An Exploration of the System Dynamics Field:
a Model-Based Policy Analysis

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July 16, 2014

Executive Summary

This report presents a first look study at the field of System Dynamics. The objective of the study is to perform a model-based policy analysis in order to investigate the future advancement of the System Dynamics field. The aim of this investigation is to determine what this advancement should look like and how that can be accomplished. Several steps were taken to reach the objective. First, actor groups who had a stake in the future of the System Dynamics field, even if they are outside of the System Dynamics field, were identified through a network analysis and an actor analysis. These analyses ensured that no crucial group was ignored. Members of these groups were then consulted, through over forty interviews, on their views about how the System Dynamics field would advance and what positive advancement would look like. These interviews were analyzed resulting in the identification of five main perspectives called *collaboration*, *oversimplification*, *broad System Dynamics and domain support*, *academic growth engine*, and *no problem*. The first three of these viewpoints were further specified into System Dynamics models and used for policy testing based on criteria determined from the interviews. From interviewee responses, five policies were identified for testing: 1) certification programs for practitioners of System Dynamics & clear labeling of System Dynamics types, 2) broadening the power base of System Dynamics, 3) setting up beneficial platforms for practical applications of SD, 4) including less traditional applications of System Dynamics in the System Dynamics Review (the main academic journal of System Dynamics), and 5) improving the network benefits of Special Interest Groups (these groups are within the System Dynamics Society, which is the main authority on System Dynamics). These policies were tested on the basis of six Key Performance Indicators as identified through interview questions. Following from this preliminary investigation, five policy combinations were identified to have the best relative effect considering the three models and all Key Performance Indicators: 1) all policies are enacted, 2) all policies except "including less traditional applications of System Dynamics in the System Dynamics Review" are enacted, 3) all policies except "setting up beneficial platforms for practical applications of System Dynamics" are enacted, 4) all policies except "certification programs for practitioners of System Dynamics & clear labeling of System Dynamics types" are enacted, and 5) all policies except "certification programs for practitioners & clear labeling of SD types" and "including less traditional applications of System Dynamics in the System Dynamics Review" are enacted. While no policy combination clearly showed an improvement across all perspectives and all Key Performance Indicators, the analysis of the models did show that policies that might work well for one perspective did not always work well for another. Further, each perspective was found to be credible and thus, no single perspective can reasonably removed. Therefore it is a main conclusion of this study that all valid perspectives should be considered while determining long-term strategy.

Keywords: system dynamics; model-based policy analysis; multiple models

1 Introduction

In *The Global Citizen*, Meadows (1991) defines a paradigm as "not only an assumption about how things are; it is also a commitment to their being that way." System Dynamicists, Meadows (1991) argues, are able to see beyond the “normal paradigm of everyday life” to see the systematic nature of the world around us. This understanding comes from the training that System Dynamicists receive in System Dynamics (SD), the focus of this study. SD is a method that is used to aid in the understanding of complex systems (Sterman, 2000). The tools of the SD method are used to document relations in order to see a more holistic system (Meadows, 1991).

Since the inception of SD in the 1950s (Forrester, 1971), the field has evolved simultaneous to other methods, tools and frameworks aimed at aiding decision makers. Leaders in the field, especially stemming from the System Dynamics Society (SDS), are concerned about the lack of advancement of SD compared to other policy advising tools, such as econometrics, systems engineering and the balanced scorecard (Richardson, 1996; Homer, 2013; Warren, 2013). However, concern about the SD field is not seen only from its prominent leaders.

Instead, much of the discourse about the SD field is unofficial; it is heard during conversations at SD conferences, read on the SDS’s SD forum, or part of discussions in systems based LinkedIn groups. Discussions range from conjectures about why visible SD work does not always follow the highest known standards to questions about why not more SD work is being done or demanded. In addition to these informal discussions, recent publications have been bringing the characterization of the SD field to a forefront.

For example, Homer (2013) argues that low growth of conference attendee numbers and “sub-par” quality work are part of a deeper problem. Homer sees this problem as an “identity crisis”. A clear definition, and labeling of “full SD” are presented as a remedy. Größler (2013) answers Homer by presenting a view where the SD identity is not the underlying problem and instead calls for increased diversity of people in the SD field. These strong opinions from two leaders in the field show that there is potentially a crisis in the SD field regarding which long-term strategy will ensure that the SD field advances on par with other fields in terms of growth and quality of work. This study will further explore these differences of opinion.

However, this study is not the first to look at the evolution of SD. Studies as early as Fey’s 1981 SD model of the SD field show that studying the dynamics of the SD field is not new. More recently the topic has gained further attention by SD leaders such as Kim Warren, Jack Homer and George Richardson. Warren created a model of the SD field as described in his 2013 address. Homer’s and Richardson’s SD models are currently in progress (Homer, 2014; Richardson, 2014). Furthermore, John D. Sterman’s SD work on Kuhn’s Structure of Scientific Revolutions (John D. Sterman, 1985; Sterman and Wittenberg, 1999) could also be considered as SD work that analyzes the SD field.

In addition to the examples of studies on the SD field presented in the previous paragraph, studies using methods other than SD have also been proposed. For example, Scholl (1992) proposes a benchmarking study of the SD field. Moreover, several publications, reports and speeches outline strategies for the future of, or discuss problems in, the SD field (Lyneis, 2008; Richardson, 1996; Homer, 2013; Forrester, 1998, 1987, 2007; Homer, 2007; Walker, 1982; Oliva, 2010; Moxnes, 2009; Lane, 2011; Ford, 2012). Yet, with all of these studies, the discussions mentioned in the second and third paragraphs of this introduction persist. This shows that no definite solution that will ensure positive growth and high quality SD work has been agreed upon.

Furthermore, these discussions and studies can be tied together under an an overarching body responsible for the advancement of the SD field. The SDS is the main authority on the System Dynamics (SD) field. As “an international, nonprofit organization devoted to encouraging the development and use of system dynamics”, the society has a vested interest in the promotion of the SD field (System Dynamics Society, 2014). Additionally, reports to the Policy Council of the SDS reflect the desire to understand the development of the field (Andersen et al., 2002; Warren, 2014). Responses can be seen in new policies in the SDS, as well as in the System Dynamics Review (SDR), the academic journal of the SDS.

The examples of opposing discourse (Homer, 2013; Größler, 2013), previous studies (Fey, 1981; Homer, 2014; John D. Sterman, 1985; Sterman and Wittenberg, 1999; Scholl, 1992; Richardson, 2014), and informal discussions presented above lead to a closer look at the problem in the SD field.

1.1 Problem Description

In order to take a closer look at the differences of opinion described in the Introduction, a step is taken back from the SD method to look at policy advice as a whole. Lomas (2000) neatly describes the market for policy advice as a “retail store” in which researchers stock the shelves with a collection of applicable studies hoping for policy makers to come into the store. Yet many of these studies are not being used. Therefore, simply providing evidence or models with excellent policy advice is not enough.

Like the greater field of policy advice, SD studies have been providing decision makers with insight to their problems. Yet, demand for SD seems to be lower than desired. Especially since Forrester’s 2007 address, people involved in the SD field (SDists) seem to have been feeling discontent with the progression of the SD field. This can be seen in discussions between SDists, during speeches by influential SDists (Forrester, 1998; Oliva, 2010; Moxnes, 2009; Lane, 2011; Ford, 2012), and through critical articles on the state of SD (Richardson, 1996; Homer, 2013; Forrester, 1987, 2007; Homer, 2007; Walker, 1982; Größler, 2013). Considering these speeches, articles, and conversations, the discontentment seen with the SD field can be characterized by different actors who are seeing different problems in the field as well as proposing different solutions. This prevents the problem from being straightforward. Some examples of possible problem descriptions are given below.

One possible problem may be the relative small size of the SD field in comparison to similar fields. For example, statistics courses are being taught throughout high schools and universities, while SD seems to be taught in select niche programs at a few universities. Alternatively, the SDS could conjecture that the problem deals with the number of members and health (financial or otherwise) of the society. For example, the SDS has around 1,100 members (Spencer, 2014), while the International Council on Systems Engineering (INCOSE) has over 7,000 (INCOSE, 2014). Actors with a more application centered view might focus on the real world impact that SD has –wondering why so few of today’s problems are solved using SD.

The examples given above highlight the multiplicity of the underlying problem of this study. Hence, the problem needs to be further examined. Literature was reviewed to define the type of problem faced. Therefore, De Bruijn and Heuvelhof’s (2008) view on problems is used to help understand the problem further. De Bruijn and Heuvelhof consider problems based on *values* and *knowledge*. In this case, values can be represented by the underlying beliefs of what the purpose of SD is, what the function of the SDS is, where the field should go, etc. Knowledge is information that actors know to be true and is often gained through experience in the field and the education received. For example, certain groups may *know* that clearly defining the SD field will lead to a more professional and respected field, while others will *know* that the opposite case is true.

Moreover, De Bruijn and Heuvelhof (2008) define such a problem, where there is no consensus on values and no consensus on knowledge, as a wicked problem. Rittel and Webber (1973) additionally describe the properties of a wicked problem. Some of these properties will be used to demonstrate the wicked nature of this problem. First, a wicked problem has no definitive formulation (Rittel and Webber, 1973); this is shown through the opposing views of Größler and Homer as demonstrated in the Introduction.

Second, wicked problems have no stopping rule, meaning there is never a final end where the problem is completely solved (Rittel and Webber, 1973). In the case of advancing any field, a stopping rule is difficult to define since the world continuously changes. If attempts are made to determine a stopping rule for this problem, they fail. For example, if the state of the SD field is defined by membership to the SDS, a stopping rule could be that SD is sufficiently advanced once the society has 10,000 members. Considering this stopping rule, though, it is not reasonable. Perhaps when the society reaches this number of members, the norm for membership of similar societies will be much higher.

Similar to the no stopping rule, wicked problems also have no immediate or ultimate test of the solution (Rittel and Webber, 1973). Using the same example of membership numbers, no specific number would show that the field is advancing as desired. Moreover, when quality of work is considered, a test of the solution would become even less clear. Even if an exact definition of quality were determined, cataloging of all SD in all forms of institutions across all countries would be unlikely. Following these characterizations as well as the definition of De Bruijn and Heuvelhof (2008), the state of the SD field will be addressed as a wicked problem with multiple viewpoints. Therefore goals of this study, as described in the next section, will address the wicked problem of the advancement of the SD field.

1.2 Goal

To address the wicked problem described above, the goal of this study is to provide a new outlook on the future progression of the SD field in order to promote an educated discussion of strategy leading to acceptable advancement of the field. This study aims to consider multiple models that represent the stances of stakeholders. Once these stances are better understood, the goal is to provide model-based policy advice towards the betterment of the SD field. This matches Walker and van Daalen's (2013) view that policy analysis models aim to support decision making in policy. Note that this study is a first take on looking at the advancement of the SD by a novice SDist.

To address the goals of this study, a main research question has been formulated:

What long-term strategy should be followed for the advancement of the SD field?

To answer the main research question, several subquestions were also formulated:

- *What actors are relevant to the SD field?*
- *What is meant by advancement of the SD field and how is this viewed by different actors both inside and outside of the SD field?*
- *According to actors, what factors affect the advancement of the SD field?*
- *Considering the different actors and their views, which policies are effective, across all viewpoints, in advancing the SD field?*

1.3 Structure of the Report

In Section 2, methodologies are determined in order to answer the research questions. In Section 3, the process in which a network analysis, an actor analysis and interviews were conducted is detailed. Section 4 describes the insights gained from the implemented methods. Five main perspectives are represented and explained. Three of these perspectives are further specified into SD models and used for policy testing in Section 5. Section 6 summarizes and discusses the results. Lastly, Section 7 discusses the main conclusions of this report and returns to the research questions listed above. Reflections and future work are also included in Section 7.

The term *perspective* is used throughout this report to denote a standard viewpoint of the SD field recognized in multiple interviews. Further, in this report the SD field refers to the accumulation of any work conducted using any of a broad range of SD concepts. In other words, the field is considered a broad body of work that uses some form of SD.

2 Methodology

This section describes the purpose behind each method chosen to address the research questions. The results from each subquestion are used to answer the next question; thus, each method leads to the following one. In this study, five main methodologies were applied. First, a network analysis was used to identify connections between actors in part of the SD field. Next, an actor analysis was completed in order to classify the different actors. Interviews were then conducted to determine actor viewpoints on the advancement of the field. Fourth, causal loop diagramming was used to visualize the content of the interviews. Lastly, the SD modeling approach was used to test policies that were previously determined from the interviews.

2.1 Network and Actor Analysis

The methods described in this section were used to answer the question:

- *What actors are relevant to the SD field?*

To address this question, an initial list of people practicing SD or somehow involved (especially at the fringes) in the SD field was compiled by recommendation. The list started with approximately twenty names and was increased based on recommendations given during individual interviews with the initial group; the names can be found in Appendix A.1. This *snowball* method of determining which actors are in the field was checked using a network analysis.

The network analysis was chosen as a method in order to determine clusters of key actors. This is useful because it ensured that members from each cluster were interviewed. It should be noted that this analysis only shows part of the SD field, and especially only academics –the network analysis is based on co-authorships. Thus, this method is not meant to show a complete picture of the field, but rather the relations between the actors previously identified.

The network analysis was followed by an actor analysis. Actors were categorized based on the power-interest grid by Ackermann and Eden (2011). The insight gained from the network analysis was used to help determine which actor groups should be included. Actor groups were then classified based on indications of their power to enact change in the SD field and by their desire to do so. This method was chosen because it provides a clear illustration of where actors lie and how important it is to consider each actor group for a particular issue. Additional information on this method can be found in Appendix B.2.

2.2 Interviews

The method described in this section was used to answer the question:

- *What is meant by advancement of the SD field and how is this viewed by different actors both inside and outside of the SD field?*

Interviews were chosen to answer this subquestion because this study takes a multi-actor policy analysis approach, and thus assumes multiple viewpoints. Interviews allow for follow up questions and better understanding of these viewpoints through clarification of answers (Legard et al., 2003). A simple survey would not allow for the depth and breadth of content as interviews do.

The interviewees were selected based on the actor groups identified in the previous network and actor analyses. The goal of the selection was to represent each actor group. Especially to answer this subquestion, both actors from within the SD field as well as actors not directly involved in the SD field were consulted.

2.3 Causal Loop Diagramming

The method described in this section was used to answer the question:

- *According to actors, what factors affect the advancement of the SD field?*

To help answer this subquestion, the information gathered from the previous method –interviews– was used to batch groups of SDists with similar stances. These groups were then compared to the grouping structure determined from the network and actor analyses. Causal loop diagrams were used because they provide a visualization of relations with the possibility of multiple diagrams. The relations of the causal loop diagrams made for this study will show which factors affect the advancement of the SD field. As described in Section 1.1, the problem of this study is wicked problem and therefore multiple viewpoints on the problem are considered. Additionally, the method was chosen because it provides illustrations that help clarify system structure. These illustrations show a quick overview of the system while allowing for further analysis in the future.

2.4 System Dynamics Modeling

The method described in this section was used to answer the question:

- *Considering the different actors and their views, which policies are effective, across all viewpoints, in advancing the SD field?*

Finally to address the last subquestion, the causal loop diagrams of the previous question can be directly used to construct SD models. Following from the possibility of multiple causal loop diagrams, multiple models are also considered to address the multiple viewpoints on the problem. SD was chosen as a method due to its characteristics in solving complex problems. Policy testing using multiple SD models will address the subquestion.

For example, SD, when compared to other simulation methods, lends itself well to tackling strategic problems (Tako and Robinson, 2012; Morecroft and Robinson, 2005; Lane, 2000; Brailsford and Hilton, 2001; Randers, 1980). In SD, understanding behavior gives insight for strategic decisions where exact predictions are often not possible (Lane, 2000). The interviews used to determine conceptual models show perspectives on the SD field as a nonlinear system. Hence, in order to address this subquestion, the behavior of the system needs to be understood. SD allows for this type of analysis.

Furthermore, feedback effects and soft variables arise in the system; these effects are explicitly handled in the SD approach (Brailsford and Hilton, 2001). This study follows Sterman's (2002) view that it is better to include and represent soft variables in some way rather than to leave the effects of these variables out entirely. Using SD will allow for aggregated models that can cope with both quantitative and qualitative data (Sweetser, 1999).

3 Implementation

This section describes the implementation and outputs of the first three methods discussed in Section 2. First, a network analysis was conducted using co-authorships to present a visual representation of part of the SD field. This representation was used to cluster groups of SDists. These groups were then further analyzed and classified in an actor analysis according to their power to enact change in the SD field as well as their interest to do so. Finally individuals within each identified actor group were interviewed.

3.1 Network Analysis

The process for the network analysis was adapted from Chappin and Ligtvoet's (2014) bibliometric analysis of transition and transformation. Because the goal of this network analysis is to determine key actors and groups, co-authorships instead of references were used. A more detailed description of the process of the network analysis can be found in Appendix B.1.

Using this process the resulting network is depicted in Figure 1. Each circle on the map represents an author; circles are sized based on the degree of each author's connections. Larger circles mean the author is more connected in the network. Different shades are used to identify similar clusters, based on modularity. The map shows several main clusters; for the larger clusters key names were identified based on the degree of connection of the author.

Next, Figure 1 was further analyzed to determine groups of SDists. Each major cluster was individually examined with a focus on the key authors in each cluster. Key authors were determined by their degree of connectivity –those with higher degrees of connection were considered key authors. These authors were then further investigated to determine their research topics and associated institutions. This information was used to define the clusters seen in Figure 1.

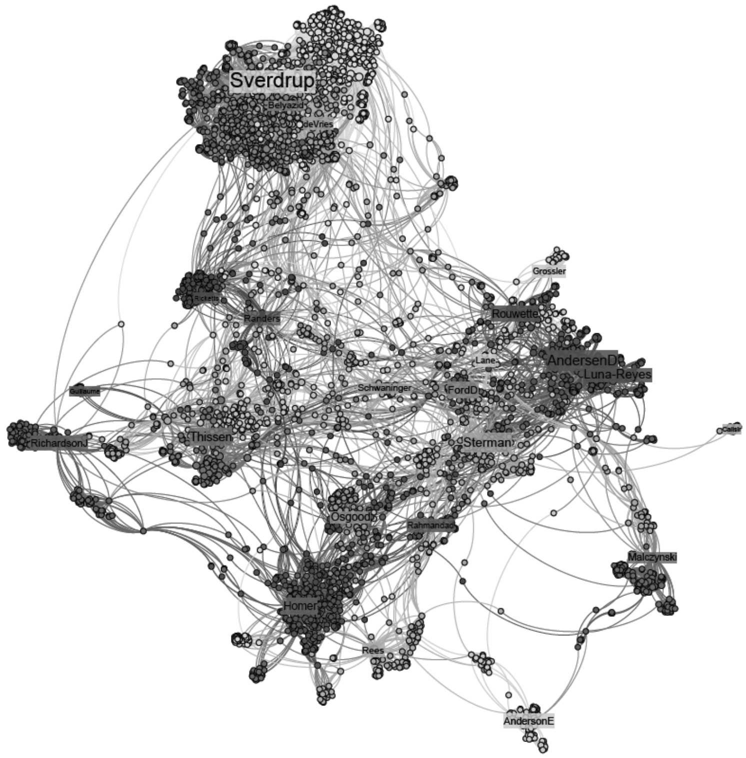


Figure 1: Network of Part of the SD Field

The definition of the clusters resulted in the identification of five main groups of SDists, as well as a group called *Outsiders to the SD Field* and *Founder of SD*, as depicted in Figure 2. Note that these groups are a broad categorization meant only as an indication to the possible groups of SDists. The groups identified are described below:

1. First, the cluster *Core Academic SDists* showed key authors who mainly stemmed from the Massachusetts Institute of Technology (MIT). These main authors are well-known in the SD field and include some past SDS presidents, such as Rogelio Oliva and George Richardson. The name *Core Academic SDists* was chosen because these SDists have held important roles in the SDS, are mainly associated with MIT where SD was founded, or both. Hence, they compose the core of the field.

2. Second, the cluster *SDists Outside of the Field* is characterized by SDists who are practicing SD, but do not associate with the SD field. Here the name was chosen because the work of these SDists shows that they are indeed practicing some form of SD. However, these individuals are not involved in the SDS and, in some cases, not using the term System Dynamics for their work.

3. Next, *SDists Practicing Alternative forms of SD* were identified. This cluster is stretched along the *Core Academic SDists* cluster. The cluster *SDists Practicing Alternative forms of SD* is mainly composed of two groups of SDists, 1) the SDists who are practicing Group Model Building (GMB), mainly at Radboud University and the University of Albany and 2) SDists practicing Exploratory System Dynamics Modeling and Analysis (ESDMA) mainly at the Delft University of Technology. The GMB part of this cluster partially overlaps with the *Core Academic SDists* due to George Richardson who is part of both clusters. The name of this cluster is chosen because the authors use forms of SD that are not necessarily recognized as traditional SD.

4. Fourth, *SD Consultants* are found at the fringes of the figure. These authors are identified by associated institutions and by their publications, which often have clear clients. Thus, they are named consultants; these authors may be consulting directly for a consulting firm or from within institutions.

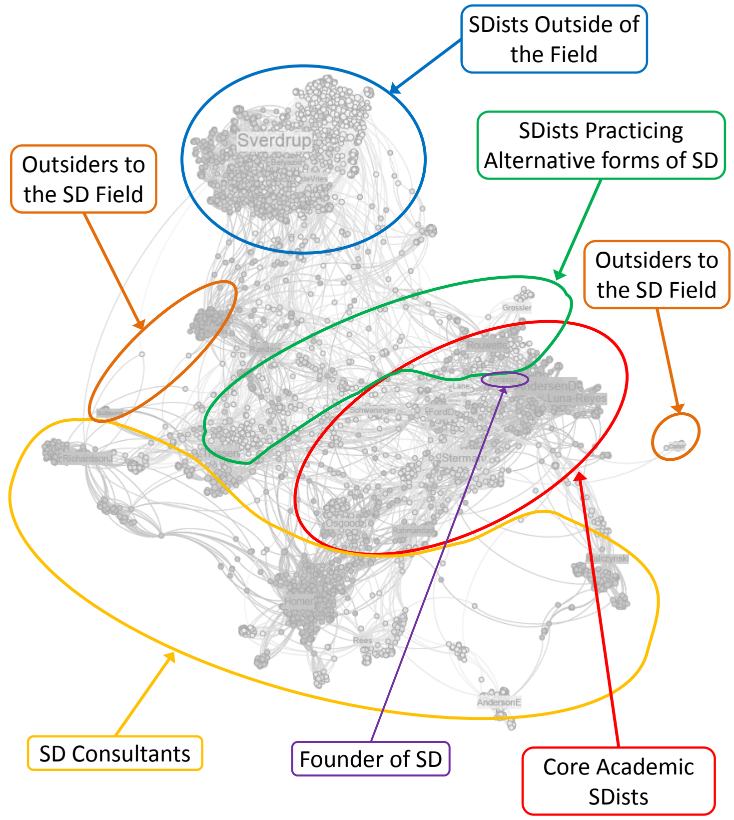


Figure 2: Select Identified Groups of SDists

5. The final SD group, *Academic SDists Outside of the Core*, is not depicted because these SDists are scattered throughout the figure. For example, these SDists may work frequently with *Core Academic SDists* or *SDists Practicing Alternative forms of SD*, but they themselves are not strongly affiliated with these groups. The name *Academic SDists Outside of the Core* was used because this group is less specific than the others and is comprised of SDists not historically part of the core group.

6. The cluster, *Outsiders to the SD Field*, is comprised of authors who have no clear connection to SD. Upon examination the key authors of these clusters are simply not publishing SD related work. *Outsiders to the SD Field* was chosen as a name to make the separation clear.

7. Finally, *Founder of SD*, Jay Forrester, was added to the diagram for historical context.

Furthermore, it is hypothesized that the majority of the actors in each of the different groups will share a viewpoint unique to the other groups. However, it could be that the actors within each cluster do not necessarily share the same viewpoint. The hypothesis is later explored through the interviews and addressed in Section 4.1. In order to address the hypothesis and to help reduce bias, each cluster identified in Figure 2 should be represented in the interviewees.

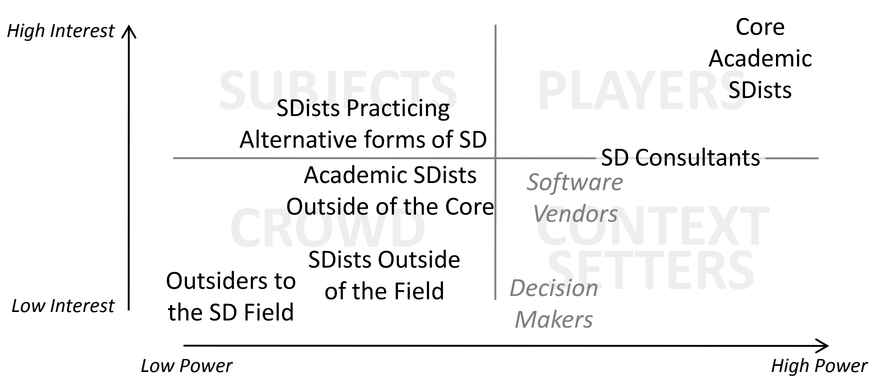
3.2 Actor Analysis

Next, insights of the cluster identification from the network analysis, combined with a review of literature on the SD field, formed the first sketch of the actor analysis. Reviews of literature included Andersen et al. (2002); Forrester (1971, 1987, 1989, 2007); Homer (2007, 2013); Richardson (1996); Scholl (1992); System Dynamics Society (2014); Warren (2013); Sterman (2002); Spencer (2014); Oliva (2014, 2010); Moxnes (2009); Lane (2011); Homer (2014); Größler (2014); Ford (2012).

Considering the previous network analysis, the actor analysis was completed to help understand the positions of the actor groups, in terms of influence on the SD field, better. Further, if the earlier hypothesis (from Section 3.1), that the majority of the actors in each of the different groups will share a viewpoint unique to the other groups, holds, then the actor analysis will make it clear which viewpoints are most important to consider. If the hypothesis does not hold, the actor analysis will still help to determine the relative importance of considering specific actor groups and thus could allow for more specific allocation of resources when considering policy actions.

The same six groups (without *Founder of SD*) identified in the network analysis were used in the actor analysis, with two additional groups *Software Vendors* and *Decision Makers*. These two groups were not part of the network analysis which, due to the use of co-authorships in scientific papers, only showed an academic part of the SD field. *Software Vendors* and *Decision Makers*, though included in the actor analysis for completeness due to their high power, were not considered further than the context of the actor analysis.

The eight identified actor groups were analyzed in terms of their power and interest based on the actor analysis of Ackermann and Eden (2011). In this analysis, power is defined as power over changes in the SD field, and interest is defined as motivation to enact desired changes. Thus high power could come from current and historical roles in the SDS, resources (frequently financial), or an ability to affect the implementation of SD. Interest is a more fuzzy classification. Directly asking actors may not lead to a true determination of interest; historical actions can help determine interest and therefore were considered. Assumptions of power and interest are described, by quadrant, below; the grid is depicted in Figure 3. Note that additional information on the grid and definitions of *crowd*, *subject*, *players* and *context setters* can be found in Appendix B.2.



Note: additional information about the grid can be found in Appendix B.2.

Figure 3: Power-Interest Grid of Actors in SD Field

Crowd The bottom left quadrant, the *crowd*, identifies groups with the least power and interest. The *crowd* was identified to contain three actor groups: *Academic SDists Outside of the Core*, *Outsiders to the SD Field*, and *SDists Outside of the Field*. Within the quadrant, *Academic SDists Outside of the Core* have the most power and interest. However, relative to others who associate with the SD field (*Core Academic SDists*, *SD Consultants*, and *SDists Practicing Alternative forms of SD*) the interest of *Academic SDists Outside of the Core* is low. Lack of organization is an indicator of the interest level. Additionally, by considering themselves part of the SD field *Academic SDists Outside of the Core*, do show a higher interest to enact change in the field than *Outsiders to the SD Field* and *SDists Outside of the Field*.

Moreover, regarding power, *Academic SDists Outside of the Core* have slightly more power than *SDists Practicing Alternative forms of SD*, but still less power than *Core Academic SDists* and *SD Consultants*. Historically, *Academic SDists Outside of the Core* have not as frequently had high power roles in the SDS, though this is currently changing. Additionally, as academics, their resources are not as extensive as other parties. At the same time, the power of *Academic SDists Outside of the Core* is not completely diminished because the size of the group does give it more power in terms of their ability to affect the implementation of SD. Ackermann and Eden (2011) note that in this method it is important to consider how the power and interest of actor groups might change based on satisfaction with the current state of affairs. Hence, in this context the power of *Academic SDists Outside of the Core* could increase. This would require a extensive coordination, which seems unlikely due to geographical and institutional divides.

Next, the *Outsiders to the SD Field* and *SDists Outside of the Field* are both also separate from the core of the SD field and furthermore do not identify themselves as being within the field. Not being in the field, these groups have no power in terms of roles in the SDS. Being academics, these groups also have little power in terms of resources. *SDists Outside of the Field* do have slightly more power in terms of affecting the implementation of SD. For example, highly public and successful studies using SD, even if not named as such, could change the *daily use* of SD by the other groups. *Outsiders to the SD Field* have little power in this context. Both groups, characterized by not identifying themselves with the field, logically have little motivation to enact change and thus low interest.

Subjects The next quadrant, *subjects*, contains groups that have at least slightly more interest than the *crowd*. This quadrant contains the actor group *SDists Practicing Alternative forms of SD*. This group is characterized as being part of the SD field. This shows that these actors maintain a higher interest than those who do not even consider themselves inside the field. Publications such as Größler (2013) show that this interest is higher than those in the actor group *Academic SDists Outside of the Core* (note that Größler is part of the group *SDists Practicing Alternative forms of SD*).

In addition, the power of this group is similar to *Academic SDists Outside of the Core*. The main difference is that the group, *SDists Practicing Alternative forms of SD*, is not as large as *Academic SDists Outside of the Core*. Thus *SDists Practicing Alternative forms of SD* have less power in affecting change in the implementation of SD.

Players Next, the top right quadrant of the grid shows actors with the highest power and interest. *Core Academic SDists* make up the *players* quadrant of the grid. They have high power mainly due to their historical roles in the SDS. By prestige and reputation these actors are also able to affect the implementation of SD. For example, one of the most prominent textbooks written on SD, *Business Dynamics*, is written by John Sterman (2000), a member of this group. Because many members of this group were taught directly by the founder of SD, their interest is assumed to be high.

Furthermore, *SD Consultants* enjoy a similar stance at a lower level in both power and interest. Their power stems partially from their roles in the SDS, which are not as frequent as *Core Academic SDists*, and partially from their resources, which are backed by clients. Since *SD Consultants* are characterized as working for clients, their interests are less aligned with SD and more with those of their direct clients.

Context Setters The last quadrant contains *Software Vendors* and *Decision Makers* who represent the *context setters*. First, *Software Vendors* have lower power in terms of roles in the SDS. However, they do have higher resources and a substantial ability to affect the implementation of SD. By changing software or simply doing nothing (leaving the software as is), this group influences what is computationally possible with SD. Only few SDists who are trained in software development would be able to counteract the action or inaction of *Software Vendors*. However, because the market for simulation software allows for competition their power is not excessive. Moreover, in terms of interest, it is assumed that *Software Vendors* focus on profits, not the SD field. These profits do indirectly relate to the state of the SD field, and hence this group's interest is in the middle.

Finally, the power of *Decision Makers* stems from their resources, which they enact through their demand, or lack of demand, for SD related studies. Because enacting their power through demand is assumed to have a substantial delay time, power of *Decision Makers* is not near that of *Core Academic SDists*. Regarding interest, as mentioned in literature, such as Lomas (2000), decision makers look for solutions not specific methods in policy studies. Thus *Decision Makers*' interest specifically in SD is low.

3.3 Interviews

Finally, the groups identified in the network and actor analyses were used to ensure a diverse selection of interviewees. Interviews were conducted with over forty people (the bold names listed in Appendix A.1). *Software Vendors* and

Decision Makers from the actor analysis were not interviewed (although some *Decision Makers* who were also members of the other actor groups were interviewed).

Further, these interviews aimed at getting a basic understanding of the interviewees' view of the SD field. Interviews were conducted according to location and the convenience of the interviewee –either in person, via telephone or via Skype (or similar software). Most interviews lasted between thirty to fifty minutes. A sample of the interview questions can be found in Appendix B.3. These questions were used as a guideline during interviews in order to elicit responses that showed the interviewee's perspective on the SD field. Questions were not asked verbatim; slightly different questions were used for different types of interviewees –students and seasoned SD professors, for example. Those outside the field were asked in less detail about SD specific questions. Depending on interviewee responses different questions were asked in order to determine the perspective of the interviewee. Interviewees are coded to actor groups in Appendix C.1. This coding is based on interview summaries as found in Appendix C.2.

4 Analysis

This section contains analysis of the research that was conducted. First the interviews were analyzed to batch groups of interviewees who held similar viewpoints on the SD field. An analysis was conducted to determine which actors groups adhere most to which perspectives. The perspectives were then described in more detail. Additionally, the information gathered from the interviews was analyzed through the creation of causal loop diagrams. These diagrams were first used to describe the views of the interviewees and then to be a starting point for SD models. Finally, for completeness, additional interesting findings, that were not spread across many interviewees, were discussed qualitatively.

4.1 Interview Analysis

Using the information gathered from the interviews as described in Section 3.3, interviewees with similar stances were batched together. For each group, a qualitative description was constructed, called a *perspective*. These perspectives were constructed based on the theme of each interview. Differences between perspectives were too great to reconcile in one model. It is important to note that these conceptual models were made to reflect the views of the interviewees, but were not made together with the interviewees.

To accomplish this, interviews were examined to determine which relations in the system of the SD field were emphasized by the interviewee. Patterns of frequently mentioned relations were identified and further investigated. Across the interviews no single question was identified to be able determine how the interviewee saw the system of the SD field. Each interviewee seemed to *open up* about their view of the system at a different part of the interview. However, five main questions do show the most frequent signs towards a particular perspective:

1. *How would you gauge the quality of the SD work being produced?*
2. *How do you think the current state (as defined above) of the SD field could be better? Do you feel there are any issues in SD as a in field? What specific issues do you see in the field?*
3. *From your perspective, what led the field to be where it is today?*
4. *Given it's current path, what do you think the state of the field will be the future?*
5. *What policies do you think need to be implemented to result in a fruitful future for SD?*

When interviewee answers to these questions were further examined, similar patterns of system descriptions were identified. Next, each of the interviews was searched through looking for these repeated relations or ideas. Finally, the main concepts were expanded upon. Thus, mainly from these questions, five main perspectives were identified:

1. *collaboration* – identified through interviewees who frequently spoke of the need for SDists to work with other other fields or methods

2. *oversimplification* – identified through comments about the misunderstanding of the complexity of proper SD as well as about the dilution of SD

3. *broad SD and domain support* – identified through frequent mentions by the interviewee of needing more support in his particular domain or frequent mentions of less traditional SD methods and their acceptance in the SDR

4. *academic growth engine* – identified through descriptions about growth of the SD field through the academic hierarchy (master students moving to become PhD candidates who then move to become professors)

5. *no problem* – identified through phrases such as *it just takes time* or the interviewee questioning if other fields feel the need to assess themselves as negatively as SD does

Moreover, these perspectives are described in more detail in Section 4.2. The explicit choice to deal with several standard perspectives separately ensued from the policy analysis approach. After perspectives were identified, interviewees were categorized by perspective with the allowance of multiple perspectives per interviewee. The percentages of people adhering to each perspective, classified by the interview data, are enumerated by actor group in Table 1. A full list of interviewee classifications can be found in Appendix C.1.

Thus, percentages and counts in Table 1 reflect the categorization of interview data by the author. These percentages do not reflect the entire SD field and are solely based on interpretations of interviewee responses. Due to the small sample size of interviewees, Table 1 is only meant to show an indication towards an inclination of adherence to certain perspectives and cannot be used to draw any solid conclusions. The table shows that actor groups do not correspond directly to one perspective; one perspective cannot be mapped onto only one actor group.

	Identified Perspectives*					**Total**
Actor Group	*Coll*	*Over*	*B&DS*	*AG*	*NP*	**Count**
Academic SDists Outside of the Core	44%	0%	22%	33%	11%	9
Core Academic SDists	19%	25%	13%	.63%	0%	16
Outsiders to the SD Field	50%	0%	0%	0%	50%	2
SD Consultants	50%	25%	25%	0%	0%	4
SDists Outside of the Field	60%	0%	40%	0%	40%	5
SDists Practicing Alternative forms of SD	71%	0%	57%	14%	0%	7

**collaboration = Coll; oversimplification = Over; broad SD and domain support = B&DS; academic growth engine = AG; no problem = NP*

Table 1: Percentage of Perspectives by Actor Group

The values from Table 1 were then used to create Figure 4; Figure 4 maps which actor groups adhere to which perspective. The shade of the block denoting each perspective represents the total percentage of adherence (note this percentage was normalized). Darker shades of the blocks representing each perspective denote a higher adherence (total adherence to the perspective). Furthermore, arrow width is based on count of interviewees who adhere to each perspective based on actor group. Thicker arrows denote higher counts of adherence.

Lastly, in order to check the identification and categorization of interviewees, a short description of each perspective was sent to all interviewees, who were asked if they recognize the perspectives. The response rate for this was low –less than 30%. However, those who did respond, with the exception of one interviewee, said they recognized the perspectives.

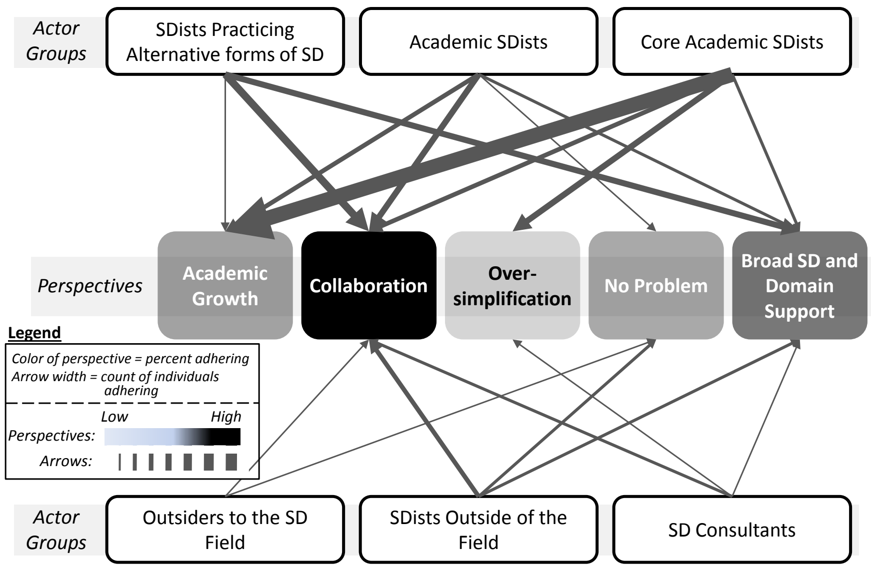


Figure 4: Mapping of Actor Groups to Perspectives

4.2 Further Descriptions of Perspectives

This section includes descriptions of the perspectives that were identified from the initial interviews as described in Section 3.3. These perspectives are called *collaboration*, *oversimplification*, *broad SD and domain support*, *academic growth engine* and *no problem*. The basic aging chain, which forms the basis of each perspective, is first described.

Note that it is assumed that any policy implemented in one model should be implemented in all models. Moreover, these conceptual models were made based on insights gained from the interviews with the goal to mirror the interviewees' outlook. However, they were not made in collaboration with the interviewees. Hence, the author holds all responsibility for the shortcomings in visualizations.

4.2.1 Basic Aging Chain

The perspectives were based on a basic aging chain of the SDist, as depicted in Figure 5. For these models, [the fraction of] *good SD work*, [the fraction of] *bad SD work*, *reputation of SD* and *real world impact* were identified from the all interviews as key performance indicators (KPIs) of the state of the SD field. Specifically, the question *What do you believe defines the "state" of the SD field?* was used to identify KPIs (See Appendix C.2). The same KPIs are used across all three models. Additionally, growth of the field –the changes in the stocks of SDists– were often seen as paramount for the development of the field. The basic aging chain contains a stock of *Newcomer SDists* and *Mature SDists* to represent this.

The general assumption here is that *Newcomer SDists* produce lower quality work than *Mature SDists*. For the sake of these models, *Mature SDists* are assumed to produce generally high quality work while those who have been in the field for a long time will simply remain *Newcomer SDists* until their work improves. Therefore, as the *proportion of Newcomer SDists to total SDists* increases, *bad SD work* increases, while *good SD work* decreases. So, the more *Mature SDists* there are, the more *good SD work* is produced. Good and bad SD work then affect the *reputation of SD* and this in turn increases the *dispersion rate of SD*. This then closes the feedback loop by increasing those attracted to the field and thus the number of *Newcomer SDists*.

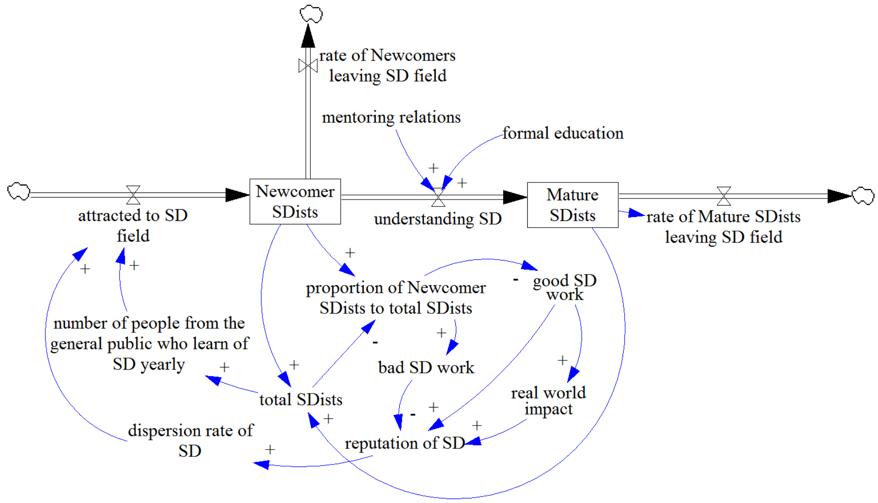


Figure 5: Basic Aging Chain of SDists

4.2.2 Collaboration Perspective

This perspective, depicted in Appendix C.3, represents the concept that increasing collaboration between SD and other fields or methods, such as agent based modeling, operations research or behavioral decision analysis, has the greatest impact on the SD field. The main premise is that more collaboration with other fields will increase the KPIs *reputation of SD*, *good SD work* and *real world impac*t. The extent of this increase remains uncertain.

In this perspective, outsiders to the SD field have a fear of the SD field that is amplified by the insider mentality that some SDists show. This insider mentality negatively impacts the willingness that non-SDists and SDists have to work with each other. To complete the feedback loop, collaboration in turn positively affects diversity in SD work, which increases the willingness of non-SDists and SDists to work with each other.

Considering the interview analysis in Section 4.1, as enumerated in Table 1, of all perspectives, *collaboration* has the highest count of actors. The actor group *SDists Practicing Alternative forms of SD* adheres most to this perspective. While *SDists Practicing Alternative forms of SD* show the highest percent of their members adhering to this perspective, four other actor groups, *Academic SDists Outside of the Core*, *Outsiders to the SD Field*, *SD Consultants* and *SDists Outside of the Field*, show the collaboration perspective as the highest adherence percentage within their respective actor group. These actors frequently cite the limitations of SD and their frequent work with other methods. They therefore see the collaboration of SD with other methods as a must. Software that can handle multiple modeling approaches could show that some of the *Software Vendors* also adhere to this perspective. However, single method software is still prevalent.

4.2.3 Oversimplification Perspective

This perspective, illustrated in Appendix C.3, follows from the difference between the larger systems thinking movement and SD modeling, or "full SD", as some call it. The conceptual model shows the dilution of SD fueled by misconceptions of the complexity of SD. The main assumption is that the misrepresentation of SD as systems thinking leads to the use of a diluted form of SD.

In the *oversimplification* perspective, people are first attracted by the basic ideas of SD, as presented in a systems thinking way. Soon they realize that SD is more complex than their initial understanding (as represented by the variable *misconceptions about the complexity of SD*). These misconceptions decrease the *dispersion rate of SD*, as they confuse nonSDists about what SD actually is. Soon the misconceptions further affect SD by increasing the frustration newcomer SDists feel when they learn SD a lot slower than expected. This effect then leads to more newcomers leaving the field.

Next, the analysis of actor groups to perspectives from Section 4.1 is considered. In contrast to the *collaboration* perspective, Table 1 shows that fewest number of actors adhere to this perspective; only two groups, *SD Consultants* and *Core Academic SDists*, do. These groups cite poor quality SD work as evidence of too many inexperienced people practicing SD. The inexperienced practitioners are not receiving enough support in the modeling aspects of SD.

4.2.4 Broad SD and Domain Support Perspective

This perspective, visualized in Appendix C.3, is characterized by the increase of support for SDists working in specific domains, such as energy, health, or security –often with less traditional SD methods. The assumption is that more support for SDists in these domains will have the greatest impact on the growth of the SD field.

Hence, the main relations in this perspective are based on the question of where domain applications of SD should be housed –with the SD society, in domain journals, or both. Thus, the model focuses on SD publications attempted. This affects both the SD work in domain journals and the acceptance rate of the SDR. A higher acceptance rate decreases frustration that is felt when SD related publications cannot get into the SDR. SD work in domain journals increases the dispersion rate of SD through additional exposure. However, because SD work is then scattered across many different domain journals, this also increases the *fragmented way of working.* A more *fragmented way of working* decreases how well the public understands SD and thus also decreases the number of people who are *attracted to the SD field.*

Another part of this perspective focuses on domain support aiding SDists in their ability to pinpoint relevant issues in their specific domain. This in turn increases the amount of domain issues that are solved by SD and thus also good SD work. The reputation of SD is then increased, which results in more people attracted to SD.

Considering the interview analysis from Section 4.1, similar to the *collaboration* perspective, *SDists Practicing Alternative forms of SD* adhere to this perspective. This could be to be due to the nature of their work, which frequently takes place in a domain. These actors feel the practical tips and tricks specific to their domain could be shared more clearly and effectively through domain support. This actor group cites this lack of support as the cause of poor quality SD work.

4.2.5 Academic Growth Engine Perspective

This perspective represents education as the main growth engine of SD. This perspective is captured in Kim Warren's model of the SD field as described in his presidential address *Taking the Opportunity* (Warren, 2013). Additionally, it seems Richardson's current work will reflect a similar perspective. Hence it is assume enough work has been done from this perspective and therefore it is not visualized here. The main idea, the generic growth engine of SD through education, includes professors teaching SD to their masters and PhD students. These students then expand the field in both academia and practice, although some do leave the field. The expansion of the field in academia and practice then increases the demand for SD, which in turn further drives the engine as more students want to learn SD.

Hence this traditional growth engine represents the diffusion of SD from teacher to student. With a low number of initial professors, and, if few students stay in the SD field, this engine works slowly. Within this perspective some highlight the importance of primary and secondary education, while others focus more on university and higher education.

When returning to the analysis of interview content in Section 4.1, logically *Core Academic SDists* generally adhere to this perspective. This actor group cites their experience in the field and those of their students. They see master students become PhD candidates and these PhD candidates become professors.

4.2.6 No Problem Perspective

This perspective is also defined by the traditional academic growth engine, simply with slow growth. Thus, people who adhere to this perspective see no problems in the progress of the SD field. They view the growth of the SD field with the attitude that it *just takes time*. Some interviewees are also classified into this perspective due to their apathy towards the progression of the field.

This apathy can mainly be seen in *Outsiders to the SD Field*, who mostly adhere to this perspective, as shown in Section 4.1. Those who are not involved in SD were shown by the interviews to either seek collaboration with other methods they employ or simply consider SD a tool that they do not need to use. Thus, they feel the method is sufficient as it is. Hearsay during interviews showed that *Decision Makers* usually are completely apathetic to the growth of the field as they seek solutions not methods. Hence perhaps this actor group also adheres to this perspective.

4.3 Additional Findings from Interviews

This section discusses some interesting findings from the interviews that were not represented or only partially represented in the perspectives described above. The findings below are discussed qualitatively for completeness. However, because it was not deemed reasonably feasible, they were not included in their own individual perspectives.

4.3.1 A hidden part of the field

The SD field is often characterized by the number of members in the SD society. This is one of the few measures available to determine how large the SD field actually is. However, some interviewees were adamant that this was not a reasonable number to use because the SD field has a large invisible or hidden part to it. Most interviewees with this view mentioned that this hidden part was composed of practitioners who do not solely use SD. Another interesting hidden aspect of the field, mentioned by Interviewee 33 (see Appendix C.2), is classified work completed by the United States government. For example, the United States government may commission an SD project on determining the best responses to terrorist threats. This project, due to its implications to national security, would not be made public. Lastly, a mentioned by Interviewee 7 (see Appendix C.2), certain regions may also remain hidden SD areas due to cultural differences that make organization of formal groups less likely. In opposition, a Bain and Company report *Management Tools and Trends* (Rigby and Bilodeau, 2013), where SD is not mentioned, can be taken as evidence that a hidden section of the SD field is unlikely.

4.3.2 Crisis needs SD

The world seems to be in crisis, or at least the media makes it clear that we are almost permanently in crisis. This ranges from visible global warming, to debt crises to the current crisis in Crimea. A handful of interviewees discussed these crises as an opportunity for SD. Specifically, Interviewee 29 (see Appendix C.2) mentioned that complex questions are not asked when everything is going well. However, now that things in the world are not going so well, SD has an opportunity to solve these problems. Hence, while the major world economies were stable prior to 2008, there was little need or demand for solutions. Now that crisis is prevalent, we need to use SD and it will be demanded.

4.3.3 Software

As expected interviews showed a divide between younger and older generations when it came to the importance of software for SD. Younger generations tended towards the view that software was a vital part of SD. Specifically mentioned, by Interviewee 12 (see Appendix C.2), were the interfaces of software, which could greatly aid in the communication of SD. Older generations lean towards fundamentals of SD without needing software. Specifically Interviewee 37 said the focus of improvements to SD should be on human capacity (see Appendix C.2). The importance of this gap might not be so great, as the younger generations were not all the young and the older generations were often close retirement or already retired.

4.3.4 A religion

SD was sometimes likened to a religion where the inner circle of SDists were untouchable. Interviewee 20 (see Appendix C.2) referred to the "Gods" and "Semi-Gods" of SD, while Interviewee 36 (see Appendix C.2) mentioned a "saga culture" where people in the field simply follow the big names without any real reason. The religious metaphor was not always this strong and instead a similar feeling was mentioned by explaining how SDists were likely to have strong emotional attachments to their method. During his presentation, *Why experimenting with system dynamics as a methodology is a no no*, at the 2014 Benelux SD Chapter meeting, Größler (2014) hypothesized this might be due to the strong value base that SDists have. Some SDists see this from a different angle; Interviewee 7 (see Appendix C.2) mentioned enjoying the society exactly for its weakness –the SDS is a small society and hence everyone knows everyone. This aspect was taken into account more mildly in the *collaboration* perspective through the variable *insider mentality*.

5 Results

This section describes the SD models created from the conceptual models in Section 4. First the specification and behavior of the models is discussed. Then model testing can be found in Appendix D.2. Policies determined from the interviews, as well as their implementations in the models, are then described. Policy testing is then completed individually and next with policy combinations. Finally, additional considerations beyond the models is included in this section.

5.1 System Dynamics Models

The perspectives first identified in Section 4 were used as a basis for several small SD models. Like the conceptual models, the author holds all responsibility for the shortcomings in these models. From the identified perspectives, only the first three perspectives, *collaboration*, *oversimplification*, and *broad SD and domain support*, were used to create specified system dynamics models. The *academic growth engine* perspective was not further specified as to prevent duplication of work. This perspective is exemplified by Kim Warren's SD field architecture model for the SDS Strategy Committee. The *no problem* perspective was not specified or modeled as the interviewees who adhere to this perspective tend see the field in terms of the *academic growth engine* perspective with slow but steady growth. Thus another model of this perspective would be redundant.

5.1.1 Specification

The model structures created for this study were based on conceptualization as described in Section 4.2. Each of the models were specified in Vensim. Additionally, the models were run through the SDM-Doc tool provided by the SDS for model documentation. This documentation for each of the models can be found in Appendix E. Models can found be in Figures 14, 15, and 16 in Appendix D.1.

The interviews used for the conceptualization showed certain areas with uncertainty in each model; these factors were included in the specification of the models and marked as *Parameter Uncertainties*; these are marked blue in the Vensim models. The models were made to reflect the different perspectives on one system, hence the models also include *Common Effects*, marked orange in the Vensim models. These effects are valued differently in each model with the intent that a model user can adjust them to match their own perspective.

Furthermore, as a summary of the models, a table describing the system boundaries, main factors and resulting main loops for each model can be found in Appendix D.1. Please note that the KPIs *good SD work* and *bad SD work*, are modeled as a fraction of SD work, not as absolutes.

5.1.2 Behavior

In order to determine model behavior, the models were run using a base case of assumed parameter values, as found in the documentation in Appendix E. For each model, the base case was run over twenty years with no policies enacted.

Collaboration The base behavior of the KPIs, including the growth of the SD field *(Mature SDists* and *Newcomer SDists*), is depicted in Figure 6. In the *collaboration* perspective, the behavior shows *good SD work*, *real world impact* and *reputation of SD* quickly decaying to zero. For the *reputation of SD* this behavior comes from one the main loops of the model: outsiders' fear of the SD field leads to less *collaboration* and hence a lower reputation. This loop leads to decay since the base case of this model has a relatively high *initial fear* and low *initial collaboration.*

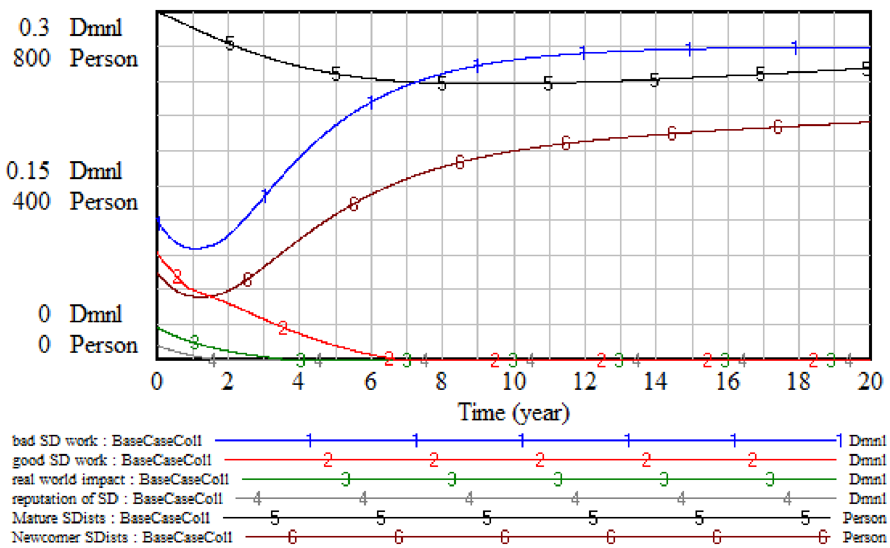


Figure 6: Collaboration Base Case KPIs

Furthermore, the decaying behavior of *real world impact* also results from the low *initial collaboration.* This KPI is only minimally dependent on *SDists solving domain issues*; the base level of this is again relatively low. Lastly, *good SD work* also decays to zero. This behavior is based on a low *diversity in SD work*, which again is due to low *collaboration* and also due to high *insider mentality.*

Despite the low KPIs, the growth of the SD field is positive. Both *Mature SDists* and *Newcomer SDists* eventually increase, though with an initial dip. For *Newcomer SDists*, the dip stems from a delay in the aging chain between learning about the SD field and finally becoming part of *Newcomer SDists.* A similar though longer delay causes the drawn out dip of *Mature SDists.* Soon the SDists both increase. Here this behavior is due to a relatively high *base dispersion rate of SD.* Finally, *bad SD work* also shows undesired behavior, as it practically doubles. However, compared to the other models, the stagnation of *bad SD work* near 0.3, is not excessive. This behavior is due to the increase in *Newcomer SDists* as compared to *Mature SDists.*

Oversimplification The base case behavior for the *oversimplification* model can be seen in Figure 7. While the *oversimplification* perspective also shows a base case with little promise for the SD field, *good SD work* is relatively high. This behavior is partially based on the *base factor of good SD work* and partially based on *pure SD work.* Since it is assumed in this perspective that some SD work will always be pure, *base pure SD work* is high enough to keep *good SD work* relatively high.

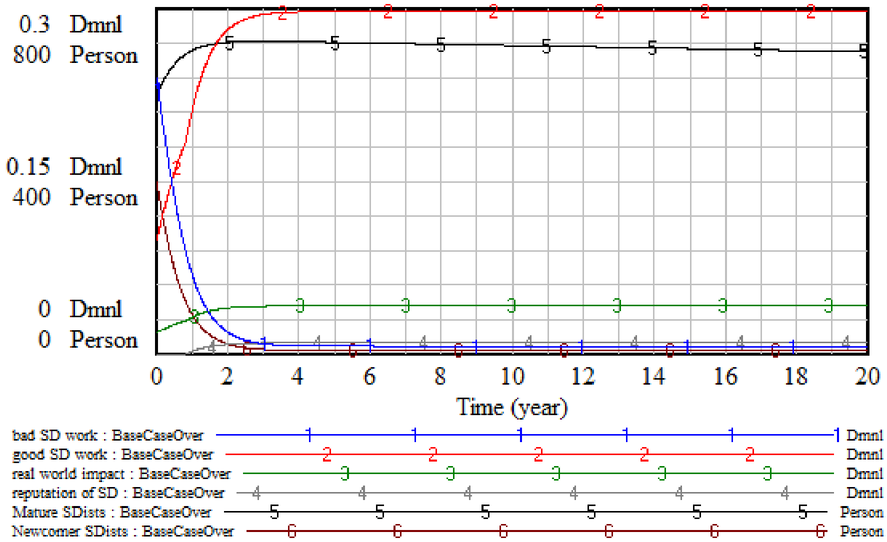


Figure 7: Oversimplification Base Case KPIs

In addition, *diversity in SD work* and *SDists solving domain issues* also do impact *good SD work*. However in this perspective, these effects are negligible. Note that 0.3 is not a desired fraction of *good SD work*, desired levels would be closer to 0.7. Next, *reputation of SD* and *real world impact* both start relatively low and only increase slightly in the first few years. *Real world impact* shows slightly higher values than *reputation of SD*. In this model most of the behavior for *real world impact* stems from *good SD work*; however, much higher *good SD work* is needed to have an effect on *real world impact*. A similar phenomena is seen with *reputation of SD*, though this KPI has three main inputs: *good SD work*, *bad SD work*, and *real world impact*.

Next regarding growth of the SD field, *Newcomer SDists* decay relatively quickly due few new people *attracted to SD field*. Additionally, those who are already *Newcomer SDists* either quickly move to *Mature SDists* or leave the field all together. The lack of new *Newcomer SDists* and high *rate of Newcomers leaving SD field* can be traced back to high *misconceptions about the complexity of SD*. *Mature SDists* are not affected nearly as quickly as *Newcomer SDists* in leaving the field. This behavior is due to the delay, the longer leaving time that *Mature SDists* have before they leave the field.

Like the *collaboration* perspective, *bad SD work* follows the behavior of *Newcomer SDists*. Since *bad SD work* is almost solely a product of the *proportion of Newcomer SDists to Total SDists*, *bad SD work* substantially decreases as *Newcomer SDists* become significantly less compared to *Mature SDists*. This reflects that high *good SD work* and low *bad SD work* are not enough to increase other KPIs as long as *misconceptions about the complexity of SD* persist. A higher level of good work is needed to have an impact. Unlike the *collaboration* perspective, here the low KPIs also show a reduction in the size of the SD field, specifically *Newcomer SDists* are greatly effected.

Broad SD and Domain Support Lastly, the base case behaviors for the *broad SD and domain support* perspective are illustrated in Figure 8. This model shows an only somewhat favorable outcome for *good SD work*. This stems from a high *base factor of good SD work* and from a reasonable, positive, level of *change in SDists solving domain issues*.

First, as a result of this higher *good SD work*, *reputation of SD* and *real world impact* both also show higher values than in the other models. Their behavior, similar to the other models, quickly stagnates. Like *good SD work*, *real world impact* shows higher values due to the level of *change in SDists solving domain issues*.

Like the other two perspectives, *Newcomer SDists* decay relatively quickly due few new people *attracted to SD field*. In this model, this is due to a high degree of fragmentation in the way SDist work. This results in basically no

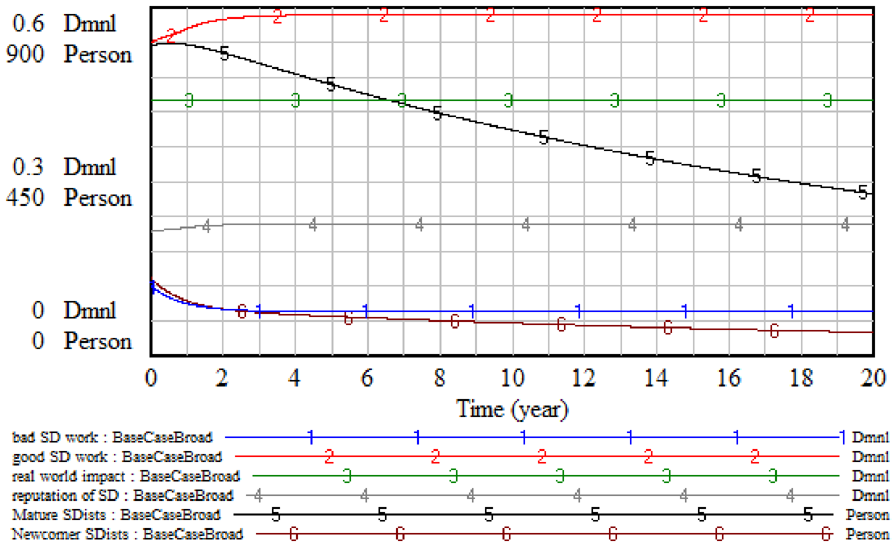


Figure 8: Broad SD and Domain Support Base Case KPIs

understanding of SD by the public, which in turn leads to a negligible *dispersion rate of SD*. Thus, no *Newcomer SDists* enter the field and the stock quickly diminishes. The *Mature SDist* stock sees a similar effect. However, the longer leaving time of *Mature SDists* slows the effect.

Again like the other two models, *bad SD work* follows the behavior of *Newcomer SDists*. *Bad SD work* substantially decreases as *Newcomer SDists* become significantly less compared to *Mature SDists*. Additionally, in this model, favorable results in *bad SD work* and *good SD work* are not enough to result in healthy growth of the field. Instead the field diminishes with dwindling numbers of *Mature SDists* and almost no *Newcomer SDists*. This reflects the view that SDists will simply relabel their work or move to other fields if they are not accepted in the SD field.

5.2 Policy Testing

This section contains a description of each policy and results from testing policies. First, five policy actions, defined by the interviews, are described. Then these policies are individually tested on each each model under uncertainty –found in Appendix D.4. The results are summarized to determine which policies show the most favorable results across all models and all KPIs (also found in D.4). Finally, all combinations of the policies are testing across each model, again under uncertainty. The results for these policy combinations are analyzed.

5.2.1 Policy Descriptions

First, policies are devised. Mostly from the question *What policies do you think need to be implemented to result in a fruitful future for SD?*, five policies were identified from the interviews. See Appendix C.2 for a summary of interviewee responses to policies. Visualizations of the implimentations of each policy can be found in Appendix D.3.

Policy A The aim of this policy is to increase the public's understanding of SD and what it means to be an SDist. This policy comes from the *oversimplification* perspective. In this perspective, the policy works to reduce misconceptions about SD in order to reduce frustration that *Newcomers SDists* feel when their expectations are not met about the field.

For example, an individual may become excited about the simplicity of SD as a method when they are first exposed to causal loop diagrams. However, after entering the field, the individual learns that SD is actually more complex than this. Since SD is far more mathematically challenging than the new SDist expected, she becomes frustrated with the method and leaves the field. Policy A is enacted to make that first impression of SD clear.

This is done by two means. First, SDists would be certified to a particular level. This way it is clear that practicing proper SD requires substantial effort. It also becomes clear exactly what an SDist can accomplish at each level, giving some insight to how the method can be used. Second, SD work would be given a clear label to show exactly what type of SD work it is. Thus proper or "full" SD would be marked as such, while more qualitative work would have its own mark. This way the interested party knows better what to expect from each kind of work. Together these two means make the policy variable *making the complexity of SD clear*.

Furthermore, Policy A is enacted in the *broad SD and domain support* model in a similar way as it in enacted in the *oversimplification* model, specifically on to the variable *understanding of SD by public*. The underlying structure behind the effect of the policy differs since the model structures themselves differ. In the *collaboration* perspective Policy A is enacted by reducing the fear outsiders feel towards the SD field (via the variable *fear of SD field by outsiders*). The assumption here is that if outsiders understand the field better they will have less fear of it.

Policy B The aim of this policy is to broaden the power base of SD, for example, by allowing for actors outside of the actor group *Core Academic SDists* to more frequently hold higher power positions in the field. This policy comes from the *collaboration* perspective. In this perspective, the policy works to reduce the *insider mentality* that SDist are observed by interviewees to have. Reducing this mentality in turn decreases the fear outsiders feel towards the SD field as well as increases the diversity in SD work (because SDists start looking outside of their own field).

For example, as newer members of the SD field start to become more prominent, they will bring their own experiences. Because these members have not historically been as involved in the field, they are assumed to have a new outlook on the field and less of an insider mentality. Thus, as the power base of the SD field shifts, the character of the field will change to be more open.

Again, in the *broad SD and domain support* model Policy B is enacted in a similar way to the *collaboration* model. The main difference is the extent of the impact of variables such as *insider mentality* and *diversity in SD work*. In the *oversimplification* perspective Policy B again impacts *insider mentality*, which in turn affects the rate at which *Mature SDists* leave the field. In the case of this perspective *insider mentality* actually makes *Mature SDists* feel welcome and at home in their field, hence decreasing the rate at which they leave the field. This effect is slight, since it is not the focus of this perspective.

Policy C The aim of this policy is to provide useful and beneficial outlets for SD work of a practical nature. This policy comes from the *broad SD and domain support* perspective. In this perspective, the policy works to present a more united image of SD by providing a clear platform where practical SD work can be presented. For example, if a non-SDists is facing a policy problem in urban planning, he may decide to look to SD as method that could help analyze his policy options. Such a platform would allow this non-SDists to quickly see the work done in the field and learn from these cases. This particular aspect of the policy is enacted by reducing the variable *fragmented way of working*.

Moreover, through such a platform or outlet, the policy also directly increase support for SDists in a particular domain. Thus it increases the variable *domain related support*. Lastly this policy also helps to decrease the frustration that some SDists feel when they are unable to publish their work in the SDR. For example, if an SDist who has been muddling through domain specific issues hopes to share this knowledge, she might become frustrated with her inability to publish her work in the SDR, the main academic journal of SD. This frustration is partially alleviated if a suitable alternative is presented.

Additionally, in the *collaboration* model, this policy was implemented in the same way as the *domain related support* part of the policy was implemented in the *broad SD and domain support* model. The difference is that *domain related support* has a lower impact in the *collaboration* model. Lastly, Policy C is implemented in the *oversimplification* model by reducing the misconceptions about SD. This implementation is similar to the *fragmented way of working* part of the implementation of Policy C in the *broad SD and domain support* model.

Policy D The aim of this policy is to increase the spectrum of work that is considered for publication in the SDR. This does not mean lower quality work. Instead this policy increases the type of SD work that is accepted in the SDR. This policy comes from the *broad SD and domain support* perspective. In this perspective, this policy works to broaden the work shown in the SDR by increasing the number of publications in the SDR. This in turn increases the acceptance rate of papers in the SDR, which again in turn decreases the frustration that some SDists feel with not being able to publish their SD related work in the SDR. For example, Policy D would broaden the base of SD work in the SDR to include more less traditional applications and alternative forms of SD.

Furthermore, in the *collaboration* model, Policy D is implemented by increasing the *diversity in SD work*. Through this variable the policy affects the willingness of SDists to and non-SDists to seek collaboration with each other. As diversity increases, collaboration thus also increases. Lastly, in the *oversimplification* model this policy has an adverse effect. Policy D increases the *misconceptions about the complexity of SD*. As described before, misconceptions about the field fuel frustration that *Newcomer SDists* feel about being in the field when their expectations are not met.

Policy E The aim of this policy is to increase the support that SDists active in a particular domain receive. This support is assumed to be given through the Special Interest Groups (SIGs) set up by the SDS. This policy comes from the *broad SD and domain support* perspective. In this perspective, this policy works to directly increase support in the domains by further developing the SIG networks. Then SDists can better solve domain issues. For example, stronger networks would boast participation, and hence strengthen the benefits of the SIG network. In this way the benefits of being active in a SIG increase.

Lastly, in both the *collaboration* and *oversimplification* models Policy E is implemented in a similar way as in the *broad SD and domain support* model. The effect in both the *collaboration* and *oversimplification* models is less significant.

5.2.2 Combined Policy Testing

While individual policy testing, found in Appendix D.4, helps to give an idea of how policies affect KPIs, policy combinations are also possible, and hence are investigated. Determining the exact *best* policy was not straightforward. A high availability of data, due to the necessity of multiple models as well as uncertainties in parameters and policies, resulted in fuzzy and frequently inconclusive results.

Resulting from this overwhelming amount of data, choices had to be made regarding the method of analysis. For pragmatic reasons, policy combinations were further examined by using the same process, for calculating *maximum* and *minimum* differences from the base case, as was used in individual policy testing to create heat maps (see Appendix D.4). For policy combinations, however, no heat maps were made.

Instead, again for reasonability and feasibility, the three *best* or *most favorable* policies were taken from each model, by KPI, in both the maximum and minimum values. Again the data from Table 17 in Appendix D.5 was used. In most cases the top three policies were clear. However in some models certain KPIs showed the exact same result throughout either the minimum or maximum values. For simplicity, if this was the case, the top three of the other value group (maximum or minimum) were taken. An example can be found in Appendix D.6.

Finally, the most frequent policy combinations were counted, as shown in Table 2 (note policies with a total of less than two counts in both minimum and maximum were removed). As Table 2 illustrates, still eleven policy combinations remain. For practicality, the top five policy combinations were further investigated; see Figures 30 and 31. Full results by model and KPI can be found in Appendix D.8. Note that, due to the process in which these policy combinations were chosen, in some cases the best possible policy for a particular KPI in a single model may have been removed.

Policy	Count Max	Count Min	Count Total
Policy ABCDE	8	9	17
Policy ABCD	3	3	6
Policy ABCE	4	3	7
Policy ABDE	4	9	13
Policy ABD	3	0	3
Policy ACE	0	3	3
Policy ADE	3	0	3
Policy BCDE	7	5	12
Policy BCE	3	4	7
Policy CDE	3	0	3
Policy DE	4	0	4

***Note**: policies with a total of less than two counts in both minimum and maximum were removed.*

Table 2: Most Frequent Favorable Policies

The resulting Figures 30 and 31 (found in Appendix D.7) show that for each policy combination the models have different results. However, these results, per model, seem to follow similar behaviors across all combinations. The results seen in Figures 30 and 31 are further explained, by model, below.

Collaboration First, in the *collaboration* model each policy combination visibly improves the latter five KPIs (*good SD work*, *Mature SDists*, *Newcomer SDists*, *real world impact*, and *reputation of SD*). The KPI *bad SD work*, however, does not seem to be changed by any of the policy combinations. The *collaboration* model shows the highest, and very similar, results in policy combinations ABCDE and ABCE. Policy BCE shows the lowest results compared to the other policy combinations depicted.

Oversimplification Next, in the *oversimplification* model the policy combinations have less exact results. Policy combination ABCDE seems to improve only the KPIs *Mature SDists* and *Newcomer SDists*, while actively increasing *bad SD work* (which makes this KPI worse) and decreasing *good SD work*. The remaining KPIs seem unmoved. Policy combination ABCE shows similar results with less improvement seen in *Mature SDists* and *Newcomer SDists*.

Additionally, interesting behavior can be seen in the KPIs *Mature SDists* and *Newcomer SDists* for policy combination ABDE. Here these KPIs have a high potential for increase. However, again, *bad SD work* and *good SD work* show undesired behavior, while *real world impact* and *reputation of SD* are unmoved. Finally policy combinations BCDE and BCE show almost no change from the base case.

Broad SD and Domain Support Finally, in the *broad SD and domain support* model each policy combination visibly improves the KPIs *good SD work*. *Bad SD work*, *real world impact*, and *reputation of SD* remain mostly the same compared to the base case. Growth of the SD field, through the KPIs *Mature SDists* and *Newcomer SDists* increases in the policy combinations ABCDE, ABCE, and ABDE. Considering these two KPIs, the greatest improvement seems to be in policy combination ABCDE. Further, if *good SD work* is considered, the greatest improvement is seen in policy combinations BCDE and BCE.

5.3 Considerations beyond the Models

This section considers possible implications of the resources of the *best* policy combinations. Since the models do not consider the resource implications of policies, the assumptions and conclusions drawn in this section are considered reflections, not model-based conclusions. To recapitulate, the individual policies include

1. Policy A – certification programs for SDist & clear labeling of SD types,

2. Policy B – broadening the power base of SD,
3. Policy C – setting up beneficial platforms for practical applications of SD,
4. Policy D – including less traditional applications of SD in the SDR, and
5. Policy E – improving the network benefits of SIGs.

Policy A First, certification programs, part of Policy A, can be assumed to entail both set up and maintenance. While substantial resources would most likely be required for these, a direct influx of financial resources could be expected if SDists must pay for such certification. Clear labeling of SD types, the second part of Policy A, could be assumed to necessitate considerable resources of time because all types of SD would need to be cataloged. Additionally an agreed upon framework for this would need to be established.

Policy B Second, broadening the power of SD, Policy B, should practically not call for extensive financial resources. At first it would seem simple to open opportunities for new SDists or SDists coming from non-traditional backgrounds. However, on further examination, this policy could be difficult to implement. On one hand, questions arise such as: *How does one ensure SDists with a new outlook take up the given opportunities? How* new *does the outlook need to be?* On the other hand, time will surely broaden the power base as new faces will inevitably enter positions of power.

Policy C Third, setting up a platform, or platforms, for practical SD applications, Policy C, could be assumed to require considerable resources. Effective platforms need to be identified and then implemented. Further, cooperation from domain experts will surely be required to make the implementations beneficial to SDists in their particular domain. Thus some sort of maintenance would be required.

Policy D Fourth, including less traditional applications of SD in the SDR, Policy D, would most likely not demand extensive resources. Mainly a similar resource requirement would be needed as for the domain experts in Policy C. In order to include less traditional SD work, this work needs to be evaluated on a reasonable scale. Thus, experts of that particular area of SD would most likely need to be consulted. Though not as extensive as other policies, this does require time.

Policy E Lastly, providing further support to the domains through an improved network, Policy E, would most likely involve similar resources as Policy C, especially in distinguishing benefits of the SIG network. Since the network effect makes networks substantially more valuable with the more members they have, this policy might also have a threshold that was not considered in policy testing.

Reflections on Best Policy Combinations The *best* combinations of these were identified to be ABCDE, ABCE, ABDE, BCDE, and BCE. With these considerations, policy combination ABCDE, logically, requires the most resources. Policy combination ABCE would probably require slightly more resources than ABDE, since setting up advantageous platforms for practical SD work most likely is more resource intensive than providing further network support through the SIGs. Since ABDE is assumed to demand fewer resources, ABDE is compared to BCDE.

Furthermore, policy combination BCDE would require less resources than ABDE in certification and labeling, but would require more in having to implement both platforms for practical SD work and additional network benefits for SIGs. Since certification offers a direct intake of financial resources, it is assumed that policy combination BCDE is more resource intensive than ABDE. Additionally, policy combination BCE is assumed to have almost identical resource requirements as BCDE, since including alternative SD work in the SDR, Policy D, requires few resources. Therefore, policy combination ABDE is most likely to demand the fewest resources.

6 Summary and Discussion

This section briefly summarizes the implementation, analysis and results of this report. First, the academic nature network analysis and the following actor analysis are discussed. Next, the outcomes of analyzing the interviews are briefly summarized. The high adherence rate to the *collaboration* perspective is further considered. Finally, the SD models themselves are discussed.

6.1 Network and Actor Analysis

First, the network analysis identified six main clusters: *Core Academic SDists*, *SDists Outside of the Field*, *SDists Practicing Alternative forms of SD*, *SD Consultants*, *Academic SDists Outside of the Core* and *Outsiders to the SD Field*. This first analysis of the field helped frame the actor groups and ensured that each group was represented in the interviews.

While the network analysis showed an interesting mapping of academics, it was limited by exactly that –it only shows academics. If, for example, a part of the SD field includes practitioners who rarely or never publish scientific papers, these were entirely left out. Thus, while the map was useful to discern actor groups, it was flawed in completeness. This flaw made the SD field seem highly academic. However, this could follow from the academic nature of the most visible part of the SD field –the SDS. During the interviews, if time permitted, interviewees were asked for suggestions for further interviewees. Through this attempts were made to discover more non-academic parts of the SD field; they were not as successful as desired. Perhaps, this study could also reflect a true academic nature of the field.

Next, the actor groups identified in the network analysis were placed on a power-interest grid to illustrate which actors were key stakeholders. This analysis showed *Core Academic SDists* as key players, and with *SD Consultants,* also having slightly less power and interest. In this analysis, *SDists Practicing Alternative forms of SD* were placed on the grid in a higher power position than *Academic SDists Outside of the Core* although non-traditional forms of SD are not always accepted. The higher power of *SDists Practicing Alternative forms of SD* perhaps stems from their higher interest. Their interest captures the attention of the SDS, which in turn results in more *SDists Practicing Alternative forms of SD* having roles in the SDS.

6.2 Interview Analysis

Moreover, in the next steps of this study –interviews– *Core Academic SDists*, due to their relatively high power, were a focus for determining who was interviewed. However, care was taken to ensure that the lower power groups also had some representation in the interviews. Thus, over forty interviews were next conducted with members in each of the six actor groups. The interviews were then used to identify different viewpoints on the advancement of the SD field; these showed the heterogeneous nature of the SD field. As expected, many different actors lead to multiple perspectives on the advancement of the SD field.

Then these perspectives and the actor groups from the network and actor analyses were considered together. During the implementation of the network analysis it had been hypothesized that the actor groups held one particular view that was shared within the group, but unique to the views of other actor groups. This hypothesis was tested here. Further analysis of the interviews showed that the hypothesis was false; different viewpoints did not match to the identified viewpoints. Though outside the scope of this study, it would be interesting to investigate the division of viewpoints further.

Following from the interviews, the identified viewpoints, called *perspectives*, were

1. Collaboration – characterized by the need for SDists to work more closely with other fields or methods
2. Oversimplification – characterized by a frequent misunderstanding of SD by those interested in entering the field

3. Broad SD and Domain Support – characterized by the need for more support in domain specific SD problems and the use of less traditional SD methods
4. Academic Growth Engine – characterized by a diffusion model of SD through professors to master students or PhD candidates
5. No Problem – characterized by an assumption that the SD is doing fine, simply growing slowly

Since the interviews, see Appendix C.1, tended towards actors from the group *Core Academic SDists*, the perspectives may have been biased by the sample. This could be seen in the results, which had a relatively high adherence rate, of interviewees to perspective, to the *academic growth engine* perspective. However, the *collaboration* perspective did have the highest adherence rate. Part of this is based on the what seems to be the greatest message about what is holding SD back –an insider culture.

Considering this cultural element, perhaps the history of the development of the field could be one of the causes of this insider culture. As many cultural differences, the implications of this are two sided. On one side, this could make being an SDist feel comforting. Thus, many SDists simply like being SDists. On the other side, this can result in looking mostly inward, which alienates many outsiders. These outsiders then can find it difficult to understand why others like it so much to be an SDist. If a cultural element is indeed holding back the SD field, this might be difficult to change since culture can be deeply engrained. Thus it may take several generations of SDists to move beyond this.

Further considering the interviews, one question asked was *How would you gauge the quality of the SD work being produced?*. The aim of the question was to discover what the interviewee saw as criteria for determining the quality of SD work. These criteria ranged from showing new and counter intuitive insights to data based studies to work that helped the user. The list goes on. There seems to be little consensus about what is actually high quality work. With no consensus on quality criteria, the direction of advancement is difficult to determine. This type of phenomena, amplified by doing so many interviews, makes it difficult to draw exact conclusions.

6.3 SD Models

The first three perspectives identified from the interviews were then captured by conceptual models, which were later further specified into SD models. The base case of the *collaboration* model showed growth in the field despite decayed KPIs. The *oversimplification* model showed a quick decay of growth in *Newcomer SDists*, while the *Mature SDists* were only slowly declining. Finally, the *broad SD and domain support* model showed a similar quick decay of *Newcomer SDists* with a slightly faster decay of *Mature SDists*. Other KPIs for the latter two models were not favorable. Thus, the base cases can be summarized as not showing favorable behavior. Since, these models aim to reflect how interviewees see the field, this reflects that interviewees see a need for action.

Next, the models were tested to determine their validity. These tests showed that the models could greatly benefit from more initial information with the a larger sample. This, for example, could be through a substantial survey to individuals within each of the actor groups. Further one or two champions per model could also help to reduce uncertainties. Both of these require significant resources that were beyond those of this study. However, since the models were deemed fit for the purpose of this study, they were used further in policy testing. Five policies were devised based on information from the interviews. Briefly, the policies included

1. Policy A – certification programs for SDist & clear labeling of SD types,
2. Policy B – broadening the power base of SD,
3. Policy C – setting up beneficial platforms for practical applications of SD,
4. Policy D – including less traditional applications of SD in the SDR, and
5. Policy E – improving the network benefits of SIGs.

Next, each of the policies were tested individually on each of the models. The policies themselves were tested over a range of possible policy levels. This was done because the exact effect of each policy is uncertain. With three models, five policies, and six KPIs, a summary of these results showed no overarching *best* policy. However, if growth of the field, through the KPIs *Newcomer SDist* and *Mature SDists*, are most important, Policy A has the *best* over all result. In this analysis, the choices made for analyzing the large amount of data limited the robustness of the conclusions that could be drawn. Exploring and implementing multiple methods for the analysis of large amounts of data could help solidify the conclusions.

While, individual policies were tested to help show the impact of each, it seems unrealistic that strictly only one policy will be followed. Therefore it is important to test combinations of policies. Every possible combination of policies was tested. Due to the use of three models, the data resulting from this testing was substantial. Practical choices had to be made in order to analyze the large amount of data.

Thus, the minimum and maximum values of each policy combination were compared to the minimum and maximum values of the base case respectively. Other methods could also have been used to determine effective policies. For example, robustness measure would help to identify the most resilient policies. Policy testing would benefit from future work along these lines. Finally, this policy testing, using the described minimum and maximum values, resulted in five *best* combinations of policies. Even with these *best* combinations, the results were not straightforward. Thus no exact recommendation could be made. However, each of the top policy combinations included the policy to broaden the power base of SD. Perhaps this particular policy, which would mostly likely require few resources, should be investigated further.

7 Conclusion

This report shows the complexity of developing policies for the future of the SD field. Even the message that the SD field is not advancing as it should is not universal. The research questions from Section 1.2 are revisited in order to determine how well this study was able to address its goals. The main research question, *What long-term strategy should be followed for the advancement of the SD field?*, is addressed by answering the subquestions.

The first subquestion: *What actors are relevant to the SD field?* has been addressed through a network analysis and actor analysis. In the implementation of the network analysis, co-authorship of scientific papers were used, causing the focus to be mostly limited to academia.

The network analysis showed that the actors in the field are closely connected by revealing certain clusters of SDists which seemed to be grouped by location and university as well as in some cases by type of SD (specifically this was seen in the SDists practicing alternative forms of SD). The groups identified in the network analysis were further used in the actor analysis. The actor analysis was key to determining which actors needed to be considered for the advancement of the field. This was accomplished by mapping actor groups in terms of their power to implement change in the SD field and their interest to do so.

The next two questions, *What is meant by advancement of the SD field and how is this viewed by different actors both inside and outside of the SD field?* and *According to actors, what factors affect the advancement of the SD field?* were addressed through over forty interviews. Specifically KPIs were identified from the interviews, in order to address the terms of the advancement of the SD field. Further, these interviews were then used to put together five different perspectives on the SD field, each with its own unique characteristics. These perspectives explicitly show the relations and factors that the interviewees believe effect the advancement of the field. Three of these perspectives were visualized and further specified into SD models.

The different perspectives show that there is enough disappointment in the lack of progress of the field to warrant action. Further these perspectives confirm the problem as a wicked problem; there is no consensus among SDist (or outsiders) on knowledge or values. Knowledge, given by the relations in the perspectives, is uncertain. Interviews also showed that SDists also have different underlying beliefs on the purpose of SD and what *good SD work* actually is.

Finally, the question *Considering the different actors and their views, which policies are effective, across all viewpoints, in advancing the SD field?* was addressed. The specified SD models of the three perspectives were used in policy testing, which showed five *best* policy combinations:

1. ABCDE – certification programs for SDist & clear labeling of SD types, broadening the power base of SD, setting up beneficial platforms for practical applications of SD, including less traditional applications of SD in the SDR, and improving the network benefits of SIGs.

2. ABCE – certification programs for SDist & clear labeling of SD types, broadening the power base of SD, setting up beneficial platforms for practical applications of SD, and improving the network benefits of SIGs.

3. ABDE – certification programs for SDist & clear labeling of SD types, broadening the power base of SD, including less traditional applications of SD in the SDR, and improving the network benefits of SIGs.

4. BCDE – broadening the power base of SD, setting up beneficial platforms for practical applications of SD, including less traditional applications of SD in the SDR, and improving the network benefits of SIGs.

5. BCE – broadening the power base of SD, setting up beneficial platforms for practical applications of SD, and improving the network benefits of SIGs.

Returning to the subquestion, the addition of the uncertainty of the future of the field makes this problem exceedingly complex. Thus, the last subquestion cannot entirely be answered. No policy or policy combination was found to be effective across all KPIs and viewpoints.

Returning again to the main research question of this study, *What long-term strategy should be followed for the advancement of the SD field?*, it also cannot fully be answered. No exact long-term strategy can be devised from the specific policies tested in this report. However, since it was found that all given perspectives are sufficiently credible, no single perspective can reasonably removed. Thus, a main recommendation of this report is for decision makers in the SD field to consider multiple perspectives in policy actions.

7.1 Reflections

The process of this study is reflected upon in this section. First, the network analysis is revisited. Then, the process of gathering and converting interview information into models is discussed. Finally, the steps taken in policy analysis are reviewed.

7.1.1 Network Analysis

First, reflecting on the process used for the network analysis, the network analysis showed a limited view of the field. Since the network analysis was based on an initial list, it was already bias towards this part of the field. Additionally, the analysis was bias towards academia. Using the database Scopus for this analysis limited it to only scientific papers. This then only showed part of the SD field. Data from other sources could, perhaps, have shown a more complete representation of the field.

Alternatively, two sources come to mind: the SDS and LinkedIn groups for SD. First, using the SDS as a source, papers from all past conferences or activity in the society, for example through the SD forum, could have been considered. Like using Scopus, however, this would have also given a bias view of the field –showing only the field in terms of the SDS. Second, using the SD themed LinkedIn groups could have presented a less bias view of the field. Here, either group membership –and the connections among members– or activity in discussions could have been used as sources. Especially for group member connections, data accessibility and privacy would have been major concerns for this approach. Moreover, this assumes that SDists use LinkedIn. Perhaps this would single out a younger generation of SDists who are more likely to be active in social media.

Further reflecting on the network analysis, the use of co-authorships only showed the connections between authors. This results in a limited view that can only be used to determine relations. However, other representations of the SD field may have been more useful. For example, determining the most prominent academic SDists. This could have been accomplished by using references (how many times an author was referenced by other authors in the field). Like the use of co-authorships, this has drawback. Specifically for this study, for example, this could have made it difficult to identify actor groups on the fringes. These groups may be working on new applications and therefore still have few citations. Additionally, this approach may have bias the interview selection towards prominent SDists, while the goal was the ensure that all groups were represented.

7.1.2 Interviews and Resulting Models

Next, the process of the interviews was reflected upon. Over forty interviews were conducted with individuals both part of and outside of the SD field. While the anecdotes from these interviews, though not always implementable in the models, shed a bright light onto SD as a field and onto the people in the field, the direction was not always clear. Using interviews meant that interviewees could answer questions in whatever way they wished. This resulted in many different types of answers for the same question, making it difficult to classify interviewees into one perspective –and even to identify the perspectives.

Further, the process seemed highly subjective because responses were to some extent open to interpretation. Although interviews allow for clarification, the bias of the interviewer is always present, even, for example, subconsciously in the intonation of certain words while asking questions. To help make this study more objective, perhaps after two or three interviews, criteria should have been designated. Such criteria could have been used to determine the perspectives more objectively and directly.

Additionally, perhaps a more rigorous framework or method for data gathering would have made the study more straightforward. For example, a few initial interviews could have been conducted and then followed by a massive survey. Survey results could have been interpreted more objectively. A drawback of this is that survey respondents would not have the same ability to convey additional information as the interviewees did.

For example, further reflecting on attempting to capture the viewpoints of the interviewees, a clear difficulty was discovered in determining what advancement of the field actually means. One of the interview questions asked was *How would you gauge the quality of the SD work being produced?* The aim of the question was to discover what the interviewee saw as criteria for determining the quality of SD work. In a survey, this criteria would perhaps already be suggested with an option to add additional criteria. However, once presented with given criteria, the respondent may not come up their own, as was done in the interviews. Thus, information that would have perhaps been revealed during interviews would have been missed through a survey.

7.1.3 Policy Testing

Finally, the process of policy testing for this study was based on responses given by interviewees. These policies were therefore not directly devised to have the greatest possible impact on the KPIs of the models. This process was used to reflect interviews. One implication of this was that the policies that were devised were not necessarily the best for all perspectives –or even reasonable across all perspectives. No attempt was made to find policies that would work well in each perspective. Thus, looking back, this process could have been improved by devising policies in addition to those determined from the interviews. If such policies were devised with all three models in mind, perhaps this could have also given more clear results and thus more solid conclusions.

Further, reflecting on the process for policy testing, a large amount of data made analysis complex. This stems from the use of three models that were each tested under uncertainty. With such an overwhelming amount of data for analysis, conclusions were unclear. Looking back an incorrect way to deal with this would have been to use only one model. This is would have been erroneous because, while it may give more clear results, other valid viewpoints would have been discounted and ignored. Thus, those who adhere to the other perspectives would have quickly found the one remaining model invalid and dismissed the results. Thus, while it could seem enticing to reduce data output, this would not give valid results. The continued further development of analysis tools for complex results will surely help in interpretation of similar studies.

7.2 Future Work

The current state and future of the SD field remains uncertain. Thus in order to better determine the state of the field as well as practical policy recommendations, further work needs to be done in specifying and using additional SD models for this problem. As a preliminary study, this work should be considered as a starting point for further investigations. Therefore, resulting from the reflections, some areas for future work have been identified.

First, in order to create a clear picture of the SD field, additional processes for the network analysis should be conducted. The analysis should be expanded to also include a representation of the SD field based on a non-academic source –for example, LinkedIn. With multiple representations of the parts of the field, this analysis would be more complete.

Subsequently, in order to further develop the models created for this study, three main aspects should be addressed as future work. First, a clear, accepted goal of where the SD field would like to go should be further investigated. Although it is unlikely that an exact goal is determined, further examination of this could help reduce uncertainty in the models.

Next, this models in this study should serve as a starting point for future investigation. Thus, the second aspect that should be addressed is solidifying the relations and parameters of the models. This could be either through a mass survey, additional interviews, or a champion per perspective. These actions would help to further enrich the models and reduce uncertainty. For example, as determined from Section 4.1, a small sample size was only able to give an indication towards the inclination of adherence to specific perspectives on the SD field. Future work could build off of this study by implementing a wider survey to a significant number of individuals within each actor group.

Third, all perspectives should be addressed. Therefore, the two perspectives, *academic growth engine* and *no problem*, should also be tested against the ones that were specified. Further, additional perspectives, such as one including the further development of SD software, could be identified from the further findings in the interviews as mentioned in Section 4.3.

Finally, future work for the analysis of policies is considered. First, policies should be devised not only using interview responses, but also through analysis of the models. For example, the patient rule induction method could be used to determine where policy actions would have the greatest effects. Investigation and application of further analytical methods could thus improve the results. For example, robust optimization could allow for policies to be analyzed and adapted over time (Hamarat et al., 2014). Policies would be adapted to become more effective. Further, multiple objective optimization could be used to determine when adaptations are more effective based on certain criteria. Additionally, this method could have show the consequences to the criteria. Lastly, comparing multiple methods for data analysis could help give clearer conclusions for which policies have the more favorable impacts across all models. Similarly, criteria for exactly what it means that a policy is effective across all KPIs and viewpoints could have devised.

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