Influencing Factors of Successful Transitions towards Product-Service Systems: a Simulation Approach

Nicola P. Bianchi, Steve Evans, Roberto Revetria, and Flavio Tonelli

***Abstract*—** Product-Service Systems (PSS) are new business strategies moving and extending the product value towards its functional usage and related required services. From a theoretical point of view the PSS concept is known since a decade and many Authors reported reasonable possible success factors: higher profits over the entire life-cycle, diminished environmental burden, and localization of required services. Nevertheless the PSS promises remain quantitatively unproven relaying on a simple theory that involves a few constructs with some empirical grounding, but that is limited by weak conceptualization, few propositions, and/or rough underlying theoretical logic. A plausible interpretation to analyze the possible evolution of a PSS strategy could be considering it as a new business proposition competing on a traditional Product-Oriented (PO) market, assumed at its own equilibrium state at a given time. The analysis of the dynamics associated to a possible transition from a traditional PO to a PSS strategy allows investigating the main parameters and variables influencing an eventual successful adoption. This research is worthwhile because organizations undergoing fundamental PSS strategy are concerned about change and inertia key processes which, despite equilibrium theory and because of negative feedback loops, could undermine, economically, the return of their PSS proposition. In this paper Authors propose a qualitative System Dynamics (SD) approach by considering the PSS as a perturbation of an existing PO market featured by a set of known parameters. The proposed model incorporates several PSS factors able to influence the success of a PSS proposition under a set of given and justified assumptions, attempting to place this business strategy in a dynamic framework.

***Keywords*—** Business strategy, market transition, product service systems, system dynamics.

I. Introduction to Product-Service Systems

NEW business models propositions based on a greater focus on after sale services and on integration with products required to provide services according to a wide systemic view have been proposed in the last decade. These business models have been translated into different strategies. One of these strategies is Product-Service Systems (PSS).

PSS can be thought of as a market proposition that extends the traditional functionality of a product by incorporating additional services [1], [2]. For some Authors the concept of a PSS also embraces sustainability in terms of social, economical, and environmental aspects. A complete state-of-the-art on PSS can be found in Baines *et al*. [3].

PSS concept and terminology have been conceived from Academic Industrial Sustainability Community, but industrial organizations are not still correctly informed about them.

PSS is a potentially valuable concept for manufacturers based in developed economies with products at their maturity stage or facing an intense global economic crisis such in the last year. Other external drivers of PSS appraisal are: legislation, competition, consumerism, and quality of life. Hence, the adoption of a PSS based competitive strategy, which uses deeply product, process and customer knowledge to lead a more sustainable consumption/production paradigm, over all the life cycle stages, seems to be very interesting for different stakeholders (manufacturers, governments, end-users, policy makers, …).

The concept of PSS has been discussed in the literature for over a decade [4], [5], [6], [7], [8], however the use of such strategy, in the industrial context, appears limited. Organizations undergoing fundamental PSS change are, indeed, concerned about change and inertia key processes undermining economical return of their value proposition. Hence, even if this strategy promises extremely interesting benefits, its practical adoption has been prevented by many different factors. Many open issues can be identified ranging from a development of the service engineering discipline [9], identification of drivers that offer the best leverage for change [5], designing methodologies [10], [11], relationships between providers and potential adopters [12], [13], and communication support material for the transition from the conceptual level to the practical level [14].

Summarizing PSS is, today, mainly a prescriptive improvement strategy, focusing on adding value instead of cost reduction. However, qualitative and quantitative decision making approaches, to differentiate the traditional PO offering

Manuscript received January 31, 2009.

N. P. Bianchi is with the Institute of Intelligent Systems for Automation (ISSIA), National Research Council of Italy (CNR), Genova, ITALY (e-mail: bianchi@ge.cnr.it).

S. Evans is with the School of Applied Science of Cranfield University, Cranfield, England, U.K. (e-mail: steve.evans@cranfield.ac.uk).

R. Revetria is with the Dept. of Production Engineering, Thermo-Energetic and Mathematical Models (DIPTEM), University of Genoa, Genova, ITALY (e-mail: roberto.revetria@unige.it).

F. Tonelli is with the Dept. of Production Engineering, Thermo-Energetic and Mathematical Models (DIPTEM), University of Genoa, Via All'Opera Pia 15, Genova, ITALY (phone: +39-010-353-2888; fax: +39-010-317-750; e-mail: flavio.tonelli@diptem.unige.it).

toward the PSS transaction, have not really addressed [15].

II. Critical Factors and Risks

Traditional manufacturing business models cannot be changed instantaneously through a revolution in innovating both product and services; they need to act small changes and obtain few, but increasing, benefits from the business point of view in order to become PSS providers.

A high degree of coherence between PSS concepts (production and services integration), and internal capabilities (production management and service delivery) of the organizations, is the *"conditio sine qua non"* a PSS strategy can be successfully implemented.

PSS implementation is, indeed, a complex cross-functional problem for which traditional manufacturers, especially from the organizational point of view, are not ready, typically facing PSS barriers during the first implementation steps [16]. Further barriers are: lack of market demand (i.e. because PSS do not exist or else), high localized labour price (i.e. trade-off between labour and logistics costs), fear of consumer reaction, fear of accepting risks that are not known, and business-as-usual attitude.

Risks or issues associated with social, economic, and environmental aspects permeate all the designing, testing, manufacturing, operating, supporting, and disposing phases of the analyzed products and services [17]. Others source of risks should include not foreseen functional and operational requirements, immature or emerging products, new quality requirements, and political or organizational changes [18].

Internal and external capabilities play a fundamental role: internally, in terms of designing skills required to develop and innovate products and services, and externally in developing and maintaining a supply network to provide the PSS services as well as transferring the meaning of PSS value to market end-users.

A PSS proposition could, unfortunately and rapidly, convert in a failure when promises exceed changing ability and adaptability or when market dynamics have not been correctly investigated.

Because of the holistic approach required to analyse, implement and sustain a PSS proposition, Authors present a simple basic qualitative and quantitative model (a first step toward the modelling phase).

III. Research Questions

A Product-Service System (PSS) could be considered a new business proposition competing on a traditional Product-Oriented (PO) market, usually assumed to be in an equilibrium state at a given time; looking at a well known analogy it can be also viewed as "prey-predator" relationship. A PSS proposition can be or not successful, depending on some factors, as many Authors claim.

Starting from these considerations, two research questions (RQ) can be formulated:

- **RQ1:** What is the main dynamic acting during the transition from traditional PO to PSS market?
- **RQ2:** What are the main parameters and variables influencing a successful transition?

Even if PSS adoption is strongly context-to-use, these quite general questions can be considered interesting for all the main PSS stakeholders (suppliers, manufacturers, PSS providers, end-users, and government), and particularly for traditional organizations going to become PSS providers at least in terms of relationships with market end-users.

In fact, the significant investment in a PSS would require a qualitative approach (better a quantitative one), in order to identify main influencing factors and assessing/evaluating related risks over some time horizon.

To investigate these latter aspects requires a preliminary understanding of the dynamics related to the transition process described by some theory.

Unfortunately, PSS transition theory is still an undeveloped one that involves a few constructs with some empirical or analytic grounding but that is limited by weak conceptualization, few propositions, and/or rough underlying theoretical logic. Moreover, existing PSS designing methods and tools have properly addressed designing and life-cycle considerations but the economical and social acceptance of PSS has been left uncharacterized in terms of important relationships and trade-offs.

In order to provide a first answer to RQ1 Authors developed, through a System Dynamics (SD) simulation approach [19], a basic transition model, incorporating some of the main factors influencing a successfully adoption of a PSS strategy, to be explored over different possible scenarios, in order to better understand the transition dynamics.

In the last part of this paper an attempt to define several influencing factors, in order to improve the basic model and the accuracy of it, have been reported.

IV. PSS Value Propositions

In the following, Authors will try to provide the reader a synthetic summary about PSS value propositions to be investigated and verified by a more extensive research. In this paper Authors verify explicitly proposition number 1 and implicitly proposition number 2.

- P1–To favour a larger initial introduction of PSS, a government intervention (economic incentive) at national level would be required.
- P2–PSS has to be economical convenient (for providers and end-users) at same time in order to become auto-sustainable over the long term; in other words it has to reach a critical mass.
- P3–Changes in legislation are different from country to country (think about Extended Producer Responsibility), making global thinking of solutions a big challenge, and governments have to protect organizations doing long-term investments instead of sub-optimal short-term strategies.
- P4–Good drivers for PSS adoption are: marketing

conditions, legislation, and environmental worries, even though these drivers that cannot be found in all the countries and for all the industries.

- P5–PSS is a win-win concept to improve economical and environmental performance of firms (toward the sustainability concept), but a corporate commitment increasing the receptivity of this strategy is required, and environmental pressure alone is not sufficient to ensure success [4].
- P6–Simply increasing services does not imply material use reduction, at least, until organizations will not work on big-scale industrial logic and consider a local trade-off between material usage, energy, and labour required for logistics movements [20].
- P7–Receptive firms are usually linked to local development networks (in order to consider the local and global or *glocal* dimension of a PSS), and have a product portfolio featured by:
    - High item value,
    - Important service component, or
    - Updateable products (i.e. technology and fashion).

V. Why System Dynamics for PSS Transition Analysis

From a systemic point of view, PSS requires a functional thinking process based on strategic partnerships sharing a common vision about how deliver a conceived solution idea. The development of a theory able both to promote the PSS paradigm and to identify the critical factors of a successful market transition is not a trivial task. The simulation approach to analyse the dynamic of a PSS strategy requires capabilities to manage interrelated factors featured by non-linear complex dynamics and negative/positive reinforcement loops. Considering these factors, Authors choose the SD methodology, according to the Sterman seminal book [19], that is an evolution of the *Industrial Dynamics* approach, born fifty years ago [21], able to deal with business management problems that industrial organizations were called to face.

Further evolutions included aspects inhering innovation [22], organizational change [23], and organizational learning [24], [25].

In the SD world there are significant theoretical studies as well as case studies concerning transitions in the automotive industry [26], [27], [28], [29], a possible candidate for preliminary PSS proposition.

Since its inception, SD approach has been used in theory building [30] and its validation [31], distinguishing between validation of real world models and validation of theory models [32], [33]. In the SD toolbox, clear guidelines are reported both for model building [34], [35], [36], and for analysis and validation [37], [38]. Moreover, difficulties related to the use of soft variables have been faced to and discussed [39], and a qualitative approach has been suggested [40]. Furthermore, interesting solutions have been found out concerning attractiveness metrics [41], [42]. Effective procedures have been developed in order to facilitate stakeholders' involvement in the model building process [43], [44].

Furthermore, the SD approach can be easily combined with other methodologies, such as multi-criteria decision analysis (MCDA) [45], [46], [47], [48], in order to assess performance of a PSS proposition and to provide a conceptualization on which a decision support system (DSS) could be built on.

Finally, the good ranking position achieved by SD with respect to the benchmark performed by Boulanger and Bréchet [49], among six modelling paradigms, corroborate Authors' decision to adopt it. In this benchmark, trial criteria were concerning interdisciplinary potential, long-term and intergenerational issues, uncertainty management, local-global interaction, and stakeholders' participation; all these aspects are prevalent in PSS context study.

VI. Modelling Phase

A. Model Assumptions

As discussed in the previous sections, Authors' approach is going to investigate a hypothetical organization deciding to invest or not in a PSS strategy depending on its successful likelihood.

From literature it is possible to derive the main stakeholders to be involved in a PSS strategy:

- Government,
- PO manufacturers,
- PSS providers, and
- End-users.

Since a PSS strategy is strongly context-of-use (different solutions for a wide range of markets), with different stakeholders point of views, articulated on economical, social, environmental aspects, several assumptions to clarify the developed basic model are required.

In the proposed basic model the considered stakeholders are only PO manufacturers and PSS providers belonging to the same market (i.e. a PO market manufacturers becomes a PSS provider in the same market).

Manufacturers and providers have been considered members of the same market; so members represent large PO organizations, interested in becoming PSS providers.

The model implicitly considers mainly durable functional goods for which a transition from PO manufacturers (emotional ownership concept) to PSS providers (functional usage concept), it is possible or already started (i.e. car sharing, car pooling, agriculture machines, aircraft fleets, aircraft engines, copier machines, laundrette services, food services [50], etc). Anyway, the basic model can be used as a starting point for analyzing other product-service proposition since they are not incorporated in the model, but it is needed to verify the correctness of a transition model instead of a splitting of the market or a new market niche creation.

B. *Time Horizon Identification*

PSS most conventional approaches focus on studying this class of problems over a short period of time because of an event-oriented outlook. In the PO/PSS transition study it is needed to realise that the proposition might have originated a long time back, and also that actions taken now may cause effects that are far displaced in time and space (possible unintended consequences of a PSS strategy).

More important, studying transition model, the time can be considered as the target variable to be discovered. From the experimental campaign, in fact, it is clear that, by changing PO market initial parameters and PSS influencing factors values, different equilibrium states can be achieved in different time horizons. So we can conclude that the time required to reach the new equilibrium state is the main variable to be investigated, in accordance with some strategic policy and related expected results.

C. *Main Variables*

The PO/PSS markets have been featured by the following parameters (in squared brackets the unit of measure):

- Market initial number [members],
- PO initial members [%],
- PSS initial members [%],
- Aptitude to PSS transition for PO members [members per year],
- Disappointed with PSS for PSS members [members per year], and
- Barriers to PSS [members per year].

These initial parameters have been set in order to have an equilibrium state over time.

To modify this state and achieve a new equilibrium state, a leading variable has been inserted. This variable is an economical incentive for PO members in becoming PSS members. This incentive have been divided in three sub-variables (in squared brackets the unit of measure):

- Intensity [members per year],
- Duration [years], and
- First time of activation [time].

Criteria for evaluating the PSS success or failure can be expressed in terms of lagging indicators. In the proposed model, Authors introduced the following one (in squared brackets the unit of measure):

- Percentage of members moved to PSS compared to a critical mass threshold for which it has been assumed the PSS proposition can be considered auto-sustainable [members].

According to SD methodology [19], PO Manufacturers and PSS Providers interactions have been implemented as simulation model through two diagrammatic tools: Causal Loop Diagram (CLD) and Stock and Flow Diagram (SFD).

D. *Casual Loop Diagram*

A CLD, or signed diagraph, sketches the relationships among the elements of a system. The arrows indicate the causality direction (who/what influences whom/what). A plus sign beside the arrowhead means that a variation (increasing or decreasing) in the influencing element will cause a variation of the same type in the influenced element. Instead, a sign minus denotes an inverse variation type between the two element connected by the arrow.

In the SD approach, CLDs belong to the preliminary modelling phase: the so-called conceptualization phase.

The developed basic model (the "concept model," according to Richardson [51]) includes the two main stakeholders (PO and PSS market members), featured by several parameters such as initial number, initial acceptance, and others related to the PSS barriers. These parameters have to be considered just as a starting point being possible to extend and complicate the model at successive steps. The dashed lines in the CLD, show relationships of the concept model, not yet implemented in the simulation study described in this paper.

The CLD of PSS concept model has been depicted in Fig. 1 and should be self-explicative.

E. *Stock and Flow Diagram*

After the conceptualization step the new SD simulation packages requires drawing the SFD.

The SD approach simplifies the representation of the dynamical system equations through a hydraulic analogy: the state variables become reservoirs (also named accumulators, stocks, or levels), and the derivatives (or velocities) are flows (or rates). There are two other building blocks in SFD: auxiliary variables (also called converters) and constant parameters (which include the initial values of stocks). Converters and parameters take part in the flows calculation.

Constant parameters and initial values of stocks are the manoeuvrable levers for policies testing within simulation runs.

Stocks are represented as rectangles, flows as stylized valves, converters as circles, and parameters as rhombi (or still circles in some SD software tool). Note that the visual representation through a SFD (as well as a CLD) makes easier the model intelligibilty.

The main variables of the concept model are two stocks interconneted: *PO_Manufacturers* and *PSS_Providers*. Two flows modify their amount: *TransitionToPSS_Rate* and *FailingRate*, i.e. a flow of manufacturers converted to PSS and a flow of PSS providers renouncing the new activity. The *TransitionToPSS_Rate* flow is calculated adding the parameter *AptitudeToPSS* to the *TransitionToPSS_Flow*. The latter is specified rather unexpectedly as stock, because in this case we need a type of variable able to keep memory of the perturbation of incentives to the market share. *TransitionToPSS_Flow* is incremented by the *IncentiveToPSS* flow, whose intensity and time length is determined by the parameters *intensity* and *duration* of a STEP time function, and decremented by the *ReductionOfTransitionFlow*, calculated only when *TransitionToPSS_Flow* has a positive value multiplying the *thresholdRule* by the parameter *BarriersToPSS*. The *thresholdRule* is a converter and is computed according to a simple algorithm: if the percentage of *PSS_Providers* is greater than the value we set through the parameter *PSS_criticalMass* (i.e., the PSS proposition has reached the auto-sustainability), then the *thresholdRule* takes the value of the ratio between the percentage of *PO_Manufacturers* and the total number of entrepreneurs (*PSS_Providers* plus *PO_Manufacturers*, i.e. 100%), otherwise the value of the *thresholdRule* is determined by the ratio between the difference of the *PSS_criticalMass* minus *PSS_Providers*, and the *PSS_criticalMass* itself.

Finally, the *FailingRate* flow of PSS providers quitting the service activity is calculeted multiplying the *thresholdRule* by the parameter *DisappointedWithPSS*.

The corresponding SFD has been depicted in Fig. 2.

VII. Experimental Outcomes

Even if the basic model is very simple, the transition dynamics resulting from different types of incentives are very interesting. In this preliminary study phase, Authors investigated several transition behaviours belonging to different parameters sets over a time horizon expressed in years. After several trials the time horizon has been set to 12 years because of most of the transitions reach a steady state (anyway, specific set conditions lead to a steady state only in longer time). A model-defined special unit of measure is given by [members per year], hereinafter called [mpy]. The initial market population has been set to **100** members in order to use value parameters expressed directly ad percentage of the population. The PO members are **95** and the PSS are **5**. The market population cannot growth over time; only transition between PO and PSS (and vice versa) are allowed.

The parameters included in the model are:

- **p1:** AptitudeToPSS [mpy]
- **p2:** BarriersToPSS [mpy]
- **p3:** DisappointedWithPSS [mpy]
- **p4:** IntensityOfIncentive [mpy]
- **p5:** LenghtOfIncentive [years]
- **p6:** StartingTimeOfIncentive [years]
- **p7:** PSS_criticalMass (threshold in which PSS proposition becomes auto-sustainable) [%]

Note: The parameter **p6** have been set to **0** (first year) for all the experiments.

Two different sets of experiments have been done:

- **Set1:** investigation of the influence of the incentive (**p4** and **p5**) having fixed value for **p1**, **p2**, **p3**, and **p7** (respectively **1**, **3**, **5, 40%**).
- **Set2:** searching for extreme equilibrium states setting the incentive intensity **p4** to the value of **5** and the length **p5** to the value of **2** (this corresponds to a hypothetical situation in which the government gives economical incentive equal to the **5%** of the market population for two years), and varying **p1**, **p2**, **p3**, and **p7**.

Set1 reveals that it is more important the intensity of the incentive (**p4**) instead of its length (**p5**). In fact, with **p4**<5 and 3<**p5**<6 the PSS does not reach the critical threshold and the market equilibrium comes back to the original situation stating the PSS failure (see Fig. 3). For values of **p4**>5 and **p5**=4 a new equilibrium state is achieved splitting the market in 70% of PO members and 30% of PSS members (see Fig. 4). For values of **p4**=6 and **p5**=3 the splitting is 60% of PO members and 40% of PSS members. For **p4**>=6 and **p5**>=4 the transition completely occurs and the market population becomes composed only by PSS members (even if this situation could not be real since no PO manufacturers remains in the market). For this last situation see Fig. 5. So, with the fixed values of **p1**, **p2**, **p3**, and **p7**, the transition happens but with large and long economical incentives provided by the government.

In **Set2**, Authors tried to understand if a different set of initial conditions **p1**, **p2**, **p3** (that could be achieved for instance by reducing PSS Barriers thanks to the increment in social and environmental perceived advantages), could lead to partial transition and to a splitting of the market with a minor economical effort (for intensity and time lenght), provided by governments.

The experimentation starts from a **Set1** failure condition (**p4**=5 and **p5**=2, see Fig. 6) and keeps constant these parameters along all the trials of **Set2**. Increasing **p1** to value 1.5 and halving **p2** to 1.5, a equilibrium (30% of PSS and 70% of PO) can be reached (see Fig. 7). Reducing **p3** to value 4, a better equilibrium is reached (45% PSS, exceeding the preset critical mass; see Fig. 8). Reducing **p3** further on to 3.5, a 'perfect' equilibrium (50% PSS) is reached (Fig.9). Setting **p3** to 3, there will be more PSS then PO after nine years (Fig. 10). Reducing further on **p3**, we obviously shall obtain better transition values. A rough interpretation of these concept model results could allow us to suppose that the transition should start "only" increasing by 50% *Aptitude*, halving *Barriers*, and decreasing by 40% *Disappointment*, combined with economical incentives for two years.

Of course, parameters combinations are numerous and, by varying them, it is possible reproducing other analogue positive results. Fig. 11 shows an interesting interpretative condition: doubling *Aptitude*, halving *Barriers*, and halving *Disappointment*, still combined with "small" economical incentives for two years, a stable transition could be reached (critical mass reached after seven years and PSS at 70% at the end of the 12 years simulation run. This last interpretation confirms the general idea that new business strategies can be strongly facilitated by stakeholders' perception and attitude. In other words, strong economical incentives not related to declared and shared strategies, most likely bring to a sure failure. Thus, the proposed qualitative and quantitative model can be used to investigate the current stakeholders' maturity level before proposing a new highly expensive and risky business strategy, searching for the appropriate proposition time and incentive framework.

VIII. Further Developments

A. *Toward a More Complete Casual Loop Diagram*

PO and PSS propositions have been modelled through the attractiveness concept (for the different stakeholders and with respect to different measures).

Word of Mouth loops have been considered from internal organization side and external market side, and a learning loop, related to the manufacturers (derived from information about what real customers do and moderated by the efficiency in collecting data on product and services provided), included.

Other factors like organization actual risk identification and future risk perception (i.e. competition, money losses, loss of control), and attitude toward technological innovation (involved by a PSS proposition), have been, finally, considered.

The diagrammatic representation gives a clear frame of processes involved in a transition from PO to PSS and the following consolidation phases (Fig. 12).

Note: the proposed CLD, which can be named the 'PSS take-off "theory",' does not include the delay specification in the cause-effect relationships and the explicit part of the limitation barriers of PSS diffusion and expansion.

In the following, detailed descriptions of the main variables and their cause-influence diagrams have been reported.

End user attractiveness, with respect to the PSS consumerism style, depends, as Fig. 13 depicts, on a set of factors: economical advantages deriving from paying only what used (these advantages are going to increase over time because of PSS providers competitiveness), benefits allowed by the legislator for substitution of product with a service, number of PSS providers operating on the market, marketing campaigns to favour this new lifestyle, perceived social and environmental advantages, and satisfaction level about PSS proposition diffused through the word-of-mouth.

The key-element in the PSS proposition and supporting processes for public administrators and policy makers is, in Authors' opinion, a strong conceptualization and theory [52], supported by an objective DSS. Undertaken actions of persuaded public decision-makers will be a reinforcement loop through which the social marketing campaigns outlining benefits for end-users and society undergoing a PSS transition (see Fig. 14).

The percentage of PSS providers, operating on the market, depends, instead, on the industrial manufacturers converted to the PSS strategy and on new service organizations born to catch the PSS opportunity. For both of them, the reason for the numerical growth are proportional to the benefits allowed by public administrators, positive experiences of PSS, reported successful case-studies, and by quantitative DSS support to manage risk identification, assessment, and mitigation of a PSS proposition (see Fig. 15).

A preliminary Casual Loop Diagram describing the logic of PSS adoption is depicted in Fig. 12, and can be considered as the basis for the following modelling phases.

Concerning the equation identification a panel of experts on PSS will be interview in order to describe qualitatively the basic dynamic behaviours of the different subsystems: providers, manufacturers, end-users, and public decision makers.

B. *Evaluating PSS Successful Transition*

Since performance expresses the degree to which the system reflects (meets or exceeds) the expected operational characteristics (a criteria to verify compliance or success), a performance specification [53], defining the functional requirements for the PSS proposition, the environment in which it must operate, and the interface and serviceability requirements, should be developed. Three main performance dimensions have been identified during the literature survey: economical, social, and environmental.

Taking into account the three aforementioned dimensions at the same priority level could be problematic because of the viewpoint assumed for this research: possible PSS providers and end-users. These stakeholders are mainly interested in economical considerations. So that from the PSS provider point of view the PSS is viewed as the total implementation cost and it refers to investments for innovating, proposing, sustaining the products and the services, and recovering, recycling, disposing the products at the end of the life cycle. While from the end-users point of view the PSS is seen in terms of total cost of ownership against functional requirements fulfilment.

Criteria for evaluating the PSS success or failure can be expressed in terms of lagging indicators. In the proposed model, Authors introduced the following ones:

- Compliance to stakeholders in 'meeting of needs,'
- Efficiency of PSS solution, and
- Effectiveness of PSS solution.

On the other side, to achieve the targeted lagging indicators different leading variables have to be considered:

- Internal process perspective such as process efficiency/effectiveness,
- Internal learning capabilities and growth perspective such as the growth in knowledge and market opportunities instead of in size.

Finally, in order to evaluate the success of a PSS proposition, success and attractiveness matrixes have to be defined for the considered stakeholders (manufacturers, providers, end-users, …). Possible measures to be included in the attractiveness matrix are: cost, quality, time, flexibility, efficiency, risk, and environment.

IX. Conclusion

The developed research tries to move the PSS discussion from the prescriptive strategic domain to the qualitative/quantitative modelling domain in order to provide additional validity proofs to organizations interested in a PSS change. The research started with a complete literature review outlining the gap in qualitative and quantitative modelling approaches. Then an analysis about PSS critical factors and adoption barriers has been performed in order to focus on the main PSS issues. These issues have been summarized in a research question, and then, brought to a smaller operational framework setting several assumptions since a complete holistic approach to PSS, because of its context-of-use dependence, it is, probably, impossible to face.

In the second part of the paper, Authors explained the reasons for which a System Dynamics approach has been chosen after a review of the most common and prominent simulation methodologies for theory development.

In the third part of the paper, starting from the research question, some concepts, propositions, and variables have been identified. Their identification and explanation is far to be complete but it should be considered as a starting point toward a more complex definition of the problem. The acquired knowledge about PSS, allowed Authors to build a simple quantitative/quantitative model. The diagrammatic representations (causal loop and stock and flow) of this 'concept model' have been described and simulation results discussed, indicating some convenient parameters combination facilitating the transition.

In conclusion, a CLD scheme of a possible PSS take-off theory has been shown and discussed also by the means of its related causes trees.

Future steps will be directed toward a SD complete modelling, identifying and parameterizing basic blocks and equations in order to validate the proposed PSS theory and suggest the correct strategies for its successful implementation.

REFERENCES

[1] O. Mont, "Institutionalisation of sustainable consumption patterns based on shared use," *Ecological Economics*, vol.50, no.1-2, 2004, pp. 135–153.

[2] O. Mont, "Product-service systems: panacea or myth?," PhD thesis, IIIEE, Lund University, Sweden, 2004.

[3] T. S. Baines *et al*., "State-of-the-art in product-service systems," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol.221, no.10, 2007, pp. 1543-1552.

[4] M .J. Goedkoop, J. G. van Halen, H. te Riele, and P. J. M. Rommens, *Product service systems, ecological and economic basics*, The Hague, NL: Vrom EZ, 1999.

[5] O Mont and A. Tukker, "Product-Service Systems: reviewing achievements and refining the research agenda," *Journal of Cleaner Production*, vol.14, no.17, 2006, pp. 1451-1454.

[6] R. Meijkamp, "Changing customer needs by eco-efficient services," in *Proceedings of the 2nd International Conference 'Towards Sustainable Product Design,'* London, 1997.

[7] R. Meijkamp, "Changing consumer behaviour through eco-efficient services – an empirical study on car sharing in the Netherlands," Thesis. TU Delft, Delft, Netherlands, 2000.

[8] E. Manzini and C. Vezzoli,. *Product service systems and sustainability. Opportunities for sustainable solutions*, Paris: UNEP, 2002. Available: http://www.uneptie.org/pc/sustain/design/pss.htm

[9] T. Sakao and Y. Shimomura, "Service Engineering: a novel engineering discipline for producers to increase value combining service and product," *Journal of Cleaner Production*, vol.15, no.6, 2007, pp. 590-604.

[10] J. C. Aurich, C. Fuchs, and C. Wagenknecht, "Life cycle oriented design of technical Product-Service Systems," *Journal of Cleaner Production*, vol.14, no.17, 2006, pp. 1480-1494.

[11] N. Morelli, "Developing new product service systems (PSS): methodologies and operational tools," *Journal of Cleaner Production*, vol.14, no.17, 2006, pp. 1495-1501.

[12] A. Tukker and U. Tischner, "Product-services as a research field: past, present and future. Reflections from a decade of research," *Journal of Cleaner Production*, vol.14, no.17, 2006, pp. 1552-1556.

[13] A. Tukker and U. Tischner, Eds., *New business for old Europe: Product-Service development, competitiveness and sustainability*, Sheffield, UK: Greenleaf Publ., 2006.

[14] L. Krucken and A. Meroni, "Building stakeholders networks to develop and deliver product-service system: practical experiences on elaborating pro-active materials for communication," *Journal of Cleaner Production*, vol.14, no.17, 2006, pp. 1502-1508.

[15] U. Karlsson, "Service based manufacturing strategies implications for product development, production and service operations in global companies," in *Meeting of the Production and Operations Management Society (POMS)*, College of Service Operations, London Business School, London, 2007. Available: http://www.poms.org/conferences/cso2007/talks/14.pdf

[17] P. Giribone, R. Revetria, M. Schenone, F. Oliva, E. Nikolaeva Nikolova, and G. Chavdarova Peneva, "Tools and techniques for supporting reverse logistics optimization: methodology, case study and project proposal," *International Journal of Mathematics and Computers in Simulation*, vol.2, no.2, 2008.

[16] M. B. Cook, T. A. Bhamra, and M. Lemon, "The transfer and application of Product Service Systems: from academia to UK manufacturing firms, *Journal of Cleaner Production*," vol.14, no.17, 2006, pp. 1455-1465.

[18] B. Shahzad and S. Afzal Safvi, "Effective risk mitigation: a user prospective," *International Journal of Mathematics and Computers in Simulation*, vol.2, no.1, 2008.

[19] J. D. Sterman, *Business dynamics: Systems thinking and modeling for a complex world*, Boston : Irwin McGraw-Hill, 2000.

[20] S. Evans, P. Partidario, and J. Lambert, "Industrialization as a key element of sustainable product-service solutions," *International Journal of Production Research*, vol.45, no.18, 2007, pp. 4225-4246.

[21] J. W. Forrester, *Industrial dynamics*, Cambridge, MA: MIT Press, 1961.

[22] N. P. Repenning, "A simulation-based approach to understanding the dynamics of innovation implementation," *Organization Science*, vol.13, no.2, 2002, pp. 109–127.

[23] E. R. Larsen and A. Lomi, "Representing change: a system model of organizational inertia and capabilities as dynamic accumulation processes," *Simulation Modelling Practice and Theory*, vol.10, no.5-7, 2002, pp. 271–296.

[24] P. M. Senge, *The fifth discipline: The art and practice of the learning organization*, New York: Doubleday, 1990.

[25] J. D. W. Morecroft and J. D. Sterman, Eds., *Modeling for learning organizations*, Portland, OR: Productivity Press, 1994.

[26] A. Ford, "Simulating the controllability of feebates," *System Dynamic Review*, vol.11, no.1, 1995, pp. 3-27.

[27] J. Struben, "Identifying challenges for sustained adoption of alternative fuel vehicles and infrastructure," in *Proc. of the 24th International Conf. of the System Dynamics Society*, Nijmegen, NL, 2006. Available: http://www.systemdynamics.org/conferences/2006/proceed/papers/STRUB391.pdf

[28] M. Bosshardt, S. Ulli-Beer, F. Gassmann, and A. Wokaun, "Conceptualising the main micro processes of technological change in the Swiss car fleet," in *Proceedings of the 24th International Conference of the System Dynamics Society*, Nijmegen, NL, 2006. Available: <http://www.systemdynamics.org/conferences/2006/proceed/papers/BOSSH235.pdf>).

[29] Q. Zhang, "A study of diesel vehicle diffusion in Europe: Calibration and analysis of a consumer acceptance and adoption model," in *Proceedings of the 25th International Conference of the System Dynamics Society*, Boston, 2007. Available: http://www.systemdynamics.org/conferences/2007/proceed/papers/ZHANG384.pdf

[30] R. A. Hanneman, *Computer-assisted theory building: Modeling dynamic social systems*, Newbury Park, CA: SAGE Publ., 1988.

[31] Y. Barlas, "Formal aspects of model validity and validation in system dynamics," *System Dynamics Review*, vol.12, no.3, 1996, pp. 183-210.

[32] Y. Barlas,. "Comments on 'On the very idea of a system dynamics model of Kuhnian science'," *System Dynamic Review*, vol. 8, no.1, 1992, pp. 43-47.

[33] M. J. Radzicki, "Reflections on 'On the very idea of a system dynamics model of Kuhnian science'," *System Dynamic Review*, vol.8, no.1, 1992, pp. 49-53.

[34] J. W. Forrester, *Principles of systems*, Cambridge, MA: Wright-Allen Press, 1968.

[35] G. P. Richardson and A.L. Pugh, III, *Introduction to system dynamics modeling with DYNAMO*, Cambridge, MA: MIT Press, 1981.

[36] N. H. Roberts, D. F. Andersen, R. M. Deal, M .S. Grant, and W.A. Shaffer, *Introduction to computer simulation: The system dynamics modeling approach*, Reading, MA: Addison-Wesley, 1983.

[37] J. W. Forrester and P. M. Senge, “Tests for building confidence in system dynamics models,” in *System dynamics*, A. A. Legasto, Jr., J. W. Forrester, J. M. Lyneis, Eds., *TIMS Studies in the Management Sciences*, vol.14, New York: North-Holland, 1980, pp. 209-228.

[38] C. Tank-Nielsen, “Sensitivity analysis in system dynamics,” in *Elements of the system dynamics method*, J. Randers, Ed., Cambridge MA: MIT Press, 1980, pp. 185-201.

[39] C. F. Nuthmann, “Using human judgement in system dynamics models of social systems,” *System Dynamics Review*, vol.10, no.1, 1994, pp. 1-27.

[40] R. G. Coyle, “Qualitative and quantitative nodelling in system dynamics: Some research questions,” *System Dynamics Review*, vol.16, no.3, 2000, pp. 225-144.

[41] P. M. Senge, “Multiplicative formulations in urban dynamics,”. in *Readings in urban dynamics*, W. W. Schroeder, III, R. E. Sweeney, and L. E. Alfeld, Eds., vol. 2, Cambridge MA: Wright-Allen Press, 1975, pp. 115-132.

[42] K. R. McNaught, “Influences and connections between system dynamics and decision analysis,” In *Proceedings of the 21st International Conference of the System Dynamics Society*, New York City, 2003. Available: <http://www.systemdynamics.org/conferences/2003/proceed/PAPERS/369.pdf

[43] D. F. Andersen, G. P. Richardson, and J. A. M. Vennix, “Group model building: Adding more science to the craft,” *System Dynamics Review*, vol.13, no.2, 1997, pp. 187-201.

[44] J. A. M. Vennix, D. F. Andersen, G. P. Richardson, and J. Rohrbaugh, “Model-building for group decision support: Issues and alternatives in knowledge elicitation,” *European Journal of Operational Research* (Special Issue: Modelling for learning), vol.59, no.1, 1992, pp. 28-41.

[45] P. Antunes, R. Santos, and N. Videira, “Partecipatory decision making for sustainable development: The use of mediated modelling techniques,” *Land Use Policy*, vol. 23, no.1, 2006, pp. 44-52.

[46] J. P. Brans, C. Macharis, P. L. Kunsch, A. Chevalier, and M. Schwaninger, “Combining multicriteria decision aid and system dynamics for the control of socio-economic processes. An iterative real-time procedure,” *European Journal of Operational Research*, vol.109, no.2, 1998, pp. 428-441.

[47] E. Pruyt, “Dealing with uncertainty? Combining system dynamics with multicriteria decision analysis or with exploratory modelling,” in *Proceedings of the 25th International Conference of the System Dynamics Society*, Boston, 2007. Available: <http://www.systemdynamics.org/conferences/2007/proceed/papers/PRUYT386.pdf>).

[48] S. P. Santos, V. Belton, and S. Howick, “Adding value to performance measurement by using system dynamics and multicriteria analysis, *International Journal of Operations & Production Management*, vol.22, no.11, 2002, pp. 1246-1272.

[49] P.-M. Boulanger, T. Bréchet, “Models for policymaking in sustainable development: The state of the art and perspectives for research,” *Ecological Economics*, vol.55, no.3, 2005. pp. 337–350.

[50] P. Partidario, J. Lambert, and S. Evans, “Building more sustainable solutions in production-consumption systems: the case of food for people with reduced access,” *Journal of Cleaner Production*, vol.15, 2007, pp. 513-524.

[51] G. P. Richardson, “Concept Models,” in *Proceedings of the 24th International Conference of the System Dynamics Society*, Nijmegen, NL, 2006. Available: http://www.systemdynamics.org/conferences/2006/proceed/papers/RICHA331.pdf).

[52] J. P.Davis, K. M. Eisenhardt, and C. B. Bingham, “Developing Theory Through Simulation Methods,” *Academy of Management Review*, vol. 32, no. 2, 2007, pp. 480-499.

[53] P. Taticchi, F. Tonelli, M. Sameh, and M. Botarelli, “Performance Measurement and Management: What is Next?, ” *WSEAS, Transaction On Business and Economics*, vol. 5, no. 11, 2008.

APPENDIX A - THE PSS CONCEPT MODEL

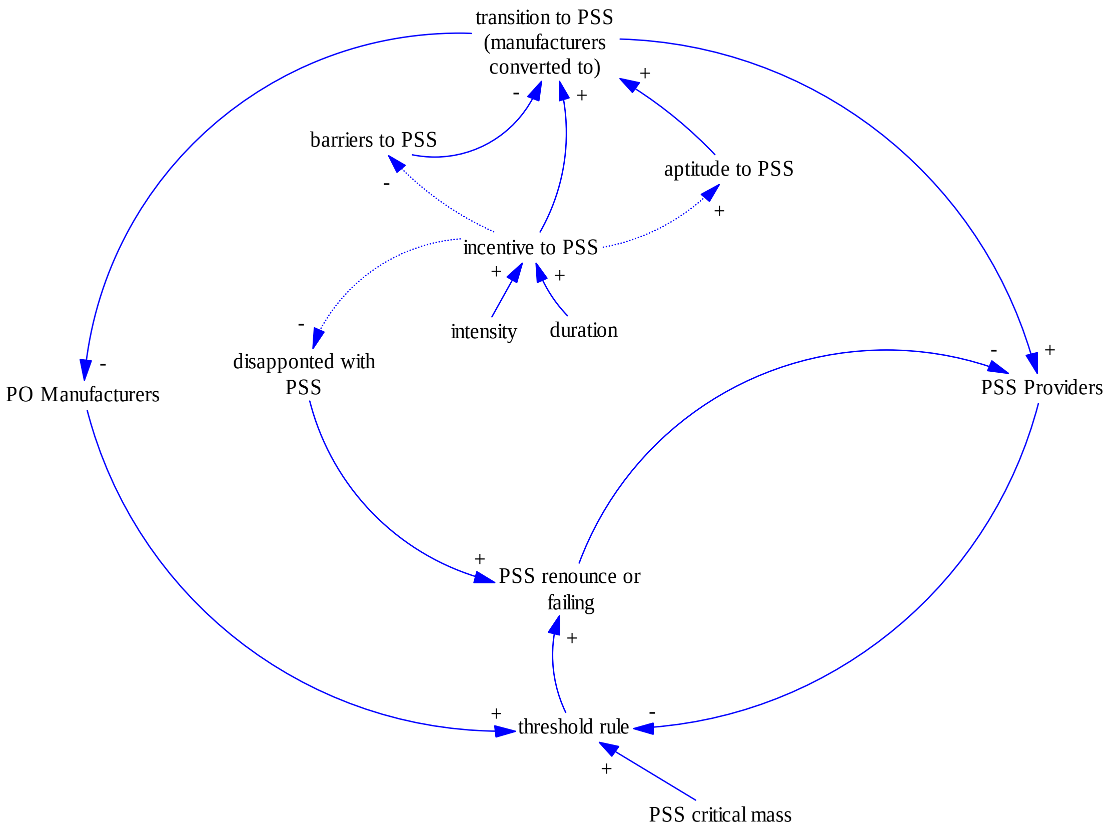

Fig. 1 – The Casual Loop Diagram

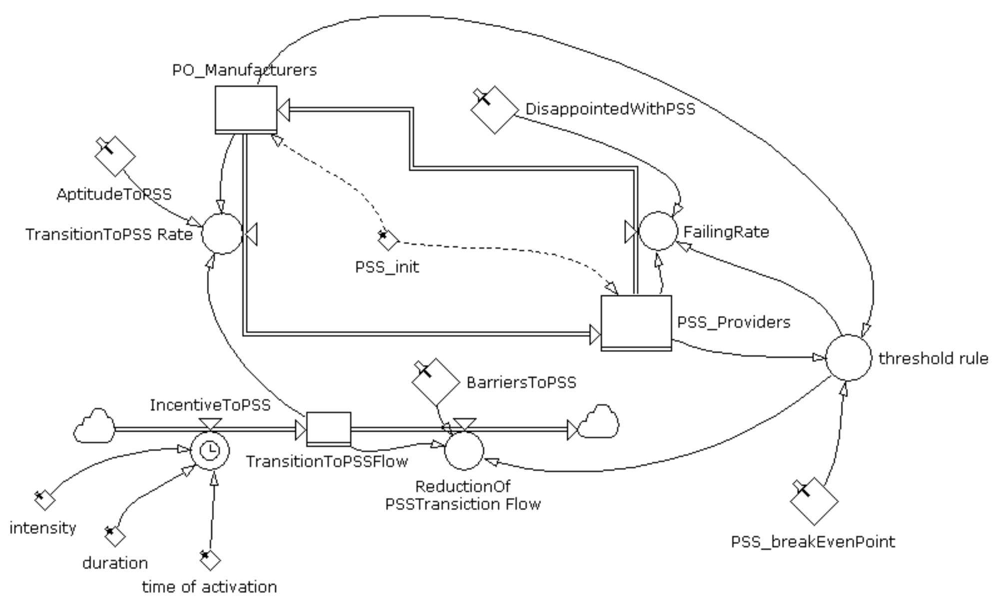

Fig. 2 – The Basic Stock and Flows Diagram

APPENDIX B - RESPONSE TO ECONOMICAL PSS INCENTIVES POLICIES TIME-GRAPHS WITH BARRIERS PARAMETERS CONSTANTS (APTITUDE=1, BARRIERS=3, DISAPPOINTED=5)

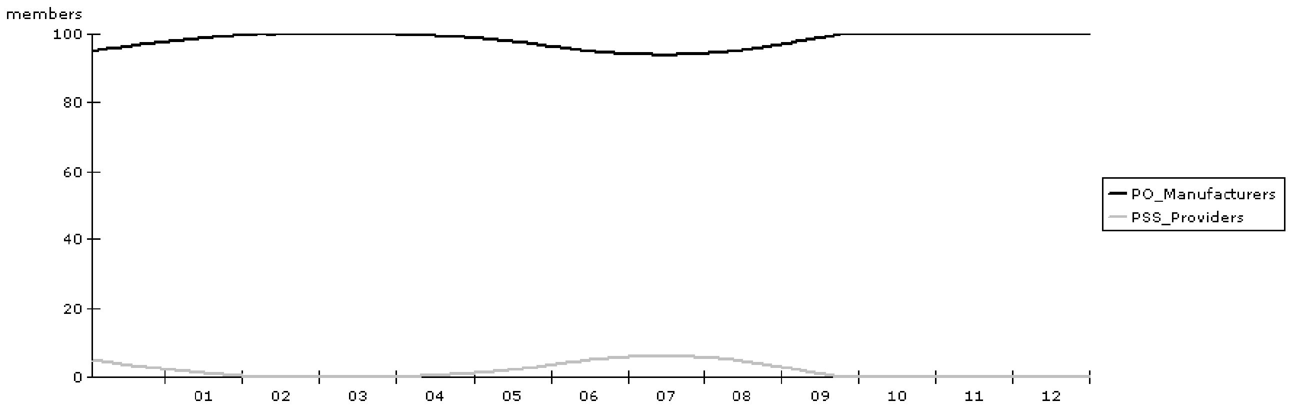

Fig. 3 – 6 years incentives, intensity 4

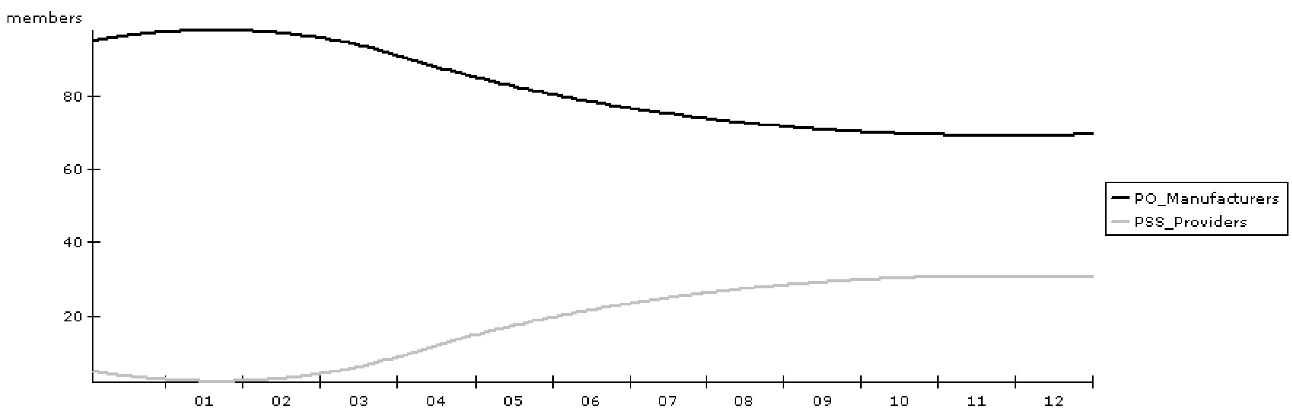

Fig. 4 – 4 years incentives, intensity 5

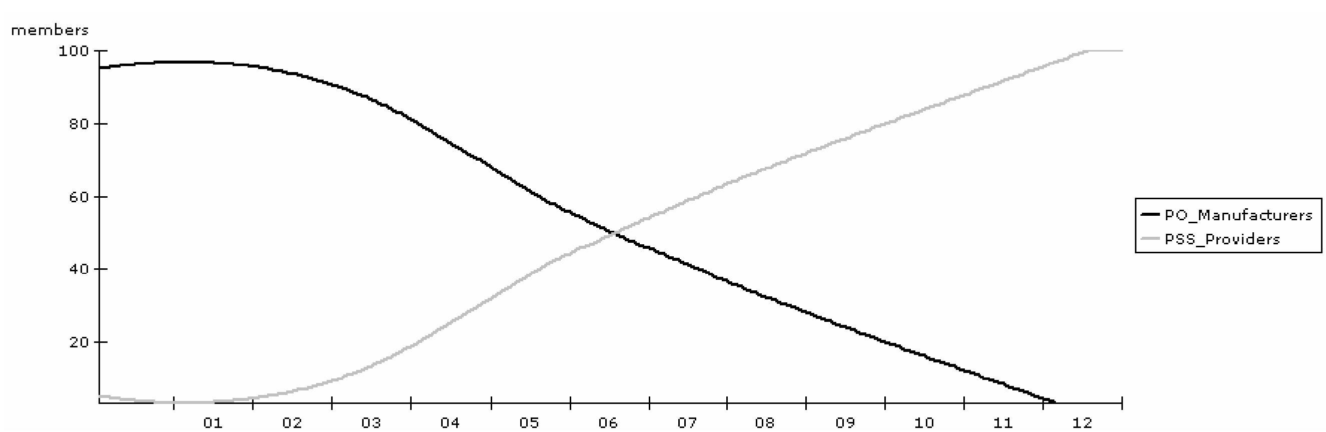

Fig. 5 – 4 years incentives, intensity 6

APPENDIX C - RESPONSE TO TO OTHER PSS STRATEGIES TIME-GRAPHS WITH WITH ECONOMICAL INCENTIVES CONSTANTS (INTENSITY=5 PER 2 YEARS)

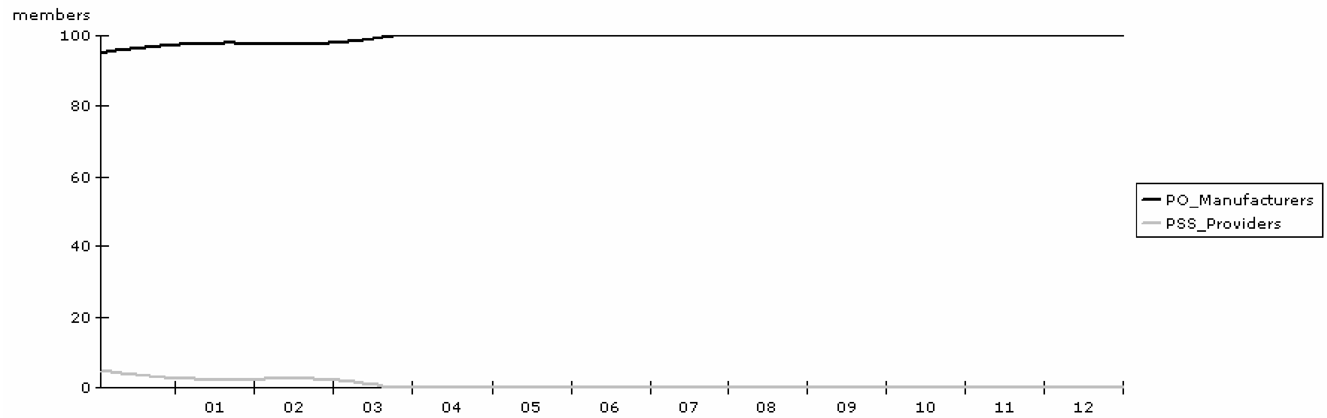

Fig. 6 – aptitude=1, barriers=3, disappointed=5
(i.e. the fixed parameters for the economical incentives)

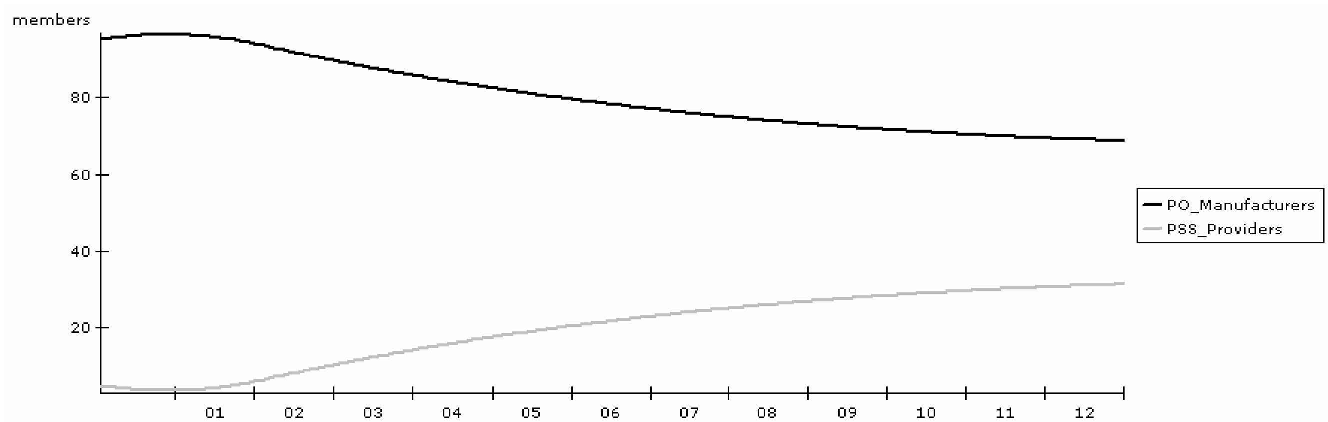

Fig. 7 – aptitude=1.5, barriers=1.5, disappointed=5

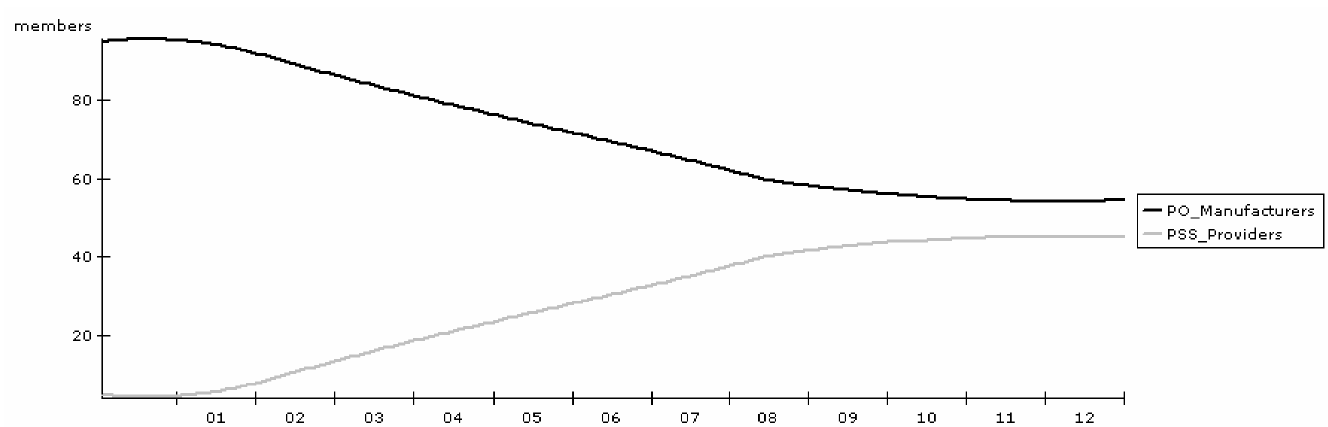

Fig. 8 – aptitude=1.5, barriers=1.5, disappointed=4

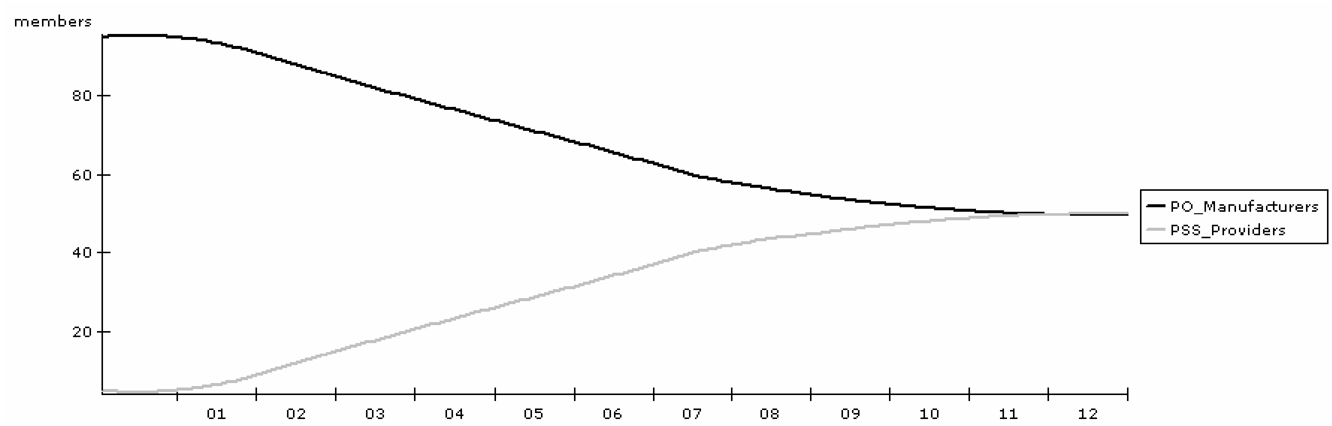

Fig. 9 – aptitude=1.5, barriers=1.5, disappointed=3.5

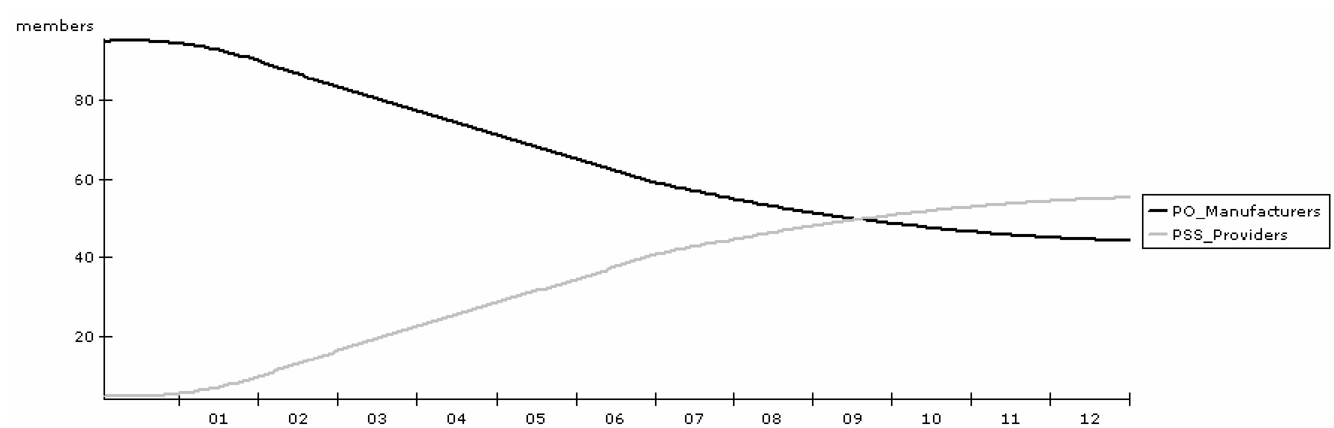

Fig. 10 – aptitude=1.5, barriers=1.5, disappointed=3

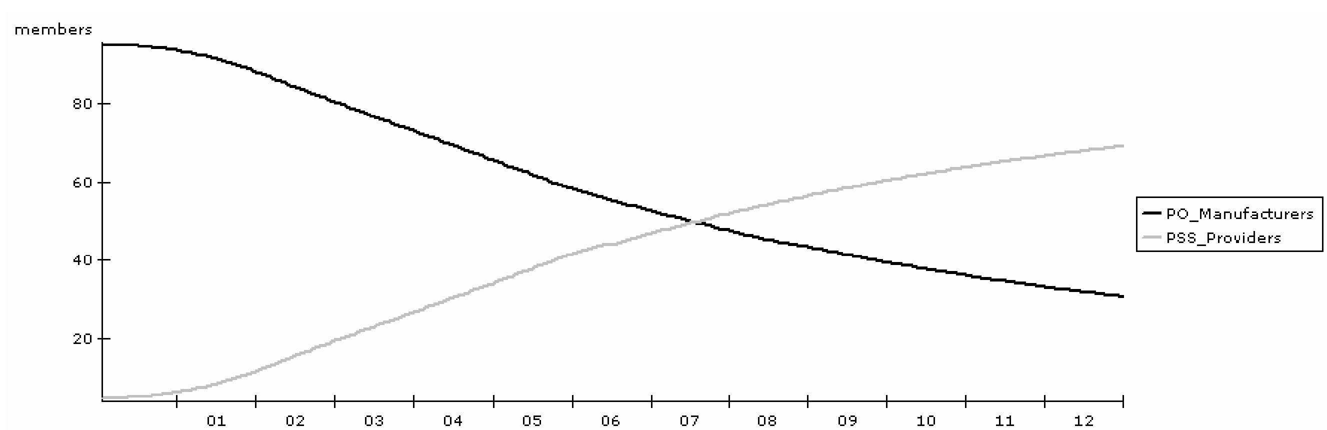

Fig. 11 – aptitude=2, barriers=1.5, disappointed=2,5

Appendix D - The PSS take-off

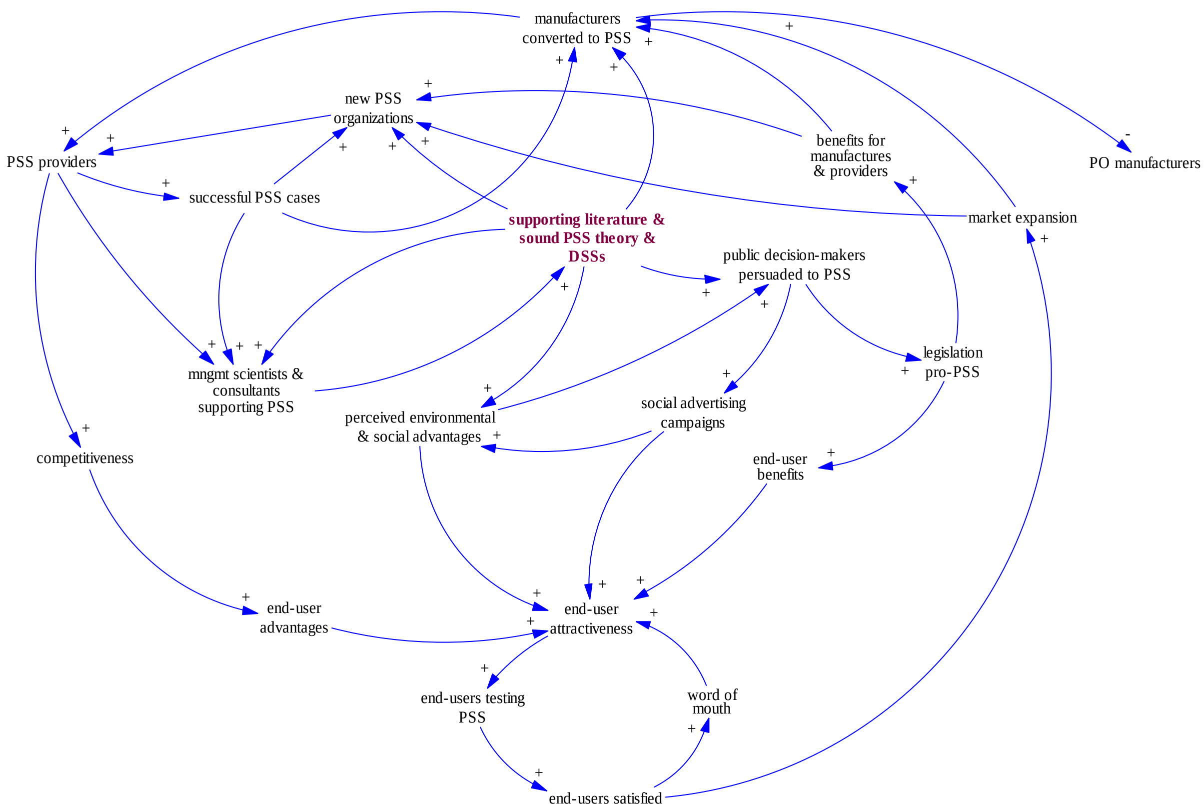

Fig.12 – The Casual Loop Diagram

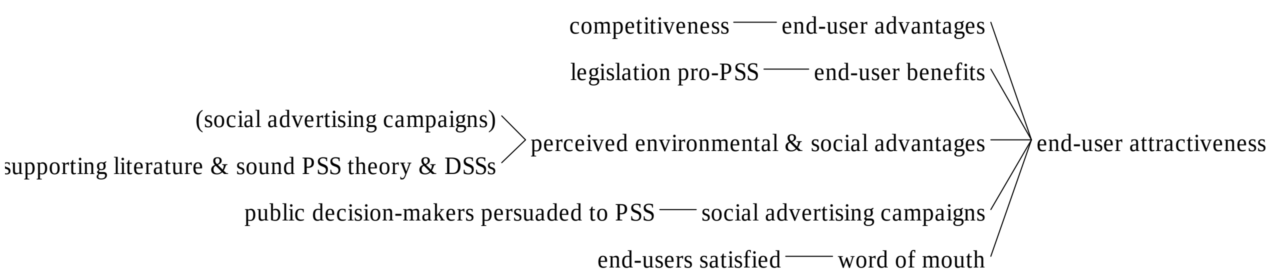

Fig. 13 – Causes tree of “End-user attractiveness”

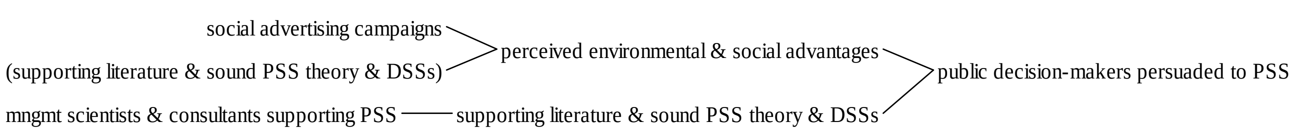

Fig. 14 – Causes tree of “Public decision-makers persuaded to PSS”

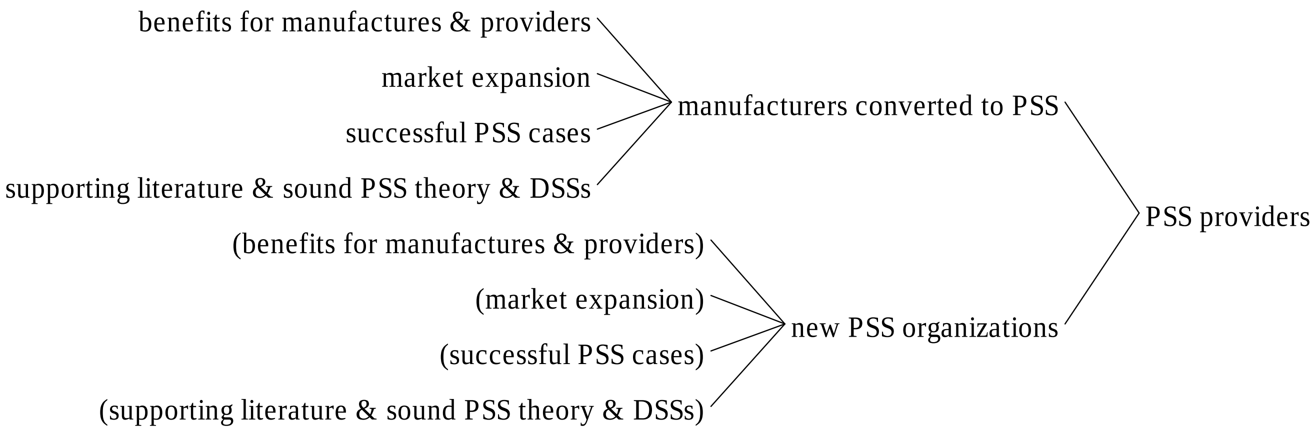

Fig. 15 – Causes tree of "Percentage of PSS providers"