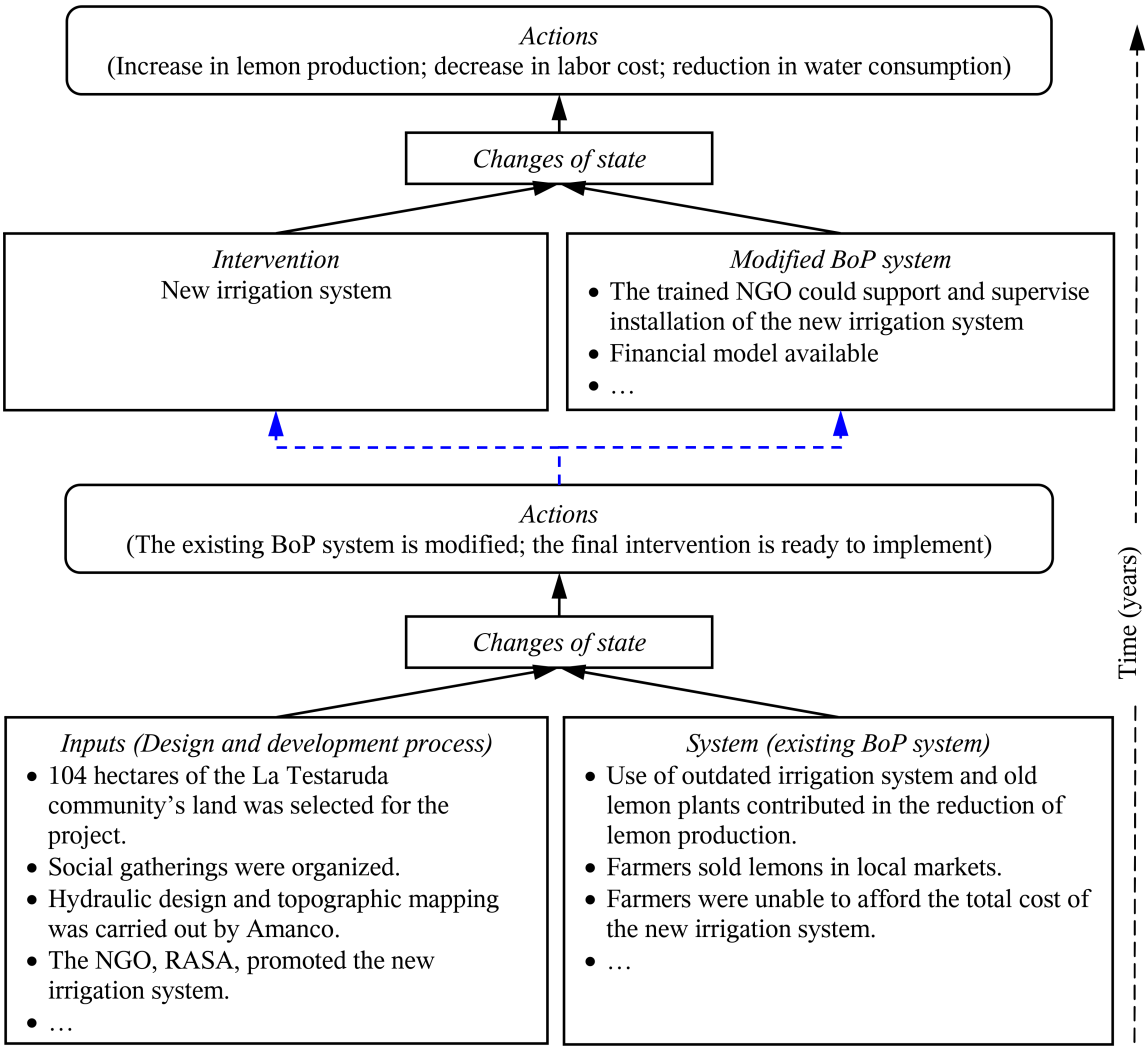

Figure 6 Diagrammatic representation of information using the CMSTS.

A single construct or a combination of constructs (e.g. actions plus intervention) can be used to search for similar cases or interventions. For example, in the design of a new irrigation system for a BoP market, practitioners might search a database of BoP-cases using the following criteria:

- 'action' to increase agricultural productivity (simple search);
- 'action' to increase agricultural productivity plus 'intervention' consisting of a drip irrigation system (combination search).

The search results can help the practitioners to generate appropriate solutions to tackle the problems they are solving.

5.2. Impact assessment

The assessment of the impact of the interventions aimed at social development is important [4, 14, 20]. The impact assessment (IA) in BoP markets helps to understand the effects of an intervention on BoP-clients. The information, gained through IA, on the performance of an intervention is useful in the design and development of a new intervention or re-designing an existing intervention. Furthermore, this information can be useful in commercial promotion, marketing, or to expand the intervention to other locations in BoP markets.

The CMSTS can be useful in IA. This can be achieved by using the following constructs or relationships between the constructs of the CMSTS:

- the construct 'changes of state';
- the relationship 'interpreted as' used to arrive at 'actions' from 'changes of state'.

An intervention in a BoP-system brings about some changes of state. These changes of state reflect the

impact of the intervention. This requires information on states of a target BoP-system before and after employing DDPI and final intervention. As shown in Figure 7, the initial state (i.e. State 1-target) and final state (i.e. State 2-target) of a target system can be compared to assess the impact of an intervention. The information on a BoP-system (i.e. control system) where the DDPI and intervention are not implemented can also help in IA. The control system needs to be as similar as possible with the target BoP-system. The comparison of 'State 2-target' with 'State 2-control' is useful in assessing the impact of an intervention (see Figure 7). It is important that 'State 2-control' is obtained over the same time period as 'State 2-target' is achieved. Different objective parameters such as income of BoP-people, number of products and services available to them, etc. can be used to specify a state of a BoP-system.

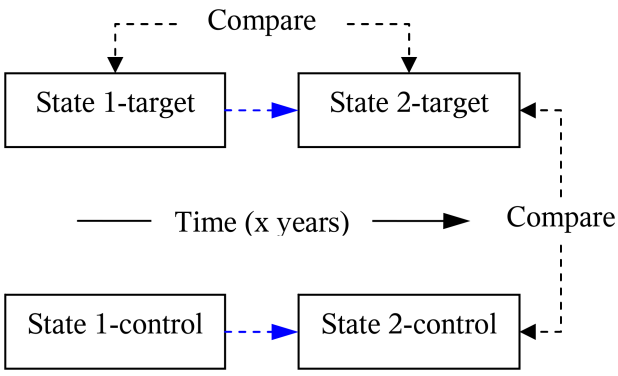

Figure 7 Using the construct changes of state of the CMSTS to assess impact.

The relationship 'interpreted as' of the CMSTS used to arrive at 'actions' from 'changes of state' can also be useful in IA. This is explained as follows. Sometimes, information on 'State 1-target' and a control system is not available. In addition, there can be insufficient number of objective parameters required to completely specify a state of a BoP-system. Under such circumstances, the perceptions of the people affected by an intervention are useful in IA. These perceptions are their interpretations of the changes of state due to an intervention. Regarding these perceptions in IA, Eaton at al [14] state, "...these perceptions are what will determine their behaviour in the future and possibly play as important a role than "actual" performance (*of an intervention*)". As mentioned in Section 4, the positive impact of the intervention in the La Testaruda community is reflected in the perception of one of the farmers of this community as, "there is a renovated hope as we are starting to see the transformation". Different methods such as surveys, interviews, participatory learning and action, etc. can be used to identify BoP-clients' perceptions or interpretations of the changes of state due to an intervention.

6. CONCLUSIONS

Designing products and services for BoP markets requires addressing different issues such as access to financial services, gaining market information, underdeveloped regulatory frameworks, etc. In order to address these issues, businesses bring about systemic changes in these markets through the design and development process. Our study systematically explained how businesses bring about these systemic changes in BoP markets.

This study simplified the Sym-SAPPhIRE model of causality, originally developed for technical systems, to explain causality in socio-technical systems. In this simplified model, called CMSTS, the 'system' consists of relevant elements in it such people, technical systems (e.g. products), and operating procedures. We have implicitly included the construct 'organ' of the Sym-SAPPhIRE model in the construct 'system' of the CMSTS, and the construct 'stimuli' in the construct 'inputs' of the CMSTS. We also added time dimension in the CMSTS.

In addition, this study contextualized the CMSTS for the BoP. In the case of the BoP, the inputs to the BoP system can be seen as an intervention designed and developed by businesses for these markets. This intervention can be comprised of people, technical systems, and processes. The intervention and the existing BoP system activate some physical effects, and thereby bring about some changes in state, which are interpreted as actions (e.g. increased profits, satisfying un-met or under-served needs of BoP customers).

In the case of BoP markets, the process of designing and developing an intervention can affect or modify the existing system, and this process can be seen as 'inputs' called DDPI. This DDPI changes the existing BoP system before implementing the developed intervention.

This study tested the CMSTS for the BoP by using a case study, namely, Amanco's integrated irrigation system in Mexico. However, there are limitations to this study. We tested our CMSTS for the BoP using a single case study. A larger number of cases can help refine this model to increase our understanding of how businesses bring about systemic changes in

the BoP by designing and developing products and services for these markets.

Our study has important practical implications. This study systematically explains the importance of:

- gaining an in-depth understanding of the existing BoP system to bring about desired changes of state and actions;
- including different stakeholders from the BoP in the design and development process;
- appropriately modifying existing BoP system before implementing the final intervention.

Furthermore, the CMSTS can be used to support the practitioners involved in designing, developing and assessing interventions for BoP markets. The CMSTS can be useful in structuring information on the past and existing BoP-cases, and this information can be used in the design and development of a new intervention or in the redesign of an existing intervention. In addition, the CMSTS's construct 'changes of state' and the relationship 'interpreted as' used to arrive at 'actions' from 'changes of state' can help in assessing the impact of an intervention.

This study explored the causality in BoP markets at a system-wide level. While studies at micro level focusing on some particular issues in the BoP are important, they may provide insufficient attention to the interactions between different parts of a broader system. We believe greater effort should be made to carry out research in the field of BoP markets to understand different aspects at a macro or system-wide level.

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REFERENCES

[1] Aurisicchio, M., Bracewell, R.H., and Wallace, K.M., (2007), "Characterising Design Questions That Involve Reasoning", Proceedings of the International Conference on Engineering Design, ICED'07, Paris, France.

[2] Azapagic, A., (2003), "Systems Approach to Corporate Sustainability: A General Management Framework", Process Safety and Environmental Protection, Vol. 81 (5), pp. 303-316.

[3] Ball, L.J., Ormerod, T.C., and Morley, N.J., (2004), "Spontaneous Analogising in Engineering Design: A Comparative Analysis of Experts and Novices", Design Studies, Vol. 25 (5), pp. 495-508.

[4] Becker, H.A., (2001), "Social impact assessment", European Journal of Operational Research, Vol. 128 (2), pp. 311-321.

[5] Bell, J., (2004), "Representation of Function", University of Wales, Aberystwyth, UK, 2004.

[6] Blessing, L.T.M., and Chakrabarti, A., (2009), "DRM, a Design Research Methodology", Springer-Verlag London Limited, London

[7] Boston, J., (2000), "The challenge of evaluating systemic change: the case of public management reform", International Public Management Journal, Vol. 3 (1), pp. 23-46.

[8] Buchholz, T.S., Volk, T.A., and Luzadis, V.A., (2007), "A participatory systems approach to modeling social, economic, and ecological components of bioenergy", Energy Policy, Vol. 35 (12), pp. 6084-6094.

[9] Chakrabarti, A., (1993), "Towards A Theory for Functional Reasoning in Design", Proceedings of the International Conference on Engineering Design, ICED'93, The Hague.

[10] Chakrabarti, A., and Johnson, A., (1999), "Detecting Side Effects in Solution Principles", Proceedings of the International Conference on Engineering Design, ICED'99, Munich.

[11] Chakrabarti, A., Sarkar, P., Leelavathamma, B., and Nataraju, B.S., (2005), "A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas", Artificial Intelligence in Engineering Design and Manufacturing, AI EDAM, Vol. 19 (2), pp. 113-132.

[12] Chandrasekaran, B., and Josephson, J.R., (1997), "Representing Function as Effect", Proceedings of the Proceedings of Functional Modeling Workshop, Electricite de France, Paris, France.

[13] Duczynski, G., (2004), "Systems approaches to economic development for indigenous people: a case study of the Noongar Aboriginals of Australia", Futures, Vol. 36 (8), pp. 869-888.

[14] Eaton, D., Wiersinga, R.C., and Danse, M., (2009), "Impact of high quality vegetable seeds for smallholder farmers in South East Asia", Proceedings of the International Conference on Impact of Base of the Pyramid Ventures, Kandachar, P., Jongh, I.d., Halme, M. (Eds.), Delft, Netherlands.

[15] Gradl, C., Sobhani, S., Bootsman, A., and Gasnier, A., (2008), "Understanding the markets of the poor: A market system approach to inclusive business models", in: Sustainability Challenges and Solutions at the Base of the Pyramid, Kandachar, P., Halme, M. (Eds.), Greenleaf Publishing Limited, Sheffield, UK.

[16] Harrison, M.I., Koppel, R., and Bar-Lev, S., (2007), "Unintended Consequences of Information Technologies in Health Care—An Interactive Sociotechnical Analysis", J Am Med Inform Assoc., Vol. 14 (5), pp. 542–549.

[17] Hoffman, R.R., Coffey, J.W., Haye, P.J., Cańas, A.J., Ford, K.M., and Carnot, M.J., (2002), "One Small Step for a Diagram, One Giant Leap for Meaning", Proceedings of the Diagrammatic Representation and Inference : Second International Conference, Diagrams 2002, Callaway Gardens, GA, USA.

[18] Holyoak, K.J., and Thagard, P., (1995), "Mental Leaps: Analogy in Creative Thought", MIT Press, Cambridge, MA, USA.

[19] Hubka, V., (1982), "Principles of Engineering Design", Butterworth Scientific.

[20] Hulme, D., (2000), "Impact Assessment Methodologies for Microfinance: Theory, Experience and Better Practice", World Development, Vol. 28 (1), pp. 79-98.

[21] Jagtap, S., and Kandachar, P., (2009), "Towards Linking Disruptive Innovations and BoP Markets", Proceedings of the International Conference on Engineering Design, ICED-09, Stanford, California.

[22] Jagtap, S.N., (2008), "Capture and Structure of In-Service Information for Engineering Designers", Thesis (PhD), University of Cambridge, U.K.

[23] Kandachar, P., and Halme, M., (2008), "Farewell to pyramids: how can business and technology help to eradicate poverty?", in: Sustainability Challenges and Solutions at the Base of the Pyramid, Kandachar, P., Halme, M. (Eds.), Greenleaf Publishing Limited, Sheffield, UK.

[24] Kokotovich, V., (2008), "Problem Analysis and Thinking Tools: An Empirical Study of Non-Hierarchical Mind Mapping", Design Studies, Vol. 29 (1), pp. 49-69.

[25] Leveson, N., Dulac, N., Marais, K., and Carroll, J., (2009), "Moving Beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems", Organization Studies, Vol. 30 (2-3), pp. 227-249.

[26] London, T., Anupindi, R., and Sheth, S., (2009) "Creating mutual value: Lessons learned from ventures serving base of the pyramid producers", Journal of Business Research, Vol. In Press.

[27] Nielsen, C., and Samia, P.M., (2008), "Understanding key factors in social enterprise development of the BOP: a systems approach applied to case studies in the Philippines", Journal of Consumer Marketing, Vol. 25 (7), pp. 446 - 454.

[28] Pahl, G., and Beitz, W., (1996), "Engineering Design", 2 ed., Springer-Verlag, London.

[29] Prahalad, C.K., and Hart, S.L., (2002), "The Fortune at the Bottom of the Pyramid", strategy+business, 2002.

[30] Prahalad, C.K., (2004), "The Fortune at the Bottom of the Pyramid: Eradicating Poverty through Profits", Wharton School Publishing, Upper Saddle River: Nj.

[31] Salustri, F.A., Weerasinghe, J.S., Bracewell, R.H., and Eng, N.L., (2007), "Visualising early engineering design information with diagrams", Journal of Design Research, Vol. 6 (1-2), pp. 190–217.

[32] Sembugamoorthy, and Chandrasekaran, B., (1986), "Functional Representation of Devices and Compilation of Diagnostic Problem-Solving Systems", in: Experience, Memory and Reasoning, Lawrence Erlbaum Associates, Hillsdale, NJ.

[33] Subrahmanyan, S., and Gomez-Arias, J.T., (2008), "Integrated approach to understanding consumer behavior at bottom of pyramid", Journal of Consumer Marketing, Vol. 25 (7), pp. 402 - 412.

[34] Temel, T., (2005), "A systems approach to malaria control: an institutional perspective", Health Policy, Vol. 71 (2), pp. 161-180.

[35] UNDP, (2008), "Creating Value for All: Strategies for Doing Business with the Poor", United Nations Development Programme, 2008.

[36] Whitney, P., and Kelkar, A., (2004), "Designing for the Base of the Pyramid", Design Management Review, Vol. 15 (4).

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