



D3.1 TRANSITION FROM CONCEPTUAL TO IMPLEMENTABLE MODEL

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1. Summary

Given the objective of the IAMRRI project focusing on innovation value chains (IVCs), webs of IVCs and openings for responsible research and innovation (RRI), we have reviewed existing models of innovation processes. The review resulted in choosing the agent-based model SKIN¹ as a foundation for further work. SKIN is a recognized model, well documented and tested in various contexts, and has been actively used in policy-oriented research (e.g., Ahrweiler, 2017; Ahrweiler et al., 2015; Gilbert et al., 2018). The basic elements of SKIN such as “kenes” (the set of competences and knowledge an organization possesses), market mechanisms and innovation processes are assessed to be adequate and useful for modelling the additive manufacturing (AM) industry. The original SKIN model is described in chapter 4, p16. of this document. Note that the description is *complementary* to other SKIN publications—while we describe the whole model, we detail most carefully those parts of the model that are targets for adaptations for the IAMRRI SKIN model.

The adaptations and extensions we make to the original SKIN model in order to meet the objectives of the IAMRRI project are summarized in the following paragraphs at a general level. More details are provided in the subsequent chapters.

Firstly, the proposed IAMRRI model incorporates more complexity in the way the innovation process is modelled, covering the stages of idea generation, development and implementation, corresponding to the findings in D2.4 (“Final conceptual model on web of innovation value chains in additive manufacturing”) and our simulation review. The extended model permits generating ideas where not all the capabilities and abilities are readily defined, allowing agents to develop *innovation hypotheses* (see chapter 4) over extended periods of time and in cooperation with other agents, not all of whom necessarily profit directly from the sale of the innovation. These idea generation/development and diffusion processes constitute the separate Innovation Value Chains. The model allows for criss-crossings between different IVCs resulting in the development of webs of IVCs.

Secondly, additional attention is paid to timing in the IAMRRI SKIN model. Unlike in the original SKIN model, innovation and market-related processes may unfold over several time units (ticks, or iterations, in modelling and software development terms). This makes it possible to simulate processes of various durations and use time-related variables in addition to price-related and other mechanisms regulating agents’ decision making. This part of the modelling will necessarily require data from future work packages.

Thirdly, in line with the empirical observations in the AM industry, learning mechanisms are extended so that the agents can learn from each other in more ways (compared to the original model) in the processes of idea generation, development, and diffusion.

Fourthly, the RRI policy agendas, also called policy keys (open access, public engagement, ethics, and science education) are introduced, mainly through parameters influencing decision-making processes. These RRI policy keys play a key in allowing the model to address the research objectives of the IAMRRI project.

Finally, some relatively minor extensions are introduced in order to adapt the model to the automotive and medical cases. New classes of agents are added, model initialization parameters are adjusted, probabilistic functions are altered, and additional performance indicators are added. Fortunately, we were able to draw on the considerable experience of the collective SKIN community through their academic publications and other interactions (such as the excellent feedback we got from our Strategic Advisory Board member, Associate Professor Cristina Ponsiglione).

It is important to note that the final chapter, chapter 6, does not fully explain the meta-model. The reasons for this are several: first, the variables explained in the meta-model will necessarily be constrained by the data available to the project. Due to the Covid-19 crisis WP4’s in situ observational data collection has been halted indefinitely. In its place, historical case studies are to be employed in

¹ SKIN = Simulating Knowledge Dynamics in Innovation Networks.

order to collect data. As of now, the richness of the data is still unknown, making the boundaries of the data—and therefore the boundaries of the meta-model—undetermined. WP3 remains committed to cooperate with WP4 to ensure a sufficient match between the meta-model requirements and the data collection process in WP4. Second, the Covid-19 crisis has reduced the capacity of our partners in Italy. Because of this, some of their workload has been shifted to D3.2. Since their contribution constitute the bridge between D3.1 and D3.2, we do not consider this a major issue. It is, however, important to note that while D3.1 stands on its own, its implementation details are relegated to D3.2. In the summary chapter—chapter 6—we begin outlining the transition from D3.1 (model development) to D3.2 (model implementation) through an incomplete meta-model.

2. Introduction

This report contains a qualitative description of the simulation model for the IAMRRI project. The **research target** of the IAMRRI project is ***building a dynamic model of webs of innovation value chains (IVCs), in the context of additive manufacturing (AM), and identifying the openings for doing responsible research and innovation (RRI)***. To achieve this target, we first need to develop an understanding of the system of innovation in additive manufacturing, including who the involved actors are, how they interact, and how RRI may be relevant to the activities they carry out. This understanding, which will be derived from a theoretical conceptual model in the Deliverable 2.4 (Final conceptual model on web of innovation value chains in additive manufacturing) in the present project and interviews with key stakeholders (in WP6), will then form the basis of a model that we will develop using agent-based modelling (ABM) simulation methodology. This report, Deliverable D3.1, aims at building a baseline model describing the most essential details of the AM ecosystem and incorporating RRI openings into the model so that it can be translated into a simulation model in the next step.

The key idea of the IAMRRI project is to *build a model that can describe the dynamic interactions in the webs of IVCs for additive manufacturing, including the interaction related to RRI*, using agent-based modelling (ABM) simulation. ABM is “a form of computational modelling whereby a phenomenon is modelled in terms of agents and their interactions”, where an agent is defined as “an autonomous computational individual or object with particular properties and actions” (Wilensky & Rand, 2015, p. 1). The reason for choosing the ABM simulation method for IAMRRI is three-fold (Wilensky & Rand, 2015):

- ABM can model a heterogeneous population of actors who interact with each other and with the environment in a complex system with unpredictable results. Additive manufacturing is an emerging technology used in a fast-changing environment involving interactions among a multitude of actors. An innovation system (specifically in the AM industry) is a complex system. Thus, the advantages offered by ABM make this method well suited to modelling the additive manufacturing ecosystem consisting of multiple agents interacting with each other and their environment.
- ABM does not require any knowledge or assumptions about higher level phenomena resulting from the agents’ activities; only individual-level behaviour is specified in the model. Since additive manufacturing is an emerging technology, little is known about the operating mechanisms of the additive manufacturing industry at the aggregate (industry or market) level. It is easier to describe the characteristics of individual actors than to create a causal description of the whole system. This makes ABM a natural choice of method for studying this field.
- ABM enables us to “move beyond a static snapshot of the system and toward a dynamic understanding of the system’s behaviour”, providing us with a “rich and detailed account of the process of a system’s unfolding in time, and not just the final state of the system” (Wilensky & Rand, 2015, p36). One key requirement of our model is that it should capture the dynamics of the web of crisscrossing IVCs. The ABM method fits well with this requirement.

3. Theory

This section describes the theoretical underpinnings for building a simulation model of webs of IVCs with focus on RRI. To reiterate, the purpose of this deliverable is practical: to translate the conceptual model described in D2.4 into the model description needed for implementing a concrete working simulation model that can handle simulation scenarios that are being developed.

Further adaptations are to be expected during the iterative implementation phase covered by other work packages. The IAMRRI model presented in this deliverable, however, serves as a general model that is anchored in the conceptual model of D2.4, compatible with the chosen modelling framework, and suitable for the iterative implementation phase described above.

Several very diverse theoretical domains inform this deliverable. As described below, some of these domains are studied and summarized in other deliverables, while others are task-specific and employed with concrete practical goals (rather than giving a full-scale theoretical analysis of these domains). The main theoretical underpinnings behind this deliverable relate to the following domains:

- The IVC and RRI literature in the context of the AM industry have been studied in detail, summarized, and discussed in D2.1. Thus, the current deliverable, D3.1, refers to these results and translates the theoretical concepts and relationships between them into concrete suggestions for how they may be applied in the computational model.
- Agent-based modelling is, in addition to being a specific method(ology), also a theoretical field. However, it is beyond the scope of this deliverable to go into a profound theoretical discussion of how ABM ontology and epistemology contrast with alternative views.
- There is a growing body of specific literature focusing on innovation simulation modelling. This literature is not described in previous deliverables, and therefore a considerable amount of effort is devoted to the relevant literature review in D3.1. A systematic literature review is outside of this deliverable's scope, so the review is done only for 1) the purposes of finding and selecting an 'off-the-shelf' model that is suitable for the IAMRRI project, and 2) for informing suggested adaptations to the aforementioned model so as to make it compatible with the model presented in D2.4.
- Modelling such a complex and dynamic socio-economic phenomenon as IVCs requires a combination of qualitative and quantitative approaches. How exactly it can be done in the general case remains a theoretical and methodological challenge. For example, Lenz-Cesar and Heshmati (2010) combined qualitative and quantitative data in an attempt to simulate the processes of cooperative R&D in the manufacturing sector of South Korea. While D3.1 is not fully able to describe how qualitative data will be used to inform the model due to the aforementioned restructuring of the qualitative data collection process in light of the Covid-19 crisis (see chapter 2), we leave comments throughout the document where WP4's qualitative data collection can prove especially useful. Chapter 6 also ends with a presentation of the initial data collection framework that will be fully developed in D3.2.

3.1 Literature review

In this section we describe the review process undertaken in order to create a solid overview of the innovation simulation literature as it pertains to the aims of the IAMRRI project. First, we focused on finding an 'off-the-shelf' framework or existing model that could be adapted for our purpose. There are many advantages to such an approach, for example, existing solutions have proven track records, the required development time is reduced, and the risk of making errors is lowered. For the criteria finally used to select the off-the-shelf solution, see the section "Evaluation criteria for adaptation candidates", p. 10. Second, the literature review served as a basis for making suggestions on model conceptualization, mechanisms, parameterization, and how other modelers have dealt with issues like the ones identified in the IAMRRI project. The solution we chose has been adapted for many other

public policy-oriented publications and projects. These adaptations served as a useful guide for our adaptations and can serve as guideposts for the team that will implement the model.

3.1.1 Literature search

We followed a three-pronged approach for our literature search: online database search, using publicly accessible and privately requested reference libraries of experienced modelers, and asking for input from the simulation community, especially those familiar with agent-based modelling and social simulation.

Online database search

We chose two online databases for our literature search: Scopus and Web of Science. These databases are commonly used and cover a large number, if not most, of the sources one would expect to find in an online literature search database.

In Table 1 below, the reader will find the search strings used in both databases and the number of publications found when performing these searches. The search strings were developed by the team with the aim of finding a middle way between searching too broadly, which would yield an unmanageable number of articles, and searching too narrowly, which would result in important publications being missed. In order to ascertain if being too narrow would be an issue, we checked if all the publications found through the other techniques described below could also be found in the broad search we performed. In many cases they were found by using our search strings. This is not to say the other techniques were superfluous: they were extremely valuable since these search engines are not suited for searching for suitable books, policy-oriented publications, project reports, unpublished or work-in-progress writings, conference papers, PhD theses, and similar. The reader will note that the number of publications is quite high for both searches. We were able to join these sets and remove duplicates, leading to fewer total results. See Figure 1 for an illustration (note that the

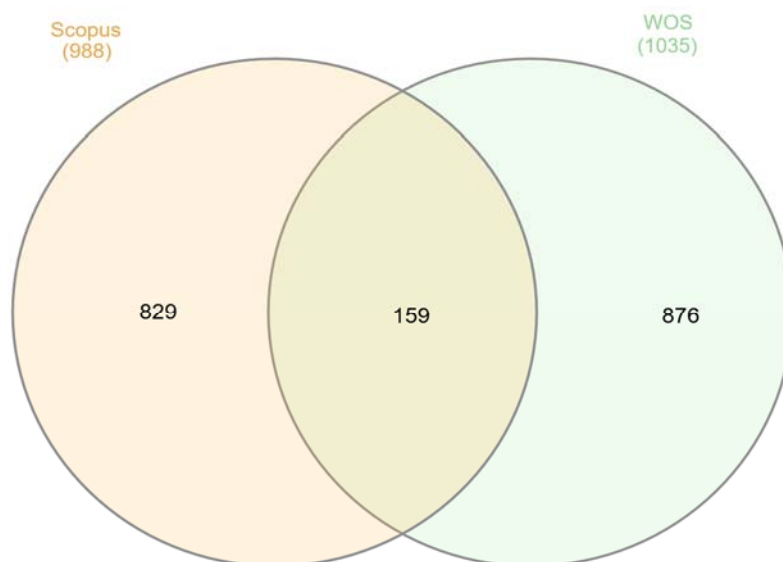


Figure 1 - Entry overlaps between Scopus and Web of Science

difference of 1 [989-988] in Scopus hits is due to a duplicate entry from the Scopus database that was excluded in the review but included in the table for transparency's sake). Firstly, all hits were screened and filtered according to their titles. This shed a great amount of articles that, for example, used simulations as to establish confidence intervals for non-parametric statistical inference, used to term simulation to refer to particular types of electronic entertainment, simulations in other fields—such as biology—that were included as they were cross-categorized into fields such as economics or management. Secondly,

abstracts were read as to gain a picture of whether the writing would contain useful models or other relevant information. This shed even more articles, leaving a manageable number of articles for the more extensive review.

Table 1 - Review search strings

Source	Search string	No. of publications
Scopus	KEY("innovation" AND ("simulation*" OR "ABM" OR "agent based*" OR "agent-based*" OR "MAS" OR "multi-agent system*" OR "multi agent system*")) AND (LIMIT-TO (SUBJAREA,"BUSI") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"DECI"))	989
Web of Science	TS=("innovation" AND ("simulation*" OR "ABM" OR "agent based*" OR "agent-based*" OR "MAS" OR "multi-agent system*" OR "multi agent system*")) AND WC=("ECONOMICS" OR "MANAGEMENT" OR "BUSINESS" OR "PUBLIC ADMINISTRATION" OR "POLITICAL SCIENCE" OR "SOCIAL SCIENCES MATHEMATICAL METHODS" OR "SOCIOLOGY" OR "COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS" OR "SOCIAL SCIENCES INTERDISCIPLINARY" OR "DEMOGRAPHY" OR "BUSINESS FINANCE" OR "BEHAVIORAL SCIENCES" OR "ENGINEERING MULTIDISCIPLINARY")	1035

Reference libraries

The second part of our three-pronged approach used both public and private reference libraries. The public libraries were either found through searching through public Zotero and Mendeley libraries, or overtly published libraries, such as the SKIN reference library at the SKIN webpage. The private libraries were found through soliciting our academic networks. While there was considerable overlap between these libraries and the online database search, the externally sourced reference libraries turned up 40 highly relevant entries, 10 of which were books and book chapters, 4 which were conference papers (several more conference papers were found, but all the relevant ones had later been published as papers were included in the review in lieu of the conference papers), and 2 of which were PhD theses.



Figure 2 - Entry overlaps between Scopus and Web of Science after filtering titles and abstracts

Input from the simulation community

The third part targeted members of the simulation community that would be able to provide insights into relevant models and publications. We primarily used our own professional networks during this phase. This resulted in 28 additional relevant publications. One of our Strategic Advisory Board members, Associate Professor Cristina Ponsiglione, has extensive experience with the model that we finally chose. Thus, we were able to, post model choice, further bolster our literature database used for our adaptation suggestions.

Literature search results

These searches provided us with 383 number of unique hits. They were reviewed according to the process described below.

3.1.2 Literature review process

During the following review process, we developed a review table in a spreadsheet format. The review table was inspired by Paredes-Frigolett & Pyka (2017), but quickly evolved throughout the review process. The evolution had a controlled start in the sense that four of our team members coded a selection of publications (40 coding results over 10 papers) within the boundaries of the source of inspiration mentioned above. We found several more features that we deemed were necessary in order to make an informed choice about which model would be most suitable for direct adaptation or inspiration for our final model. This process was repeated several times throughout the process when team members realized that we had overlooked crucial features during the template creation and earlier iterations. While this led to considerable extra work as some of the already reviewed works had to be revisited, it allowed for an holistic review template that ended up being very well suited for our purpose despite it being very different from the one we envisioned from the onset of the coding process.

While the review table went through several iterations, the rest of the review process followed a linear approach—Figure 3 illustrates the process in flowchart form, following the illustration presented in D2.1, p10. First, we screened the publications' abstracts or equivalent, e.g., introduction for theses and whole books, introductory sub-chapters for books structured around chapter specific topics and research, and so on. This reduced the number of relevant works considerably, resulting in 154 works. Next, the full text of those works we did not have at hand were searched for. In some cases, these were difficult or impossible to find either due to confidentiality issues (an issue mostly for theses and dissertations) or that they were simply not published in any open or non-open website. This was most

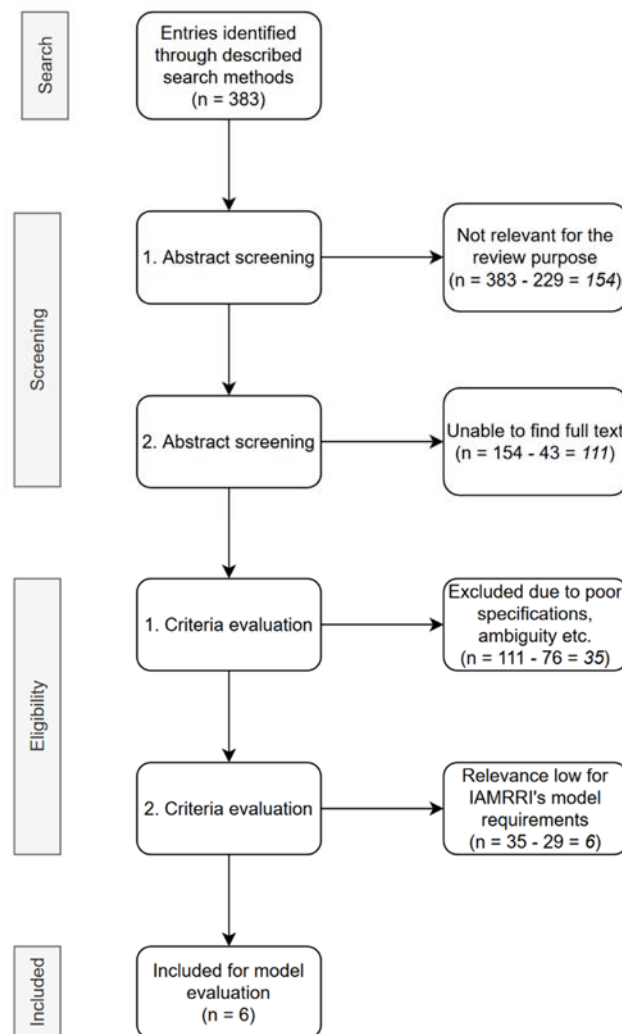


Figure 3 - Review process flowchart

often the case for works that were found in public and private reference libraries. In the end, 43 number of texts were impossible to find throughout our full text search.

The remaining 111 texts were then reviewed by two members of the team. While one reviewer had the main responsibility for the text they were assigned, all the texts and reviews were checked by both members as to make sure that there were no obvious misunderstandings or errors during the review process.

Once this process was completed, we filtered the works according to the criteria described below. Finally, we were left with six model candidates that were most suitable to adapt for the purposes of the IAMRRI project. While these are the most salient candidates, many of the others provided useful insights and inspiration for our adaptations. They are referenced in the adaptation text where appropriate.

3.2 Evaluation criteria for adaptation candidates

In this section we describe several models we identified as potential candidates for adaptation to the IAMRRI project. Before we started the review process, we established a set of criteria aimed at identifying the models that would be most useful and would lead to the least amount of implementation headaches and associated project delays. The reader will find the criteria below, in Table 2. These criteria are mostly derived from extensive experience with software development and our experience with modelling. In other words, they are professional judgements on criteria that, if taken into consideration, will lead to higher quality software models and lower likelihood of unforeseen implementation delays.

Table 2 - Model selection criteria

Criteria domain	Criteria
Technical criteria	Open source
	Permissible, open, license
	Well-documented (code-wise)
	High quality implementation
Relevance criteria	Simulation of innovation
	Simulation of networks
	Simulation of IVCs
	Simulation of organizations as agents
	Simulation of RRI
Adaptability	Source code amenable to modification
	Model amenable to modification
Track record	No. peer-reviewed publications in the past
	No. policy-oriented publications (incl. reports) in the past
	Solid grounding in best-practice
Commensurability with conceptual model	-

3.2.1 Technical criteria

In this section we describe the technical criteria used in order to evaluate the models considered for adaptation. By technical criteria we mean criteria related to the model outside of the modelling job at

hand. This includes whether the source code of the model is open source, it has a permissible, open license (some open source software is only open in the sense of being allowed to read, while others have specific requirements regarding modification), the code is well documented, and that the implementation is of high quality. Below we expand on why these criteria are important.

Open source

The model being open source has several advantages: it is possible to examine if one understands the textual description of the model in the same way as the authors do, i.e., a textual description might have several possible interpretations, but source code can only be understood in one specific way (disregarding undefined implementation specific behaviours, something that is not a concern in this case). Having the source code available, can, assuming the license is permissible enough, drastically reduce the time needed for implementing a model. The saved time can be spent searching for logical errors, i.e., software bugs, and building extensions instead of implementing the same model yet again.

Permissible, open, license

While having an open source model is beneficial, it should also have a permissible, open, license if it is to be useful as a foundation for modification. If it does not have such a license, one would be in breach of the license if one were to take the open source model and change it without explicit permission by the rights owners. Typically, software with permissible licenses are also more likely to be co-developed with others since modifications are welcome. This can lead to higher quality software.

Well-documented (code-wise)

Complex models in particular should have thorough and updated documentation so that complex algorithms can more easily be understood, and, perhaps more importantly in this context, so that one can find publications that describe the algorithms used. This is important so that one is sure to cite the authors of the original work, and so that one can understand the foundations on which the algorithms are founded.

High quality implementation

While the above criteria are useful, the implementation quality is also important. By implementation quality, we primarily mean how easy it is to follow the structure and flow of the source code, whether good software design principles are being followed, e.g., avoiding global state that can change at any moment, resulting in code that is difficult to debug and understand. While some popular simulation software tools make it difficult to follow these principles, software developers can still, to a large extent, help the situation by carefully structuring and documenting their code so that, e.g., changes to global state is done in a controlled and well-defined manner. It goes without saying that in order for it to be possible to make an evaluation on implementation quality, the source code must be available.

3.2.2 Relevance criteria

In this section we describe the criteria related to the relevance of the model regarding the aims of the IAMRRI project. These criteria focus on whether the models have commensurable ‘grand’ mechanisms, i.e., innovation, networks, IVCs, organizational agents, and RRI. In some cases, the mechanisms use different terms, but are still relevant in content. For example, Schlaile et al. (2018), use the term Responsible Innovation instead of Responsible Research and Innovation, and introduce market demand mechanisms that represent a form of public engagement, but without being named that way. Such a model would still be of relevance in terms of RRI.

3.2.3 Adaptability

These criteria are closely related to the technical criteria, but differ in important ways:

Source code amenable to modification

In many cases, source code is open source, has a permissible license, well documented, and has a high-quality implementation, but is still very difficult to modify. This is typically the case in software that has complex dependencies where changes in one part of the source code would lead to drastic implications in other parts. While this is certainly related to the quality of the implementation, in some cases this is an unavoidable consequence of the phenomena being modelled. If this is the case, the model is probably not very useful for the IAMRRI project if the model is not already a very good fit for the project's goals.

Model amenable to modification

Highly related to the above, this relates to the complexity of the conceptual model itself. In some cases, the model is itself extremely complex, or it contains fundamental concepts that are incommensurable with the phenomena one is trying to model. For example, using the SKIN model as an example, if the conceptual understanding of knowledge in a theory that one is trying to create a model for is fundamentally incompatible with the kene concept (see chapter 4 and 6 for a description and example of kenes), the model is not easily amenable to modification, even if the source code is.

3.2.4 Track record

These criteria reflect the extent to which the model has been in active use or development. While this is not a perfect criterion for quality, it does show that others have been successful at using the model for research in the past. This can serve as a proxy for the likelihood of success. Other publications also serve as useful guideposts of which modifications can be successfully implemented, and whether the model has been useful in the past for a particular outcome domain, e.g., policy-oriented research.

3.2.5 Commensurability with conceptual model

Finally, and most important of all, is whether the model provides a good fit with the conceptual model of which the simulation model is supposed to be a representation of. Without this criterion being satisfied, especially if the above criteria are not satisfied, the model is unlikely to be of use to fulfil the goals of the IAMRRI project.

Unterhalb, in Table 3 the reader will find the models deemed to be most relevant. While only one of them are chosen as the foundation for the IAMRRI model, several of them proved to be useful for the suggested extensions. This is reasonable since they were chosen to be part of the table partially because they were deemed to be the best candidates for the IAMRRI model.

Table 3(a) - Model selection candidates; asterisk indicates missing information; parentheses indicates partial coverage—both are expanded upon in the text below.

Models

Criteria domain	Criteria	SKIN	Buchman & Pyka (2013) [Siena]	Schlaile et al. (2018)
Technical criteria	Open source	x	x*	-
	Permissible, open, license	x	x*	-
	Well-documented (code-wise)	x	x*	-
	High quality implementation	x	x*	-
Relevance criteria	Simulation of innovation	x	(x)	x
	Simulation of networks	x	x*	-
	Simulation of IVCs	-	-	-
	Simulation of organizations as agents	x	-	(x)
	Simulation of RRI	(x)	-	(x)
Adaptability	Source code amenable to modification	x	x*	-
	Model amenable to modification	(x)	-	-
Track record	No. peer-reviewed publications in the past	Many	Many	None
	No. policy-oriented publications (incl. reports) in the past	Many	Few	None
	Solid grounding in best-practice	Yes	Yes	Yes
Commensurability with conceptual model	-	High	Medium	Low

Table 3 (b) - Model selection candidates; asterisk indicates missing information; parentheses indicates partial coverage—both are expanded upon in the text below.

Models

Criteria domain	Criteria	Sebastiano et al. (2010)	Landoli et al. (2012)	Tur & Azagra-Caro (2018)
Technical criteria	Open source	-	-	-
	Permissible, open, license	-	-	-
	Well-documented (code-wise)	-	-	-
	High quality implementation	-	-	-
Relevance criteria	Simulation of innovation	-	-	-
	Simulation of networks	(x)	x	x
	Simulation of IVCs	-	-	-
	Simulation of organizations as agents	-	(x)	x
	Simulation of RRI	-	-	-
Adaptability	Source code amenable to modification	-	-	-
	Model amenable to modification	-	-	-
Track record	No. peer-reviewed publications in the past	Few	None	None (new paper)
	No. policy-oriented publications (incl. reports) in the past	None	None	None (new paper)
	Solid grounding in best-practice	Yes	Yes*	Yes
Commensurability with conceptual model		Low	Low	Medium

3.3 Discussion of our choice and how we relate to existing models

We chose to use SKIN as the basis for the simulation model in the IAMRRI project. Below we go through the same criteria above and explain our reasoning behind the choice.

3.3.1 Technical criteria

Open source

Only two of the models we found to be most relevant for the purposes of the IAMRRI project had available source code. It's important to note that while the source code for Buchman and Pyka (2013) is at least partially available as a package for the R programming language², it was difficult to ascertain if any modifications or additions were made to the original source code of the model.

This makes SKIN the obvious choice in terms of source code availability.

Permissible, open, license

This criterion is only applicable to the two models presented in the section above. Both SKIN and the R package used by Buchman and Pyka (2013) have permissible open licenses, but it is difficult to ascertain if this is true of any adaptations made by Buchman and Pyka (2013).

This makes SKIN the choice in terms of licensing issues.

Well-documented (code-wise)

The SKIN source code has excellent documentation within the source code itself and a detailed log of changes and bug fixes that have been made over the years. The R package used by Buchman and Pyka (2013) share these characteristics, but the same caveats as mentioned above exists.

This makes SKIN the choice in terms of well-documented code.

High quality implementation

Both implementations are of high quality. The comments on any adaptations in Buchman and Pyka (2013) still applies.

This makes SKIN the choice in terms of implementation quality.

3.3.2 Relevance criteria

Three of the models simulate innovation, at least in a way that is commensurable with how innovation is understood in the IAMRRI project.

3.3.3 Adaptability

Source code amenable to modification

SKIN is implemented using NetLogo³, a Domain Specific Programming language (DSL), aimed at writing agent-based simulations. R is a general-purpose programming language that has a very strong feature set aimed at doing statistical and scientific computing. While both are well-proven programming languages for writing simulations, our team has more experience with NetLogo, making SKIN the preferred choice.

Model amenable to modification

While the SKIN model has some concepts that may be challenging to adapt to the IAMRRI project, where the most challenging are timing issues, it has the most useful model primitives and to our

² <https://www.r-project.org/>

³ <https://ccl.northwestern.edu/netlogo/>

understanding none of the concepts in the SKIN model are fundamentally incompatible with the IAMRRI project.

3.3.4 Track record

In terms of having an extensive track record in both academic and policy-oriented publications, SKIN is the obvious option. It has also been used in other H2020 projects illustrating the usefulness of SKIN for public policy-oriented studies. It is also the only one of the models that have been used for studying responsibility in innovation in relation to policy⁴. While the project that employed SKIN for this purpose had a different purpose than the IAMRRI project, it does illustrate that there is a potential for adapting SKIN to study RRI. While the other study that focuses on responsibility in innovation, Schaile et al. (2018), does not implement a notion of networks, it has interesting and highly relevant mechanisms on product features, including their potentially harmful nature and market reactions to them. These concepts have inspired some of our adaptations.

In sum, SKIN has the best track record as it pertains to the aims of the IAMRRI project.

3.3.5 Commensurability with conceptual model

While SKIN lacks a notion of IVCs, we nevertheless found it to be the most commensurable model to the conceptual model presented in D2.4 compared with the 5 others. However, as mentioned in the previous section, Schaile et al. (2018) provided some particularly useful insights on product features and market demand. Below, in the description of the SKIN model, we have paid special attention to the areas of the original SKIN model that are related to our adaptations. In other words, this reading should be considered complementary to dedicated SKIN papers (Gilbert et al., 2001, e.g., 2007).

3.4 Summary of model choice

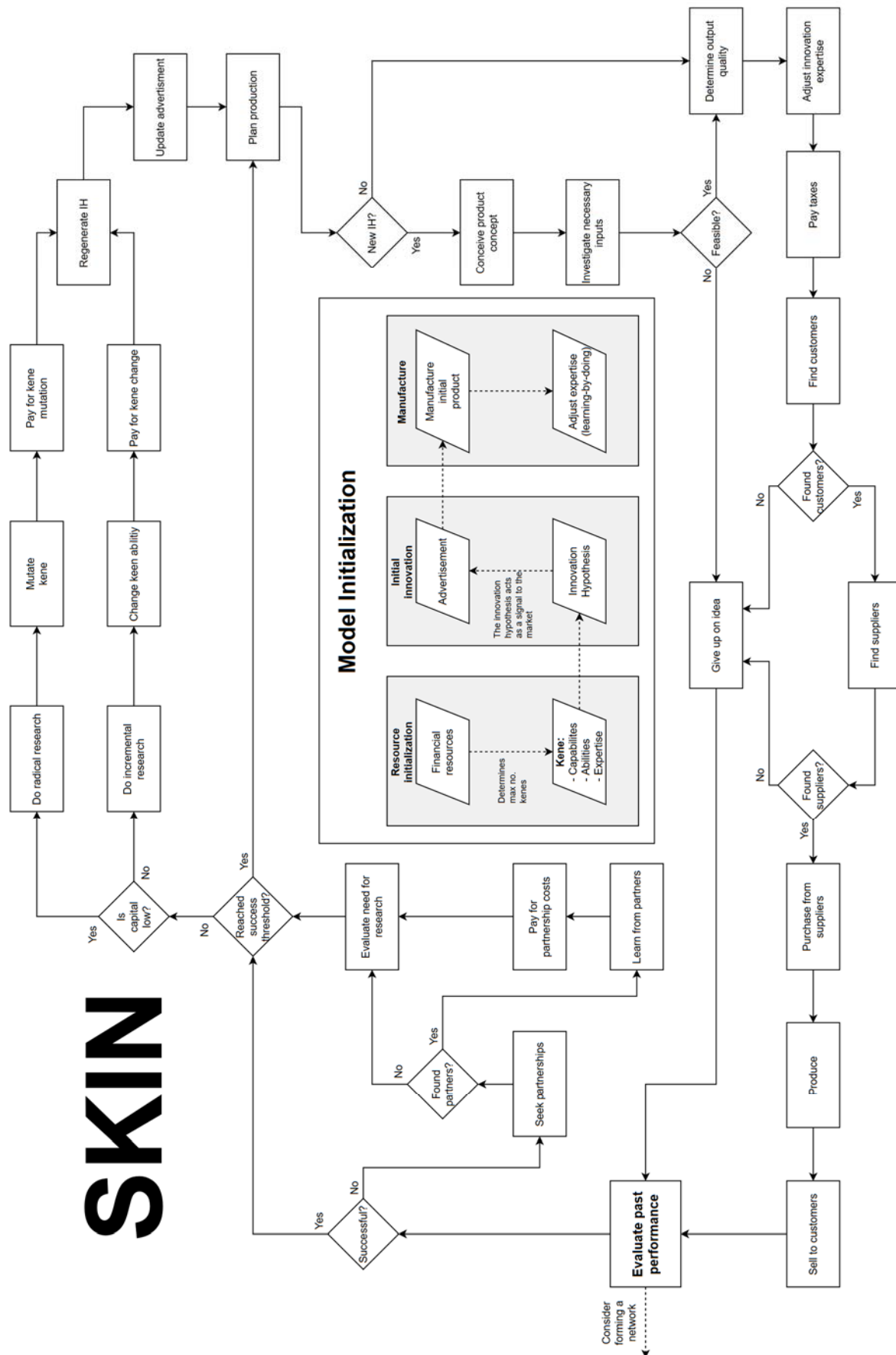
While the six models presented in Table 3 oben were relevant to some degree, SKIN was found to be the most relevant across most categories. The source code availability is a particular strength of the SKIN model as it is possible to verify and study the source code in order to make sure that our understanding is in line with that of the SKIN authors and other users. It also makes adaptations far easier, as well as dissemination to the innovation simulation community once the model has been implemented. Also, SKIN has an excellent track record for both academic and policy-oriented research. Finally, as stated in the acknowledgements, we were able to use a highly skilled member of the project's Strategic Advisory Board who has extensive SKIN experience as an informal reviewer before finalizing this deliverable.

4. Description of SKIN

SKIN is a multi-agent model of innovation networks in knowledge-intensive industries grounded in empirical research and theoretical frameworks from innovation economics and economic sociology. The agents represent innovative firms who try to sell their newly developed products to other agents and end users but who also have to buy raw materials or more sophisticated inputs from other agents (or material suppliers) in order to produce their outputs. This basic model of a market is extended with a representation of the knowledge dynamics in and between the firms. Each firm tries to improve its innovation performance and its sales by improving its knowledge base through adaptation to user needs, incremental or radical learning, and co-operation and networking with other agents.

The following description is complementary to other publications on SKIN and is structured in such a way that the adaptations following in "Description of IAMRRI SKIN extensions", p25, can be readily understood in relation to the original SKIN model. The flowchart on the next page describes the original SKIN model:

⁴ <https://cordis.europa.eu/project/id/321480>



In addition to the papers describing SKIN (Ahrweiler, 2017; Ahrweiler, Gilbert, et al., 2011; Gilbert et al., 2001, 2007; Pyka et al., 2007), one of the available SKIN code bases was reviewed in detail (the default SKIN model). The overview of the main procedures and their call hierarchy is presented in Figure 5 below:

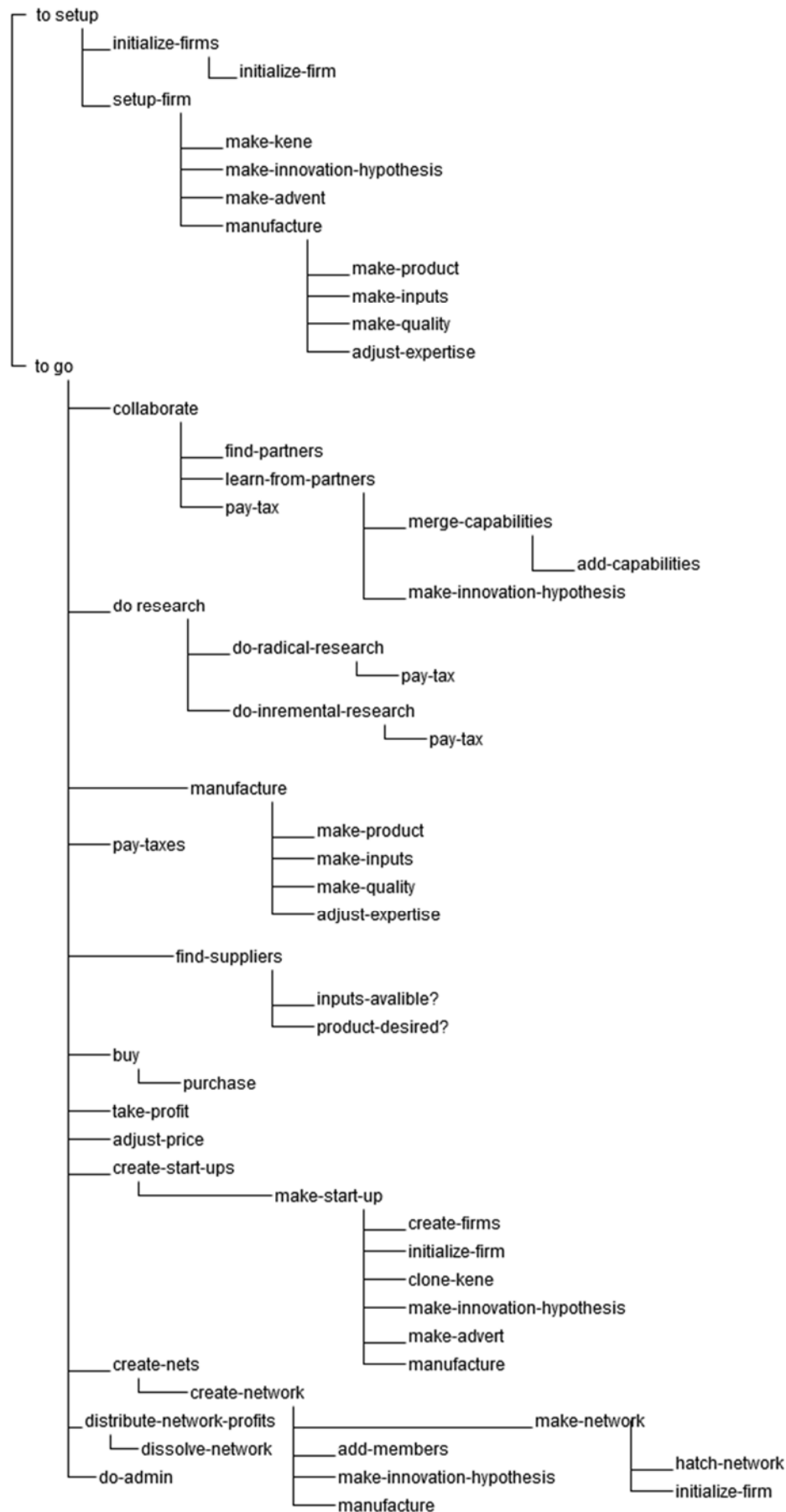


Figure 5 - Function call hierarchy of the SKIN model

4.1 Model and agent initialization

A SKIN agent begins its lifetime during the initial model initialization phase. The agent is given a set amount of resources at its disposal. This amount is equal among all agents by default, but the model also supports toggling a flag that creates some firms larger than others (10 times larger in terms of initial capital) at the beginning of the model.

The agents are endowed with a ‘kene’. Conceptually, an agent’s kene represents the agent’s knowledge base. More concretely, an agent’s kene is composed of a set (large or small) of distinct *knowledge units*. The knowledge units which together form the agent’s kene all share the same basic structure. Each knowledge unit can be broken down into three component parts:

- (1) A *capability*. This denotes a broad technological or scientific domain that is relevant to the agent’s economic activities. To draw an example from the additive manufacturing industry, the capability could be “AM materials”. By itself, the presence of this capability in one of the agent’s units of knowledge does not denote that the agent is especially good at this capability.
- (2) An *ability*. This refers to a more specific skill related to the previously listed capability – say, “Ceramics”. Again, the presence of the combination of AM materials and Ceramics in the unit of knowledge does not indicate that the agent is very good at either.
- (3) A level of *expertise*. This final component indicates the agent’s level of skill with regard to the capability-ability combo given above. In our example, the agent’s expertise with respect to the AM materials/Ceramics combination might be, for example, “low”, “high”, “medium”, or “medium-to-high”.

Below the reader will find a that contrasts several examples of what a kene may consist of, showing in more detail the possible relationships among capabilities, abilities, and expertise.

Since a kene consists of several capability-ability-expertise triads, it is often sensible to represent it in matrix form:

$$\begin{bmatrix} C_1 & C_2 & C_3 \\ A_1 & A_2 & A_3 \\ E_1 & E_2 & E_3 \end{bmatrix}$$

In this example, the agent’s kene consists of three capability-ability-expertise triads. While these triads consist of integer values in practice, their allowed ranges can be tuned to allow for combinations that fit with particular contexts. The table below illustrates how the kene concept can be implemented in the context the AM industry.

Table 4- Kene conceptualization in the AM industry and example in implementation

Conceptual (kene)				
	Agent type	Capability	Ability	Expertise
Kene	AM Tech. Company	Machine	Engineering	High
	AM Tech. Company	AM tech.	Laser	High
	AM Tech. Company	Materials	Ceramics	Low-Mid
	AM Tech. Company	Materials	Metals	Low-Mid
	AM Tech. Company	Electronics	Design	Mid
	AM Tech. Company	Electronics	Programming	Low-Mid
	AM Tech. Company	Control SW	Programming	Low-Mid
	AM Tech. Company	Business	Strategy	Mid-High
	AM Tech. Company	IPR	Patenting	Low

Implementation (kene)				
	Agent type	Capability	Ability	Expertise
Kene	1	1	1	5
	1	2	2	5
	1	3	3	2
	1	3	4	2
	1	4	5	3
	1	4	6	2
	1	5	6	2
	1	6	7	4
	1	7	8	1

The financial resources of the firm limit the individual agent's number of available capabilities, abilities, and areas of expertise. The length of the kene is defined by the capital of the firm but cannot be less than 5 triples. The length is proportional to the log of $1 + \text{capital} / \text{capital-knowledge-ratio}$ (20 by default, measured as kene length divided by capital). After the resource initialization phase, the agents create an 'innovation hypothesis' (IH). This innovation hypothesis is a direct consequence of the organizations' kenes and a search through what one could call an 'opportunity landscape'. An innovation hypothesis is a vector of locations in the kene. So, for example, an IH might be [1 3 4 7], meaning the second (counting from 0 as the first), fourth, fifth and eighth triple in the kene. The IH cannot be longer than the length of the kene, nor shorter than 2, but is of random length between these limits. When the innovation hypothesis has been created, the firm creates an 'advertisement.' This advertisement can be understood as a signal to other organizations that will be read when other organizations are searching for partners for partnerships in the future.

The third and last phase of the agent initialization starts with when the agents produce a good based on the innovation hypothesis. The number of inputs (ingredients) required for the product derived from this IH. Then firms adjust their expertise upwards as they have gained experience in producing the specific product. Expertise level is adjusted downwards for unused capabilities. If the customer is an end user, the income from a sale of the product is fixed at 'final-price', otherwise the price is set to random. The quality of a firm's product is computed from the abilities and expertise in its innovation hypothesis. Note that in the base SKIN flowchart shown in Figure 4, the model starts in the 'Evaluate performance' box and does a check whether the firm is successful. During the first step of the model, this stage is effectively skipped. This makes sense, as the agents have not yet put their product on the market in the 'normal logic' of the model. This is not in conflict with the conceptual understanding of the model in publications (Pyka et al., 2007, 2001)—it is simply an implementation artifact that is nevertheless important for the primary audience of this deliverable: the implementation team in WP3 and WP5.

4.2 Agents during model execution

4.2.1 Evaluation of past performance

After initialization, the agents start their actions by making a judgment of past performance. If this is the first step of the model, i.e., the agents have just been initialized. The model is designed so that the agents will immediately put their product on the market. During any round following the first one, the agents will decide of whether they were successful in selling a product during the previous round. If a firm's previous innovation has been successful, i.e. it has found buyers, the firm will continue selling the same product in the next round, possibly at a different price depending on the demand it has experienced.

However, if there were no sales, the firm considers that it is time for change. If the firm still has enough capital, it will carry out "**incremental**" **research** (R&D in the firm's labs). Performing incremental research means that a firm tries to improve its product by altering one of the abilities chosen from the triples in its innovation hypothesis, while sticking to its focal capabilities. The ability in each triple is considered to be a point in the respective capability's action space. To move in the action space means to go up or down by an increment, thus allowing for two possible "research directions".

Alternatively, firms can radically change their capabilities in order to meet completely different client requirements (innovative learning, **radical learning**). A SKIN firm agent under serious pressure and in danger of going bankrupt will turn to more radical measures, by exploring a completely different area of market opportunities. In the model, an agent under financial pressure turns to a new innovation hypothesis after first "inventing" a new capability for its kene. This is done by randomly replacing a capability in the kene with a new one and then generating a new innovation hypothesis.

4.2.2 Decide whether to form a network

During the first step of the run, the agents make up their mind on whether they should try to establish a **network**. A network in this context can be understood as a hybrid between a corporate spin-off (a firm that is based on another firm but is incorporated as its own entity outside the organizational hierarchy—that is, spin-offs are not simply a different business unit) and a joint venture. Networks, in contrast to partnerships, are persistent and can involve more than two actors. The organization will search among its previous partners (see below) and ask them if they want to join the network. If the network is formed, the network exists as its own corporate entity, acting just the same way as other firms in most respect. Network formation can increase the firms profits because the network will try to create innovations as an autonomous agent in addition to those created by its members and will distribute any rewards back to its members who, in the meantime, can continue with their own attempts, thus providing a double chance for profits. Networks are "normal" agents, i.e. they get the same amount of initial capital as other firms and can engage in all the activities available to other firms. The kene of a network is the union of the triples from the innovation hypotheses of all its participants. If a network is successful it will distribute any earnings above the amount of the initial capital to its members; if it fails and becomes bankrupt, it will be dissolved.

4.2.3 No sale during previous round

In cases where the agents were unable to sell any product in the previous round, they will seek out bilateral **partnerships** with other firms, attempting to learn useful capabilities from their partners.

This capability (and its ability) is added to the firm's kene (if it has sufficient capital). The relevant expertise level is set to 1 less. For each capability that is not new, if the other's expertise level is greater than it is of the firm, its ability and expertise level is adopted. It is important to note that the partnerships in the original SKIN model has this knowledge exchange as its sole purpose: this partnership does not entail any e.g., cooperation in making a new product. It is during this behaviour, the advertisement described in the model initialization phase comes into play as it represents the organizations' current focus, both in terms of focus, but also expertise development. The SKIN model offers an option to change whether organizations should seek out agents that are similar or dissimilar to themselves (conservative v. progressive strategy). Both strategies involve comparing the firm's own capabilities as used in its innovation hypothesis and the possible partner's capabilities as seen in its advertisement. Applying the conservative strategy, a firm will be attracted to a partner that has similar capabilities; using a progressive strategy the attraction is based on the difference between the capability sets. The decision whether and with whom to co-operate is based on the mutual observations of the firms, which estimate the chances and requirements coming from competitors, possible and past partners, and clients. In the SKIN model, a marketing feature provides the information that a firm can gather about other agents: to advertise its product, a firm publishes the capabilities used in its innovation hypothesis. Those capabilities not included in its innovation hypothesis and thus in its product are not visible externally and cannot be used to select the firm as a partner. The firm's "advertisement" is then the basis for decisions by other firms to form or reject co-operative arrangements.

To find a partner, the firm will look at previous partners first, then at its suppliers, customers and finally at all others. If there is a firm sufficiently attractive according to the chosen search strategy (i.e. with attractiveness above the "attractiveness threshold"), it will stop its search and offer a partnership. If the potential partner wishes to return the partnership offer, the partnership is set up.

The model assumes that partners learn only about the knowledge being actively used by the other agent. Thus, to learn from a partner, a firm will add the triples of the partner's innovation hypothesis to its own. For capabilities that are new to it, the expertise levels of the triples taken from the partner are reduced in order to mirror the difficulty of integrating external knowledge as stated in empirical learning research. For partner's capabilities that are already known to it, if the partner has a higher expertise level, the firm will drop its own triple in favour of the partner's one; if the expertise level of a similar triple is lower, the firm will stick to its own version. Once the knowledge transfer has been

completed, each firm continues to produce its own product, possibly with greater expertise as a result of acquiring skills from its partner.

If the firm finds a partner, it pays a “tax”. This fee is not directed at any particular agent or the model itself: it merely represents the costs involved in forming such a partnership and the resources spent during the learning activity.

4.2.4 Evaluation of success threshold

Even if the agents were able to make sales in the previous round, they might be dissatisfied with the absolute value of that success (i.e. their financial performance). If the agents are satisfied with their performance, they will simply plan their production for the next round. If not, they will decide that they must change their product through **research**.

4.2.5 Is the organization under financial duress?

In cases where the organization has decided that they have not been able to reach their success threshold they will decide on whether they are in extreme duress. In this context, this entails having a low stock of capital. If yes (and enabled in the model—this feature can be disabled), they will perform **radical research**. The radical research will result in a mutated kene, including new capabilities, making their innovation hypothesis substantially different. This mutation incurs a cost on the organization. In cases where the organization is not in extreme peril, i.e., their capital stock is not below the threshold, the organization will instead change their kene to a lesser extent (**incremental research**), i.e. only abilities are changed. This change also incurs a cost. In both cases, this research leads to the organization to regenerate their innovation hypothesis and therefore their product and the associated advertisement.

4.2.6 Plan production and feasibility analysis

The next action of the agent is to plan their production. If the agent has generated a new innovation hypothesis, the agents will determine whether the resulting product is feasible to produce. At this stage the price for a new product is set: if the customer is an end user, the income from a sale of the product is fixed at 'final-price', otherwise the price is set to random. This stage also involves making a judgment on whether the necessary inputs can convincingly exist at all (this judgment is based on an evaluation of the kene parts necessary for the production). If the product is determined to be unfeasible to produce at all, the organization will give up on the product and end its turn. If the agents have not changed their innovation hypothesis since the last turn, or they have decided that the product is feasible, they will go on to determine the products quality.

4.2.7 Determine quality and learning by doing

The quality of a firm's product is computed from the abilities and expertise in its innovation hypothesis. Manufacturing affects the expertise level of the kene parts involved in the production. In short, the higher levels of expertise the organization has in the kene parts related to the production of their product, the higher quality of product they will produce. This quality in turn affects how buyers perceive their product in cases where several actors are selling complementary products similarly priced. During this process, the firm 'learns by doing.' The expertise level increase for the capabilities used and decrease for unused capabilities. If an expertise level has dropped to zero, the capability is forgotten. It is important to note that even if this learning occurs a cost to the learning organization, this cost is not associated with the production itself. For the production to take place, the necessary inputs and customers must be found in the market.

4.2.8 Finding customers and suppliers

This is the first step where the market comes into play. In iterative elimination rounds the model prunes agents that are unable to find customers and suppliers in the market. While all this is done as the model runs this algorithm, we can conceptually understand this as process where the agents

attempt to find customers for their product. If they are unable to do so, they give up on the idea and the current round. If they can find customers, they will attempt to find suppliers of the inputs necessary for producing their product. If they are unable to do so, they also give up on the idea and the current round.

4.2.9 Found both customers and suppliers

In cases where the organization can find both customers and suppliers, they will purchase inputs, produce, and sell. The amount of firm's capital increase by the total sale and the costs are subtracted. This will lead to a profit that is retained within the firm. As a respond to market conditions the price of the product is adjusted: If in the last round the product is sold to more than 4 customers, the price increases by 10%. If there were no buyers, the price is reduced by 10%.

4.2.10 Start-ups

If a sector is successful, new firms will be attracted into it. This is modelled by adding a new firm to the population when any existing firm makes a substantial profit. The new firm is a clone of the successful firm, but with its kene triples restricted to those in the successful firm's advertisement and these having a low expertise level. This models a new firm copying the characteristics of those seen to be successful in the market. As with all firms, the kene may also be restricted because the initial capital of a start-up is limited and may not be sufficient to support the copying of the whole of the successful firm's innovation hypothesis.

At this stage, the round is finished. In the next round the agents again do an evaluation of past performance, and so on.

5. Description of IAMRRI SKIN extensions

In this section we describe extensions to the SKIN model so that it will fit the aim of the IAMRRI project. First, we describe the concepts introduced in the adaptations, then we describe the 'flow' of the model. The flowcharts presented in Figure 6 through Figure 12 are useful companions throughout this section.

5.1 Model and agent initialization

A SKIN agent begins its lifetime during the initial model initialization phase. Here we describe changes to the original SKIN initiation procedure. The agent is given a set amount of resources at its disposal. This amount is equal among all agents by default, but the model also supports toggling a flag that creates some firms larger than others (10 times larger in terms of initial capital in the original SKIN⁵) at the beginning of the model. In addition, agents are assigned to one of the types (AM technology firms, banks etc. described above). The number of companies in each type is to be specified. Each agent has a set of 4 RRI variables with (semi)random values reflecting the mean differences between the types of agents. The agents are endowed with a 'kene' (see description box). The financial resources of the firm limit the individual agent's number of available capabilities, abilities, and areas of expertise. Kenes are distributed considering the type of agents and the role it may play in an IVC. After the resource initialization phase, the agents create an 'innovation hypothesis'. This innovation hypothesis is a direct consequence of the organizations' kenens and a search through what one could call an 'opportunity landscape'. When the innovation hypothesis has been created, the firm creates an 'advertisement.' This advertisement can be understood as a signal to other organizations that will be read when other organizations are searching for partners for partnerships in the future. The third and last phase of the agent initialization starts with when the agents produce a good based on the innovation hypothesis, and then adjust their expertise upwards as they have gained experience in producing the specific product. Note that in the flowchart showing the changes to the base SKIN model (Figure 6), the model

⁵ This and some other values are given in the original skin model. We do not know if the exact value is based on empirical studies or just a random value that passes the calibration procedure.

starts in the 'Evaluate performance' box and does a check whether the firm is successful. During the first step of the model, this stage is effectively skipped. This makes sense, as the agents have not yet put their product on the market in the 'normal logic' of the model. This is not in conflict with the conceptual understanding of the model (Pyka et al., 2007, 2001), it is simply an implementation artifact that is nevertheless important for the primary audience of this deliverable: the implementation team in WP3 and WP5.

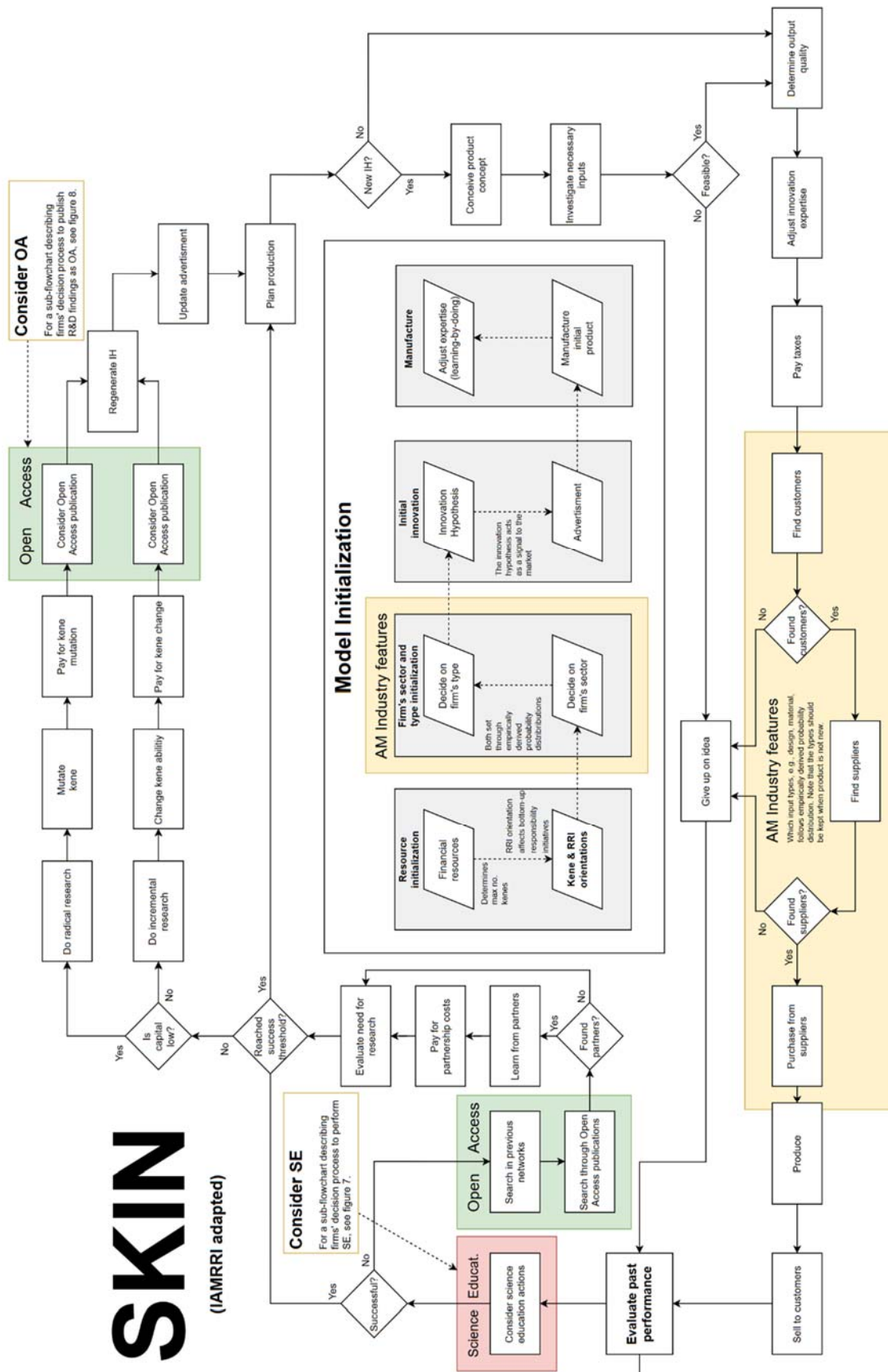


Figure 6 - Base SKIN model adapted to IAMRRI

5.2 Double industry model

Since there are knowledge exchange paths between the two industries in this study, they should not be studied in isolation. While base-SKIN does not currently support this functionality, it can easily be implemented by, e.g., a two bit bit-field where [01] = MI (medical industry), [10] = AI (automotive industry), and [11] = BA (broker agent). When an IVC is forming in either industry, eligible members would be excluded if they belong in the opposing group (an [01] chain would exclude any [10] firm but include [11] firms). By broker agent we mean the agents that represent the paths between the two industries. What separate them from firms in the MI and AI industries is that their knowledge and outputs are useful to both MI and AI. An example of this would be a material that could be used in both a widget used in car manufacturing, but also in the production of medical implants. Another example would be software that controls machines used in manufacturing. In some cases, this could even extend to the machines themselves.

This extension to SKIN opens many interesting opportunities for examining knowledge transfer between the two industries, and how this can be stimulated. It is then possible to get a better understanding of, for example, how RRI initiatives in one industry can have ripple effects in the other.

The double industry model has another consequence. As discussed in the section starting on page 28, we suggest that agents may take it upon themselves to internalize externalities tied to behaving in a responsible way. (Also see the associated discussion on funding.) If carrying this burden leads to more ‘societally beneficial’ products getting to the market, this is likely to improve the public’s perception of the technology, leading to spill over effects.

The same is true for another suggested extension that involves agents supporting science education initiatives targeted at youths and students. At its core, the extension accounts for the costs, and opportunity costs, involved in undertaking such efforts, and the delayed positive effect targeted at the industry.

In other words, there are likely complex interaction effects at play that the model will help elucidate.

5.3 Workforce capacity

At the IAMRRI Workshops, AM industry partners highlighted the difficulty of recruiting engineers and other staff with a high level of AM-related expertise. Since AM is a young, comparatively little-known industry with few educational programs devoted to it, the supply of qualified staff is limited, which creates a barrier to growth. Some of the industry partners mentioned that the only way for them to stimulate education in AM was to participate in such educational efforts directly, e.g. as guest lecturers. From the perspective of IAMRRI, this observation is significant because science education is an RRI key⁶; it appears that at least some AM industry actors have a strong motive for practicing this aspect of RRI. However, WP4 will collect more data to clarify the role of industry actors in science education. For now, we suggest that as AM industry actors participate in science education, the work force available to the AM industry increases.

5.4 RRI: Societal benefits, ethics, science education, open access, funding, governance, and public engagement

In this section we describe several extensions that must be considered together in order to understand the extension’s underpinning logic. The section describes an interplay between organizations taking societal responsibility themselves (in essence bottom-up RRI) and thereby internalize externalities or costs that does not yield them immediate benefit, delayed positive effects of this internalization, and the role of public funding as a catalyst or inhibitor in this process (in essence top-down RRI).

⁶ For further explanations see <https://www.rri-tools.eu/about-rri>

5.4.1 Proxies for RRI keys

Deliverable 2.4 describes 6 RRI keys and, based on consultation with industrial partners and literature review, concludes with 4 RRI keys that are most important: open access, public engagement, ethics and science education.

These 4 RRI keys will be modelled as 4 respective variables for each agent. These RRI variables have values ranging between 0 and 1, where 0 means that the agent is not concerned with the particular RRI aspect at all, whereas 1 means that the agent weights this RRI key to the maximum in decision processes involving RRI.

Initial RRI values are set to a random number around the mean value for each type of agents. It means that some types of agents are expected to be, on average, more concerned with ethical values. The following ranking (starting with agents with highest average RRI values) is suggested:

- End-users
- Customers
- Educational/training institutions
- Research providers
- AM technology companies
- Funding organizations
- OEM Producer designers
- Suppliers
- Banks
- Insurance firms

Note that, depending on whether the simplifications suggested in “Supporting many organization types” (p. 33) are adopted, not all these agents will be implemented.

As described below, ethical values for individual agents may change over time. This means that average RRI key for a particular type of agents vary and the new agents appearing during the model run will get initial values that are correlated to the current average for the type.

5.4.2 Learning RRI keys

RRI values of single agents in the model may vary over time (D2.4, p18, see “adaptive” RRI dimensions). We model RRI key value changes through the following mechanisms:

1. When an agent is involved into a network or IVC where the average RRI value (of any of the 4 RRI keys) for all partners is higher than his own, the agents RRI key value increases to the level between his own value and the average value for the network. This increase may be conditioned on the results of networking (negative effect, decrease in RRI values) when networking results is positive resultant and positive when results are positive.
2. Under certain scenario, the exogenous regulators may set a minimum level for certain RRI key (mimicking the impact of RRI key “governance”, or the consumers/end-users may require some minimum level). In this case, the firms are forced to increase their RRI values gradually. The firms unable to reach the required minimum level are first blocked from networks and then dissolved.

5.4.3 Societal benefits

It is important to conceptualize and define societal benefits so that we can explain how we intend to measure it in the model. We take societal benefit to mean impacts on society that are beneficial in their very nature. Two examples of this provided by the industrial partners in the IAMRRI project are medical implant that help patients in ways that conventional approaches cannot and automotive parts that can drastically reduce the harm to pedestrians in case of a car crash. From this understanding, and based on the conceptual model from D2.4 and the data collection with stakeholders and other sources,

there are four obvious ways as to how societal benefits manifest themselves: (1) through market demand of products that are more beneficial to society, (2) through AM organizations taking upon themselves to do good in society, manifesting itself through a higher likelihood of wanting to participate in such projects, placing emphasis on NGO involvement, and a higher likelihood of withdrawing from an IVC if the generated or developed idea turns out to not be beneficial to society or even detrimental to society—this can be thought of as a bottom-up driving force for RRI, (3) an increased likelihood of receiving funding from the EU if one is attempting to develop innovations that are beneficial to society or receiving more resources and/or on better terms, and (4) through an increased number of youth and students willing to become part of the AM workforce as they see that the AM industry are producing tangible results that are beneficial to society as a whole. This has four primary consequences before accounting for any emergent effects in the model: First, by increasing societal benefits one ought to increase demand for products produced in the AM industry. While this demand might only be directly observed in the business-to-customer (B2C) segment of the market, it goes without saying that this effect will echo through suppliers for said products—a well-known and fundamental concept in economics. Second, by improved funding conditions for such innovations and organizations that are more aggressive at pursuing public engagement, e.g., through NGO involvement, it seems more likely that such innovations will thrive. Third, by attracting more people to the AM workforce, AM companies can grow their operations. This seems to be a simple, linear, relationship, but there are, however, interactions that can impede on such efforts directly, or indirectly. Market timing or preference mismatch, e.g., firms attempt to produce societally beneficial innovations but market demand is low, funding that does not make up for the increased likelihood of NGOs halting or slowing down the innovation process, and science education efforts that may be costly for individual firms, but beneficial for the whole industry—a type of tragedy of the commons effect or organizational internalization of externalities that the industry as a whole is responsible for. In other words, such efforts can lead to decreased financial performance for the individual firm in the present moment but be beneficial for the industry at a later date. More on this below.

We suggest that this can be implemented in the form of a boolean variable related to the idea. Depending on its truth value, the idea is either socially beneficial or not. We also suggest that, if possible, depending on the availability of empirical evidence in WP4, that ethically oriented organizations are more likely to come up with ideas or innovations that are socially beneficial.

5.4.4 Ethics

Organizations may, due to strategic or simply altruistic reasons, decide to accept higher levels of risk and lower levels of potential profits if they come to understand that their products will likely have more than usual societal benefits. For example, a firm inventing a technology that may lead to medical implants that bring benefits to patients that are not helped by existing technologies—such as one case from our industrial partners—may take it upon themselves to bear the opportunity costs associated with investing in an innovation process that have higher risks and potentially lower profits. If done altruistically, this is simply done as the organization acts according to their established responsibility to society. If done strategically, it may be due to wanting to appear responsible or expectations of future market demands. The behaviour will likely be the same. While this may lead to more products that can help such patients, it may also lead to financial distress of the firm in question, especially if they are in a vulnerable financial situation. If more societally beneficial products are brought to market, it will likely increase the perception of AM in the society. In that sense, taking this risk represents an internalization of the externality of profitability at the cost of societal benefit.

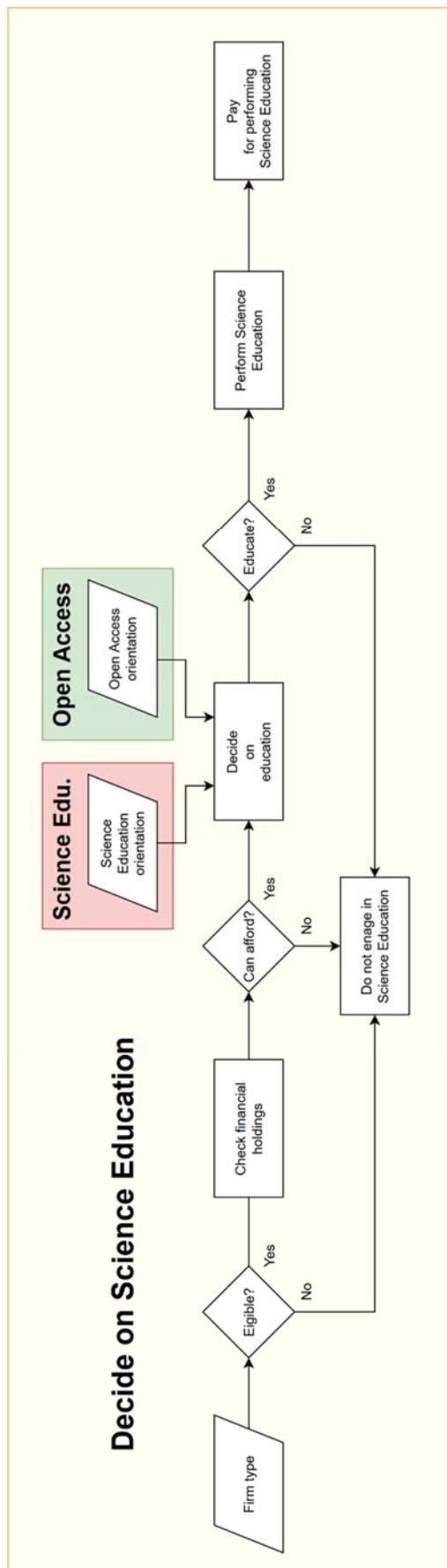


Figure 7- Decision on Science Education participation

5.4.5 Science education

As with organizationally ethical behaviour, some agents may take it upon themselves to encourage youth and students to learn more about AM, or even begin this knowledge transfer themselves. This can also be considered an internalization of the externality of lacking a stable labour pool in the AM industry. Since the industry is still young, there is a chicken-and-egg problem where there is still hesitation among students whether a career in AM is a good option, and at the same that hesitation is itself limiting the attractiveness of the industry since it itself cannot grow without a growing labour pool. By educating youth and students about AM, it is likely that more of them will be aware of the benefits of AM and therefore either become more conscious consumers of AM products, or undertake an education that allows them to work in the AM industry. In short, the organization can take it upon themselves to do science education at little immediate benefit and at some cost, but the whole industry can benefit from this in the future. To the left, in Figure 7- Decision on Science Education participation, the reader will find a flowchart showing this process. Note that industry partners indicated that science education may lead to innovations that are more societally oriented. The basis for this claim is that they have observed that students and those just entering the AM workforce have a strong drive to develop innovations that are beneficial for society. We only have anecdotal evidence for this claim so it should be investigated in WP4. Due to its anecdotal nature of its evidence, we have not suggested any mechanisms covering the connection between science education and societally beneficial innovations.

5.4.6 Open access

The base SKIN model does not support any functionality for open access publications. For most organizations, except universities and research institutions, the R&D stages in Figure 6 show the general logic of the R&D process in SKIN (the R&D process in base SKIN is described in more detail in the section “Evaluation of success threshold”, p24. It is important to note that D2.4, (p20, table 7) points out that not all organizations are in a position, or are likely, to publish open access. This may be due to the nature of the R&D efforts—R&D in a design company will likely entail a very different process than R&D in an AM technology company. Whereas the latter’s R&D efforts are more likely to lead to tangible results that are more publication friendly, the former may be and harder to translate into an open access publication. For more reasoning on this topic we

refer to D2.4, section 3.2 (pp18-20). When the eligible firms decide on whether to publish When the eligible firms decide on whether to publish open access. Since R&D entails costs, the agents have reduced their financial holdings during the R&D process. Therefore, the first step is to check their holdings to ascertain whether they are in a position to afford publishing open access. If the answer is no, the open access publication consideration is terminated. If the agent can afford to publish open access, the agent will weigh their ethics and open access orientation and decide on whether to publish. While the weights have a strong effect on this decision, there is also an element of randomness to the decision, representing other factors influencing the decision maker. If the decision is negative, the publication consideration is terminated. If the decision is positive, the publication takes place, and the agent pays the open access fee.

5.4.7 Funding

A common policy measure for avoiding negative externalities from industry are coercive pressures in the form of regulations (and associated fines in cases of non-compliance). Another policy measure is supporting industry actors that are doing the right thing. While this practice may be controversial, e.g., one might disagree that policy makers support organizations that would act to societies benefit due to profit motives alone, in some cases the profit motives are not present, at least not for the individual firm. In such cases, policies may be put in place to partially, or fully, internalize the externality on behalf of the organization attempting to do the right thing. For example, policy makers can mandate that public procurement processes should give a higher score to firms choosing to only use ethically sourced products, or firms that encourage gender balance in their work force. If this becomes common place and a societal norm, private industry may start to make the same demands. For example, many large institutional investors (such as the Government Pension Fund of Norway) actively pursue a policy of “ethical investing”. Funding in such instances can be seen as both a ‘top-down’ RRI measure, but it can possibly also be considered as a catalyst of the bottom-up efforts presented above. This outcome is not obvious and ought to be examined in the model.

5.4.8 Governance

Governance is an RRI dimension that was recommended by D2.4 to be left out of the model. This seems like a reasonable suggestion due to the lack of emphasis on this dimension from the stakeholders, but also due to the complexity involved in modelling governance. As can be seen in the description of the transition from the Idea Development phase to the Diffusion phase, we suggest a simple mechanism for governance only related to regulations and public reactions. The latter is an expanded understanding of the term governance inspired by Schlaile et al. (2018) but has similar effects in that the public can react by

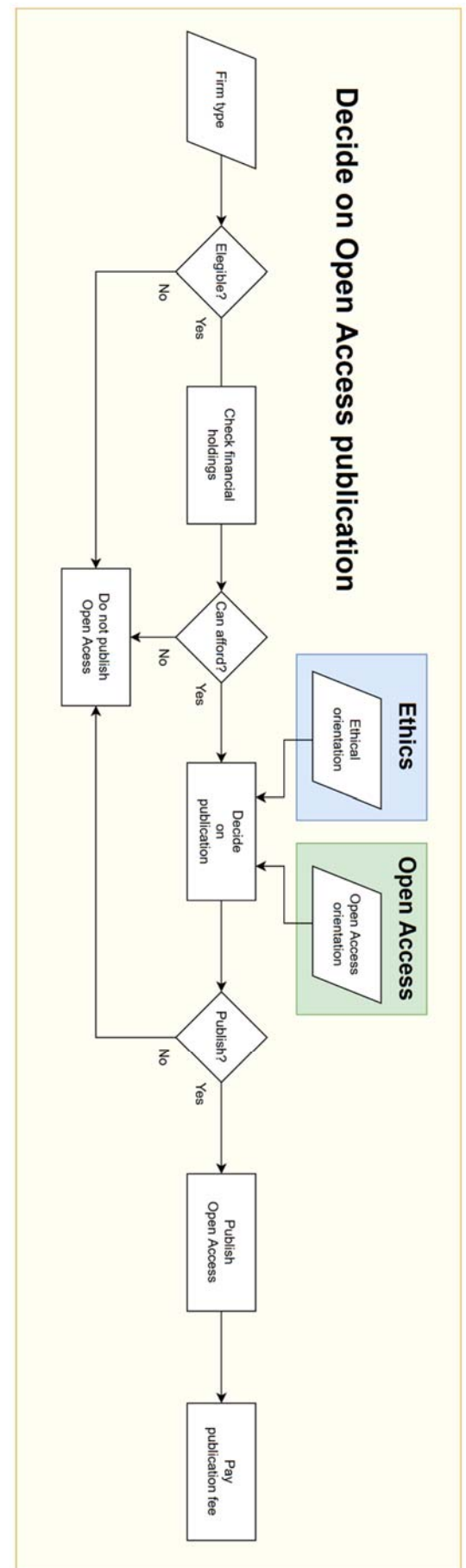


Figure 8 - Decision on Open Access publication

boycotts, seeking prohibitive injunctions, and similar. While we do not make a hard distinction between the two, we note that involvement by NGO at the Idea Generation phase will lower the likelihood of any adverse governance effects at this stage. This can be implemented in several ways, e.g., by a boolean flag similar to the inherent societal benefits of some ideas. The adverse effect could instead be an inherent trait of the idea that NGOs would be particularly apt at discovering. This represents an advantage of involving NGO during the early phase of the IVC that does not manifest itself until later.

5.4.9 Public engagement

Public engagement works through two mechanisms in the model: (1) NGO involvement as a way to represent society's interests in the IVC; and (2) market effects due to providing society with societally beneficial innovations. In this section we describe the first mechanism, while the second is described in the section on consumer markets effects in the model. In addition, a study using the SKIN model to explore university-industry links has shown that having universities in the co-operating population of actors raises the competence level of the whole population and increases innovation diffusion in terms of quantity and speed (Ahrweiler, Pyka, et al., 2011 p.218).

As D2.4 points out, public engagement is particularly salient during the early stage of the IVC. This is supported by empirical data from stakeholders. Therefore, we have limited NGO involvement to the Idea Generation phase. That is not to say that NGOs are necessarily absent in the latter phases, but that their influence are influencing the IVC process only in the earliest phase.

We suggest that NGOs act as 'guardians' against potential societally detrimental effects that are tied to innovation ideas. Examples of this could be products that, while technically feasible, may run afoul of societal expectations and considerations. A particularly salient example of such innovations are the legislations and regulations faced by certain self-driving vehicle technologies. While those technologies are not dichotomously inherently societally detrimental or inherently societally beneficial, they represent a potential feature of the idea that may lead to issues as the idea transitions from the Idea Development to Diffusion phase. We suggest that, if involving the public at an early stage, the idea will be less likely to invoke reactions from the government or the public. Relating this to the examples above, Uber could have involved actors potentially affected by their innovations so that they could have developed better conditions for their drivers and less of a disruptions for individuals employed in the taxi industry, Airbnb could have involved citizens vulnerable to changes in the housing market in order to minimize the negative effects it can have on house price development.

For the model implementation, we suggest implementing a 'veiled' boolean variable representing societally detrimental features of the idea that NGOs are particularly apt at uncovering. While NGO involvement can reduce development speed, their ability to predict adverse as the ones described above during the transition from the Idea Development to Diffusion stage, may make them an important IVC member addition even if it leads to increased short-term costs. This could also be implemented as a two bit bit-field where, e.g., [00] represents neither societally beneficial nor detrimental, [10] represents societally beneficial and not detrimental, [01] represents societally detrimental and not beneficial, while [11] represents both. This is an implementation detail.

5.5 IVCs

Arguably one of the two most important extension (together with the RRI-related extensions) presented in this deliverable, is the IVC related extensions.

Extending SKIN with IVC support requires several sub-extensions: supporting many organization types, a representation of IVCs, rethinking the duration of steps in the model, and refining parts of the kene concept from the SKIN model so that it supports multiple organization types.

5.5.1 Supporting many organization types

The base SKIN model does not support creating organizations that are different in type. There is some distinction between material providers, producers, and consumers (Gilbert et al., 2007). However,

these agents are parts of supply chains, not IVCs. (For a more technical description of how this is implemented, see Gilbert et al. (2001).) Some extended versions of SKIN include multiple types of agents. Korber & Paier (2014) used three types of agents (universities, research organizations, and industry agents) while additional heterogeneity is modelled by different attribute values for each particular agent type. Governmental authorities and financial organizations are modelled as exogenous entities that take part in determining funding likelihoods and extents (government), interest rates (banks), and risk in general (risk-reducing financial devices such as insurance).

Table 23 in D2.4, p. 49, summarizes the roles that different actors may take in an IVC. Performing these roles requires knowledge in specific domains (D2.4 mentions research, legislation, design, AM production, AM machines, AM materials, AM software, insurance, and funding). To simulate different types of agents possessing different knowledge domains, the *kenes* may be used. In original SKIN, *kenes*' abilities are unnamed. In the IAMRRI model, additional meaning may be assigned to the individual numbers (IDs) of the abilities. For example, abilities with ID-numbers from 1 to 100 are within the design domain, abilities from 101 to 200 are related to software etc. This approach to assigning explicit meaning to *kenes* has previously been implemented in a SKIN extension (for concrete example see Hintze & Lüthje, 2014 p.56). The exact set of important knowledge fields will come from other work packages dealing with concrete cases. While the original idea of *kenes* remains unchanged in the IAMRRI model, these additional meaning has consequences for initiation of the model, formation of Innovation hypothesis and learning procedures.

During the initiation, the agents are initially provided with abilities that are specific for their main role (for example insurance firms have only abilities within insurance). That contrasts with the random distribution in original SKIN. Larger forms may have abilities within several domains (for example AM technology company may have competence within software and AM production).

Any Innovation hypothesis must include at least one of each types of abilities as a prerequisite for going from idea development to diffusion. The missing parts of *kenes* are acquired at the idea development stage.

Agents are more likely to learn new abilities within their domain, while they still can learn totally new abilities. Costs of learning are smaller for the actor's key domain than for learning something totally new.

Based on the empirical data from two industries and workshops 13 types of actors and stakeholders are identified (D2.4, p10). The roles of different agent types are described in general in table 1, D2.1. and table 23 in D2.4. Here the agents are described more concretely in relation to the model.

As in original SKIN, three types of agents are directly involved into supply chain: Supplier, AM technology company and customer.

All agents may be involved in IVC. Minimal AM IVC includes an AM technology company and a customer. In the automotive industry, an OEM product designer might also be necessary in a minimal AM IVC.

1 AM technology company is much like a standard SKIN producer. An agent of this type is necessary for diffusion of any innovation. In IAMRRI terms, an AM technology company is an agent type necessary for generation and diffusion of any innovation. An example would be an AM machine producer. They are typically agents that own the AM means of production.

2 Supplier is basically a standard SKIN material provider. The model is extended through distinguishing between three subtypes of suppliers: **hardware, software and raw material/component suppliers**. This distinction is important for distinguishing between different IVC, and for including open access (software is related to open access while materials/components and machines are not). The distinction is made through allowing different types of suppliers to have capabilities specific for the three respective areas. An agent of this type is necessary for diffusion of any innovation. Suppliers' motivation to cooperate is higher in the industries with higher average turnover (Heshmati & Lenz-Cesar, 2015).

3 OEM product designer. An agent of this type may be necessary for idea development in the automotive industry, but, according to our stakeholders, are seldom present in the medical sector.

4 Customer is basically a standard SKIN consumer. Agents of this type do not produce any products in the model. An agent of this type is necessary for diffusion of any innovation. Customers' motivation to cooperate increases when the speed of technological change is increasing (Heshmati & Lenz-Cesar, 2015).

5 Research provider. This type of agents represents research institutes and other organizations that can develop knowledge currently unavailable on the market (missing knowledge elements). An agent of this type is necessary for development of innovation hypotheses that include knowledge elements unavailable from the existing agents. How universities and other research providers engage into collaboration with the industry has been described in multiple settings (Boutifour et al., 2015). Collaboration is expected to be more intensive when the research organization and business are geographically close to each other and when the research organization has relatively large variety of programs (Boutifour et al., 2015, p. 106). Research providers are less likely to cooperate with partners abroad compared to domestic partners (Heshmati & Lenz-Cesar, 2015). There is a SKIN model extension which includes universities as an additional agent type (Ahrweiler, Pyka, et al., 2011 p.218). Referring to this paper, universities in IAMRRI model have knowledge that are twice as long as those of the firm agents. University agents do research, form partnerships with firms, and participate in larger networks. In the described SKIN model, for the sake of simplicity, universities do not link with each other. This last simplification may be re-evaluated in IAMRRI model. If a university agent is successful, it breeds a firm (university spin-off). This is an enterprise that can buy, sell, and produce. A spin-off's knowledge is a clone of the university's innovation hypothesis. If a spin-off is created, a university loses one third of its knowledge and gets a new random one (to represent the turnover of researchers); all expertise levels of the spin-off are reduced by one unit. Unlike the firm agents, university agents are non-profit organizations (they do not produce for the market, they do not sell) with stable public core funding. Their success is measured by the economic gains of their firm partners.

6 Bank. The bank provides funding and receives payments with rents. Only actively used in case of insufficient capital, but interest rates affect financial decisions. Is suggested to be abstracted away through interest rates below.

7 Funding organization. These organizations provide funding and no payback is expected (for example EU funds for innovation support).

8 Insurance firms sell insurance to the partners involved into the development stage. They also compensate in case of innovation failure. Is suggested to be abstracted away through insurance rates below.

9 Educational/training institution. May be required at the diffusion stage for training of employees. A SKIN-model studying university-industry links shows that having universities in the co-operating population of actors raises the competence level of the whole population, increases the variety of knowledge among the firms, and increases innovation diffusion in terms of quantity and speed (Ahrweiler, Pyka, et al., 2011 p.218). Educates customers and end-users influencing societal acceptance of AM technology.

Previous empirical studies provide a clue on relative number of agents. In biotech industry, the agent population was constituted by 62.50% industry agents, 20.59% university agents, and 16.91% research organization agents. Industry agents were further divided, following the EU definition for SMEs⁹ into 45.6% small and medium-sized enterprises (SMEs), and 16.91% multi-national companies (MNCs) (Korber & Paier, 2011). Further adjustments to the AM, medical and automotive industries are to be made later based on input from other work packages.

The roles and places in IVCs of different types of agents are summarized in the table below:

Table 5 - The roles and places in IVCs of different types of agents.

Agent type	Role(s)	Place in IVC		
		Idea generation	Idea development	Diffusion
AM technology company	Production of end products.	O	o	e
Supplier	Supplies hardware, software or raw material/components. Necessary for diffusion (production).	O	o	e
OEM product designer	Provides design. Necessary for diffusion (production). See notes above regarding medical vs. automotive sector.	O	e	-
Customer	The actual buyer of the products (not end-user)	O	o	e
Research provider	May develop missing parts of IH when no one has it on the market.	O	o	-
Bank	Funding, paid back	-	o	-
Funding organization	Funding including grants (no payback expected).	-	o	-
Insurance firm	Sells insurance to the partners involved into the development stage. Compensate in case of failure.	-	e	-
Educational/training institution	May be required at the diffusion stage for training of employees. Educates customers and end-users.	O	o	o

e – essential; o - optional for the given IVC stage.

Functions of **regulators, standardization organizations and government** (as they are described in D2.4, table 1) are modelled as exogenous set of variables because there is no need to represent these stakeholders as agents who are not influenced by other agents in the model, not competing and stable over time. There is a version of SKIN model focusing on the effect of public research funding on companies, universities and research organizations (Korber & Paier, 2014). The effects of alternative government policies on firms has previously been modelled (Tedeschi et al., 2014). These studies may provide useful input for the implementation team.

End-users. In the IAMRRI model there is a difference between Customers and End-users. Customers (large car producing firms and doctors) are taken from the original SKIN. Customers order the product, evaluate quality and pay for these products. However, neither drivers nor patients are customers in our case – they are end-users. In the automotive case end-users may not know that the AM-manufacturing products are used in their cars. In the medical case the end-user has no competence to make his choices regarding design and technology without doctors advise and guiding. This situation is analysed in an SKIN-related publication devoted to B2B markets (Hintze & Lüthje, 2014 p.48): “In these markets, suppliers are confronted with the following problem: Demand for their industrial goods is ultimately derived from demand for the customers’ products (...). Due to suppliers’ dependence on derived demand, their innovations have to be canalized through many stages in the value chain and need to be accepted and forwarded by many firms in the downstream direction”.

Since the number of end-users is very large it is rational to simulate end-users as a single aggregated agent for each industrial context (automotive vs medical) characterised by the following variables:

- 1) Industrial context (0=automotive vs 1=medical).
- 2) Number of end-users.
- 3) RRI values. Previous ABMs of innovation diffusion support the hypothesis on the role of values (see Zhang & Vorobeychik, 2019 for a review).
- 4) Total capital to be spent on the relevant products.

Table 6 - The role and places in IVCs of the stakeholders (not simulated as multiple agents in the model).

Agent type	Role(s)	Place in IVC		
		Idea generation	Idea development	Diffusion
Regulator	May impose restriction on certain products or technologies. Limits the possibility to copy existing products (through patenting). May ban “unethical” products.	o	e	e
Standardization organization	May impose restriction on certain products or technologies.	o	e	e
End-users	Influence demand from Customers – higher RRI orientation results in higher RRI orientation among customers.	o	o	e

e – essential; o - optional for the given IVC stage.

The role of **banks** can also be simplified as it mainly affects interest rates. Increased interest rates lower the attractiveness of loans and increases the attractiveness of placing financial assets in banks and vice versa. Therefore, investment decisions are positively affected by low interest rates, while they are negatively affected by high interest rates. For examples of how this is taken into account in the model, see Figure 10, p41.

As with banks, insurance firms’ involvement can also be simplified as their function is solely risk reduction. For example, without insurance backing many medical innovations would be severely impeded as firms would not dare to engage in their development. Therefore, the willingness of firms to insure themselves during the development process (and further if they chose to partake in the diffusion phase), reduce risk. According to informants among the stakeholders, AM firms operating in the medical sector are particularly affected by this as many of their innovations are completely reliant on being insurable due to the risks involved. Due to this, insurance rates are comparatively higher in this sector, something that should be accounted for in the model. As with the role of banks, the reader can find an example of how this is taken into account in the model in Figure 10, p41.

5.5.2 Representing IVCs in the model—adapting SKIN’s network organizations

It is assumed that mechanisms and determinants affecting the structural evolution of networks are industry-specific and strongly dependent on the industry life-cycle stage (Buchmann et al., 2014). Therefore, the networking procedures from the original SKIN are adapted to the AM industry. The SKIN model supports the notion of network organizations—organizations that are composed of resources pooled from network partners with the aim of inventing and getting a new product on the market – but these network organizations does not take part in an IVC in the traditional sense of the word. Instead, when the network organization are created, the composing organizations’ kenés are put together which will generate an innovation hypothesis which in turn is developed into a product which will be made (assuming it will be profitable and inputs for the product is found in the market) and sold on

the market *all in one turn*. This is not suitable for the IAMRRI model as we rely on studying the different steps in IVCs that take differing amounts of time, e.g., idea iteration loops or warnings issued by NGOs. The existing network implementation, however, is a natural point of departure for implementing the notion of IVCs. While network organizations *conceptually* represent separate organizations in the current SKIN model, the implementation can easily be duplicated and changed so that participation in the IVC is instead considered as a *project* in the firms starting the network organization (now networked project). This allows us to study the performance of the IVC in relation to the organization and allows us to create several IVCs that any given firm can belong to (currently SKIN only supports being in one network at a time, but this can readily be adjusted). It is important to note that there must be a tighter interplay between IVC and the organizations that participate in them than is currently allowed in SKIN. For example, if a given organization (org A) is part of an IVC in the idea generation stage and the IVC transitions into the idea development stage, any new organizations that partake in the network must be added to org A's network. This represents a break from the SKIN model as the latter only allows for generating networks organizations where all members are already networked to everyone else through previous partnerships (see description of the base SKIN model, starting on p16). In other words, the search for potential partners is limited to those you have already had a partnership with in the past. Modifying the partner selection process from depending mainly whether two agents have already collaborated to selection based on both attractiveness and previous collaboration experience was previously used in other agent-based models (Tur & Azagra-Caro, 2018). The RRI extensions described in the section starting on p28 is intimately tied to this, extending firms' search capabilities through side effects of open access.

AM industry is closer to science-driven than to scale-intensive type. Modelling of science-driven industries suggests that technological heterogeneity positively influence the attractiveness of potential cooperation partners (Buchmann et al., 2014). Since the kenés in the IAMRRI model are assigned additional meaning, it is possible to model these relationships by increasing the probability of networking for the firms with relatively similar kenés. The real-world empirical data and the agent-based simulation performed by (Heshmati & Lenz-Cesar, 2015) shows that certain characteristics of an organization increase motivation to cooperate (firm size, R&D intensity and capability constraints). Some other characteristics have effect only for certain agent types (described in the section of D3.1 devoted to agent types).

5.5.3 Veiled Innovation Hypotheses

One prime reason to start an IVC and invite members to it, is that an idea has been sparked, but the initiating firm (1) lacks the capabilities and abilities to develop it by their own, and (2) parts of the idea is inherently still unknown. Since the IVC is a process that goes through several stages, and possibly through several iterations in each phase, the idea must somehow be developed. In SKIN parlance this can be thought of as the unveiling of an innovation hypothesis. The organizations involved in the IVC phase are likely to influence the nature of the idea as it is developed—in technical term this can entail the IVC members imprinting part of their kene on the innovation hypothesis. (This mechanism can be readily adapted from the already existing algorithm for innovation hypothesis generation in the base SKIN model.) Note that once the firm has imprinted part(s) of their kene on the innovation hypothesis, the part is no longer associated with the firm type. The logic behind this ties to that while the idea requires different inputs from different firm types, e.g., design, once the design is in place, the other firms in the IVC does not need to understand how the design came to be—it is simply enough to know how use the design (and this knowledge in turn will naturally be conveyed within the IVC to other members as part of the development). Therefore, an innovation hypothesis that has been developed in part by an AM design company during idea generation does not require the AM design company for, e.g., diffusion. Once all the parts have been 'unveiled' the idea is ready for the next phase. As the idea transitions between phases, so does the innovation hypothesis through adding more columns that must be unveiled. This reflects the complexity of an innovation that requires an IVC and the empirical observation that other firm types are required for subsequent IVC phases. Because of this, some of the

firms' participation may no longer be required, and they will naturally transition out of the IVC, while others must be found either through remaining members existing networks or through searching for relevant capabilities and abilities in open access publications. If the idea makes it all the way to the diffusion stage, base SKIN mechanisms take over (see description of the three phases below).

5.5.4 The IVC stages and timing

The base SKIN model also assumes that an organization's research, prototyping, production, and market related activities can all take place, for a specific product, during one step of the model. Since the IVC process can take several steps and are not necessarily equally long for any given innovation, it is necessary to adapt the SKIN so that innovation processes can take more time than what is currently represented in one step in the SKIN model.

This can be implemented in several ways, e.g., attempt to compress the IVC events into one step of the model, or, as we suggest below, make each step represent a shorter amount of time. The issue of timing in this process has been difficult to pin down so far, but WP4's ethnographic data collection provides an excellent opportunity for gaining a clearer picture of how timing should be implemented and adjusted to match reality.

Both theoretical publications and input from participants indicates that dividing innovation process into three phases is necessary (D2.4, pp7-8). These phases are: Idea Generation, Product Development and Innovation Diffusion.

Original SKIN implicitly contains processes of the idea (innovation hypothesis—IH) generation and development in a single step. This process is influenced solely by kenos of firms and IH is randomly generated from the set of available kenos. In the extended version, new IH will be more likely to appear when a new raw material, software or other input is developed on the demand from another firm. Appearance of new IH may be initiated by the actors other than the firms: universities, regulating organs and open innovation sources (D2.4, p7).

Product idea development phase is not explicitly presented in the original SKIN model. The extended version suggests that the innovation hypotheses may be developed further in two ways: 1) if the necessary input is absent, the firm owning IH asks other firms to develop this kind of input and 2) if IH is not feasible, the firm may try to adjust it internally or in partnership with, for example, Research Institutes.

In the original SKIN Innovation diffusion means selling to the market depending on costs while demand is essentially fixed. Customers choose the cheapest product or, if the price is equal for several products, the products with highest quality. In the extended version, additional factors influence the product choice. RRI values are inherited by the product from the firms involved into relevant IVC. Customers with relatively high RRI values may choose products that are high on RRI values, even if they are more expensive than alternative products or have lower quality. The thresholds for respective value-added decisions are to be finetuned at the model validation stage.

Idea generation phase: It is suggested in the modelling literature that creative ideas can be generated locally (within a unit), across different units, or obtained from external sources (Kusiak, 2009). During the idea generation phase a firm of random type may come up with an idea that requires an IVC in order to be developed. In model terms, this can be represented as an innovation hypothesis that has hidden parts that can only be unveiled through idea iterations together with IVC partners. The concept of a 'Veiled innovation hypothesis' is described in more detail in the section starting on p38. There are several ways for how this can be implemented, e.g., as an oracle that picks random firms that will start an IVC, or it can be decided on the firm level. We consider this to be an implementation detail.

IAMRRI-SKIN

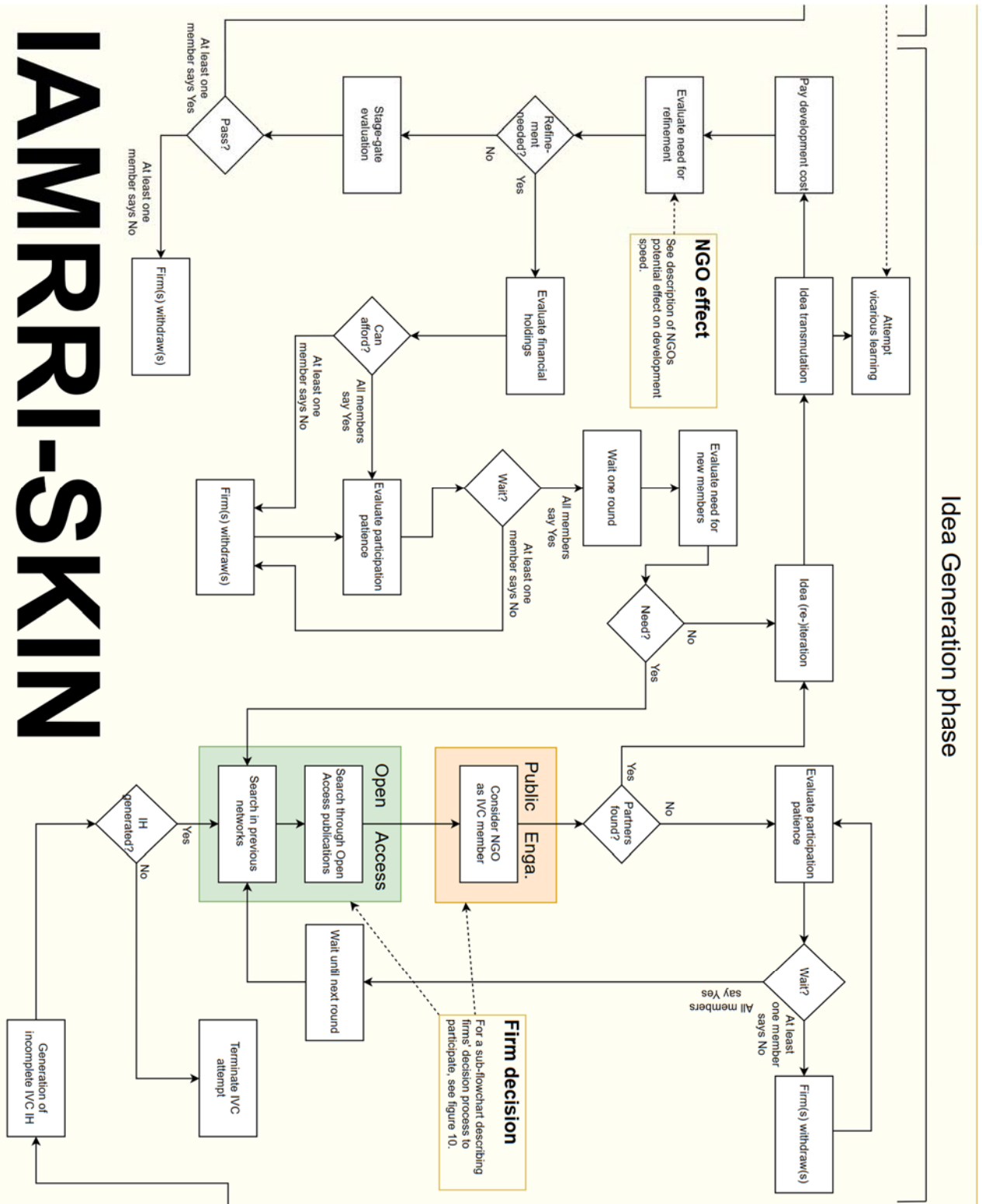


Figure 9 - IVC Idea Generation phase

For the agent to start the IVC proper, it must find IVC partners. In base SKIN, one search feature is the firms' previous networks. These networks are, in base SKIN, developed as firms are unable to achieve success in the market with a particular product and therefore attempts to learn from another agent so that they can create a new product that may be more successful. We suggest that this mechanism be modified such that partnerships are still the preferred channel for IVC member search, but that

searching through open access publications that signal a particular set of skills. One may assume that open access' primary function is knowledge sharing, but from interviews and workshops with AM stakeholders we came to understand that much of the information contained within AM publications would be prohibitively difficult to make use of oneself. It could also be that the agent type searching through open access publications would be different from the agent publishing the open access information. If one were to involve the company or researchers behind the publication, however, open access publications act as useful signalling devices for particular sets of skills. One example of this could be an open access publication describing a new material type that could be useful to an agent that can produce something with the material. In this way, open access publications act not only as adding to a repository of knowledge, but also as signalling devices.

During this phase, firm preferences come into play. Figure 10 shows a flowchart of the process. Since both ethics and public engagement are closely tied to the norms and behaviours of AM actors (D2.4, pp52-53), we suggest that firms' decision to join the IVC are strongly influenced by their Ethical orientation and public engagement orientation (see the sections "Ethics" (p30) and "Public engagement" (p33) for descriptions of these orientations; they can be understood as the norm strength of individual agents). In addition to these evaluations, the agent will also take financial risk and opportunity cost into consideration. Just as, in the original SKIN model, a firm's level of capital is a determinant of what kind of innovation it will choose to engage in, we propose that the level of capital (and the associated bankruptcy risk) plays a role in the decision to participate in an IVC. Joining an IVC is time-consuming and risky, so only firms with a certain level of capital will decide to do so. At the same time, opportunity cost enters the picture because the model allows for interest rates to vary. If interest rates are high, agents will demand a higher expected return from joining the IVC since, at least conceptually, they have the option of investing their capital in other projects that would yield a high return.

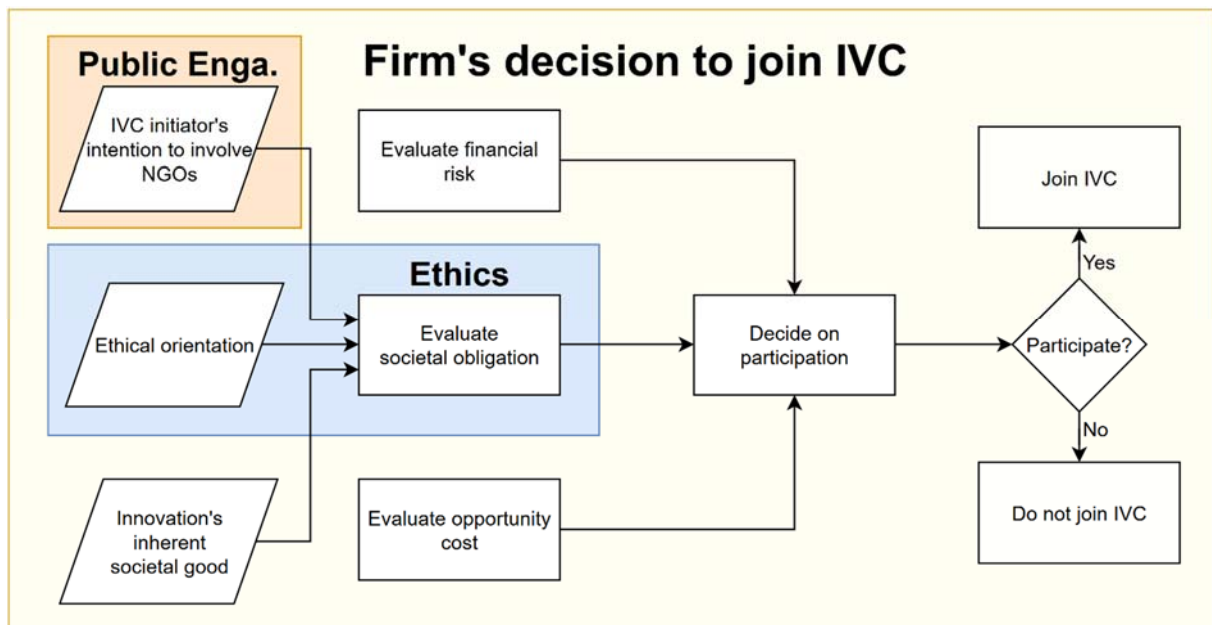


Figure 10 - Firm's decision to join IVC

In cases where not enough partners are found, the partners that have been found, as well as the Idea Generation instigator, will evaluate their participation patience. Their patience will be related to how they evaluated whether to join the IVC. In other words, if the firm perceives that ethical and public engagement requirements are exceeded and financial risk and opportunity costs are low, they are more likely to extend their participation for another run of the model. In addition, their patience will be affected by the number of partners in the IVC so that the more partners there are in the IVC the lower the likelihood of leaving. This reasoning is based on group size conformity effects, a well-known effect from social psychology explaining how individuals, in this case those representing their firm in

the IVC, are less likely to leave a group if it is above a certain size. In short, this represents a group-think-like effect that makes on second-guess ones one judgement if making a different judgement than the rest of the group (Campbell & Fairey, 1989). This has the potential to create a cascading effect where if one firm leaves, others are more likely to leave. Therefore, we suggest that this is modelled in a cyclical fashion until no more firms are willing to leave. This can be modelled similarly to base SKIN's mechanism for market matching of buyers and sellers. Those firms that are willing to stay, will reduce their patience for each round they chose to stay, so that the longer they have been on hold, the less likely they are to remain. If the IVC is not dissolved after these determinations, the IVC is put on hold until next round of the model. This process is not an infinite loop or recursion since the partner pool might have changed during the remainder of the round if other the actors remaining in the network have extended their networks during the round, or if firms outside the network have published open access. If that is the case, the IVC have a different pool of potential partners to choose from. If they are unable to find new partners during the next step, they will begin the process described in this paragraph anew. Note that this patience determination interacts with the RRI keys so that in cases where IVC members that are highly ethically oriented and cares deeply about public engagement are more likely to have patience if the idea societally beneficial or NGOs are involved, respectively.

When the funding decision has been made, the IVC members iterate on the idea. This entails a stochastically determined outcome of unveiling one of the columns of the innovation hypothesis (see section "Model and agent initialization", p20, for a description of the innovation hypothesis). How likely this unveiling is should be based on data collected by WP4. If they, e.g., find that ideas must be iterated over a long period of time, the likelihood of unveiling a part of the innovation hypothesis would be lower than if ideas quickly transition into the idea development stage. During this iteration phase, agents have the possibility to learn from the other IVC members (see Figure 11). Since financial outcomes are difficult to ascertain at the idea generation phase (D2.4, p. 51), this learning opportunity represents the chief performance outcome on the firm level for participating in the idea generation phase. In that sense, it is conceptually like forming partnerships in the base SKIN model. Being involved in this idea iteration incurs costs to the agents involved. The size of this cost is unknown at this point and should be elucidated by data collected in WP4. While it may be difficult to ascertain a perfectly accurate number, a rate of cost compared to other model activities, such as internal R&D, base SKIN partnership creation, will provide a very useful way for calibrating the cost of this participation.

When learning from each other the partners are more likely to learn from the firms with kenes that are relatively alike their own (Shou & Sun, 2010).

After the idea has been iterated over, in cases where NGOs are involved, the NGO may warn of potential issues that must be dealt with before the

IVC should proceed. This represents the 'guardian' role NGOs can have if unethical or otherwise socially undesirable ideas are being developed, highlighting the potential drawbacks of involving NGOs (D2.4, p54). If such a warning is issued, this ensures that the idea must be reiterated over, increasing costs

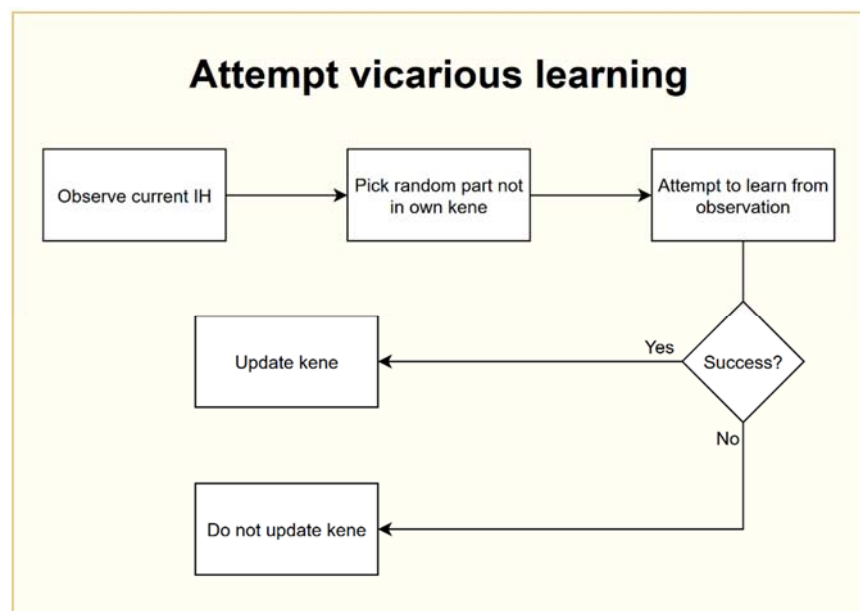


Figure 11 - Vicarious learning attempt

and possibly leading to IVC members withdrawing from the IVC. The inclusion of NGOs is not without its advantages on the IVC level—it can lower the likelihood of adverse effects in the future (see the next section on the Idea Development phase). This reiteration does not occur only due to NGO warnings: it will also occur if the innovation hypothesis has not been sufficiently unveiled for it to proceed to the idea development phase. In any case, this reiteration is similar in effect to the partner involvement patience evaluation presented earlier. In cases where some members withdraw, the IVC must start anew with member search. Note that we assume that applying for more funding is automatically rejected since it is the same application performed twice. Data from WP4 may show that, e.g., it is possible that an IVC may ‘fail’ but have a sufficiently unveiled idea so that they can reapply for funding. If that is the case, the IVC may reapply for funding in order to rebuild their financial buffer against idea refinement and warnings from NGOs.

If the iterations complete and the idea is ready for the next phase, idea development, then the firms will perform a stage-gate evaluation. While this stage-gate has been deemed to be important in both EU’s, it is not mentioned in D2.4, so we suggest a simple mechanism: the agents involved will examine their participation in the idea development phase (see Table 7, p43, for the probability of specific agent type involvement) in much the same way they would any other reiteration as they are described above. If no firms are left after this iteration, the IVC will be terminated. That does not mean that the IVC has been unable to provide any useful outcomes: the increased knowledge among the agents that have participated may lead to other IVC participations at a later stage, and can help the agents as they develop their own innovation hypotheses independent of the IVC. While it may seem counter-intuitive that the whole IVC is terminated at this point, it is more reasonable when considering that none of the agents receive any financial gains when participating in the IVC: their primary gain at this stage is the knowledge from idea iteration together with the participating partners. This assumption should be carefully examined by WP4 as they develop a dataset on agents’ behaviours during transitions from one phase to another.

Table 7 - Phase participation probabilities gathered during Düsseldorf workshop

Agent type / Idea phase	Idea Generation	Idea Development	Idea Diffusion
AM technology company	50%	55%	75%
Supplier	55%	55%	45%
OEM product designer	80%	40%	0%
Customer	80%	80%	100%
Research provider	25%	50%	5%
Funding organization	5%	25%	30%
Educational/training institution	20%	20%	5%

Idea development phase: The required members for this phase is stochastically determined by the probabilities shown in Table 7, p43. This may, but not always, entail that more members must be added to the IVC. For the sake of brevity, we will not explain the search process as it is quite identical to the one described in the idea generation phase with one exception—there is the opportunity for funding at this stage. Early during the idea development phase, the agents will consider applying for EU funding. Simulating the EU funding system is a great undertaking in and by itself so we suggest a simplified model that is chiefly concerned how EU might weight RRI dimensions of the idea so that those ideas that are more RRI friendly are more likely to receive funding. Specifically, if the IVC members involved NGOs during the idea generation phase and are developing an idea that is inherently socially beneficial, they are more likely to receive funding. This has the consequence of

reducing the financial risk going forward, and the likelihood of firms having to withdraw from future idea iteration due to financial constraints. Note that this represents an interaction between bottom-up RRI efforts—caring about NGO involvement on the firm level and being concerned with ethics—and top-down efforts—preferring to fund ideas that are more closely aligned to RRI keys and ideals.

Idea Development phase

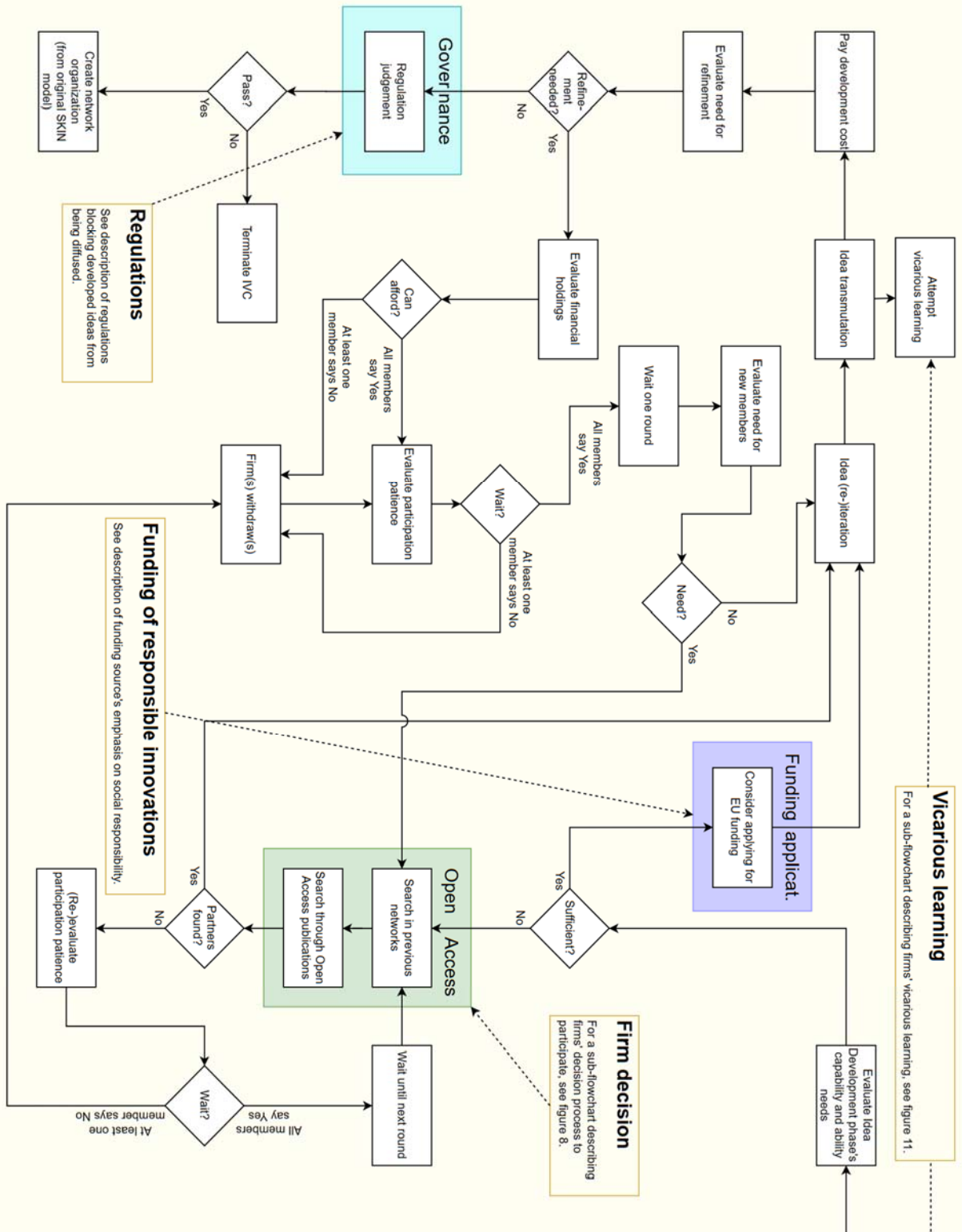


Figure 12 - IVC Idea Development phase

While this funding search comes into play after the idea generation phase, the delayed effect of NGO involvement nevertheless corresponds to D2.4's emphasis on the idea generation being the focal stage at which RRI keys have the largest influence (p32). Most of the other parts of the idea development phase is identical to the idea generation phase—that is not to say that the same actions occur in practice, but rather that it follows the same circular pattern of iteration, possible refinement, possibly

partners leaving, new partners coming into the IVC, then reiteration if sufficient members are found. One important part (besides funding) differs, however, and that is the possibility of regulation or other interventions by either the public, e.g., in forms of prohibitive injunctions to stop sale or diffusion of products, or the government, e.g., the government interprets the idea as going against existing laws or it considers creating new regulations and laws preventing the sale or diffusion of the resulting product or service. The likelihood of this happening is considerably lower if an NGO has been involved at an earlier stage. In other words, the involvement of NGOs at the idea generation phase can lower the likelihood of adverse events in the transition from the idea development phase to the idea diffusion phase. As with the likelihood of NGOs issuing warnings in the idea generation phase, WP4's input on how frequent or likely such public and government interactions are needed for successful generation of a realistic base model and the successive calibration.

If the idea development phase is successful, the IVC transitions into the diffusion phase:

Diffusion phase: Fortunately, the diffusion stage described by D2.4 is quite similar to the network organization already implemented in base SKIN. The major exception is the requirement of the participating firms already having partnered with each other. We propose that the transition from the Idea Development phase into the Diffusion phase follows the same logic as from the Idea Generation phase to the Idea Development stage. If the necessary agents are found, based on the probabilities in Table 7, p43, they take part in forming a network organization as described in the base SKIN model. How this transition is done, e.g., are there any IPR transfers with corresponding resources transfers, i.e., payments for patents that protects the diffused innovation, licensing schemes, and last but not least, the payment allocation between current—at the end of the idea development phase—and historical IVC members, is not dealt with in D2.4 or other deliverables so far in the project. Who will receive such compensation, and the form it takes, should be examined in WP4. A useful starting point would be statistics on who is typically left with IPR at the end of idea development phases before the diffusion process begins. We also suggest that the creation of the network not only hinges on the idea being successfully developed, but also on the feasibility of the product in the market. This feasibility search can readily be coupled with the existing market mechanisms in base SKIN—if any products were attempted bought, but not supplied, in the market during the previous round, a network is more likely formed to handle the diffusion. An experienced SKIN modeler will notice that this seems to be incompatible with the way base SKIN handles how agents behave after not being able to find inputs (they will immediately—in the following round—attempt to produce something else). This is an issue that will be elucidated through the retrospective case studies done in WP4. Originally, this issue was to be dealt with in detail through the ethnographic studies planned in WP4, but due to the Covid-19 crisis, close observation in the AM firm social setting is currently impossible. Fortunately, the retrospective case studies appear, at the present moment, to contain a wealth of information that is useful for dealing with the issue.

5.6 Summary of adaptations within IAMRRI SKIN

Significant changes to the base SKIN model are summarized in the table below. The reader will find these more closely related to the implementation phase in the next chapter.

Table 8 – Significant changes between base SKIN and IAMRRI SKIN

Original SKIN	IAMRRI SKIN
Model initialization	
Single industry.	Double industry.
One to two types of agents.	Max. 9 types of agents, but simplification groupings are suggested.
No RRI.	4 RRI keys assigned to each agent.
Kenes randomly assigned to agents.	Purposeful assignment of Kenes to different types of agents.
IVCs and Veiled Innovation hypothesis	
IH is static and readily formed based on single firms' kene, except in network organizations.	In addition to IHCs in original SKIN, IHCs in IVCs are initially incomplete and developed over time borrowing the missing kene elements from other agents. The innovation idea goes through three stages (idea generation, development, and diffusion; diffusion is similar to the network organization agent 'collective' in original SKIN).
Time frame	
All stages of innovation process performed in one tick. No delays happen.	Innovation processes stretch over time. Innovation idea goes consequently through generation, development, and diffusion phases over multiple ticks. Delays happen.
Networks	
Network organization is created, the composing organizations' kenos are put together, a new innovation hypothesis is developed into a product which will be made and sold on the market <i>all in one turn</i> .	Participation in the IVC is considered as a <i>project</i> in the firms starting the network organization (networked project).
A firm may participate in only one network at a time.	A firm may participate in multiple network projects at a time (but keeping the network concept from SKIN as a separate concept).
The search for potential network firm partners is limited to those a firm has already had a partnership with in the past.	Firms' can also search partners through open access.

6. Transitional summary for implementation phase

The aim of this section is to present the methodology through which will be capitalised - in the next deliverable D3.2 - the outcomes and concepts of the previous sections of this deliverable, D3.1, dedicated to present the IAMRRI adaptations and extensions to SKIN modelling framework. This section is mainly a preliminary introduction to what will be detailing presented in the deliverable D3.2, mainly dedicated to describing the IAMRRI Metamodel and the Data Collection Framework, as well as the implementations of the IAMRRI adaptations and extensions in code constructs.

6.1 Requirements for the Metamodel

6.1.1 What is a Metamodel and why is it useful?

For the IAMRRI purposes, a Metamodel is a set of general reusable schemes and templates able to provide a few starting modelling primitives in terms of a) the Agents/Actors that the IAMRRI model will include, b) their behaviours and characteristics, c) their (inter-)Actions, d) their Decision Mechanisms, e) the ways in which the RRI keys will be introduced at modelling level (e.g., as Variables at the Agents/Actors level, as Variables influencing their behaviours and characteristics, as well as their (inter-)Actions, or their Decision Mechanisms).

Other than describing Agents/Actors, their behaviours, and characteristics, their (inter-)Actions, or their Decision Mechanisms in the context of interest, in our case the AM industry, the Metamodel will be also used in an additional two-fold purpose:

Firstly, to provide simple examples of instances of the IAMRRI model using the conceptual representations of the theoretical 3-stage IVC model and scenarios examples extended to AM industry from the deliverable D2.4. Secondly, to provide simple data collection templates to be used in gathering data for initialization and calibration of IAMRRI model instances.

The Metamodel, that will be the core of the next deliverable D3.2, it is so aimed to:

1. **Detail - in something close to codable forms - the IAMRRI adaptations and extensions** necessary to derive from the Conceptual model of IAMRRI, situations in which Agents/Actors are acting in terms of general and reusable modelling primitives for ABM of AM IVCs, to support the modelling work of the next steps in terms of an easy translation and adaptation of these templates and schemes to several model instance examples into the IAMRRI simulation framework.
2. **Schematically introduce these modelling primitives** in order to provide a clear perspective on what IAMRRI Agents/Actors are, how they behave and how they interact, in order to facilitate *ad-hoc* translations of these primitives in the simulation code.
3. **Use the conceptual representations of the theoretical 3-stage IVC model and scenarios examples extended to AM industry from the deliverable D2.4, to provide simple examples of instances of the IAMRRI model.**

To provide simple example of instances of the IAMRRI model, from which start to iteratively work introducing the changes presented into the above sections to the SKIN modelling framework, in terms of code adaptations and extensions, we will need to introduce: a) *Agents/Actors* (who is acting); b) characterising *Functions* (through which these Agents/Actors are acting - what they exchange in their (inter-)Actions), and c) how the Agents/Actors are related one another in terms of these (inter-)Actions.

According to this, the first step it will be so to provide an Agents/Actors list, and then to describe the Functions characterise them. Speaking in modelling terms, some of these Functions will be described through local and global Variables that when they reach a certain threshold value (to be identified),

trigger a change (to be identified too). These changes during Agents/Actors (inter-)Actions will be also part of the (inter-)Actions description in the following steps.

As general modelling framework, the Metamodel should try to answer these questions:

*What are the **Agents/Actors**?*

*What **properties** do they have?*

*What kind of **Actions** can the Agents/Actors take?*

*What kind of **Environment** do the Agents/Actors exist in (phases of the IVC model)?*

*What is the order of **Events** that occurs in the evolving of examples of IVC processes (narratives of some modelling examples)?*

*What types of **Outputs** will these Events generate?*

*What do we expect to observe as a **Result** of the simulation (how the RRI-keys can trigger some Agents/Actors behaviours)?*

Following, to make this approach clearer, an example of what it will be presented in the next deliverable D3.2. It represents an Idea Generation example of instance, and its implementation-oriented translation.

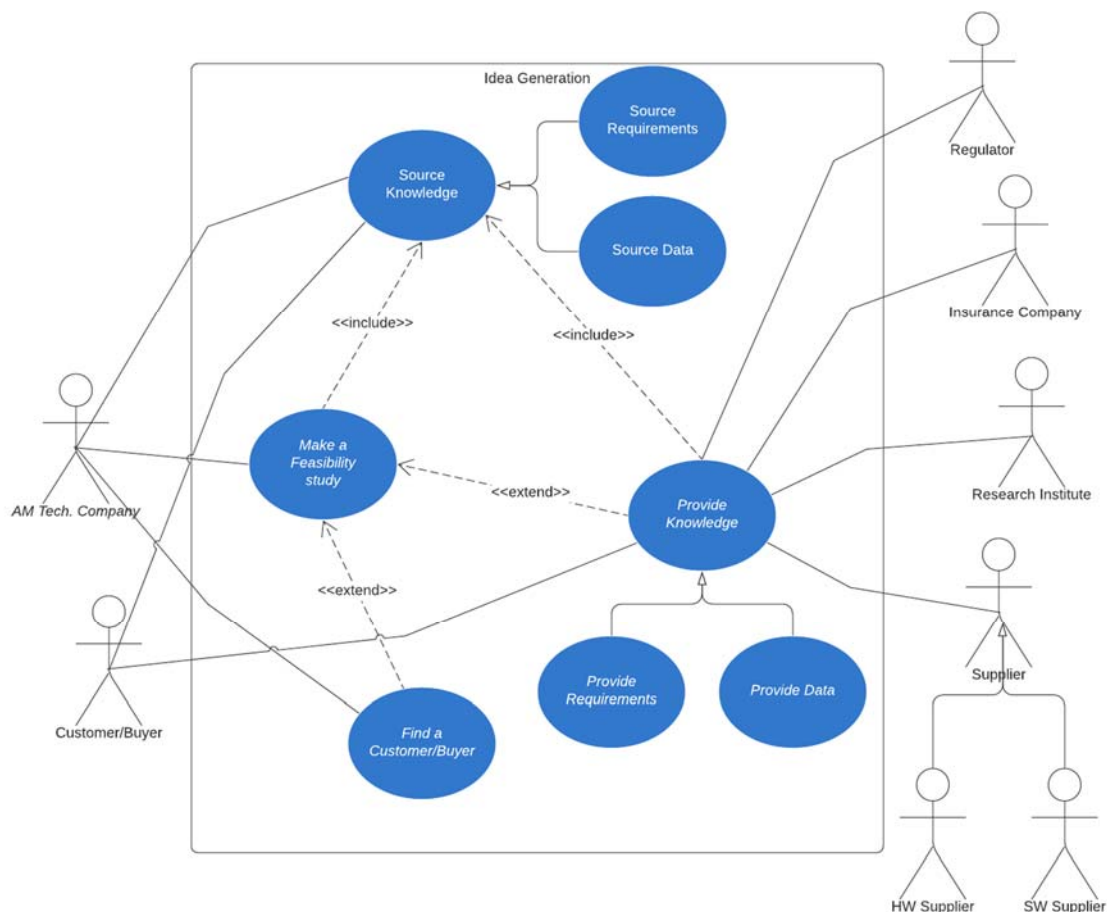


Figure 13 – Idea generation

- An AM Tech. Company, that has developed a machine for producing parts suitable for the Biomedical sector, wants to assess the potential re-engineering of that AM machine, to be used to answer to the request of the market for personalised Biomedical implants.

The Idea Generation system modelled has 6 types of Agents/Actors involved:

1. AM Tech. Company.
2. Supplier.
3. Regulator.
4. Research Institute.
5. Customer/Buyer.
6. Insurance Company.

Table 9 - Idea Generation system with 6 types of agents/actors

Agent/Actor		Description
1	AM Tech. Company	Company delivering AM Tech. (products, machines, tools, components/parts) to other businesses
2	Supplier	Company supplying HW or SW to AM Tech. businesses
3	Regulator	Certifying or Standardising Institution
4	Research Institution	Research Institution that provides Knowledge
5	Customer/Buyer	Company delivering the final product to the market
6	Insurance Company	Company selling insurances

These Agents/Actors belong to 2 different families: *Company* and *Institution*.

- The Idea Generation system implements 4 Functions. These Functions are offered to the Agents/Actors that interact with the system. These Function are:

“Make a Feasibility study”, which includes → *“Source Knowledge”*.

“Provide Knowledge”, which includes → *“Source Knowledge”* and extend (or represent an extension or an enrichment of) ← *“Make a Feasibility study”*.

“Find a Customer/Buyer”, which extend (or represent an extension or an enrichment of) ← *“Make a Feasibility study”*.

“Source Knowledge”.

The AM Tech. Company is the primary Agent/Actor of the system, and the initiator of the innovation process. The Customer/Buyer is also a primary Agent/Actor, since it represents the needs, the requests of the market. The AM Tech Company “Source(s) Knowledge” in order to “Make a Feasibility study” able to assess the innovation potential. In doing this, the AM Tech. Company Agent/Actor interacts

with the Agent/Actor Supplier, with the Agent/Actor Insurance Company, with the Agent/Actor Regulator, and with the Agent/Actor Research Institute. The Customer/Buyer Agent/Actor, that is looking for innovative solutions to answer to its needs and requests, is also interacting with the other Agents/Actors of the system, those that are Knowledge providers. On the other hand, it is also providing Knowledge related to the needs and requests it is looking to answer. The Knowledge it is represented by Data and/or Requirements. In case the result of the Feasibility study will be positive, the AM Tech. Company Agent/Actor it will be encouraged to find a Customer/Buyer, and to proceed to the next stage of the IVC.

The system can be thought as a building block of autonomous functionalities, a phase of the process, or the overall model itself, anyway a *Domain* or *Context* clearly separable for modelling purposes from all the rest.

Every Agent/Actor plays a specific role, within the system. A role corresponds to a certain family of related (Inter-)Actions that the Agent/Actor undertakes with the system.

There are *Relationships* between the Functions implemented by the system. These Relationships are: The *inclusion Relationship* between Functions, represented by a dotted line indicating the term <<include>>, it means that the Function at the base of the arrow completely includes the Function at the tip. This relationship can also be expressed with the expression the Function “Uses”.

The *extension Relationship* between Functions, represented by a dotted line indicating the term <<Extend>>, it means that the Function at the base of the arrow can be used in the Context of the “extended” Function (the Function at the tip), or it represents a sort of its extension or enrichment.

The *generalisation Relationship* can be applied to Functions, but also to Agents/Actors. For the semantics of generalization, a “sub-Actor/Agent” should therefore be able to perform all the Functions in which the “super-Actor/Agent” participates; if necessary, it can perform additional Functions, or participate in a different way in the execution of an “inherited” Function. A “sub-Function” should provide the same type of general service as the “super-Function”, possibly producing additional value, or providing it to some type of additional Actor/Agent; or following a partially different process to obtain the result, and so on.

As we have seen from the above example of Idea Generation instance:

- Agents/Actors are generally assigned only to one type.
- Each Agent/Actor is characterised by specific *Functions*, where these Functions represent its potential (inter-)Actions capabilities⁷.
- The (inter-)Actions that an Agent/Actor may undertake are based on commercial (e.g., *selling, procuring, delivering, receiving*), or non-commercial (e.g., *learning, knowledge, joint research*) exchanges, or both of these - this is a further generalisation.

(inter-)Actions between Agents	(inter-)Actions
Commercial	Selling, procuring, delivering, receiving, ...
Non-commercial	Learning, knowledge, joint research, ...

⁷ This is an ontological specification, that means that it could not necessarily be a direct correspondence between the computational Agents in the model, and the real-world Actors. On the other hand, several simplifications are needed, at least in the starting model.

In introducing the Variables characterising Agents behaviours, we have to make a clear distinction between a) the Variables directly impacting on the IVC natural/internal uninfluenced dynamics, and (b) the Variables that can be triggered and piloted using the RRI keys.

The Variables characterising the Agents/Actors in terms of direct impact on the IVC natural/internal uninfluenced dynamics, belong to the following *macro-areas*:

- A. Market, customers and competitors** - e.g., new market segments, closeness to customers/buyers' needs, innovation level with respect to competitors, etc.
- B. Innovation characteristics and technology** - e.g., specific features, lifetime, accessibility, usability, degree of innovation with respect to past, etc.
- C. Organization, strategy, production** - e.g., profits increasing, costs reductions, resources use, etc.
- D. Global factors and Megatrends.**
- E. Local factors and Contexts.**

These Variables will be further detailed in the next modelling steps, mainly through the development of the simulation experiments, from data coming from real innovation processes analysis (as for the WP4), and from retrospective studies.

For the Variables that can be triggered and piloted using the RRI keys, it can be useful the following table:

Table 10 - Preliminary meta-model transition

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Success determination	Can conceptually be understood as a determination of whether the firm was 'successful' (was able to sell product/service in previous round) and reached it is 'success threshold' (profits over a certain threshold). These determinations lead to decisions on partnership search and R&D.	X		Can be left as is. See description.
Partnership for K=knowledge exchange	Agents can, if unsuccessful in selling their products or services, search for other Agents for knowledge exchange	X		Action=selling of a product or a service - can trigger a partnership for K exchange. Suggests search in open-access sources as an addition to partnership search algorithm.
R&D process	The agents will perform R&D if they have been unsuccessful at selling their product/service (otherwise unable to create new IH).	X		Can remain unchanged, except for the last stage where the firm may decide to provide results from their R&D in an open-access fashion.

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Production planning	Can conceptually be understood as production planning; in implementation an algorithm attempting to create inputs for the IH decides on whether inputs are possible. Not run if previous IH turned out to be viable. Attempt aborted if inputs cannot exist.	X		Can remain unchanged. At the present moment no data exists on which inputs are needed for a typical product for a given agent type. Suggests probability distribution to set input types, i.e., AM production firm needing input from AM design firm has a given probability, for output if such data can be found. An output can have several inputs, so such assignment is possible.
Output quality establishment and learning-by-doing	The quality of the output (product/service) is determined based on expertise part of kene used in IH. Expertise is incremented for kene part used in IH. Other parts' expertise is decremented and removed if expertise is 0.	X		Can remain unchanged. See description. Consider implementing algorithm that treats RRI orientations in the same way, e.g., if open access was employed, the agent increases their open access orientation. Suggest that implementation decision depends on qualitative data collection in WP4.

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Market function	An iterative process where input providers are matched with output providers in such a way that all inputs and output requirements are matched, if possible. Those agents that are matched produce and sell as expected in a market. Others abort their attempt and are considered 'unsuccessful' (see flowchart).	X		Can be left as is; if changes to production planning are implemented a flag indicating agent type should be checked to make sure that the market match reflects input source.
Create 'network organization'	Firms may decide to create a 'network organization' together with previous partners if they form a fully connected sub-network. The new organization mainly behaves as an ordinary organization. The network organization will derive knowledge from members' kenos and the members will in turn learn from the networked organization as it acquires knowledge. Networked firms' profits are distributed among members. Lifetime of networked organization is dependent on market success.	X		Can be left as is. Consider determining member agent type composition based on probability distribution from real world data. Algorithm be used as a basis for IVC membership search.
IH re-generation	Agents can re-generate incomplete IHs that can be developed together with other Agents in new IHs. The incomplete IHs are thought of as consequences of agents' prior knowledge base.		X	Incomplete IHs can be re-generated in new IHs through K exchange.
RRI orientations	RRI orientations describe how strongly Agents pursue any given RRI domain.		X	RRI orientations of each Agent can be described through value in [0,1].

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Double industry model	Exchanging of knowledge and resources within AM industry, that needs of a unified model of different production sectors.		X	Agent/Actors characterized by belonging to innovation paths common between different production sectors - modelled with an additional Capability for identifying these Broker Agents/Actors.
RRI keys	4 RRI keys: open access, public engagement, ethics, and science education. See below for exact descriptions.		X	Modelled as 4 respective variables for each Agent/Actor described through value in [0,1].
Learning RRI keys	RRI key values can change by means of specific learning mechanisms.		X	Variables updated every specific time unit or basing on events happening (FLAG/S).
Societal benefits of the IH	Measuring the IH impacts on society that are beneficial in their very nature.		X	Modelled as a Boolean variable - 1 OR 0 - related to the presence OR not of societal benefits spanning from the innovation idea
Ethics	Ethics orientation takes part in determining whether an agent will accept invitation to join an IVC, whether they want to involve NGOs, and whether they want to provide R&D results in an open access manner.		X	It can be modelled as a honour/excellence FLAG/S of the Agent/Actor.

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Science education	Science education orientation takes part in determining whether an agent will take part in performing science education actions.		X	It can be modelled as an internal mechanism according with the flow chart scheme presented in sec. 5.
Open Access	Open access orientation takes part in determining whether an agent will publish R&D results in an open access manner and whether the agent will perform science education.		X	It can be modelled as an internal mechanism according with the flow chart scheme presented in sec. 5.
Public engagement	Public engagement orientation affect NGO involvements and market effects due to providing society with societally beneficial innovations through valuing both highly during IVC participation decisions.		X	NGO involvement and societally beneficial innovations impacts will be modelled as Environment variables that can accelerate o decelerate the innovation development process
Funding	Funding decisions by a central funding source, e.g., EU projects, are affected by the participation of NGOs and the nature of the innovation.		X	The funding function depends on NGO participation and whether the innovation is inherently societally good or bad.
Governance	Mechanism for Governance only related to regulations and public reactions.		X	FLAG/S similar to the inherent societal benefits of the IHs.

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
IVC support to multiple Actor/Agent types	9 types of Actors/Agents, divided in 4 main families.		X	Not all Actors/Agents will be integrated in the first iteration of adaptation, but using a parsimonious approach, they will be integrated through modelling steps of increasing complexity.
IVC stages	Innovation model adopted goes through generation, development, and diffusion.		X	IVC stages will be modelled with the approach one stage-one model. These models will be then interfaced and linked to cover all the IVC development, in the refinement phase.
Network	The network is created to running a project in a single innovation stage.		X	Different networks can be necessary to complete a project during all the innovation development (3 stages). This entails having agents joining and leaving during the IVC process.
Vicarious learning in IVCs	Agents in IVCs may not directly financially benefit from participation unless taking part in the diffusion phase. They can, however, gain knowledge according to stakeholder informants. This learning takes place as incomplete IH is developed.		X	Can be modelled as a process during idea transmutations where the agent has a given probability to gain knowledge based on the other members' involved kene parts.

Conceptual modelling block or idea	Short description	Base SKIN	IAMRRI extension	Suggestion for the Metamodel
Work force pool	This measure quantifies the available work force for AM agents. In the model, this is primarily affected by science education per the conceptual model in D2.4. The ability of AM agents to grow is limited by workforce capacity. Suggestions from the internal review indicates that the attractiveness may be increased by the success of AM agents. Knowledge of this is inconclusive at this time but can be examined in detail by WP4 if deemed necessary.		X	A pool of workers as a function of work force capacity. This pool is drawn upon as firms grow.

Additional to this, the deliverable D2.4 has identified *5 potential stereotypes of Innovation Environments* that represent examples of simple instances of the IAMRRI model:

1. **Product produced by AM** - the innovation that has as main output a product is triggered by the demand and use of the AM products, driven by Actors that use the AM products or by buyers of AM products.
2. **AM digitalization and SW** - the innovation that has as main output a SW is triggered by an emerging necessity of the supply and production chain at the level of product's digital design and AM machines design. Organizations/firms drive this type of innovation.
3. **AM services** - innovation that rises from the AM production - from the AM feedstocks to finished AM product and their distribution. Organizations/firms drive this type of innovation.
4. **AM machines and technologies** - innovation that rises from AM production, and it is triggered by the technological evolution. Organizations/firms drive this type of innovation.
5. **AM materials** - innovation that rises from AM production, and it is triggered by the technological evolution. Organizations/firms drive this type of innovation.

6.2 Output variables (indicators)

In order to cover the necessary outcome domains suggested by D2.4, we have included a brief description of potential output variables (indicators in D2.4's terms) that will be helpful in the implementation phase.

Based on the existing ABM models within the topic of innovation and IAMRRI extensions described above, the outcome variables need to cover the following areas:

- 1) economic performance,
- 2) network, IVC and webs of IVCs characteristics, and
- 3) knowledge

6.2.1 Economic performance

Economic performance of the AM industry is measured as a sum of individual firm performance. The total profits of all actors in a given time period provide a basic measure of the total value created by the industry during that period. In addition, aggregate return on assets (or "capital" in the SKIN terminology) gives information about the effectiveness of competition in the model. While aggregate profits and the aggregate level of capital may fluctuate a great deal over time, one would expect the aggregate return on assets to be more stable since agents can enter or leave the industry in response to profit opportunities (or the lack thereof). For simplicity, as in the original SKIN model, it is generally assumed that firms in the model are financed entirely by equity and have no liabilities; thus, there is no major difference between return on assets and return on equity.

Another measure of success that has been employed in the literature is the average lifetime (in time steps) of all firms during a run (Ahrweiler, Pyka, et al., 2011 p.227).

6.2.2 Network IVC and webs of IVCs indicators

For evaluation of innovation networks, the implementation team might find Kudic (2015)'s techniques and concerns useful, as well as Ludeña et al. (2008)'s study of networks in the nanotechnology technology domain.

For example, several indicators suggested for analysing innovation networks in nanotechnology (Ludeña et al., 2008) may be adopted in IAMRRI model:

- Number of joint projects

- Number of agents involved in networks,
- Heterogeneity of agents in networks (measured as an average number of different agent types in networks),
- Centrality
- Capital
- Technology transfer (number of cases when the ideas generated by universities are turned into innovation)

Moreover, separate stages of network development process (beginning, growth, consolidation and maturity) may have specific sets of indicators (Ludeña et al., 2008).

For evaluation of IVCs see (Hintze & Lüthje, 2014; Kusiak, 2009, p. 442).

The SKIN model by itself, of course, has existing features that can also be used for analysing networks, e.g., on partnerships and network organizations. Those can readily be found in the SKIN model's NetLogo description and will not be reiterated here for the sake of brevity.

6.2.3 Knowledge indicators

We suggest to use an already existing way of measuring knowledge flows in the model (Ahrweiler, Pyka, et al., 2011 p.227). In short, this technique assesses the sum of knowledge increase of firm agents as they learn from their partners.

6.3 Modelling the Complexity

These are some of the ingredients and the expected methodology that it will be used for the deliverable D3.2. After having discussed the scope of using and adapting SKIN to our (IAMRRI project) purposes, the procedures and methods for adapting SKIN to IAMRRI scientific objectives, and having presented a brief roadmap, for the next steps, an important and last point to close this section and the deliverable D3.1, is that linked to how to face the complexity of coding all the adaptations and extensions presented in the above sections.

The original SKIN model is already a complex model in terms of code complexity, counting several pages of written code (in NetLogo), and it is not too much easy (and maybe unfeasible) to adapt the code to the adaptations and extensions presented above, in which are listed several changes, in only one shoot. It is pretty much unfeasible, from a programming point of view, to proceed in a one-step translation, it is necessary to proceed by iterative steps, increasing the complexity at every iteration.

That means, that starting from simple model instances, with the minimum complexity, the suggestion is to add, through different iterations, Agents/Actors, Variables, Decision Mechanisms and so on, step by step, iteration after iteration.

More than one model instance can be used as starting point, and through the following development algorithm - starting from a model instance of min. complexity (*parsimonious approach*).

- Modifying the model.
- Testing and calibration of the model.
- Verification of the model.
- Next step of adaptation.

It is also suggested to develop each phase independently in a modular fashion, as to reduce complexity and increase the ease of calibration and verification. The approach could be that to have two or three different modules (one for every phase of the IVC), developed separately according with the parsimonious approach presented above, that we can try to interface in the refinement stage.

6.4 Requirements for the Data Collection

Last and not least the data collection framework, with which we intend the dynamic framework that will evolve with the evolving of the model complexity, starting from an initial framework drafted on the base of the initial model instances with min. complexity from which we will start the adaptation. These data will be mainly used to initialise the model and to calibrate the model.

The SKIN model considers 3 types of *Knowledge* domain in which every agent (a firm) has:

- Capabilities.
- Abilities (to perform specific actions).
- Expertise (generated as result of the abilities).

	Conceptual (<i>kene</i>)				Implementation (<i>kene</i>)			
	Agent type	Capability	Ability	Expertise	Agent type	Capability	Ability	Expertise
KENE	AM Tech. Company	Machine	Engineering	High	1	1	1	5
	AM Tech. Company	AM tech.	Laser	High	1	2	2	5
	AM Tech. Company	Materials	Ceramics	Low-Mid	1	3	3	2
	AM Tech. Company	Materials	Metals	Low-Mid	1	3	4	2
	AM Tech. Company	Electronics	Design	Mid	1	4	5	3
	AM Tech. Company	Electronics	Programming	Low-Mid	1	4	6	2
	AM Tech. Company	Control SW	Programming	Low-Mid	1	5	6	2
	AM Tech. Company	Business	Strategy	Mid-High	1	6	7	4
	AM Tech. Company	IPR	Patenting	Low	1	7	8	1

Science - Technology - Business.

The first step in data collection should be to understand who our Agents/Actors are (firms, individuals, institutions, etc.). Additional to this, we should be able to map the Agents knowledge through their *kenes*.

For every Agent/Actor involved in the innovation process, we should quantify, by triples (*C, A, E*), the units of knowledge the Agent can provide and/or exchange with other Agents/Actors. This means to identify the *kenes* of the Agents/Actors, describing so their *virtual Knowledge bases*.

	SCIENCE	TECHNOLOGY	BUSINESS
Capabilities			
Abilities			
Expertise			

RRI virtual bases (RRI orientations), will have also to be introduced as they are *Variables* that has a direct impact on the *kenes* of the Agents/Actors (*RRI kenés*).

- Identifying which is the target of every innovation project: product, service, other.
- For every innovation project, identifying - according with the quantitative description in triples - the related part (subset) of the (virtual) knowledge bases that has generated the IH related to that specific innovation project.
- For every innovation project, identifying its RRI virtual bases.

ID	Type of Parameter
1	No. Agents
2	No. max. (total) Targets (products, services, other)
3	No. inputs (stochastically made)
4	% of Targets that are components/parts of other targets (not the final ones)
5	% 'big' firms
6	Initial capital of non-big firms (SMEs)
7	Partnership strategy - e.g. conservative vs. progressive
8	Partnership attractiveness threshold
9	Success threshold
10	Start-up threshold

For every network organization it will be also important to describe the partnership in terms of:

- Type of partner (Agent/Actor).
- The Knowledge every partner (Agent/Actor) is willing to exchange in that specific innovation project referring to the quantitative way we have used above to describe the Knowledge.
- Quantify - for every partner (Agent/Actor) - the number of the partners (Agents/Actors), present in that specific project, with which the partner has already collaborated. In case there is a partner with which was made more than one project, this number must be multiplied for the number of projects they jointly did in the past.

ID	Type of Parameter
1	Financial resources (<i>Capital</i>)
2	Knowledge resources (<i>KENES</i>)
3	Innovation Hypothesis
4	Advertisements
5	Manufacturing resources
6	Updating factors (<i>'Learning by Doing'</i>)

It will be also fundamental to define the parameters we want to collect (by Agent/Actor), related to:

- Financial resources.
- Innovation Hypotheses (IHs).
- Advertisements.
- Manufacturing resources.
- Upgrading factors.

According with the type of model instance we want to implement, these parameters can be different.

The work on developing the data requirements as well as collecting the associated data is an ongoing process performed in conjunction with WP4.

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