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# C-EMO: A Modeling Framework for Collaborative Network Emotions

Dissertação para obtenção do Grau de Doutor em
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*To the ones I love*

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# Abstract

Recent research in the area of collaborative networks is focusing on the social and organizational complexity of collaboration environments as a way to prevent technological failures and consequently contribute for the collaborative network's sustainability. One direction is moving towards the need to provide "human-tech" friendly systems with cognitive models of human factors such as stress, emotion, trust, leadership, expertise or decision-making ability.

In this context, an emotion-based system is being proposed with this thesis in order to bring another approach to avoid collaboration network's failures and help in the management of conflicts. This approach, which is expected to improve the performance of existing CNs, adopts some of the models developed in the human psychology, sociology and affective computing areas. The underlying idea is to "borrow" the concept of human-emotion and apply it into the context of CNs, giving the CN players the ability to "feel emotions". Therefore, this thesis contributes with a modeling framework that conceptualizes the notion of "emotion" in CNs and a methodology approach based on system dynamics and agent-based techniques that estimates the CN player's "emotional states" giving support to decision-making processes.

Aiming at demonstrating the appropriateness of the proposed framework a simulation prototype was implemented and a validation approach was proposed consisting of simulation of scenarios, qualitative assessment and validation by research community peers.

**Keywords:** collaborative networks, CN emotions, system dynamics, agent-based modeling.

# Resumo

Recentemente a área de investigação das redes colaborativas tem vindo a debruçar-se na complexidade social e organizacional em ambientes colaborativos e como pode ser usada para prevenir falhas tecnológicas e consequentemente contribuir para redes colaborativas sustentáveis. Uma das direcções de estudo assenta na necessidade de fornecer sistemas amigáveis "humano-tecnológicos" com modelos cognitivos de factores humanos como o stress, emoção, confiança, liderança ou capacidade de tomada de decisão.

É neste contexto que esta tese propõe um sistema baseado em emoções com o objectivo de oferecer outra aproximação para a gestão de conflitos e falhas da rede de colaboração. Esta abordagem, que pressupõe melhorar o desempenho das redes existentes, adopta alguns dos modelos desenvolvidos nas áreas da psicologia humana, sociologia e *affective computing*. A ideia que está subjacente é a de "pedir emprestado" o conceito de emoção humana e aplicá-lo no contexto das redes colaborativas, dando aos seus intervenientes a capacidade de "sentir emoções". Assim, esta tese contribui com uma *framework* de modelação que conceptualiza a noção de "emoção" em redes colaborativas e com uma aproximação de metodologia sustentada em sistemas dinâmicos e baseada em agentes que estimam os "estados emocionais" dos participantes e da própria rede colaborativa.

De forma a demonstrar o nível de adequabilidade da *framework* de modelação proposta, foi implementado um protótipo de simulação e foi proposta uma abordagem de validação consistindo em simulação de cenários, avaliação qualitativa e validação pelos pares da comunidade científica.

**Palavras-chave:** redes colaborativas, emoções, sistemas dinâmicos, modelação baseada em agentes.

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# List of Acronyms

| | |
|---|---|
| AB | Agent-Based |
| ABM | Agent-Based Modeling |
| ABMS | Agent-Based Modeling and Simulation |
| ABS | Agent-Based System or Simulation |
| AI | Artificial Intelligence |
| ANE | Aggregated Network Emotion |
| ANEA | Aggregated Network Emotion Appraisal |
| BDI | Belief-Desire-Intention |
| BPEL | Business Process Execution Language |
| BPMN | Business Process Modeling Notation |
| C-EMO | Collaborative Network Emotions Modelling Framework |
| CME | Computational Model of Emotion |
| CN | Collaborative Network |
| CNE | Collaborative Network Emotion |
| DE | Discrete Event |
| HCI | Human-Computer Interaction |
| IBM | Individual-Based Modeling |
| IMB | Individual Member Behavior |

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|---|---|
| IMBR | Individual Member Behavior Reasoning |
| IME | Individual Member Emotion |
| IMEA | Individual Member Emotion Appraisal |
| MAS | Multi-Agent System or Simulation |
| RTD | Research and Technological Development |
| SD | System Dynamics |
| SOA | Service-oriented Architecture |
| SSD | Spatial System Dynamics |
| VBE | Virtual Organization Breeding Environment |
| VIMS | Visual Interactive Modeling Systems |
| VO | Virtual Organization |
| XPDL | XML Process Definition Language |

# 1

# Introduction

*The aim of this chapter is to introduce the topic of this research work – the collaborative network emotions. First the problem statement and motivation is presented, followed by the research questions and corresponding hypotheses. Then the research context of the work is introduced and the adopted research method is shortly described. It finishes with an outline of this dissertation.*

## 1.1 Problem Statement and Motivation

In recent years the area of Collaborative Networks (CNs) is being challenged with the need to prevent collaboration failures (Pouly et al., 2005; Bititci et al., 2007; Vallejos et al., 2012). According to some research in socio-technical systems (Morris et al., 2010; Baxter & Sommerville, 2011), the failure of large complex systems, such as CNs, is not directly related to the technology neither to the operational systems that compose them. Rather, they fail because they do not recognize the social and organizational complexity of the environment in which these systems are deployed. In this direction, improvements not only in technical terms but also in relation to social interactions among the involved participants are being performed (Msanjila & Afsarmanesh, 2008; Rosas & Camarinha-Matos, 2010; Macedo & Camarinha-Matos, 2013; Ferrada & Camarinha-Matos, 2017).

A survey conducted by Vallejos et al. (2012), recognized that problems with trust, reputation and commitment among networks members as well as the growing number of members that increases the conflict risk leading to the lack of achievement of common objectives centered on knowledge acquisition and sharing, learning, adaptation to

change, and gains, put in jeopardy the collaborative network objectives such as equity, efficiency and adaptation, leading to failure. In addition, Morris et al. (2010) highlights that neglecting social and organizational complexity can cause large, and often serious, technological failures and also recognizes that there is a need to provide "human-tech" friendly systems with cognitive models of human factors like stress, emotion, trust, leadership, expertise or decision-making ability. In this context, an emotion based system is proposed in order to serve as another approach to avoid collaboration networks' failures.

Emotion is an important factor in human cognition and social communication (Damasio, 1994) which has been used as a mean of interaction in several fields of science like psychology, sociology, artificial intelligence (AI), and human-computer interaction (HCI) with the use of emotional agents. Furthermore, a large amount of research within the last few decades has been focusing on computational models of human-emotion and the relationship they have with human emotional processes and how they affect the surrounding environments (Bonabeau, 2002; Coenen & Broekens, 2012; Bosse et al., 2015).

In the context of collaborative networks, "emotions" can influence the experience of partners by increasing the achievement and performance level, motivation, commitment, satisfaction and excitement in interaction with each other and the CN as a whole. Furthermore, a new approach that is expected to improve the performance of existing CNs, namely the collaboration sustainability and interactions, is introduced by adopting some of the models developed in the human psychology, sociology and effective computing areas as previously mentioned. The idea is to "borrow" the concept of human-emotion and apply it within the context of CNs, turning them into a more "human-tech" friendly systems (as suggested by Morris et al. (2010)) without being intrusive, i.e. without violating the intimacy of each participant.

When thinking about complex systems such as CNs that are composed of several nodes representing organizations, small and medium enterprises, large companies, among others, collaborating with the aim to achieve a purpose, it is reasonable to imagine that all of these interacting entities might also generate "emotions" that would be affected by the dynamics of the collaborative environment. Thus, the emotional state of each participating organization (CN Member) would contribute to the assessment of the aggregated emotional state of the CN and in this way contribute for its well-functioning. The individual emotional state of a member would affect its performance and relationships within the CN (Ferrada & Camarinha-Matos, 2015).

In this way, the notion of Collaborative Network Emotion is introduced[1] as described in Definition 1 below.

Definition 1. ***Collaborative Network Emotion***

*Collaborative Network Emotion (CNE) is the "emotion" that represents the collaborative network players' "feelings". It comprises the types of emotion that are "felt" by individual members and by the CN as a whole.*

Furthermore, it might be assumed that the estimation of CNEs provides support to the CN administrator via the CN management system, allowing a better understanding of the overall emotional health of the network and also of each member in particular. On the other hand, there are some studies suggesting that **emotion** affects decision-making (Damasio, 1994; Bazzan & Bordini, 2001) that recognize that the benefits of having **emotions** comprehend more flexible and sociable decision-making, as well as creativity and motivation. In addition, according to Bazzan and Bordini (2001) there is a higher ratio of cooperation between agents when they make decisions using **emotions**. In this line, it can be assumed that the CN administrator increases awareness and flexibility when it is able to use emotions to decide which course of action to take during the collaboration process. Moreover, CNEs can support the management of conflicts within the CN. The research work conducted by Lumineau et al. (2015) is based on the inter-organizational conflicts and addresses the necessity to provide new multi-level models of conflict management. The study of emotions in the CN context can also mitigate some conflicts among members and contribute to the CN conflicts management.

## 1.2 Research Question and Hypothesis

Considering the overview of (*i*) the problem that this thesis addresses, which consists in the challenge to overcome the level of unsuccessful CNs with the introduction of socio-technical and "human-tech" systems, and (*ii*) the motivation to adapt human-emotions to the context of CNs providing in this way means to estimate the CN's and

[1] In order to distinguish among human-emotion and collaborative network emotion, whenever the term **emotion** (in bold) appears, it refers to human-emotions, while the terms CNE, CN emotion or simply emotion refers to collaborative network emotions. With the exception of sections 2.2 and 2.3, that are devoted in exclusive to human emotions.

each member's emotional states supporting the CN administrator in decision-making, the main research question is:

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| **Main Research Question** | What could be a suitable modeling framework and modeling methodology approach to support the concept and estimation of collaborative network emotions and help decision-making processes, in a non-intrusive way, within a collaborative network environment? |

The following sub-research questions give detail to the main research question:

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| **Research Question 1** | What could be an adequate conceptual modeling approach to identify and characterize individual member's emotion and aggregated network emotion in order to properly estimate their states in a collaborative network environment? |

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| **Research Question 2** | What could be an adequate modeling methodology approach to instantiate the proposed modeling framework and which methodologies would be suitable for the estimation/appraisal of collaborative network emotions? |

In order to better answer the research questions, these were divided into sub-hypotheses. Therefore, for each research question different hypotheses with potential solution approaches were formulated taking into account the background summarized on chapter 2 as follows:

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|---|---|
| **Hypothesis 1a)** | The identification and characterization of individual member's emotions in a CN environment, can be done if some concepts and theories from human related emotions, present in the areas of psychology and sociology, are borrowed and adapted to the context of organizations in a collaborative environment. |

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|---|---|
| **Hypothesis 1b)** | The identification and characterization of the aggregated network emotion in a CN environment, can be done if some concepts and theories from sociology of emotions along with mechanisms for CN sustainability, are considered and adapted. |

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| **Hypothesis 1c)** | The estimation of the involved emotions might be done if the underlying concepts, reasoning mechanisms, and the relations and interactions among the different CN players and the CN environment are represented in a single modeling framework. |

| | |
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| **Hypothesis 2a)** | The proposed modeling framework can be adequately deployed if a simulation modeling methodology is used in the process of the model building. |

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|---|---|
| **Hypothesis 2b)** | The estimation/appraisal of collaborative network emotions can be done if an agent-based simulation model is designed and developed with the purpose of representing the collaborative network environment (with its involving players) and simulating the emotion dynamics present in each agent type using a system dynamics modeling approach. |

The main aim of this research work is then to introduce the concept of emotions within a collaborative environment (CNEs) and to describe a modeling framework based on fundamental recognition that any model developed on top of it allows the integration of modeling methodologies and technologies, demonstrating in this way its feasibility. In addition, demonstrate that the modeling framework described above may be utilized within an agent-based and system dynamics simulation life cycle.

## 1.3 Research Context

The research that was done in this thesis was partially accomplished in the context of the European funded GloNet (2011-2015) project. Nonetheless, this work also benefited from the vast knowledge and experience acquired over the last 15 years through participation on a number of other EU and national research projects. In order to establish the relevance of GloNet project and the other projects to this research work, a short description is presented below.

### 1.3.1 GloNet Project

The GloNet – *Glocal Enterprise Network Focusing on Customer-Centric Collaboration* (http://www.glonet-fines.eu/) – project funded by the European Commission under the ICT-FoF programme (7th FP – 285273, 2011-2015) had a duration of three and a half years and involved eight partners from six countries in Europe, and some collaboration in India.

GloNet focuses on collaborative environments for networks of SMEs involved in highly customized and service-enhanced products through end-to-end collaboration with customers and local suppliers (co-creation) (Camarinha-Matos et al., 2011). The project aims at supporting the notion of *glocal* enterprise, which represents the idea of thinking and acting globally, while being aware and responding adequately to local specificities. It endorsed the vision of a new participative manufacturing environment supported by the Internet, hosting a new wave of services, using user-friendly technologies aimed at empowering the enterprise of the future (Figure 1.1). Achievements in this domain resulted in improved efficiency of product intelligence, enabling advanced product-centric services and new business models and capabilities for improved management of global networked operations (Camarinha-Matos et al., 2013b; Camarinha-Matos et al., 2013d; Camarinha-Matos et al., 2013e). Further to this service-based enhancement, there is a growing trend in manufacturing to move towards highly customized products, ultimately one-of-a-kind, which is reflected in the term mass customization (Pollard et al., 2008).

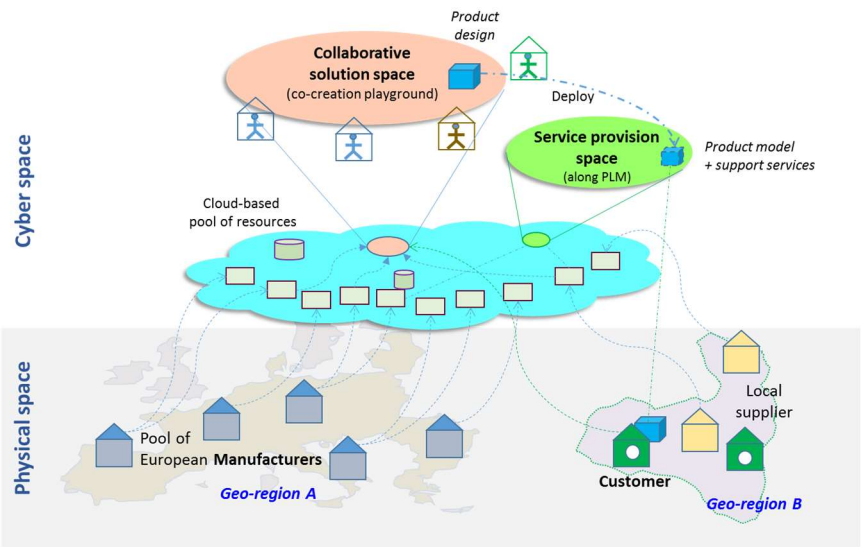



**Figure 1.1. GloNet ecosystem overview. Reproduced from http://www.glonet-fines.eu/.**

The main guiding use case in GloNet was focused on the production and life-cycle support of solar energy parks. The norm of operation in this industry is that of one-of-a-kind production. The results (products and services) are typically delivered through complementary competences shared between different project participants (organizations can range from mechanical and electrical companies to software product development enterprises in the area). A key challenge here is the design and delivery of multi-stakeholder complex services along the product life-cycle (which typically spans over 20 years). In order to extend the applicability of GloNet results, other domains with similar abstract characteristics, such as building automation and physical incubators of enterprises, were also considered.

The GloNet project contributed to the accomplishment of this work as follows:

- It helped in consolidating the knowledge on collaborative networks with the introduction of new organizational forms to its taxonomy (see section 2.1).
- It provided interactions with peers in the area of collaborative networks.
- It provided interactions and contact channels with representatives of real networks of organizations, which is the case of a network in the area of the solar energy industry and another in the area of intelligent buildings.
- It allowed the implementation of proof-of-concept prototypes, including the emotion support system.
- It supported the first validation of this work, from the feedback collected not only from the demonstrator events within the project scope, but also from the EU review meetings and also participation in conference events sponsored by the project.

### 1.3.2 Other Research Projects

**TeleCARE.** The TeleCARE (*A multi-Agent Tele-Supervision System for Elderly Care*) project was funded by the European Commission under the 5th Framework Programme (IST-2000 – 27607, 2000-2004). The project main objective was the design and development of a framework for tele-supervision and tele-assistance, following a federated multi-agent system approach, with the goal of assisting elderly people at their home environment (Camarinha-Matos & Afsarmanesh, 2004). It also included services to support elderly relatives and elderly care centers in the monitoring and assistance of elderly people.

The participation in this research project provided the first contact with the concepts of collaborative networks and virtual communities involving people, companies, and devices/software agents over the Internet. Furthermore, the Master of science dissertation of the author of this thesis (Ferrada, 2006) was a result of the participation and contribution in the TeleCARE project.

**ECOLEAD.** The ECOLEAD (*European Collaborative Networked Organizations LEADership initiative*) project, was funded by the European Commission under the 6th Framework Programme (IP – 506958, 2004-2008). The project aimed to create strong foundations and mechanisms needed to foster a collaborative and network-based industry society in Europe (Camarinha-Matos & Afsarmanesh, 2005b; Camarinha-Matos et al., 2008b). The project addresses three vertical focus areas, which constitute the ECOLEAD pillars: *VO breeding environments*, *dynamic virtual organizations*, and *professional virtual communities*. Additionally, two horizontal major support research areas were also addressed in the project: the *theoretical foundation* for collaborative networks and the *horizontal ICT infrastructure*.

The participation in this research project provided the interaction with a large number of partners/stakeholders which lead to a strengthening of the theoretical foundations and practical challenges in the different types of collaborative networks.

**ePAL.** The ePAL (*extending Professional Active Live*) project was funded by the European Commission under the 7th Framework Programme (ICT-2007.7.1 – 215289, 2008-2010). This was a coordination action project aimed at developing a strategic research roadmap focused on identifying innovative ways that best facilitate the development of active life process for retiring and retired professionals promoting at the same time, the notion of silver economy (Camarinha-Matos & Afsarmanesh, 2010). It identified a set of recommended actions covering societal, organizational and technological perspectives.

The participation in this project provided close interactions with senior professionals and networks of retired professionals which leveraged the design and implementation of innovative solutions and new organizational forms for collaborative networks.

**BRAID.** The BRAID (*Bridging Research in Ageing and ICT Development*) project was funded by the European Commission under the 7th Framework Programme (ICT 2009-7.1 – 2484852, 2010-2012). This was a supporting action project aimed at developing a comprehensive research and technological development roadmap for active ageing. This RTD agenda, which joined previous roadmap initiatives results, namely from AALIANCE, CAPSIL, ePAL, and SENIOR, defined a new and common strategic research agenda to support the socio-economic integration and wellbeing of senior

citizens, and consolidate and re-enforce EU leadership in ICT and ageing (Afsarmanesh et al., 2011; Camarinha-Matos et al., 2013c).

The participation in this research project provided new knowledge and embraced new challenges concerning different perspectives of life settings for seniors, such as independent living, health and care in life, occupation in life, and recreation in life. In addition, new challenges for the socio-technical aspects of collaborative networks were identified.

**AAL4ALL.** The AAL4ALL (*Ambient Assisted Living for All*) project is an anchor project of the Health Cluster Portugal (*Pólo de Competitividade da Saúde*) and was funded by the Portuguese Government through the *COMPETE* Programme from the *Quadro de Referência Estratégica Nacional* (QREN-COMPETE 2011-2015). The main objective of the AAL4ALL project was to develop a large-scale ecosystem with products and ambient assisted living services to support elderly people and maintain them at their preferred environments (Camarinha-Matos et al., 2012b). The project considered the scenarios elaborated in the BRAID project and implemented a large scale pilot.

With the participation in this project the accumulated knowledge comprising CNs and also the interaction with the project partners' views also contributed for the consolidation of this thesis work.

## 1.4 Adopted Research Method

The adopted research method for this PhD work is illustrated in Figure 1.2 and is based on the traditional or classical seven step research method (Camarinha-Matos, 2009), considering also the influence of the researcher's background knowledge (interdisciplinary domains) and some recursive iterations among some steps depending on the results obtained in the hypothesis testing as proposed by Dodig-Crnkovic (2002).

This research method is described as follows:

- **Problem/Research Question:** Considered the most important step in research (Camarinha-Matos, 2009), it is where the identification of the working context and motivation to formulate the research question is performed. It can be complemented with sub-questions to detail the scope of the work and must be capable of being confirmed or refuted. The main and sub research questions for this work were defined in section 1.2 of this chapter.


**Figure 1.2. Adopted research method.**

- **Background Research:** It is in this step that the background literature and state-of-the-art is reviewed. Having into account the multi-disciplinary scope of this thesis, different knowledge scientific topics were reviewed, namely: related background on collaborative networks (section 2.1); an extra effort was put on the domain of human-emotions focusing on the underlying conceptual theories (section 2.2) and on the existing computational models (section 2.3); and finally on methodologies and methods of simulation modelling focusing on the systems dynamics and agent-based modelling and simulation approaches (section 2.4).
- **Formulate Hypothesis:** The scientific hypothesis uses the background research to state the educated guess of the research problem. Hypothesis should be capable of verification or be testable. In Figure 1.2 it is illustrated the characteristic of hypothesis reformulation when unsatisfactory results are achieved. The different hypotheses for this work were defined in section 1.2 of this chapter.
- **Design Experiment/Proof-of-concept:** This is the point where the steps of the experimental phase are planned in detail. In engineering research it typically includes the design of a system architecture or a proof-of-concept prototype. In the case of this research work, this phase focuses on the design of a modeling

framework for collaborative network emotions, the C-EMO modeling framework (chapter 3), the design of the simulation modeling approaches of the C-EMO simulation (section 4.1), and the design of the emotion support prototype (sections 5.1.1.1 and 5.1.1.2 ). It is also in this phase that the design of simulation scenarios is performed (section 5.2.2.2.1).

- **Test Hypothesis/Collect Data:** This step focuses on testing if the formulated hypotheses are correct. It is where the simulation model (section 4.2) and the various iterations of the emotion support prototype (section 5.1) are effectively implemented and executed. Findings concerning the implementations and also the hypotheses are done and it might be necessary to perform adaptations (on the previous step) or reformulate one or more hypotheses (step 3). The tests results including the simulation runs are available along the section 5.2 according to the followed validation strategy.
- **Analyze Results:** The analysis of the results is also available throughout the section 5.2. It is performed a qualitative analysis to the results according to the defined criteria and also a brief discussion. In this step, it might be concluded that the hypotheses failed, then it is up to the researcher if the problem/research question is rejected or if the hypotheses reformulated.
- **Publish Findings:** Although appearing as the final step, this step runs in parallel with the previous steps through publishing, in recognized conferences and journals, the intermediate results. The followed validation strategy considers this final step with a section devoted to the validation by peers in the research community (section 5.2.3.2). The final publication will be this dissertation document.

This research method was followed during the course of this work, having been needed to perform some backward loops, principally for improving the system dynamics models and as a consequence reformulating the hypothesis accordingly.

## 1.5 Thesis Outline

This dissertation is organized into six chapters and four supporting annexes. A brief abstract of each chapter is presented in order to give an overview of this dissertation document.

**Chapter 1 - Introduction.** The current chapter. It begins with the problem statement and motivation, and is followed by the research questions and corresponding hypotheses.

Then the research context of the work is introduced and the adopted research method is shortly described. It finishes with this overview of the outline of this dissertation.

**Chapter 2 – Background and Literature Review.** The aim of this chapter is to present the theoretical body of knowledge that nourishes the work developed in this thesis. First the concept of Collaborative Network is presented along with a review of the main features and challenges that are currently present. Second, and due to the interdisciplinary nature of this thesis work, the concept of emotion is described and characterized in terms of the associated psychological and sociological theories. Third, a review of some of the computational models of emotion is presented. Finally, modelling and simulation frameworks are presented. In order to have a broader view of modeling and simulation, their conceptual constituents, lifecycle processes, associated paradigms and tools are reviewed.

**Chapter 3 – C-EMO Modeling Framework.** This chapter presents the C-EMO Framework proposal for the modeling of emotions in a CN context. First the concept of collaborative network emotion (CNE) is introduced with the description of a typology for emotions in the context of CNs and of a theory for representing CNEs. Then the two components of the C-EMO Framework, namely the individual member emotion and aggregated network emotion models are presented, respectively. Finally, the adopted simulation modeling approach for the development of both components of the C-EMO framework is presented.

**Chapter 4 – C-EMO Simulation Modeling.** This chapter presents the approach that is proposed for modelling the components of the C-EMO framework. It consists of the development of conceptual and simulation models based on the agent-based and system dynamics methodologies. This development, which follows the simulation modeling process presented in the previous chapter, is divided in two parts: one consisting of the design of two system dynamics models for the estimation of the IME and ANE, respectively, and also of the conception of an agent-based model for representing the CN and its players; and other comprising the transformation of these models into a computer model providing in this way a simulation model.

**Chapter 5 – Prototype Development and Validation.** This chapter presents the developed emotion support system prototype and the validation processes for both the emotion support prototype and the C-EMO modeling framework. It, starts with an overview of the methodological approach that was taken in the context of the GloNet project and the description of the different implementation phases. Then, the validation strategy for this research work is presented. It comprises four validation aspects: a) validation of the C-EMO modeling framework; b) validation of the C-EMO simulation

modeling approach; c) validation of this work by the research community; and d) validation of the underlying concepts and prototype in the solar energy industry area.

**Chapter 6 – Conclusions and Future Work**. This chapter presents the final considerations stating the novelty of this research area and outlines a series of open issues established for the future.

# 2

# Background and Literature Review

*The aim of this chapter is to present the theoretical body of knowledge that nourishes the work developed in this thesis. First the concept of Collaborative Network is presented along with a review of the main features and challenges that are currently present. Second, and due to the interdisciplinary nature of this thesis work, the concept of emotion is described and characterized in terms of the associated psychological and sociological theories. Third, a review of some of the computational models of emotion is presented. Finally, modelling and simulation frameworks are presented. In order to have a broader view of modeling and simulation, their conceptual constituents, lifecycle processes, associated paradigms and tools are reviewed.*

## 2.1 Collaborative Networks

The concept of *Collaborative Network* (CN) has become stronger in recent years within the academic and industrial areas. It constitutes an effort to concretize and modernize the traditional concept of cooperation networks among companies that referred essentially to shared work, which implies shared capabilities and resources, and the use of a "network" to communicate and exchange information.

Although several definitions can be found in the literature (Chituc & Azevedo, 2005; Alves et al., 2007; Parung & Bititci, 2008), in this research work, the adopted definition is:

Definition 2. ***Collaborative Network***

*"A Collaborative Network (CN) is a network consisting of a variety of entities (e.g. organizations, people, even intelligent machines) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but which decide to collaborate to better achieve common or compatible goals (e.g. problem solving, production, or innovation), and whose interactions are supported by computer networks." (Camarinha-Matos & Afsarmanesh, 2006).*

CNs manifest in a large variety of forms, moving from the classical supply chains format to more dynamic structures that are nowadays emerging in industry, science, and services. Among these CNs, long-term "strategic" alliances and goal-oriented networks are distinguishable. *Long-term strategic networks/alliances* are established to act as the *breeding environments for goal oriented networks*, namely with the purpose of getting their participants prepared for participation in response to collaboration opportunities. In other words, they are alliances aimed at offering the conditions and environment to support the rapid and fluid configuration of goal oriented collaboration networks, when opportunities arise. *Goal-oriented networks* are CNs in which intense collaboration, either towards a common goal or a set of compatible goals, is practiced among their partners and for a limited time period (Camarinha-Matos & Afsarmanesh, 2005a; Camarinha-Matos et al., 2008b).

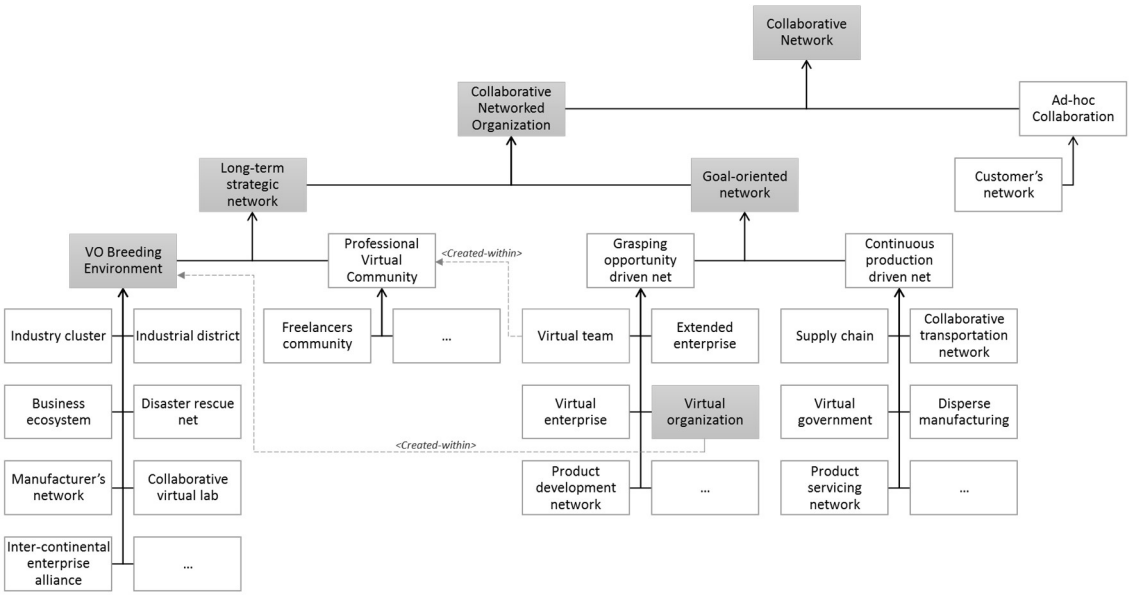



**Figure 2.1. Collaborative networks taxonomy. Adapted from (Camarinha-Matos & Afsarmanesh, 2008; Camarinha-Matos et al., 2008b; Camarinha-Matos et al., 2013e).**

The various classes of CNs can be organized in a CN taxonomy (Figure 2.1) which has been evolving along with the emergence of new manifestations of collaborative networks. The new categories added with the GloNet research project – Manufacturer's network, Product development network or Product servicing network - are an example of this evolution (Camarinha-Matos et al., 2013e).

In the context of this thesis, the work is mainly focused on the long-term type - Virtual organizations Breeding Environments (VBEs). Nevertheless, the author believes that this research work might also be applicable to the other manifestations as well. Of course taking into consideration the base differences. Table 2.1 presents the definition of some of the most relevant manifestations of CNs that are directly related to the proposed work.

**Table 2.1. Some definitions of CN forms (Camarinha-Matos & Afsarmanesh, 2008; Camarinha-Matos et al., 2013e).**

| *CN Type* | *Definition* |
|---|---|
| **Collaborative Networked Organization** | "Characterizes a collaborative network possessing some form of organization in terms of structure of membership, activities, definition of roles of the participants, and following a set of governance rules." |
| **Long-term Strategic Network** | "Characterizes a strategic alliance established with the purpose of being prepared for participation in collaboration opportunities where cooperation is practiced among their members. They are alliances aimed at offering the conditions and environment to support rapid and fluid configuration of CNs, when opportunities arise." |
| **Goal-oriented Network** | "Characterizes a CN in which intense collaboration, towards a common goal or a set of compatible goals, is practiced among their partners." |
| **Virtual Organization Breeding Environment (VBE)** | "Represents an association of organizations and a number of related supporting institutions, adhering to a base long term cooperation agreement, and adoption of common operating principles and infrastructures, with the main goal of increasing their preparedness towards rapid configuration of temporary alliances for collaboration in potential virtual organizations." |
| **Virtual Organization (VO)** | "Represents a set of independent organizations that share resources and skills to achieve its mission/goal, but that is not limited to an alliance of profit enterprises." |
| **Manufacturer's Network** | "Characterizes a long-term alliance that typically involves product/project designers, manufacturers, service providers, and some support entities, configuring a kind of VBE." |
| **Product Servicing Network** | "Represents a long-term VO organized to provide integrated or composite (multi-stakeholder) business services along the product lifecycle. This network works in close interaction with the customer and other local stakeholders." |

In the CN context, organizations interoperate and collaborate within VO and VBE networks while being facilitated by computer networks, in order to achieve certain common or compatible goals, such as the acquisition of, and response to larger, better, and more business opportunities. As a basic rule, supporting the dynamic/fluent formation of collaborative networks, such as in a short term consortium, requires its potential partners to be *ready and prepared to jointly participate* in such a collaboration environment. The foundation of this readiness should include reaching commonality agreements on aspects such as the interoperable infrastructure, operating rules, and cooperation. Any collaboration also requires that involved actors meet the required level of competency performance, and emotional equilibrium to be considered trustworthy by other partners. Therefore, the concept of long-term strategic alliances has emerged as the necessary context for the effective creation of dynamic short term consortia.

Moreover, with the development of new collaborative tools supported by Internet, the advent of Internet of Things, Industry 4.0 and Cyber Physical Systems, and with a better understanding of the mechanisms of collaborative networks, new organizational forms are naturally emerging in different sectors. Some examples are networks of healthcare institutions together with relatives involved in elderly care, networks of governmental institutions, networks of academic institutions forming virtual institutes, networks of manufacturing and servicing entities that together with customers and local suppliers give support to complex and highly customized and service-enhanced products, networks of entities involved in disaster rescue, etc.

### 2.1.1 Reference Modelling Framework

With the consolidation of Collaborative Networks as a new discipline in the last years, more emphasis is being put on the elaboration of the theoretical foundation for the area and reference models that form the basis for further sustainable developments. As a relevant contribution, the IP ECOLEAD project designed the ARCON reference modeling framework for collaborative networks as illustrated in Figure 2.2.

ARCON comprises three modeling axes – (1) the life cycle of CN (i.e. creation, operation, evolution, metamorphosis, and dissolution), (2) the environment characteristics including both the CN endogenous elements (i.e. the structural, componential, functional, and behavioral dimensions) and the CN exogenous interactions (i.e. with market, support, societal, and constituency dimensions), and (3) the model intent (i.e. general representation, specific modeling, and implementation modeling). Some attempts to identify the key modeling elements for each dimension

were also performed, and a textual description of each of these key elements is provided in (Camarinha-Matos & Afsarmanesh, 2008).

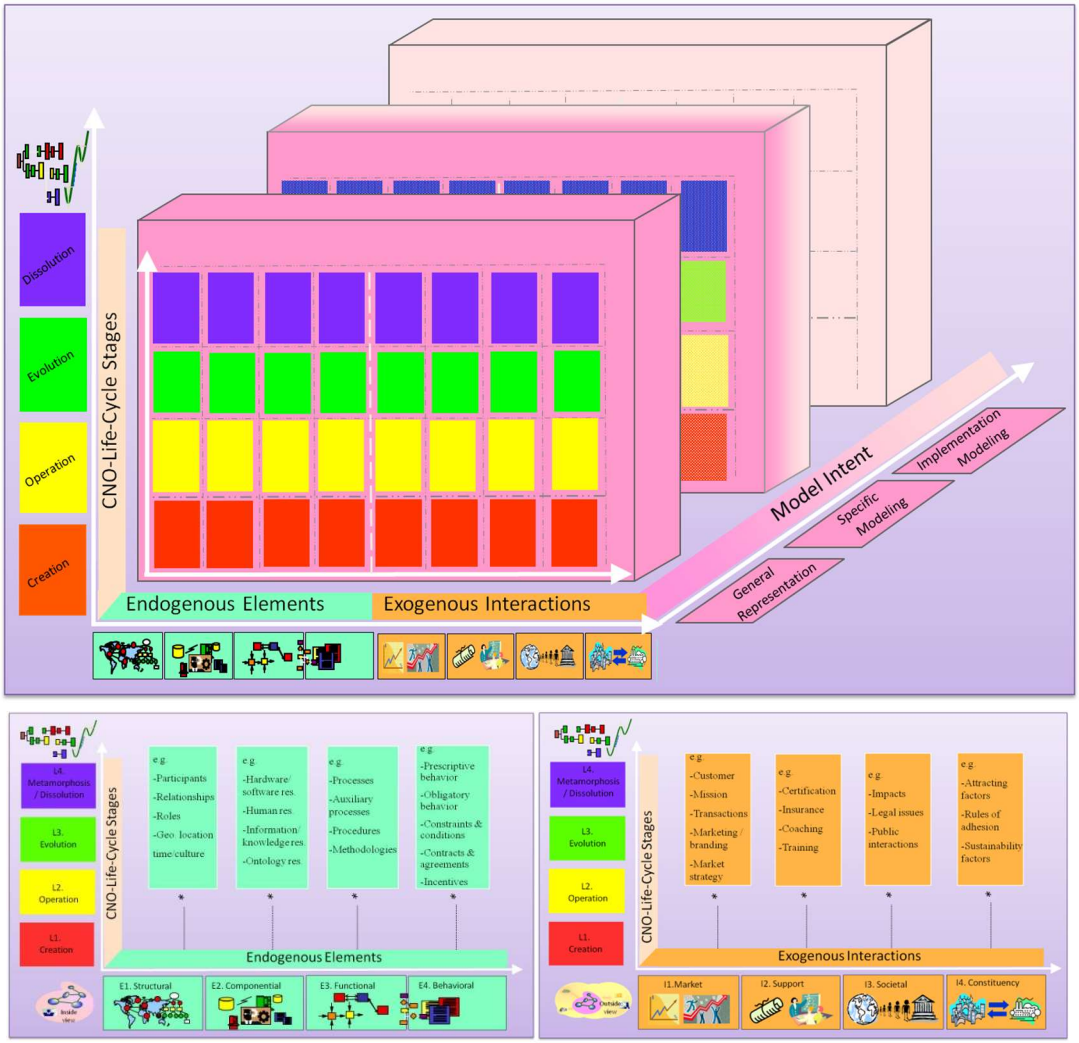



**Figure 2.2. ARCON reference modeling framework for CNs (Camarinha-Matos & Afsarmanesh, 2008).**

The results from the ARCON reference modeling framework that are relevant for this thesis work are mainly the *behavioral endogenous elements* or *behavioral dimension*. This dimension provides the context for integration and generalization of the various behavioral aspects of CNs. The principles of collaboration and rules of conduct (CN governance), where issues such as business process modeling, principles of trust, value systems, contracts negotiation and conflicts resolution, collaboration readiness, rewards and incentives, among others can be found, are addressed with special focus in this dimension. It is also within this dimension that the emotions' modeling aspect, proposed in this work, fits.

### 2.1.2 Collaborative Networks Governance

Governance of a CN plays a regulatory role, through the use of some structures, authorities, and institutions, the setting of some principles and rules for allocation of resources and assignment of rights and duties, as well as the management and supervision of both actors and activities within the CN. There is therefore a dual relationship identified between the governance and the behavioral aspects of the CNs: on the one hand the CN governance constrains or guides collective and individual behavior of the network members, while on the other hand the driving forces behind the actors' behavior (e.g. their value systems, character, culture, etc.) influence the nature of the CN governance.

When the collaboration processes are less structured, as addressed in this thesis work, more dynamic modeling formalisms are needed. This is why well-founded emotional and social models along with other behavioral models are the basis to move from the currently applied set of ad-hoc rules to a new principle-based governance of CNs. In this line, this research work aims at establishing a framework for supporting emotional behavior-based "experiments" in different CN organizational structures. Guidelines for more effective decision-making regarding partner selection, negotiation, definition of incentives and conflict resolution, are examples of governance-related mechanisms foreseen to be derived in the future on the basis of this emotion modeling approach. A further ambitious goal is to design a system that can provide proactive assistance for supporting the collaboration sustainability through the analysis and assessment of the emotions within the CN in accordance with the governance principles.

In the following sub-sections, a brief description of some factors influencing CN governance is presented.

**Social Norms and Social Protocols.** Interactions have been defined as the basis for social relations (Mucha, 2006). Social relations are regulated by ***social norms*** between two or more entities (e.g. people, machines, virtual agents, etc.), with each having a social position and performing a social role. The concept of social norm is a key element to cope with modeling of interactions among collaborators. Social norms may be considered as a set of guidelines to enable coordination and organization of interactions among groups and societies. Furthermore, according to (Bicchieri, 2006; Bicchieri & Muldoon, 2011), social norms ought to be understood as "a kind of grammar of social interactions". Like a grammar, a system of norms specifies what is acceptable and what is not in a society or group.

Social norms have been extensively studied in the human sciences, social sciences, and computer science. Anthropologists have defined the role of social norms in different cultures (Geertz, 1973). Sociologists have concentrated their research on the social functions and in the impact they have in people's actions (Durkheim, 1965; Coleman, 1998; Hechter & Opp, 2001). Economists have explored how adherence to norms influences market behavior (Young, 1998). In computer science, the focus of research on social norms has been on: *i)* interactions among software entities, e.g. research on distributed systems, workflow systems and in the recent years on service-oriented architecture (SOA); *ii)* interactions among humans sharing information, e.g. virtual workplace and electronic communication means; and *iii)* collaborative management tools facilitating and managing group activities, e.g. project management systems.

Works on interactions among software entities provide models for structured collaboration, such as Petri Nets, BPEL (Business Process Execution Language), BPMN (Business Process Modeling Notation), or XPDL (XML Process Definition Language) (Wang et al., 2007; W. Picard, 2008; Grefen et al., 2009; Danylevych et al., 2010). Works on interactions among humans sharing information focus on problems such as awareness and concurrency but they do not address the social dimension formerly mentioned (Gross, 1999a, 1999b; He & Han, 2006; Kekwaletswe, 2007). Finally, works on collaborative management tools resulted in tools which, while occasionally providing some basic support for social aspects with the concept of roles, impose some rules of interaction to the collaborators, being these rules defined by the software provider (P. M. Jones, 2001; Ollus et al., 2009). The dynamic nature of interactions within a group, i.e. evolution of social norms in time, is an important obstacle to the adoption of these tools. In this context, the importance of emotions in social interaction has been studied by several sociologists as described later in section 2.2.2.4.

The concept of ***social protocol*** in the context of CNs has been proposed by W. Picard (2006), based on the concept of *collaboration protocol* (W. Picard, 2005), where a model for structuring interactions among a group of collaborators was initially conceived. Additionally, adaptation of social protocols has been proposed by the same author, as a mean to support dynamics of interactions, allowing collaborators to modify the social protocol ruling the group they belong to (W. Picard, 2007, 2009b, 2009a). However, the support for the social dimension of interactions is still insufficient: the concept of social role is reduced to its simplest expression, i.e. role; emotions and other social aspects of collaboration are not adequately supported by social protocols.

**Rational Trust.** Establishing trust relationships among members, organizations or individuals, of a network is a pre-condition for smooth collaboration. With widely divergent goals of members and characteristics of networks, and geographically

separated parties, building and maintaining trust relationships are fundamental and even more challenging when dealing with large networks and temporary partnerships (Msanjila & Afsarmanesh, 2008).

While selecting reputable partners provides a basis, building up trust will heavily depend on a large number of factors, e.g. openness, good communication, executing tasks as agreed, etc. A partnership strategy based on a step-by-step strengthening of the tangible and measurable characteristics of collaboration aspects will allow a gradual building-up of the trust level. While informal contacts can play an important role in trust building, it is this thesis author belief that care should be taken to avoid the formation of cliques and emotional conflicts, which may interfere with the business opportunity.

Research on management and establishment of trust is conducted in a variety of disciplines, each focused on different perceptions of trust, e.g. modeling, assessing, creating, and maintaining trust and trust relationships (Povey, 1999). Various works have attempted to characterize trust and its related aspects. Most of these works focus on subjective (opinion-based) trust elements, e.g. by recommendation, ranking, reputation, and polling (Kini & Choobineh, 1998; S. Jones et al., 2000). Only a few research approaches focus on objective/rational (fact-based) trust elements, e.g. measuring the past performance and current standing of organizations/individuals as the main input for assessing their trustworthiness (Msanjila & Afsarmanesh, 2007, 2008; Msanjila, 2009). For the case of this research work, both approaches are relevant for the modeling of emotions in the CN context.

**Value Systems.** Decision making as well as the individual and joint behavior in a collaborative network depend on the underlying value system. Therefore, identification and characterization of the value system of the networks and their members are fundamental when attempting to improve and sustain a collaborative process. Value systems and their effects on the networks have been preliminarily studied in the past in diverse areas such as social sciences, economical, organizational management, and information system design.

Social sciences consider a value system as the ordering and prioritization of the ethical and ideological values that an individual or society holds, while economical sciences defend that a value system describes the activity links among the company and its suppliers, other businesses within the company's corporate family, distribution channels and the company's end-user customers (Porter, 1985). Goguen has developed, since 1978 several works on studies about value and value system in organizations (Goguen, 1994, 1997, 2004), which proposed a method for using discourse analysis to determine a value system for an organization from a collection of stories told by

members of the organization among themselves on informal occasions. Another contribution comes from the distributed artificial intelligence discipline, which has developed some value systems theories using agents (Antunes et al., 2001; Filipe, 2003; Rodrigues et al., 2003).

During the last years some works on value systems in networked environments have been developed by groups of researchers, (Katzy, 1998; Gordijn et al., 2000; Kartseva et al., 2004; Tan et al., 2004; Romero et al., 2010). In organizational sociology some authors (Hall, 1995; Hebel, 1998; Alle, 2000) studied the corporate-identity in organizations. In the last decade, several studies originated in the knowledge management discipline led to the development of frameworks to classify the value's elements inside an organization according to their nature. Sullivan (2000) and Alle (2000) demonstrated the importance of managing intangible issues for the sustainability of organizations. A research work conducted by Macedo (2011) proposes the adoption of a set-theoretical approach to model value systems, and some elements from the graph theory and causal reasoning to model the causal relationships among organization's core values, in order to analyze their interrelationships (Camarinha-Matos & Macedo, 2010; Macedo & Camarinha-Matos, 2013).

The CN decision-making process is naturally influenced both by the common value system of the network and the individual value systems of each partner. Therefore the identification and characterization of these value systems is an important issue when attempting to improve collaborative processes. As partners have different value systems, they might have different perceptions of the outcomes of the collaboration processes, which might lead to non-collaborative behavior, such as hindering knowledge sharing, and inter-organizational conflicts. These factors are also impact factors in the emotional state of the network and of its members. Therefore, the development of a common value system is a significant element for the emotional health of the collaborative network as a whole and extremely important for the sustainability of collaboration.

**Collaboration Readiness.** Collaboration readiness can be intuitively established as how well, and to which extent, an organization is ready, competent, prepared and willing to participate in a partnership. The rationality of the concept is that "higher collaboration readiness should increase the likelihood of partnership success" as presented in the research of (Rosas, 2010).

Previous research works (Gupta & Nagi, 1995; Fischer et al., 2004; Crispim & Pinho de Sousa, 2007) related to partnership performance in collaborative networks were mostly focused on "hard" factors such as competency matching or technological

preparedness, which do not consider behavioral, or soft, issues. As such, the adoption of a behavioral perspective of collaboration readiness became a topic of interest for the research community.

The research work by Rosas and Camarinha-Matos (2009), proposes that collaboration readiness involves assessing an organization's preparedness, competencies fitness, and collaboration willingness. The main focus of *collaboration preparedness* is to assess whether an organization is likely to display reliable behavior inside partnerships. The rationality of this concept relies on the idea that an organization's behavior can be to some extent predicted. When in partnerships, entities develop behaviors that typically tend to show some repetition through time, this repetition usually leads to the formation, or identification, of behavioral patterns. These patterns can in turn be associated to a set of identifiable traits. These traits together, form what is referred to as character. The underlying mapping between character traits and behavior could be used to perform behavior prediction. Specific behavioral patterns may cause positive or negative effects on collaboration. Basically, if the predictability of an organization to develop beneficial behavioral patterns is high, then its preparedness to collaborate is also higher, and the other way around. Rosas (2010) on his developments tries to assess collaboration preparedness using the concept of organization's character.

The concept of *competencies fitness* is introduced by Rosas and Camarinha-Matos (2009) as a way to assess whether a partner is able to adequately use its hard competencies in a collaboration context, in which it is also required some specific soft competencies, like the ability to share knowledge. To adequately handle this type of issues, a "hard versus soft" competencies dichotomy is considered. The idea is to identify the performance effects of the soft competencies on the hard ones, within a given collaboration context.

The success of a partnership depends on partners' active participation and commitment to achieve the shared goals, which fundamentally depends on the attitudes and intentions each partner assumes towards the partnership. If a partner shows relatively positive, but marginal, interest to engage in a partnership, its performance might not be very high. The aim of *willingness to collaborate* (Rosas & Camarinha-Matos, 2010) is precisely to assess these partners' attitudes, which may influence their willingness to commit to the partnership activities.

**Negotiation.** Reaching agreements and contracting are important elements in the process of creating dynamic collaborative networks. To improve the effectiveness of such processes and to dynamically form goal-oriented consortia, the need to develop

forms of contract negotiation (Oliveira & Camarinha-Matos, 2015) and e-contracting (Angelov, 2006) has been identified.

Several significant characteristics for e-contracting process have been proposed and initial steps towards electronic institutions such as e-notary have been presented (García-Camino et al., 2006; Cardoso & Oliveira, 2008).

Works on electronic negotiations may be split into two main areas: *(i)* automated agent-based negotiations, and *(ii)* negotiation support systems. In **automated agent-based negotiations**, negotiation tasks such as offer exchange or evaluation, are performed by software agents behaving on behalf of the users. Developments in this area include negotiation protocols, auction mechanisms, learning, multi-attribute constraint negotiation, etc. Elaboration of contract templates and repositories of clauses has been another line of development (Shelbourn et al., 2005). On a more theoretical basis, deontic logic is used to describe contract models specifying obligations, permissions, and forbiddances for specific business processes (Xu, 2004; Prisacariu & Schneider, 2012; Bartoletti et al., 2013). Moreover, models of negotiating agents are usually based on the game theory, focusing on the maximization of the users' gain. Nevertheless, there are also other models for supporting negotiation. It is the case of the EDBI model proposed by (Jiang et al., 2006), which includes support for emotions in negotiation strategies. While the vision of automated negotiations is attractive, the removal of the human factor is also the Achilles' ankle of automated agent-based negotiations, as social and affective relationships existing among negotiators, which highly influence the negotiations, are disregarded in the automated agent-based negotiations. Jonker et al. (2012), on their research work touch this point, stating that negotiation cannot be handled by artificial intelligence alone, and a human-machine collaborative system is required, presenting what they called as being the next generation of negotiation support agents.

**Negotiation support systems (NSS)** aim at supporting negotiators by providing necessary negotiation means and tools. One may distinguish two kinds of NSS: *1)* preparation and evaluation systems, and *2)* process support systems. Preparation and evaluation systems provide tools to organize information, develop negotiation strategies, and evaluate negotiation offers. Preparation and evaluation systems are to a large extent inspired by (group) decision support systems, based on multi-attribute utility representation. An example of such a system is the INSPIRE system (Lo & Kersten, 1999), which is based in a web interactive system that helps two human users negotiate a solution to a predetermined problem. Process support systems focus on collaboration during the negotiation process providing communication and authoring tools for negotiators.

As these functionalities shall not be based only on rationality, the proposed research work could contribute helping with the affecting aspects of negotiation in a collaborative environment providing, as an example, means to assess the emotional state of each organization stakeholder during the discussions.

**Conflicts Resolution.** Another relevant aspect that must be considered in collaborative environments is that collaboration and conflicts are inseparable and that conflicts may affect the organizational performance. Therefore, collaborative structures should comprise a conflict mediation mechanism if successful collaborations are sought.

Conflict has been a hot topic studied by researchers in the disciplines of psychology, sociology and business (Mayer, 2000; Rahim, 2001; Bar-Tal, 2007; Tint, 2011; Omisore & Abiodun, 2014), and has been focused essentially in the examination of conflicts between individuals and within teams. An example is the survey conducted by Lam and Chin (2005) that explored conflict in client-supplier interaction. Nevertheless, little research has been conducted in exploring conflicts among collaboration partners or inter-organizational conflicts (Parmigiani & Rivera-Santos, 2011; Lumineau et al., 2015).

In this context, conflicts research in collaborative networks or similar inter-organizational forms is starting to gain the attention of various researchers (Heidl et al., 2014; Harmon et al., 2015; Lumineau et al., 2015). Resolution of conflicts necessitates substantial efforts and is time consuming. As a consequence, the time spent in creating reasonable conflicts resolution has an adverse impact on development costs. In addition, the outcomes of such resolutions affect the quality of products or services as well as the quality of the collaborative relationships. There are a panoply of models and methods for managing conflicts (Lumineau et al., 2015) being the most common ones based on trust aspects (Msanjila & Afsarmanesh, 2008; Dirks et al., 2009). Nevertheless other collaboration aspects are also studied in the conflicts resolution methods such as: network commitment (Greenfield, 2016), emotional or affective aspects (Bar-Tal et al., 2007; Shankar Ganesan et al., 2010), value system and benefits identification (Abreu & Camarinha-Matos, 2008; Camarinha-Matos et al., 2008c), and competence-based aspects (Ermilova & Afsarmanesh, 2006, 2008; Rosas & Camarinha-Matos, 2010).

The collaborative emotion framework that is proposed in this thesis, also intends to contribute to the conflicts resolution within CNs. As later seen on chapter 4, the model approach for the estimation of collaborative emotions integrates some of the collaboration aspects referred in the previous paragraph for conflicts resolution.

**Network Commitment.** Network commitment has been the research focus of various researchers such as (Clarke, 2006; Andrésen et al., 2012; Kramer, 2014; Greenfield, 2016). This concept has been related to network performance (Clarke, 2006), network resilience

(Kramer, 2014), and recently related to network sustainment (Greenfield, 2016). However, despite its relevance, research on this network commitment reveals that there is insufficient knowledge on this topic (Clarke, 2006; Andrésen et al., 2012; Kramer, 2014; Greenfield, 2016).

Coming from the organization theory area, and based on the work from (J. P. Meyer & Allen, 1991), commitment can be divided into three components as shown in Table 2.2.

**Table 2.2. Organizational commitment components.**

| *Components* | *Description* |
|---|---|
| **Affective Commitment** | Related to the individual's emotional attachment to the organization. (*Wants to continue*). |
| **Continuance Commitment** | Related to awareness of switching costs that are associated with a termination of the relationship. (*Needs to continue*). |
| **Normative Commitment** | Related to a feeling of obligation to be attached to the organization. (*It is supposed to continue*). |

Clarke (2006), adopted these three components in the conceptualization of network commitment. On the other hand, Kramer (2014) develops the concept building on the concept of relationship commitment from the marketing research area. Relationship commitment is defined by Morgan and Hunt (1994) as "*a partner believing that an ongoing relationship with another is so important as to warrant maximum efforts at maintaining it; that is, the committed party believes the relationship is worth working on to ensure that it endures indefinitely*". According to this definition, partners with higher levels of relationship commitment are satisfied with the partnerships and have the sustained desire to keep going on. They are, on one hand, more motivated to cooperate and share resources and, in the other hand, more inclined to sacrifice own interests in favor of mutual benefits (Kramer, 2014).

In the context of a network, and in line with the concept of relationship commitment, there is the high likelihood that a network partner with higher network commitment will be available to sacrifice private interests in order to maintain the network and to work collaboratively towards the common network goals. Greenfield (2016), on his PhD thesis, summed up the main concepts presented above as shown in Table 2.3.

**Table 2.3. Summary of commitment concepts. Adapted from (Greenfield, 2016).**

| *Commitment Context* | *Designation* | *Associated Literature* |
|---|---|---|
| **Individual → Organization** | Organizational Commitment | (J. P. Meyer & Allen, 1991) |
| **Organization → Organization** | Relationship Commitment | (Morgan & Hunt, 1994) |
| **Organization → Network** | Network Commitment | (Clarke, 2006; Andrésen et al., 2012; Kramer, 2014; Greenfield, 2016) |

**Brief Summary.** Collaborative networks are influenced by several CN governance factors as seen throughout this section. The introduction of a framework for estimating and "regulating" the collaborative emotions of the CN might bring a new perspective for its governance and main influencing factors, namely:

- contribute to the regulation of social relations among CN members;
- help in the establishment of trust among members;
- contribute with emotional mechanisms for more effective assessment of members' collaboration readiness and partner selection;
- regulate the interactions of contract negotiation, using emotional awareness mechanisms;
- intervene either as reactive or proactive mechanisms for conflict resolution; and
- influence the network commitment and on its turn the collaboration sustainability.

Figure 2.3, illustrates the potential influence of emotion models in the CN governance factors.

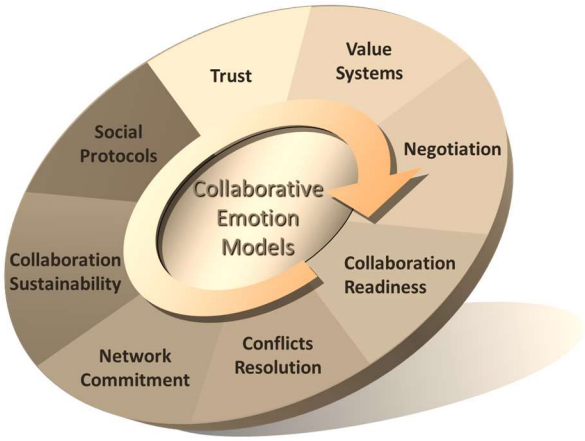



**Figure 2.3. Influence of collaborative emotion models in CN governance factors.**

### 2.1.3 Research Work in the Area of Collaborative Networks

A growing number of funded research projects have emerged during the last years in the area of CNs as a result of the challenges faced by both the business and scientific worlds. The following table highlights a partial list of some research projects.

**Table 2.4. Example of research projects in the area of CNs.**

| *Focus Area* | *Project Name* |
|---|---|
| **Business Networking** | **ECOLEAD** (www.ecolead.org)<br>European Collaborative Networked Organizations Leadership Initiative<br>**CROSSWORK** (www.crosswork.info)<br>Developing Cross-Organizational Workflow Formation and Enactment<br>**MYCAREVENT** (www.mycarevent.com)<br>Supporting Mobility and Collaborative Work in European Vehicle Emergency Networks<br>**VE-Forum** (www.ve-forum.org)<br>The European Forum for the Virtual Organization Domain<br>**THINKcreative** (www.thinkcreative.org)<br>Thinking network of experts on emerging smart organizations<br>**MASSYVE** (www.gsigma-grucon.ufsc.br/massyve/)<br>Multi-Agent Manufacturing Agile Scheduling Systems for Virtual Enterprises<br>**COVE** (www.uninova.pt/~cove)<br>CO-operation Infrastructure for Virtual Enterprises and Electronic Business |
| **Enterprise Interoperability** | **ATHENA** (www.athena-ip.org)<br>Advanced Technologies for Interoperability of Heterogeneous Enterprise Networks and their Application<br>**INTEROP** (www.interop-noe.org)<br>Interoperability Research for Networked Enterprises Applications and Software<br>**COIN** (www.coin-ip.eu)<br>Enterprise Collaboration and Interoperability |
| **Ambient Intelligent Technologies for the Product Life-Cycle** | **GloNet** (http://www.glonet-fines.eu/)<br>Glocal Enterprise Network Focusing on Customer-Centric Collaboration<br>**CO-DESNET** (www.codesnet.polito.it)<br>Collaborative Demand & Supply Networks<br>**VERITAS** (www.veritas-eu.com)<br>Virtual Enterprises for Integrated Industrial Solutions<br>**SPIDER-WIN** (www.spider-win.de)<br>Supply Information Dynamic Exchange and Control by Web-based Interaction Network |
| **Digital Ecosystems** | **SATINE** (www.srdc.metu.edu.tr/webpage/projects/satine/index.html)<br>Semantic-based Interoperability Infrastructure for Integrating Web Service Platforms to Peer-to-Peer Networks |

| | |
|---|---|
| **Roadmapping** | **DBE** (www.digital-ecosystem.org)<br>Digital Business Ecosystem<br>**VOmap** (www.uninova.pt/~vomap/index.htm)<br>Roadmap design for collaborative virtual organizations in dynamic business ecosystems |

## 2.2 Inspiration on Emotions

The meaning of emotion (*animi motus* in Latin) is expressed in the term itself that is the idea of "motion" in one's inward feelings and self-consciousness. These inward motions of the "soul" (*psyche*) signal and give rise to "moods", inner *feelings* and *dispositions*.

Even though the term ***emotion*** is used very often, the question "What is an emotion?" rarely generates the same answer from different individuals and scientific researchers. This is due to the fact that emotions concern what is most intimate and important to human life and because some of their effects, i.e. the behaviors associated to emotion, demand understanding.

Therefore, in spite of being a common word and apparently understandable by everybody, the definition of emotion has been a matter of discussion over the last 100 years and the number of proposed definitions has grown to the point where counting seems quite hopeless (Fehr & Russell, 1984; Frijda, 2000; de Sousa, 2003; Forsyth, 2004). Only in 1981 (Kleinginna & Kleinginna) reviewed more than one hundred definitions. As a consequence, no complete list can be assured but it is possible to provide a sense of the way psychologists and others have thought about the topic along the past years, by examining a few of the most influential definitions (see Table 2.5). For a more comprehensive study of the different definitions of emotion see Annex A.

**Table 2.5. Some definitions of emotion.**

| *Author* | *Definition* |
|---|---|
| (James, 1884) | *My theory… is that the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion…* |
| (Cannon, 1929) | *The peculiar quality of the emotion is added to simple sensation when the thalamic processes are aroused.* |
| (Arnold, 1960) | *Emotion is felt tendency toward anything intuitively appraised as good (beneficial) or away from anything intuitively appraised as bad (harmful). This attraction or aversion is* |

| | |
|---|---|
| | *accompanied by a pattern of physiological changes, organized toward approach or withdrawal. The patterns differ for different emotions.* |
| (MacLean, 1970) | *Emotional feelings guide our behavior with respect to the two basic life principle of self-preservation and preservation of species.* |
| (Izard, 1977) | *Emotion is a complex process that has neurophysiological, motor-expressive, and phenomenological aspects.* |
| (Kleinginna & Kleinginna, 1981) | *Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which can (a) give rise to affective experiences such as feelings of arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labeling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed, and adaptive.* |
| (Frijda, 1986) | *Emotions are tendencies to establish, maintain, or disrupt a relationship with the environment. Emotion might be defined as actions readiness change in response to emergencies or interruptions.* |
| (Lutz & White, 1986) | *Emotions are a primary idiom for defining and negotiating social relations of the self in a moral order.* |
| (Ortony et al., 1988) | *Emotions are valenced reactions to events, agents or objects, with their particular nature being determined by the way in which the eliciting situation is construed.* |
| (Lazarus, 1991a) | *Emotion (is) a complex disturbance that includes three main components: subjective affect, physiological changes related to species-specific forms of mobilization for adapted action, and action impulses having both instrumental and expressive qualities.* |
| (Lazarus & Lazarus, 1994) | *Emotions are organized psycho-physiological reactions to news about ongoing relationships with the environment.* |
| (Frijda & Mesquita, 1994) | *Emotions (…) are, first and foremost, modes of relating to the environment: states of readiness for engaging, or not engaging, in interaction with the environment.* |
| (Johnstone & Scherer, 2000) | *An emotion is a phylogenetically evolved, adaptive mechanisms that facilitates an organism's attempt to cope with important events affecting its well-being.* |
| (Ben-Ze'ev, 2000) | *Emotions direct and color our attention by selecting what attracts and holds our attention. They regulate priorities and communicate intentions. Emotions are concerned with issues of survival and social status.* |
| (Plutchik, 2001) | *Emotion is a complex chain of loosely connected events which begins with a stimulus and includes feelings, psychological changes, impulses to action and specific, goal-directed behavior.* |
| (Scherer, 2005) | *[An emotion is] an episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus-event as relevant to major concerns of the organism.* |

After analyzing these definitions, it can be said that most theories hold that emotion is a complex notion with many components: physiological, cognitive, sensorial input, and behavioral correlates (e.g. expressions of emotion). In addition, and common to all definitions, is the undeniable value of emotion for people and the society. Emotions

determine personality; prepare people for action; shape people's behavior; regulate social interactions; facilitate nonverbal communication; make life worth living by adding value to experience; allow people to respond flexibly to the environment (approaching good, avoiding bad); and have a central place in moral education and moral life through conscience, empathy, and many specific moral emotions such as shame, guilt, and remorse (which is intrinsic to moral virtues).

Furthermore, the definition of emotion changes according to the point of view taken by the researcher, i.e., in accordance with several different scientific perspectives. Figure 2.4 depicts this multidisciplinary nature of the study of emotions and, Table 2.6 describes the focus of the study of emotions according to the related scientific research areas.

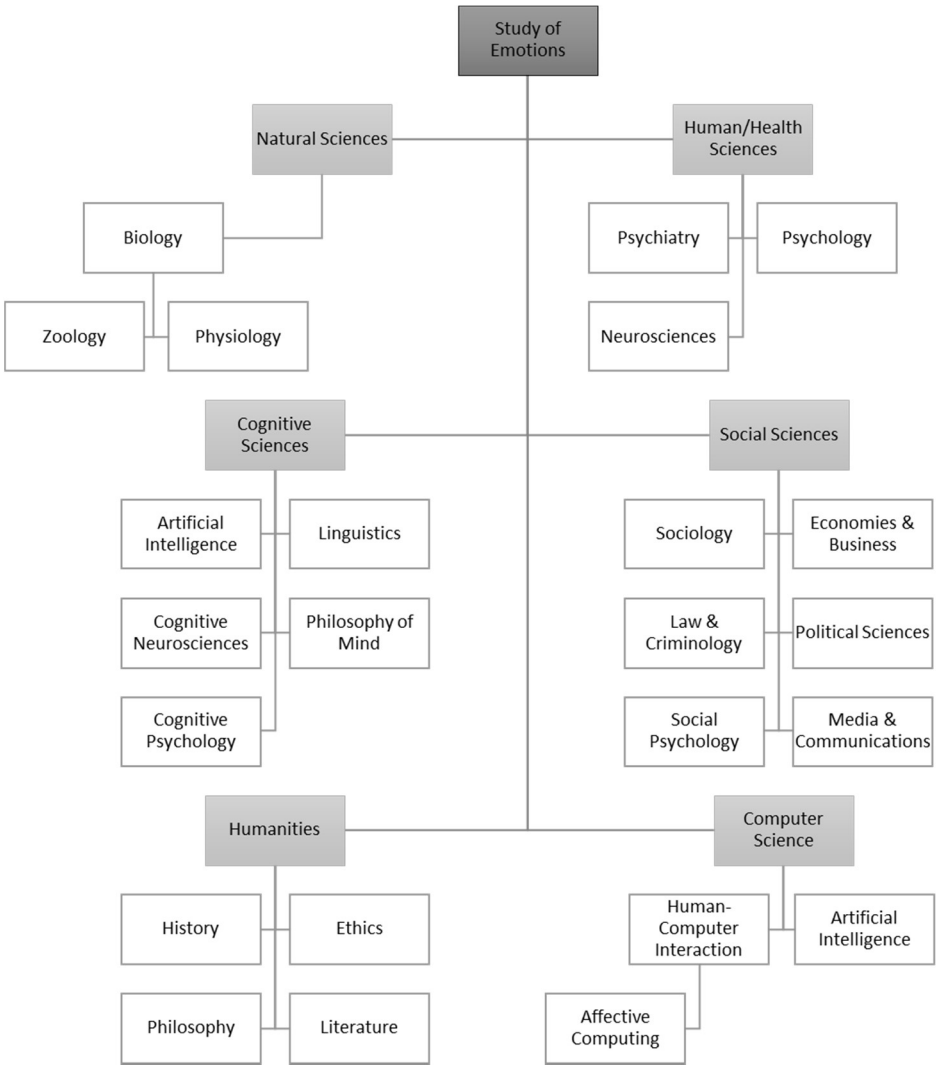



**Figure 2.4. Scientific areas of emotions' research.**

**Table 2.6. Focus of emotion study by scientific research areas.**

| *Scientific Field* | *Focus of Study* | *Researchers* |
|---|---|---|
| **Biology** | Focus on emotion via observation of physiological responses to particular situations or stimuli. | (Ashkanasy et al., 2000; Stanley & Burrows, 2001) |
| **Zoology** | Emotion is studied in non-human animals in ethology[2]. | (James, 1884; Tinbergen, 1951; Lorenz, 1970; Darwin, 1979; Lorenz, 1981) |
| **Psychoanalysis** | Explores the deeply embedded nature of human emotions such as anxiety within the context of the individual's life experience. | (J. A. Gray, 1985; Meyerson, 2000; Weiss & Brief, 2001) |
| **Cognitive Psychology** | Typically subordinates emotion to cognition, and explores it. | (Lazarus, 1982) |
| **Cognitive Neuroscience** | Focuses on the neural basis of emotional and social processes and strongly contributes to the better understanding of the biological basis of emotional processing. It integrates the results of neural and behavioral levels of analysis in healthy and clinical populations as well. | (LeDoux, 1984, 2000; Deak, 2011) |
| **Social Psychology** | Consider emotion from a behavioral perspective, within the context of interpersonal interaction and social relationships. | (Fineman, 2000; Stanley & Burrows, 2001; Fineman, 2003) |
| **Sociology** | Organizational theory, management and community studies tend towards the relational view of emotion. | (Thoits, 1989; J. P. Meyer & Allen, 1991; Tanner, 2005) |
| **Humanities/ Philosophy** | Studies are made at the level of how emotions influence authors when writing a book or what could be the sensory-emotional values found in historical or philosophical texts. | (de Sousa, 2003) |
| **Affective Computing** | Focusing on the importance of human-computer emotions, studies and develops AI models that deal with the design of systems, and devices that can recognize, interpret, and process human emotions. | (R. W. Picard, 1997; Vesterinen, 2001; R. W. Picard, 2003; MIT, 2017) |

In this thesis, the focus will be essentially on the computational perspective of emotion applied to the CN area. Section 2.3 gives an overview of the main computational models of emotion contributing to the emotion framework that is proposed in this thesis. However, contributions from the human sciences (psychological aspects), cognitive

[2] Ethology is a combination of laboratory and field science, with strong ties to ecology and evolution. Among the early ethologists were Herbert Spencer, Charles Darwin, G. J. Romanes, and William James. Zoologists Konrad Lorenz and Nikolaas Tinbergen are widely considered to be the founders of modern ethology. In 1973 they and zoologist Karl von Frisch were awarded the Nobel Prize in Physiology or Medicine for their work in shaping the science of comparative animal behavior (Allaby, 1999; ""Ethology"," 2008).

sciences (perceptive aspects) and social sciences (sociological aspects) of emotion are reviewed in order to give a foundational background for the development of the collaborative emotion framework.

Therefore, the remainder of this chapter is divided into a section that makes an overview of the physiological aspects of emotion; followed by a study of emotions in psychology, where some of the most important theories of emotion are presented as well as the psychological cognitive and social aspects.

### 2.2.1 Physiology of Emotions

The natural processes by which emotions operate in humans are concentrated in the nervous system (Figure 2.5). The *nervous system* is divided into two broad components: the central nervous system and the peripheral nervous system. The *central nervous system* comprises de brain and the spinal cord while the *peripheral nervous system* comprises the autonomic and somatic nervous systems. The *autonomic nervous* system innervates smooth muscles (e.g. the heart) and glands and is divided into the sympathetic and parasympathetic branches. Whereas the sympathetic branch generally prepares the body for action (e.g. by stimulating heart rate), the parasympathetic branch aids restorative functions (e.g. by stimulating digestion). Finally, the *somatic nervous system* innervates skeletal muscles, including those of the face.

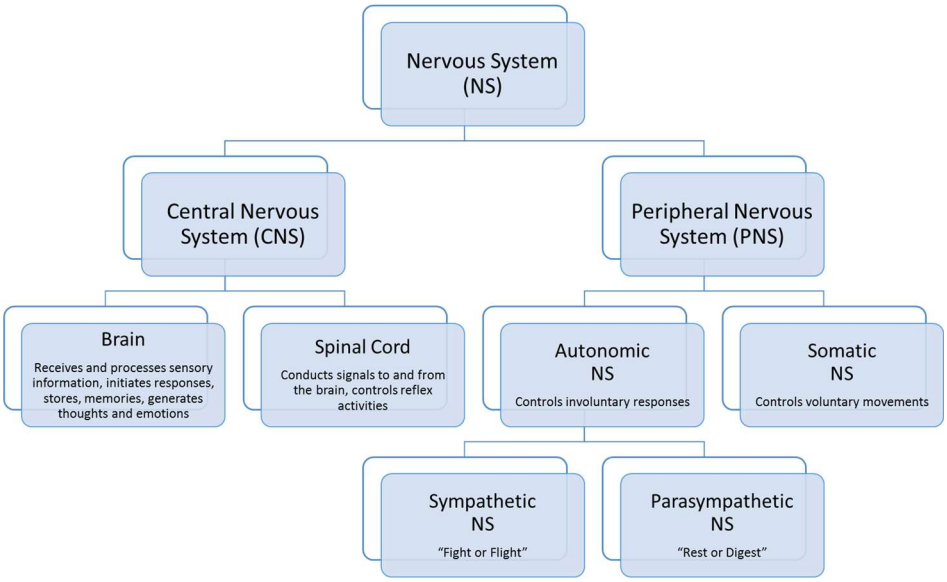



**Figure 2.5. The nervous system components (adapted from [www.studypage.in/biology/nervous-system-control-and-coordination](www.studypage.in/biology/nervous-system-control-and-coordination)).**

According to Brave and Nass (2002) the "seat" of emotion is the brain. The vast network of brain cells or neurons, responsible for the development and realization of emotion, communicate through a series of chemical signals. They utilize neurotransmitters to relay their signals to other parts of the brain or body, thus generating other emotions or causing some of the physical side effects associated to certain feelings.

In this way, certain brain structures are associated to emotions and when interconnected comprise the limbic system (MacLean, 1970). The limbic system is the home of emotions, motivation, regulation of memories, interface between emotional states and memories of physical stimuli, physiological autonomic regulators, hormones, "fight or flight" responses, sexual arousal, circadian rhythms, and some decision systems (J. A. Gray, 1985; Rolls, 2015). The limbic system is what gets "duped" when people get addicted to hard drugs or gambling (Vohs et al., 2007; Marks-Tarlow, 2017).

### 2.2.2 Psychology of Emotions

Psychologists have neglected research on emotion for years, due to its subjectivity, difficulty to achieve a common definition, difficulty to quantify, and examine with objective methods. However, more interest has been dedicated to emotions for the last 50 years.

In the history of psychology, William James (1884) published the first widely accepted theory, known as James-Lange theory. This theory brought forward the importance of the body in the phenomena called emotion. According to James, different emotion are the result of the body reacting in different ways; so consistent to his view, emotions are just the perception of a bodily response. In 1929, Walter Cannon refutes James's theory and, in conjunction with Philip Bard, made progress with the theory known as Cannon-Bard theory (Cannon, 1929). According to this theory emotion can be produced in the brain alone and physiological reactions and emotional experience occur simultaneously.

After a long period during which emotion research was ignored in this area, the *first revolution of emotion* happened. From the late 1950s, the so-called cognitive revolution became prominent among psychologists. Following this trend, Schachter and Singer (1962) suggested a two-factor theory of emotion (using as basis the physiological-based theories of James-Lange and Cannon-Bard) in which emotions are interpreted as the interaction of physiological arousal and cognitive appraisal. In the 1960s the psychologist Magda Arnold (1960) introduced the concept of *appraisal*, defining it as a

direct, immediate and intuitive evaluation able to qualitatively distinguish among different emotions. She made early advances in appraisal theory[3], proposing that an initial appraisal begins the emotional sequence by arousing both the appropriate physiological reactions and the emotional experience itself. In this way, she identified physiological changes as important to the process but not as the initiator of people's reactions and experiences. Later on the psychologist Richard Lazarus (1982) states that people are "evaluators" performing cognitive activity. Each stimulus is evaluated with respect to its personal relevance and significance. Different versions of cognitive appraisal theories of emotion can be found (Arnold, 1960; Roseman et al., 1990; Lazarus, 1991b; Scherer et al., 2001; Mortillaro et al., 2012).

The *second revolution of emotion studies* occurred in the 1990s (Damasio, 1994; Ekman & Davidson, 1994; LeDoux, 1996; Panksepp, 1998; LeDoux, 2000; Panksepp & Watt, 2011), introducing new possibilities such as using brain imaging techniques in the cognitive sciences and in the research of emotions as well. In this way, research on the neural basis of emotional and social processes in human and animals has been integrated into the discipline of cognitive neuroscience of emotions, which since then has been denominated as *affective neuroscience* (Panksepp, 1998).

Some more recent theories are the *affective events theory* (Weiss & Cropanzano, 1996; Basch & Fisher, 2000), which explores time as it is related to the influence on behavior of emotional reaction to events; and the *perceptual theory (Goldie, 2006)*, which deals with using one perception or multiple perceptions in order to find an emotion.

None of these theories are solely accepted in isolation, yet it is generally acknowledged that the "mechanics" of emotions encompass different aspects of the theories discussed above. Furthermore, there is no consensus on the particularities of emotion to take into consideration even under the same theory. The next sub-section presents a review of some of these theories of emotion, highlighting the main characteristics of each.

#### 2.2.2.1 Study on Theories of Emotion

Numerous theories involving the origins, mechanisms, nature and triggering of emotions have been generated over the years, as seen in the previous sections. All of the classic theories of emotion have fallen under criticism and disagreement at various

[3] The appraisal theory of emotion proposes that emotions are extracted from our "appraisals" (i.e., our evaluations, interpretations, and explanations) of events. These appraisals lead to different specific reactions in different people (Arnold, 1960).

times, though many modern theorists still use them as a basis to work from. As such, emotion theories may differ in many ways and may be organized in different forms. It all depends on the approaches to explain the underlying mechanisms. Note that different principles for organizing overviews can lead to different grouping theories of emotion.

Many different emotion theories or models have been proposed by many researchers, some examples are (Scherer, 2000; Gendron & Barrett, 2009; Moors, 2009; Scherer, 2009; Brosch et al., 2010; Mortillaro et al., 2012; Vornewald et al., 2015). Among this vast panoply of theories the four orientations more commonly used are: the *physiological or somatic theories of emotion*, the *basic emotion theories*, the *appraisal theories of emotion*, and the *dimensional theories of emotion*. In common they have the fact of being part of the modern discussion about emotions in the affective sciences. Consequently, they are of great importance for those conducting research about emotions.

A detailed description about emotion theories would be beyond the scope of this thesis work. As such, a summarized review of the four theories enumerated above is made in Table 2.7.

**Table 2.7. Some theories of emotion.**

| *Theory of Emotion* | *Definition* | *Emotion Theorists* |
|---|---|---|
| **Physiological or Somatic Theories of Emotion** | Somatic or physiological theories concede that emotions are primary to cognitive processes. Prior to analyzing a perceived object, and even before recording any impressions, the (human) brain is able to immediately invoke an emotion associated with this object. | (James, 1884) (Cannon, 1929) (Schachter & Singer, 1962) (Zajonc, 1984) |
| **Basic Emotion Theories** | Basic emotion theories, also called categorical theories or discrete theories, assume a certain number of basic emotions, although not consensual (they may vary from 2 to 11). From the combination of basic emotions more emotions can be created. The fundamental assumption is that a specific event triggers a specific affect corresponding to one of the basic emotions and producing characteristic expression patterns and physiological response configurations, mostly through facial expressions. In addition, they contain a feeling and motivation component. | (Darwin, 1979) (Ekman, 1992) (Izard, 1977, 1992) (Tomkins, 1980) (Plutchik, 1980) |
| **Appraisal Theories of Emotion** | Appraisal theories suggest that before the occurrence of an emotion, there are certain cognitive processes that analyze stimuli (Frijda, 1986; Lazarus, 1991a). In such a way, the emotions are related to a certain history of a human. The relation to the history should follow the process of recognition. Thus, the appraisal theory postulates a certain priority of cognitive processes over emotions. | (Arnold, 1960) (Lazarus, 1982, 1991a, 1991b) (Mandler, 1983) (Smith & Ellsworth, 1985) (Frijda, 1986) |

| | | |
|---|---|---|
| | The appraisal theories, assume an emotion architecture that is based on the individual's subjective significance of events for their well-being and goal achievement, postulating a specific set of ***appraisal criteria*** or simply ***appraisals***: *novelty, intrinsic pleasantness (valence), goal conduciveness, motive consistency, agency, responsibility, coping (handling / surviving), legitimacy, compatibility with the societal standards*. Specifying what matters in the individual's perception of the situation has been a central goal of appraisal theory, and its most original contribution. | (Oatley & Johnson-Laird, 1987) (Ortony et al., 1988) (Roseman et al., 1990) (Roseman & Smith, 2001) (Scherer et al., 2001) (Moors, 2010) |
| **Dimensional Theories of Emotion** | Dimensional theories provide a suitable framework for representing emotions from a structural perspective; defining emotions as states that can be represented on a common multidimensional space. They were firstly demonstrated in the form of emotional connotations of words by (C. E. Osgood, 1962, 1964); and, secondly organized as self-reported affective states by J. A. Russell and Mehrabian (1977).<br><br>These theories establish that emotions can be differentiated on the basis of dimensional parameters. The original models included three dimensions: pleasure, arousal, and dominance, also known as the *PAD model*. *Pleasure (or valence)* refers to the hedonic quality of the emotion – positive or negative; *arousal* refers to the physical activation of the organism; *dominance (or power)* refers to the degree of control that the person has in the situation.<br><br>J. A. Russell (1980), proposes a bi-dimensional space organized along the axes of valence and arousal (also known as the *circumplex model of emotion*) and later suggests that the subjective feeling of an emotion is the result of an interaction between core affect (i.e., the intersection of the position of the valence and the arousal in the bi-dimensional space) and a cognitive component such as interpretation or attribution (J. A. Russell, 2003).<br><br>For a comprehensive review on this theory of emotion the reader is referred to Bakker et al. (2014) | (C. E. Osgood, 1962, 1964) (J. A. Russell & Mehrabian, 1977) (J. A. Russell, 1980) (Mehrabian, 1996) (J. A. Russell & Barrett, 1999) (J. A. Russell, 2003) (Posner et al., 2005) |

Furthermore, theories of emotion that do not fit squarely into the four traditions outlined above, may focus on a **specific aspect** or **component of emotion**, such as *motivation* or *action preparation* (see next section), or **combined features from the four major orientations** (see Moors, 2009).

In this work, the dimensional approach will be adopted as basis for the modeling of the CN emotions due to its structural perspective. Some adjustments regarding the emotions to choose and some adaptations of the Russell's circumplex model are done, essentially to contextualize them with the concept of CN emotions.

#### 2.2.2.2 Components of Emotion

As a possible instrument for working towards a consensual definition of emotion, many psychologists take into consideration various aspects, or components of the emotional episode[4] (Scherer, 2005; Frijda, 2007; Moors, 2010). As a consequence, emotion theories evolved to consider emotions as a process (or emotional episode) rather than as merely affective states that influence cognition. The notion of emotion as component processes was firstly proposed by Scherer (1982). According to Scherer the emotion process can be approached on the foundation of its constituent components. The components of an emotion episode are (Scherer, 2000): *a)* cognitive, or appraisal; *b)* somatic, consisting of central and peripheral physiological responses; *c)* motivational, consisting of action tendencies or states of action readiness: *d)* motor, consisting of expressive behavior; and *e)* feeling, referring to emotional experience (Table 2.8 ).

**Table 2.8. Scherer's components of emotion and corresponding emotional functions.**

| *Emotion Component* | *Description* | *Emotion Function* |
|---|---|---|
| **Cognitive component** (*appraisal*) | Only events are judged or appraised to have significance for people's goals, concerns, values, needs, preferences, or well-being elicit emotion. | Evaluation of stimulus (objects and events). |
| **Neurophysiological / somatic component** (*bodily symptoms*) | Emotions are accompanied by autonomic nervous system activity. | System regulation. |
| **Motivational component** (*action tendencies*) | Emotions carry behavioral intentions, and the readiness to act in certain ways. | Preparation and direction of action. |
| **Motor expression component** (*facial & vocal expression*) | Emotion is communicated through facial and bodily expressions, postural and voice changes | Communication of reaction and behavioral intention. |
| **Subjective feeling component** (*emotional experience*) | The appraisal is accompanied by feelings that are good or bad, pleasant or unpleasant, calm or aroused. | Monitoring of internal state and organism – environment interaction. |

In spite of this theory being widely accepted by psychologists, there are many disagreements in what concerns achieving a consensus about the components of the emotional episode. Some disagree about the exact number and nature of the components, e.g. inclusion of a cognitive component is more likely when cognition is

[4] According to Moors (2009), the term *emotional episode* is used to indicate anything starting from the stimulus to the later components of emotion. In this way, the notion of emotional episode is potentially broader that the notion of emotion.

defined in a broader rather than in a narrow sense (cf. Lazarus, 1982; versus Zajonc, 1984). Others disagree about the components they include in or identify with the emotion (see Frijda (2007) for more details). Frijda (1986) singled out the motivational component as the phenomenon to be explained, equating emotions with states of action readiness. On the other hand, there are some theorists that include all or most components of the emotional episode in their definition of emotion like Scherer (2005) or Clore and Centerbar (2004). For a more comprehensive study about the different disagreements, consult (Moors, 2009).

#### 2.2.2.3 Taxonomy of Emotions

As seen in the existing different theories of emotions mentioned previously, emotions are not organized according to a single and unified classification model. Furthermore, discussions like the *number* and *kinds* of distinct emotions, and whether some emotions are more basic than others are being held for years (Stanley & Burrows, 2001). Some classifications, defended by some constructivists (dimensional theorists), isolate two or three main continuums of emotion such as positive-negative affect/valence; activation/arousal (J. A. Russell & Barrett, 1999) or pleasantness-unpleasantness/hedonic (J. A. Russell, 2003); whilst the evolutionary or basic emotions theorists, identify a varying number of specific emotions. The appraisal theorists are somewhere in the middle, accepting a wide variety of emotion families.

*Duration* of emotion state is another differentiator. Several emotion researchers agree that emotions can be divided into different levels according the time scale (E. K. Gray & Watson, 2001; Garcia, 2012a; Oatley et al., 2012; Siegert et al., 2012; Robbins & Judge, 2013; Handayani et al., 2014).

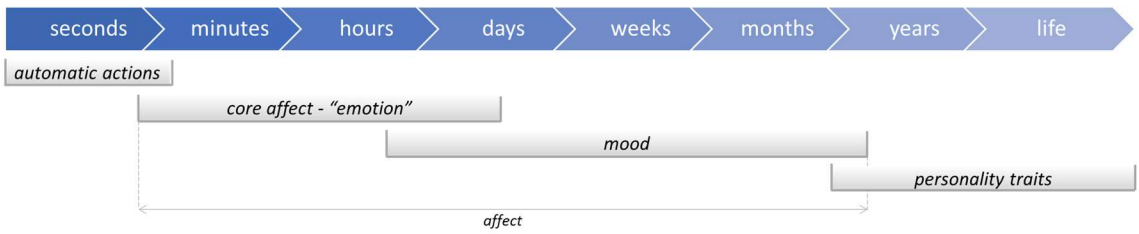



**Figure 2.6. Classification of emotions based on duration time.**

Figure 2.6 illustrates the categories of emotion based on duration time. From the fastest to the slowest in time scale, these are:

| | |
|---|---|
| **Automatic reactions** | Very short (in seconds), representing spontaneous physical reactions to changes in the environment (Ekman, 2009). Such as the fear of something in the dark or fear reaction due to pain. |
| **Core affect** | Lasting longer but with short effect. Driven by specific events, actions or objects. Related to commonly known emotions such as joy, happiness, anger, etc. |
| **Mood** | Long (lasting days or months). Moods are more chronic, usually less intense (Mandler, 1983), and less tied to an eliciting situation or event (Parrott, 2001; Siegert et al., 2012). It reflects the medium term affect and is characterized by slow, positive, or negative changes (Batson et al., 1992). Mood carries information concerning capacity to face threats of the surrounding environment, and it is not distinguishable among facial expressions (Robbins & Judge, 2013). |
| **Personality traits** | Lifelong conditions of behavior that are heterogeneous among individuals (Garcia, 2012a). Are related to emotions in two aspects: as emotional disorders, as in the case of traumas, phobias, kinds of depression, fixations, or expression patterns; and as emotions based on personality, such as shyness and neuroticism (Oatley et al., 2012). |

In addition, **affect** is the umbrella concept that covers a broad range of feelings that people experience. It can be defined as a valence evaluation in reference to the self (Baumeister et al., 2007). Affect is often used as the denominator for both emotion and mood (Robbins & Judge, 2013; Handayani et al., 2014).

Emotion and mood can influence each other mutually. Emotion if it is strong and deep enough, might turn into mood. Therefore emotion can be seen as a punctual affective state, whereas mood might be characterized as a collection of several emotional states in a certain duration of time, although this distinction is more often made theoretically than empirically (Fredrickson, 2001).

Having into account that in this work, emotions are "felt" by companies/organizations that get together for a long period of time and not by people, the adopted type of emotion according to duration will be situated in something hybrid between emotion and mood.

#### 2.2.2.4 Social Nature of Emotions

Modern work on emotion, is to some extent, congruent with Averill (1980) on his social-constructivist perspective on the social nature of emotions. He claims that emotions derive primarily from the social context, because it is in this social context that emotions have functioning and meaning. Nevertheless, some theorists stated explicitly that this does not mean that intrapersonal (individual) functions of emotions should or have been ignored (Frijda, 1986) (Oatley & Johnson-Laird, 1987; Tooby & Cosmides, 1990; Levenson, 1994, 1999). Indeed, in the example of an individual that is walking down a dark alley and hear footsteps behind him, fear is clearly functional without being social.

In addition, emotions are a social need because they give more information to the interactions and represent an important channel of communication with one-self and others. Thus, they play an important role in social interaction and rational thinking (Damasio, 1994). Emotion researchers begun to document how interpersonal problems provoke specific emotions (see Averill, 1980; Miller & Leary, 1992) and how the behavioral manifestations of these emotions trigger interpersonal interactions that can resolve the origination problem (Lutz & White, 1986; Johnson-Laird & Oatley, 1992).

While the emotion literature became more social, researchers also started to speculate more about how specific emotions were socially functional and achieved considerable consensus about these social functions (Frijda & Mesquita, 1994; Keltner & Gross, 1999). According to Keltner and Haidt (1999), emotions can be socially functional at four levels of analysis: *(i)* the individual (or intrapersonal); *(ii)* dyadic (or interpersonal – between two individuals); *(iii)* group (set of individuals that directly interact and have some temporal continuity); and *(iv)* cultural level (within a large group that shares beliefs, norms and cultural models). Consult Annex B, for a complete description of each social function of emotion.

Empirical studies in social psychology provide results on how emotions influence interaction and communication. Various works show how emotions stimulate social sharing (Rime, 2009), usually seeking functional dependencies between emotional states and social interaction. Some of these results provide an initial ground and starting point for this thesis work.

In this sense, apart from defining the emotional states of individual members of the CN, there is also the necessity to consider the interaction between them within the CN environment. In this sense, member's individual emotions are internal states that are communicated to others through their interaction and relationships within the CN context. These interactions may lead or influence the other member's individual

emotions, their subsequent behavior and contribute for the generation of the emotion "felt" by the CN as a whole. This thesis modeling and analysis proposal is in line with these formulations in social psychology and sociology, aiming at the integration with the simulation results.

## 2.3 Computational Models of Emotions

Affective computing is a research field from artificial intelligence (AI) that is concerned with the design of systems and devices that can recognize, interpret, and process human emotions (R. W. Picard, 1997). It has grown to be a cross-disciplinary field of research (R. W. Picard, 2003; Broekens et al., 2013) centralized in the interaction between human and computer (HCI). For this thesis purposes, the issue of emotional interactions (within a community) through computer networks is of more importance than the affective interactions with the computer. Nevertheless, the area of affective computing that is related to computational models of emotion is of interest.

Computational models of emotion (CMEs) are complex software systems conceived to embrace design decisions and assumptions, inherited from the psychological, sociological and computational traditions from where they emerged. They synthesize the operations and architectures of some components that constitute the process of human emotions (Marsella et al., 2010). Computational models of emotions are not new in AI, nevertheless according to Kowalczuk and Czubenko (2016) they are still undervalued. Most researchers focus their attention more on the bottom-up models of human thinking, such as deep learning/neural networks and data mining, rather than on the top-down approaches. In general, CMEs include mechanisms for the evaluation of emotional stimuli, the elicitation of emotions, and the generation of emotional responses, creating, in this way, means for the recognition of emotions from human users and artificial agents, the simulation and expression of emotional feelings and the executions of emotional responses (Rodríguez & Ramos, 2014).

A good amount of computational models of emotion have been developed. The most well-known are the ones based on the appraisal theories of emotion (with the OCC model being the most frequently used (Ortony et al., 1988)). Still many others are modeled using as theoretical framework other theories of emotion, such as the physiological or the dimensional theories (see Table 2.9).

As much as in the case of the theoretical models, computational models can be categorized according to distinct criteria. According to Kowalczuk and Czubenko (2016) the majority of systems may be classified according to the: *a)* psychological theory under

which they are created (see section 2.2.2.1); *b)* components involved in the formation of emotion (see section 2.2.2.2); *c)* phases involved in the emotion process (Scherer et al., 2010); and *d)* the applied description of emotions.

In this context, several computational models of emotion have been proposed. Some for entertainment (virtual simulation and gaming) (Elliot, 1992; Bates, 1994; Blumberg, 1994; Maes, 1995; Reilly, 1996; Bostan, 2010), others for the development of robots (Breazeal & Velasquez, 1998; Esau et al., 2003; Metta et al., 2011), some for training and education (Gratch, 2000; Papachristos et al., 2012) , and others for other specific aspects such as modelling very limited psychological problems (Colby, 1975; Kuipers et al., 2006); recognizing emotions (R. W. Picard, 1997); modeling physiological and hormonal influences of emotion (Kitano, 1995; Cañamero, 1997); modeling influences in goals and learning (Frijda, 1986; Blumberg et al., 1996); modeling emotions and intuition to guide reasoning and decision-making (Velásquez, 1998); modeling interactions among agents (Garcia, 2012a, 2012b); modeling interaction of agents in group-decision and emotional contagion (Neumann & Strack, 2000; Bazzan & Bordini, 2001; Marreiros et al., 2005a, 2005b; Duell et al., 2012; Volmer, 2012; Bosse et al., 2015); among others.

The focus of most of the computational models of emotion is dedicated to humans and all the computerized systems that relate with them (robots, virtual agents, etc.). On the other hand, the context of this work focuses on the emotions that are "felt" by organizations in a collaborative environment. Therefore, a comprehensive review of related computer models would be unnecessary. However, in order to have an insight of the different theoretical and computational approaches that are mostly applied, Table 2.9 summarizes some of the main characteristics of the most relevant computational models. For a comprehensive overview of the various computational models, the reader is referred to (Slater et al., 2008; Ziemke & Lowe, 2009; Lin et al., 2012; Handayani et al., 2014; Rodríguez & Ramos, 2014, 2015; Kowalczuk & Czubenko, 2016).

Regardless of the vast number of CMEs that are found in the literature, the complexity and quality of existing and emerging human-centered applications require the development of more flexible and robust CMEs. In addition, the aspects of emotions in organizations that are introduced in this research work involves the interplay of dynamic and complex environments. In this sense, suitable methodologies, techniques and tools are needed in order to face these challenges and meet such types of requirements. Moreover, advanced CMEs should also contribute for assisting in the completion, and evaluation of theoretical models, providing in this way feedback mechanisms to calibrate them (Marsella et al., 2010; Broekens et al., 2013; Rodríguez & Ramos, 2014).

**Table 2.9. Some computational models of emotion.**

| *Model/ Architecture* | *Psychological Theory of Emotion* | *Involved Components of Emotion* | *Computational Techniques* | *Model Characteristics* | *Main Applications* |
|---|---|---|---|---|---|
| **Cathexis**<br>(Velásquez, 1996) | Physiological: somatic marker hypnotizes (Damasio, 1994)<br>Appraisal: Roseman & Ekman<br>Basic Emotions | Motivational<br>Cognitive<br>Somatic | Marvin Minsky's Paradigm (1996).<br>Multi-Agent System: Synthetic Agents.<br>Associative model for emotional memory. | Generator of behavior, emotions and moods.<br>Reasoning and decision-making. | Decision-making in virtual and physical autonomous agents.<br>Development of Simón the Toddler (a synthetic character) and Yuppy (a simulated emotional pet robot). |
| **EMILE**<br>(Gratch, 2000) | Physiologic: Damasio<br>Appraisal: Frijda & OCC | Motivational<br>Cognitive<br>Somatic | Software agents<br>EM Architecture (Reilly & Bates, 1992)<br>Interactive Pedagogical Drama (IPD) Architecture (Marsella et al., 2000)<br>*Steve* Agent framework (Gratch & Marsella, 2001)<br>Strips Planning | Plan change.<br>Plan selection criteria. | Supports educational applications by allowing agents to appraise the emotional significance of events as they relate to students' (or their own) plans and goals, model and predict the emotional state of others, and alter behavior accordingly.<br>Application to games developments. |
| **FLAME**<br>**(El-Nasr et al., 2000)** | Appraisal: combination of OCC & Roseman | Motivational | Planning<br>Decision theory<br>Q-Learning<br>Fuzzy logic/rules<br>Markov Decision Process (MDP) | Composed of three models: emotional, decision making and learning.<br>Choice and inhibition of plans – action selection.<br>Emotion-based learning and conditioning. | Decision-making in virtual pets designed to show believable behavior.<br>Emotional virtual pets for agent-user interactions. |

| | | | | | |
|---|---|---|---|---|---|
| | | | Single Agent – does not incorporate group behavior. | | |
| **PECS**<br>**(Urban, 2000; Schmidt, 2002)** | Appraisal: Plutchik | Cognitive<br>Motivational | Multi-agent Architecture | Multi-purpose reference model for the simulation of human behavior in a social environment. Composed of four categories: physical (the agent's physical condition); emotional (agent's feelings); cognitive (agent's plans, model of the self and of the environment) and social status (relations in the community). | Modelling and simulating human behavior through the Adam simulator. |
| **ParleE**<br>**(Bui et al., 2002)** | Appraisal: Frijda & OCC<br>Rousseau's model of personality | Motivational<br>Cognitive | Multi-Agent environment<br>Multimodal communication<br>Learning and probabilistic algorithms | Models personality and motivational states. | Virtual conversation agent. |
| **KISMET**<br>(Breazeal, 2003) | Physiological: somatic marker hypothesis (Damasio, 1994)<br>Basic Emotion<br>Appraisal<br>Dimensional | Somatic<br>Cognitive<br>Motor Expression<br>Motivational | Agent-based Architecture<br>Learning algorithms | Inspired by the parent-child relationship.<br>Attentional focus, learning mechanism, and expressions and behavior selection. | Physical Robot – Kismet.<br>Emotional expressions in robots as an aspect that facilitates learning in human-agent interactions.<br>Emotional expressive agents for learning environments. |
| **EMA**<br>**(Gratch & Marsella, 2004)** | Appraisal: Smith & Lazarus, Scherer | Cognitive<br>Motivational | EMILE Architecture<br>BDI Agents | Coping: attention shift, plan changes, BDI changes, actions tendency changes. | Decision-making in virtual humans developed for training environments. |

| | | | | | |
|---|---|---|---|---|---|
| | | | Decision theory<br>Planning | Agent's expressions, attentional processes, beliefs, desires, and intentions. | Virtual scenario of dealing with angry bird.<br>Used for the development of virtual humans. |
| **MAMID**<br>(Hudlicka, 2002, 2003, 2007) | Appraisal: Lazarus, Smith & Scherer<br>Basic Emotions.<br>McCrae's personality model | Motivational | BDI Agents<br>Belief Net<br>Decision Theory<br>Planning | Biases mental constructs (data) based on emotional state.<br>Working memory capacity, speed.<br>Goal and action selection and attentional functions. | Virtual decision-making scenario<br>Emotional virtual humans developed for training and psychotherapy environments. |
| **ALMA**<br>(Gebhard, 2005) | Appraisal: OCC<br>Dimensional: Meharabian's PAD<br>Five Factor Model of personality (McCrae & John, 1992) | Cognitive<br>Motivational<br>Motor Expression | Software agent: Virtual character<br>Implemented in the VirtualHuman System (Reithinger et al. 2006), a knowledge-based framework aimed at creating 3D interactive applications for multi-user/agent settings. | Verbal and non-verbal expressions such as wording, length of phrases, and facial expressions.<br>Cognitive processes such as decision-making. | Embodied emotional conversational agents for multi-agent/user settings. |
| **KARO**<br>(J.-J. C. Meyer, 2006) | Appraisal: partial OCC | Motivational<br>Cognitive | LEA – Logic of Emotional Agents<br>BDI | Plan/agenda changes<br>Fear causes cautious planning | iCat robot. |
| **WASABI**<br>**(Becker-Asano, 2008; Becker-Asano & Wachsmuth, 2010)** | Physiological: Damasio<br>Appraisal: OCC & Scherer | Motivational<br>Cognitive<br>Motor Expression | BDI Agents<br>ACT-R | Plan utility valuation process biased towards optimism or pessimism, mapping of emotions as beliefs, action biases. | Virtual guide agent.<br>Emotional expressions and responses in virtual players. |

| | | | | | |
|---|---|---|---|---|---|
| | Dimensional: PAD (Russell & Mehrabian)<br>Basic Emotions | | | Shape of voice. | |
| **PEACTIDM**<br>**(Marinier et al., 2009)** | Appraisal: OCC & Scherer<br>Physiological: Damasio | Cognitive<br>Somatic<br>Motivational<br>Motor Expression | Software agents | Cognitive behavior in general - attention and goal shift.<br>Reinforcement learning biases (both encoding and recall). | Goal-directed autonomous agents. |

As shown in Table 2.9, the appraisal theory of emotion is common to all models, playing different roles and having different weights. Within this theoretical model, the OCC model of emotions is a popular choice for the goal-based emotional reasoning, with many successful demonstrations of its suitability. Nevertheless, it has some drawbacks that need attention such as the need for retain memory of past emotions, emotion interaction function and the impossibility to model emotion combinations (Marreiros et al., 2005a; Marreiros et al., 2006). In the context of CNs the past emotions history needs to be modeled, thus it adopts partially the OCC model as further described in chapter 3.

The dimensional theory of emotion is represented in the WASABI (Becker-Asano & Wachsmuth, 2010), KISMET (Breazeal, 2003) and ALMA (Gebhard, 2005) models. The framework proposed in this research work is based on a combination of the WASABI and KISMET computational models. Yet, instead of using the three-dimensional space as these CMEs especially due to the fact that the involved actors here are organizations and not humans, the author of this thesis adapts the Russell's circumplex model of affect (J. A. Russell, 1980) for CN member organizations. The other theories have a minor representation in the studied CMEs, because they were out of the scope of this research.

Regarding the computational implementation and techniques, the mentioned models are implemented as autonomous intelligent agents. Some are robotic agents as CATHEXIS or KISMET, others are computational agents as EMILE, MAMID, WASABI (software agents) or FLAME, ALMA (virtual characters). There are also some CMEs that are implemented in a multi-agent environment like CATHEXIS, PECS or ParleE. The proposed collaborative emotional model approach is an agent-based simulation model as further exploited in chapter 4.

## 2.4 Modelling and Simulation

Simulation modeling have been used by researchers as an important modeling technique. The recent advances in simulation methodologies and the emergent software tools have made simulation one of the most used technique for the complex systems analysis (Balci, 1990; Shannon, 1998; Singh, 2009; Majid, 2011; Robinson, 2013; Law, 2015).

In this context, the next sections introduces an overview of the concept of simulations modeling and its process and reviews some modeling and simulations paradigms and tools for development.

### 2.4.1 Simulation Modeling

According to Shannon (1975) "*simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system*". Another definition by Borshchev and Filippov (2004) states that "*a simulation model may be considered as a set of rules (e.g. equations, flowcharts, state machines, cellular automata) that define how the system being modeled will change in the future, given its present state*." In other worlds, simulation is the process of executing the mathematical model through (discrete or continuous) state changes over time, emulating the dynamic characteristics of a complex system.

In a simulation, it is possible to predict the system performance, compare alternative system designs and determine the effects of alternative scenarios on system performance. Figure 2.7, illustrates the analytical and simulation models and their relation with the real world.

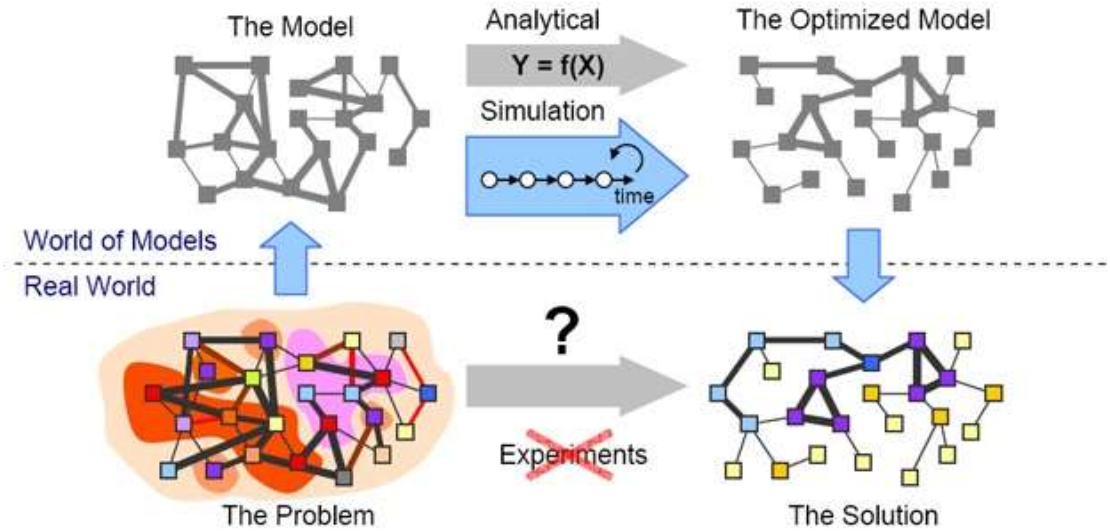



**Figure 2.7. Analytical and simulation modeling. Reproduced from (Borshchev & Filippov, 2004).**

Simulation models can be divided into three distinct dimensions (Law, 2015): static vs. dynamic, deterministic vs. stochastic, and discrete vs. continuous; as shown in Table 2.10.

**Table 2.10. Classification of simulation models.**

| | | |
|---|---|---|
| Static vs. Dynamic | Static | No attempts to model a time sequence of changes, i.e. represents a system at a particular time. |
| | Dynamic | Updating each entity at each occurring event, i.e. represents a system that evolves over time. |
| Deterministic vs. Stochastic | Deterministic | Rule based. The model does not contain probability. Every run will result the same. Single run is enough to evaluate the result. |
| | Stochastic | Based on conditional probabilities. The model contain probability. Units, processes, events or their parameters are initiated randomly using random numbers. If different runs are initiated with different random number seeds, every run will result differently. Multiple runs are required to evaluate the results. Statistics such as averages an standard deviations are used for evaluation. |
| Discrete vs. Continuous | Discrete | Changes in the state of the system occur instantaneously at random points in time as a result of the occurrence of discrete events. |
| | Continuous | Changes in the state of the system occur continuously over time. |

Simulation can be applied at different stages or levels of abstraction (Borshchev & Filippov, 2004):

| | | | |
|---|---|---|---|
| Strategic | High Abstraction<br>Less Detailed<br>Macro level | Population Dynamics<br>Ecosystems | Business Dynamics<br>**Collaborative Networks**<br>(…) |
| Tactical | Middle Abstraction<br>Medium Detailed<br>Meso Level | Transportation<br>Supply Chain | Electrical Power grid<br>Call Center<br>(…) |
| Operational | Low Abstraction<br>More Details<br>Micro Level | Computer Hardware<br>Warehouse | Factory Floor<br>Automotive Control<br>(…) |

In the context of collaborative networks, the adopted simulation level of abstraction should be the strategic one. Collaborative networks require a high level of abstraction due to the intrinsic dynamism of its constituents.

**Advantages.** Simulation provides "experimentation" with a model of a system. If the system exists, it is possible to conduct simulation without causing major disruptions to the real system. If a real system does not exist (or the access to the system's data is not available or difficult to obtain), it is possible to identify problems, bottlenecks and design gaps before building or modifying a system. Therefore the main advantages of simulation are (Maria, 1997; Shannon, 1998; Robinson, 2004; Banks et al., 2005):

- *Better understanding of the system* - by developing a mathematical model of a system of interest, and observing the system's operation in detail over long periods of time.
- *Time (real time vs. virtual time)* – time can be compressed to observe certain phenomena over long periods or can be expanded when a complex phenomenon needs to be observed in detail.
- *Control of experiment conditions* – allowing the evaluation of the effects of changes on the operation of a system by altering the system's model; this can be done without disrupting the real system.
- *Identify the "driving" variables* - those that performance measures are most sensitive to - and the inter-relationships among them.
- *Experiment with new or unknown situations* - about which only weak information is available.
- *Cost* – help developing well designed and robust systems, reduce system development time, potential risks and costs.

**Disadvantages.** Simulation modeling does not have only advantages, there are some weaknesses essentially because it can be time consuming and a very complex exercise. Thus, some disadvantages are (Maria, 1997; Shannon, 1998; Robinson, 2004; Banks et al., 2005):

- *Expensive* – Due to required expert knowledge, which has costs…
- *Time consuming* – Developing and running simulations takes much time because stochastic outputs require many runs to produce valid results.
- *Data hungry* - Simulations tend to require much input data which sometimes is unavailable or inaccessible during conceptual design.
- *Requires expertise* – Professional expertise is required to manage user expectations.

- *Unclear level of fidelity* – It is difficult to judge when the model development is finished, i.e. it is hard to specify the "right" level of fidelity simulations.

Notwithstanding these disadvantages, the simulation modeling approach is adopted in this PhD developments.

### 2.4.2 Simulation Processes

The ultimate goal of simulation modeling is to help decision-makers solve problems. Therefore, in order to guide the designer to develop a good simulation model some problem solving techniques and engineering practices must be taken into consideration and consequently merged. Various simulation modeling researchers developed diagrams and descriptions that outline the key processes in the development of simulation models. Among them are Shannon (1975, 1998), Nance (1981), Balci (1994, 2015), Banks et al. (2005), and Law (2015). Each one with their own way of clarifying the simulation processes. According to Robinson (2004) the simulation processes or life-cycles are in general very similar, outlining a set of processes that must be performed. The main differences are basically in the naming of the processes and the number of sub-processes. On his book Robinson (2004, 2014) describes a life-cycle for model development and use based on the work of Landry et al. (1983) which outlines the key stages of a simulation process. These stages are illustrated in Figure 2.8.

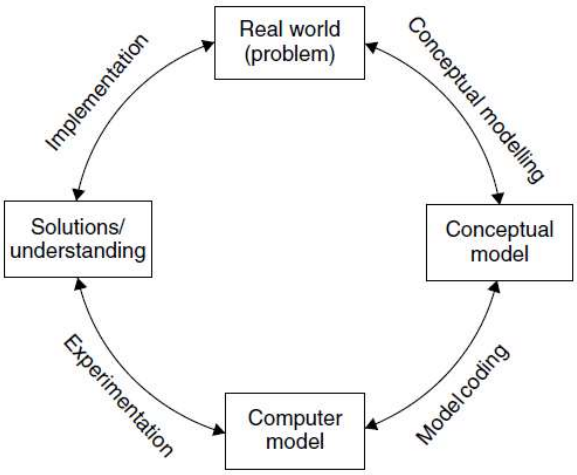



**Figure 2.8. Simulation key stages and processes. Reproduced from (Robinson, 2014).**

The boxes of Figure 2.8 are the key stages and represent the main outputs:

- *A conceptual model*: which is a description of the model that is going to be developed.
- *A computer model*: which is the simulation model implemented on a computer.
- *Solutions and/or understanding*: that represents the results of the experimentation.
- *An improvement in the real world*: that occurs when the solutions and/or understandings are implemented in the real setting.

The arrows represent the processes or activities that enable the flow between stages. For a detailed description of each process the reader is invited to consult (Robinson, 2014).

The simulation approach taken in this research work will essentially rely from the methodological point of view on the works from Robinson (2014) and Balci (2015) as further described in section 3.4.

### 2.4.3 Modeling and Simulation Paradigms

Modeling and simulation as a paradigm, is an approach of representing problems and reasoning about them as much as a solution method. These problems comprise both the analysis and design of complex systems (Vangheluwe, 2004). In analysis, simulation models are created from observations of the real world (induction) whereas in design, models are built based on the initial available knowledge (deduction) aiming at satisfying design goals, which is the case of this work. Sometimes a combination of both approaches is also used.

In this context, three common modeling and simulation paradigms of complex systems are described (Borshchev, 2013). They are System Dynamics (SD), Discrete Event (DE) and Agent Based (AB). In the context of this work, the discrete event method is not applied. This section presents the system dynamics and the agent-based modeling and simulation techniques. The definition and architecture, the modelling techniques and the application areas for the two approaches will be briefly described in the next sections. At the end of this sub-section a comparison between these two modeling and simulation methods is presented.

#### 2.4.3.1 System Dynamics

System Dynamics (SD), initially proposed by Jay Forrester (1961), is a simulation modeling approach. It comprises a methodology and set of modelling tools that allow

the understanding of the behavior of complex systems over time. SD is based on systems thinking, which underlies the notion of understanding how things influence one another within a whole. Therefore, in order to construct a SD model, it is necessary to previously understand the cause and effects of the problem. Nevertheless, reasoning about cause and effect is not enough and that is why the system's performance should also be taken into consideration. This is done through feedback or causal loops. Thus, SD deals with internal feedback loops and time delays that affect the behavior of the entire system.

In this context, the SD modeling is composed of two primary components that help in the understanding of a complex problem: the **causal loop diagrams** and the **stocks and flows diagram**. *Causal loop* diagramming describes a system in terms of the causal relationships among its components. It is used to represent the basic cause-effect mechanisms of the system and also the circular chains of those mechanisms that form a feedback or closed loop. *Stock and flow* diagrams, on the other hand, not only show the relationships between variables that have the potential to change over time (like causal loop diagrams) but also distinguishes between different types of variables (unlike causal loop diagrams). A stock represents a feature of the system that tracks the level or quantity of a certain item in the system. It is the accumulation of "something" over time. Flows affect the stocks via inflow or outflow and interlink the stocks within a system. The value of a flow is dependent on the stocks in a system along with external influences. The combination of levels, rates, and constant values allow taking a causal diagram and translating it into a quantified entity. The resulting structure of the model, built up with stocks and flows, determines the behavior of the system. It allows users to visualize the evolution of the system over time, in simulated activity, under varied conditions (by changing equations and the initial values of levels, rates, and constants) (Morris et al., 2010).

Figure 2.9 illustrates a SD simulation model for a simplified view of the population dynamics. On the right side, the causal loop diagram shows the cause and effect of the births and deaths on the population and the corresponding feedback. On the left side, it is represented the stocks and flows diagram, representing the quantified version of the model. In this case the stock *Population* represents the "accumulation" over time of the difference between the *Births* input and *Deaths* output rates.

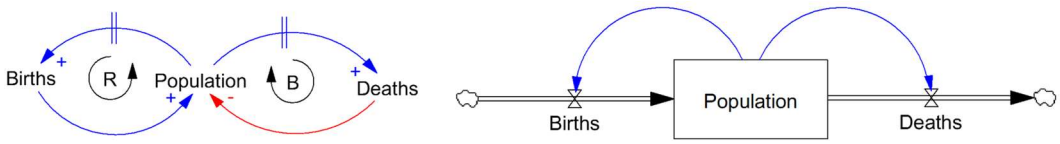



**Figure 2.9. Causal loop (left) and stocks & flow diagrams (right) of population dynamics.**

SD has been applied in many fields, such as in climate monitoring, economic forecasting, predicting social trends like technology adoption, market saturation, and predicting changes in population versus urban sprawl, etc. (Angerhofer & Angelides, 2000; Sterman, 2002; Barton et al., 2004; Wakeland et al., 2005; Eldabi et al., 2007; Vlachos et al., 2007). In general, SD is well accepted by experts in those areas and the results well established and flexible for many complex systems. In addition, they show high predictive results of the real system behavior. Another pointed advantage is the capacity to be easily explained and intuitive to understand. This is important when it is necessary to discuss complex systems behavior with experts and non-experts. Both diagrams (causal loop and stock & flow) have high explanatory value for the system they model, and are computable, with a strong mathematical foundation, which means that they are quite simple to translate to computer programs. Nonetheless, there are also some disadvantages of using SD modeling simulation approach. According to (Wakeland et al., 2004), one of the limitations of SD is the impossibility of modeling a detailed representation of real-life problems at the entity level, due to the macroscopic and high level of abstraction nature of this modeling approach. Brailsford and Hilton (2000) stated that SD is less capable at modeling detailed resource allocation problems and optimizations or direct prediction. For further insight on the advantages and disadvantages of SD the reader is invited to check (Chahal & Eldabi, 2008).

#### 2.4.3.2 Agent-Based

Agent-Based Modeling and Simulation (ABMS) is another paradigm for analyzing complex systems which has become widespread over the last 20 years. Some authors are enthusiastic in saying that it "*is one of the most exciting practical new development in modeling since the invention of relational databases*" (Macal & North, 2008), while others argue that ABMS "*should not be seen as completely new and original simulation paradigm*" (Davidsson, 2000). Independently of this debate, one can notice more agreements than disagreements among researchers in what concerns some of its underlying characteristics (see Siegfried, 2014 for more details). Generally, agent-based models are suitable for complex systems with heterogeneous, autonomous, and pro-active actors, where individuality and changeability cannot be ignored (Jennings et al., 1998; Davidsson, 2000; Macal & North, 2008; Siebers & Aickelin, 2008; Siegfried, 2014).

In ABMS, a system is modelled as a collection of autonomous decision-making entities called *agents* (either individual or collective entities such as organizations or groups). Each agent individually evaluates its situation and makes decisions on the basis

of a set of rules. In addition, ABMS provides a useful approach to understand collective phenomena by studying the rules of the agents involved.

Siebers et al. (2010) claim that an ABMS system should be used when the problem has a "natural representation" of agents, i.e., when the goal is modeling the behavior and interactions of individual entities in a diverse population in the form of a range of alternatives or futures. In the same direction, Siegfried (2014) declares that an ABMS "*usually contains different types of agents which represent different individuals from the system under investigation. Multiple, distinguishable instances of each type of agent may be present in the model*". It is in this line that this thesis work models the CN complex system and its constituents, the CN members. To be further described in chapter 4.

ABMS employs a bottom-up approach where the behavior of the agent is modeled at the micro or individual level and the macro or system behavior emerges from the panoply of interactions between the individual entities (Macy & Willer, 2002). The most common modeling technique is the statechart diagram (Harel, 1987). Statecharts clarify a model's logic and allow for efficient software implementation of complex state-based models. In addition to agent state and behavioral logic representation, visual statecharts can also be useful for monitoring agent status during a simulation, and quickly checking the underlying dynamics of complex models as a simulation evolves over time. Visual interactive modeling approaches, such the ones present in AnyLogic multi-method simulation tool (AnyLogic, 2000), include such capabilities for constructing ABMS. Figure 2.10 illustrates an agent based model of a country population dynamics from (Borshchev & Filippov, 2004). In this model a part of the agent behavior is defined as a statechart, while the houses, transports, and other physical components of a country, are represented in the environment model.

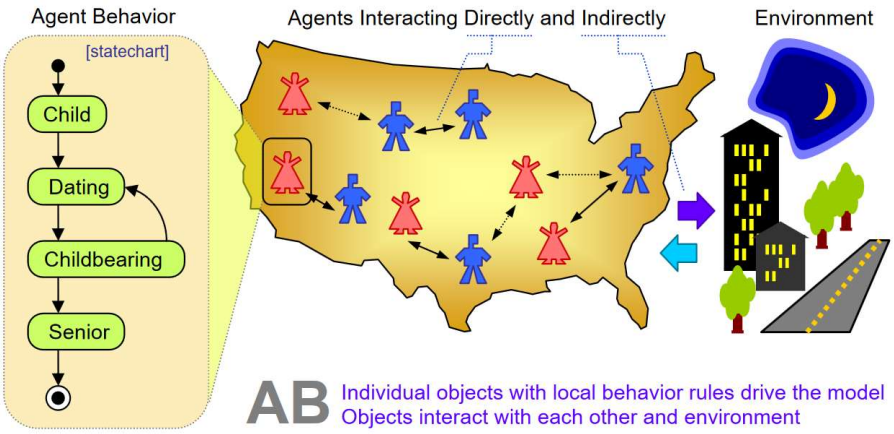



**Figure 2.10. Agent based model generic architecture and behavior (statechart) in AnyLogic. Reproduced from (Borshchev & Filippov, 2004).**

It is common to find in the literature many names or similar terms of agent-based modeling. ABMS (*agent-based modeling and simulation*), ABM (*agent-based modeling*), ABS (*agent-based systems or simulation*), MAS (*multi-agent simulation*) and IBM (*individual-based modeling*) are all widely-used acronyms (Macal & North, 2009; Siegfried, 2014; Macal, 2016). This dissertation uses the term ABMS or simply AB. Whether the term agent-based modeling or agent-based simulation is referred it should be interpreted as ABMS.

Some of the ABMS application areas are in vehicles and pedestrians in traffic situations, actors in financial markets, consumer behavior, humans and machines in battlefields, people in crowds, animals and/or plants in eco-systems, artificial creatures in computer games, among others (Macal & North, 2008). More recent research has been conducted on completely new topics such as modeling the nuclear fuel cycle (Huff et al., 2016), national culture and innovation diffusion (Desmarchelier & Fang, 2016), consensus analysis (H. Li et al., 2016), subway station evacuation (Z.-y. Li et al., 2016) and passenger terminal safety (Yatskiv (Jackiva) et al., 2016). More examples can be found in (Macal, 2016).

The key **advantages** of ABMS are:

- Distributed control, supporting parallel computations on separate machines;
- Supporting simulation of pro-active behavior;
- Ability to add or delete entities during a simulation;
- Easy to swap (exchange) an agent with the corresponding simulated entity, i.e., swapping a real person or a physical machine, (even during a simulation) making the simulation scenarios very dynamic;
- Facilitating simulation of group behavior in highly dynamic situations. Thereby allowing the study of "emergent behavior" that is hard to grasp with traditional methods; and
- Well-suited for the simulation of situations where there are a large number of heterogeneous individuals who may behave somewhat differently.

However, there are also some **disadvantages** when modeling with ABMS:

- Not widely used, especially in industry. Seems to be of more interest to academics within their research studies than to industries which could implement it within practical applications (Siebers et al., 2010);
- Lack of interest from the software vendors in having products with this methodology, which could be associated to its lack of acceptance and use in many areas;

- Computationally intensive. Playing with multiple agents trying to find their solutions which requires time to generate and demands a large capacity of computer processors to compute it; and
- Lack of empirical data (Siebers et al., 2010).

For further reading on the advantages and disadvantages of ABMS consult (Macal & North, 2009; Majid, 2011; Siegfried, 2014).

#### 2.4.3.3 System Dynamics and Agent-Based Combination

The dissimilarities between SD and AB make a difference when it comes to choose which one is more applicable in a certain situation (Wakeland et al., 2004; Macal & North, 2013; Guerrero et al., 2016). However, one paradigm alone cannot provide means to analyze the complex system under study. Thereby, it is legitimate to think that a combination of both paradigms would increase the potential to model the complex system. To verify this assumption, some characteristics that make SD and AB differ are described and then the potential benefits of joining the two are clarified.

**SD and AB Differences.** Most of the comparisons that were made between SD and AB relied on designing independent models of the same complex system and checking out the results (Davidsson, 2000; Siebers & Aickelin, 2008). Based on some of those comparisons Guerrero et al. (2016) selected five fundamental characteristics in which SD and AB differ. They include: 1) the paradigms' capacity to model continuous aggregated and discrete disaggregated system states; 2) physical space, topographies, and network structures; 3) stochastic & deterministic phenomena; 4) learning and adaption; and 5) ease of model building and interpretation. A detailed description of each characteristic is available in Guerrero et al. (2016).

Table 2.11 summarizes the differences between these two paradigms. Some characteristics pointed by other authors are also considered (Davidsson, 2000; Borshchev & Filippov, 2004; Wakeland et al., 2004; Majid, 2011; Siegfried, 2014).

**Table 2.11. System dynamics and agent based paradigms comparison.**

| *Characteristics* | *System Dynamics* | *Agent-Based* |
|---|---|---|
| Modeling Approach | Macroscopic – system level | Microscopic – individual centric |
| Underlying concept | How a collection of parts operates as a whole, overtime | Individual interactions and behavior of system components |

| Level of Abstraction | High Level | Any Level |
|---|---|---|
| Modeling Techniques (Mathematical Formalization) | Stock & Flow Diagrams | UML State Charts and Class Diagrams or Equations |
| System States | Continuous<br>Aggregated<br>Homogeneous | Discrete<br>Disaggregated<br>Heterogeneous |
| Simulation (Stochastic and Deterministic Phenomena) | Deterministic (differential equations) | Deterministic Stochastic (object oriented approach) |
| Physical Space, Topographies & Network Structures | Localized<br>No geographic info<br>Fixed Structure | Spatial diffusion<br>Propagation processes<br>Mobile agents in a network |
| Learning & Adaptation Processes | Experience based on learning effects and adaptation processes | Explicit individual learning |
| Ease of Model Building & Interpretation | System levels observables to identify the feedback loops<br>More easy interpretation of results | Agent's decision processes, interactions and behavior<br>Require knowledge on agent properties for parametrization |

In a nutshell, the differences between the two paradigms are quite evident. Starting by each paradigm's underlying concepts: whereas in SD a collection of parts operates as a whole, in AB the focus is on the individual interactions and the emerging behavior. In relation to the systems states, SD embodies homogeneous and continuous aggregated systems and has some trouble when trying to model discrete events. In contrast, AB includes heterogeneity between agents, and is more suitable to model discrete disaggregated systems (Bonabeau, 2002). Furthermore, while SD and AB can both model deterministic systems, AB has as property stochastic or probabilistic functions. Another difference is associated with the physical space and network structures. Traditional SD is not conceived to cope with spatial diffusion and propagation processes, nevertheless emerging paradigms such as spatial system dynamics (SSD), are trying to overcome this limitation (quoted in Guerrero et al., 2016). On its turn, AB is able to distinguish physical space, topographies and other network structures. Additionally, AB permits the study of the dynamics across landscapes or networks (N. Osgood, 2007). Regarding learning mechanisms, AB models may have explicit individual learning, for instance resorting to machine learning algorithms, while SD frequently models experienced based learning effects and adaption processes. To finalize, and despite the previous mentioned qualities, the AB Achilles' heel is the time consuming modeling simulation and interpretation processes in opposition to SD. Besides that, while SD models make use of system level observables to identify the feedback loops that govern the system

behaviors, AB model building requires knowledge on the individual agent's processes, interactions and behavior and on agent properties for parametrization (Macal, 2010).

**SD and AB Combination: Benefits.** After analyzing the differences between the two modeling and simulation paradigms, it can be said that both approaches are effective for complex dynamics systems although covering different partial aspects. AB as a new paradigm has become very promising even in relation to the traditional SD modeling and simulation (Jennings et al., 1998; Bonabeau, 2002; Macal & North, 2008). Independently of that, the choice of the paradigm depends of the particularities of the complex system to model and should consider the paradigm's competences, applicability, strengths, and weak points.

By combining SD with AB in the same model, the better of the two worlds might be achieved, a hybrid SD-AB model. In this way, a complex system can be modeled using components modeled in a discretely and individual way (as AB models) and on the other hand, using components modeled in a continuous and aggregate way (as SD models). In other words, different levels of aggregation and handling of time might be defined for the different components of the system. Furthermore, the different simulation techniques specifying behavior can also "live" under the same model, boosting, in this way, new approaches for integrating different simulation dimensions (see Table 2.10).

In addition, the resulting hybrid models would permit the arrangement of agents in a spatial or network structure, integrating at the same time properties of SD. Such as continuity and non-linear multi-loop feedback. It is also possible to use multiple SD sub-models to create different agent's properties across a networks structure. In this line of through, Vincenot et al. (2011) on their theoretical considerations on the combination of SD with AB defined four reference cases where this hybrid approach could be applied:

1. Represents the interaction of agents with a single SD model;
2. Illustrates the case of SD sub-models embedded in agents;
3. Exemplifies agents interacting with a space made of SD models; and
4. Demonstrates SD-AB models swapping.

For this thesis model development, the approach is based on the second case, the CN members represented by agents have embedded a SD model that continuously computes the agent variations. This will be further explained in chapter 4.

### 2.4.4 Modeling and Simulation Tools

Several modeling and simulation tools are available in the market. Some are for free use, others are proprietary toolkits for commercial use. Examples of such tools can be found in (Allan, 2011; OR/MS, 2015; Capterra, 2017).

Within the past decades, several software tools have been developed and applied by SD and AB modelers. SD tools have reached a greater stage of maturity than those for AB based modeling, but still offer many areas for growth. Better support for AB models would benefit experimentation with hybrid SD-AB modeling. A summary on some simulation tools that feature either SD and AB paradigms as well as hybrid SD-AB modeling is shown in Table 2.12.

**Table 2.12. Some of the available modeling and simulation tools for SD and AB.**

| *Tool* | *SD* | *AB* | *Characteristics* |
|---|---|---|---|
| **Vensim**<br>(www.vensim.com) | X | | Free version |
| **Repast Simphony (Repast S)**<br>(North, Collier and Vos, 2006; North et al., 2013) | | X | Dedicated AB prototyping environment<br>Large-scale (scalable) agent development environment<br>Free version |
| **NetLogo**<br>(Wilensky, 2013) | | X | Dedicated AB prototyping environment<br>Modified version of the Logo programming language.<br>Free |
| **Swarm**<br>(Minar et al., 1996) | | X | Large-scale (scalable) agent development environment.<br>Java interface<br>Free |
| **AnyLogic**<br>(www.anylogic.com) | X | X | Multi-method tool<br>Integration and interaction of the two methods<br>Large-scale (scalable) agent development environment<br>Java<br>Proprietary toolkit (free version for students) |
| **Insight Maker**<br>(www.insightmaker.com) | X | X | Online software<br>Free |
| **MASON**<br>(GMU, 2013) | | X | Large-scale (scalable) agent development environment<br>Java<br>Free |
| **Stella / iThink**<br>(www.iseesystems.com/store/products/stella-architect.aspx) | X | | Multi-method tool (depending on the products)<br>Proprietary toolkit |
| **PowerSim**<br>(www.powersim.com) | X | | Build models with the System Dynamics approach<br>Run what-if scenarios and do policy design |

| | | | |
|---|---|---|---|
| | | | Quickly assemble a flexible user interface<br>Connect to MS Excel or different Databases<br>Free |
| **NOVA**<br>(www.novamodeler.com) | X | X | Multi-method tool<br>Java-based modeling platform<br>Free version |

Nevertheless, the choice of the appropriate tool to satisfy a certain problem is not easy, due to the inherent complexity of systems. In order to cope with these issues N. Osgood (2007) raised the following questions: "*How should one best identify the most appropriate tool set for a given problem? What (if anything) are the essential differences between these modeling tool sets? How fundamental are these differences?*" According to this author, there are different aspects that must be considered to answer these questions, such as the level of granularity of a model, the way its behavior is specified, the state abstractions and the nature of the rules that are employed, among others.

In the case of this thesis, the selection criteria was first based in tools that provide hybrid SD-AB approach, second on the license character, with preference for the free licenses, and finally on the modeling tool experience of the author.

# 3

# C-EMO Modeling Framework

*This chapter presents the C-EMO Framework proposal for the modeling of emotions in a CN context. First the concept of collaborative network emotion (CNE) is introduced with the description of a typology for emotions in the context of CNs and of a theory for representing CNEs. Then the two components of the C-EMO Framework, namely the individual member emotion and aggregated network emotion models are presented, respectively. Finally, the adopted simulation modeling approach for the development of both components of the C-EMO framework is presented.*

With the aim to give support to the concept and modeling of emotions in the context of a dynamic environment such as a CN, the **C**ollaborative **EMO**tion modeling framework (C-EMO) was developed. This framework represents a system that deals with emotions of CN members and the way emotions affect those members and the entire collaborative environment. A core part of the C-EMO modeling framework is the definition of working concepts and the organization of knowledge. Moreover, it also proposes to systematize the adopted theoretical models and the computational models of **emotion** applied to the CN context. C-EMO also intends to be as generic as possible, in order to cover the different typologies of CNs and to serve as a starting point for further implementations and experiments in this area of research. In this context, the overall purpose of C-EMO is the ability of appraising emotions in a CN environment by considering CN members with different skills and characteristics collaborating within the dynamic network. Therefore, it comprises two essential building blocks:

- *Individual Member Emotion* - for appraising the emotion of each CN member individually and examining the effects this emotion has both on the CN member behavior and on the CN environment, and
- *Aggregated Network Emotion* - for estimating the overall emotion present in the CN and examine the effects such emotion has on the network environment and on its members.

Figure 3.1 illustrates a macro view of the C-EMO modelling framework comprising the relationships between the CN environment, the individual emotion of each CN member and the aggregated emotion of the CN.

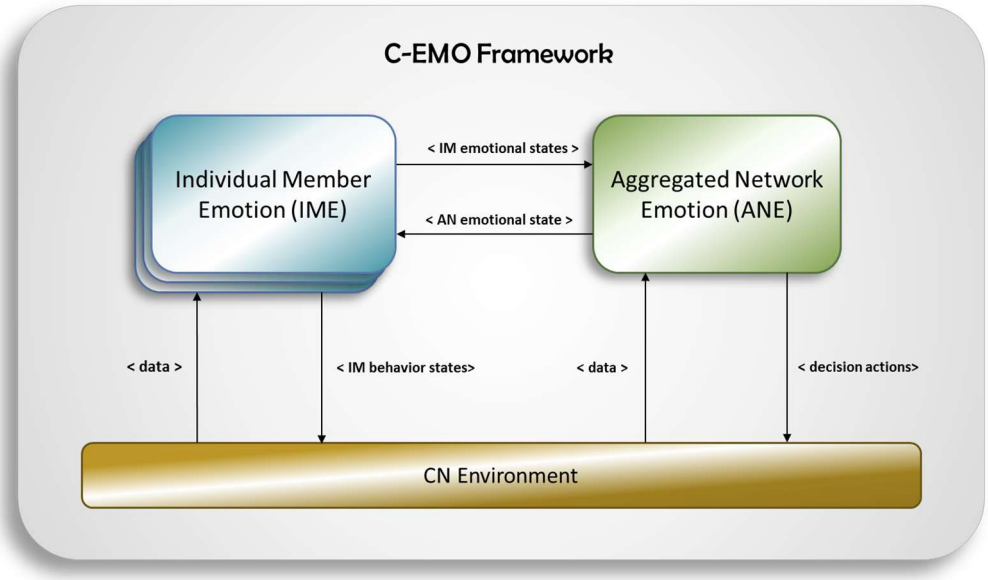



**Figure 3.1. C-EMO framework macro view.**

The remainder of this chapter is devoted to the notion of collaborative network emotion (section 3.1) and the description of the two C-EMO framework branches: the individual member emotion model (section 3.2) and the aggregated network emotion model (section 3.3), respectively.

## 3.1 Collaborative Network Emotion Concept

Three distinct types of emotion are defined in the collaborative network context. The *collaborative network emotion* (see Definition 1 in chapter 1), the *individual member emotion* and the *aggregated network emotion*. They are defined as follows:

Definition 3. ***Individual Member Emotion***

*Individual Member Emotion (IME) is the CNE "felt" by each CN Member as a result of its expectations towards the CN, the dynamics of its interactions and collaboration, and the influence of the aggregated network emotion.*

Definition 4. ***Aggregated Network Emotion***

*Aggregated Network Emotion (ANE) is the CNE that is "felt" by the collaborative network as a whole and that results from the influence of the Members' individual emotions and the dynamics of the network.*

Figure 3.2 illustrates the CNE taxonomy.

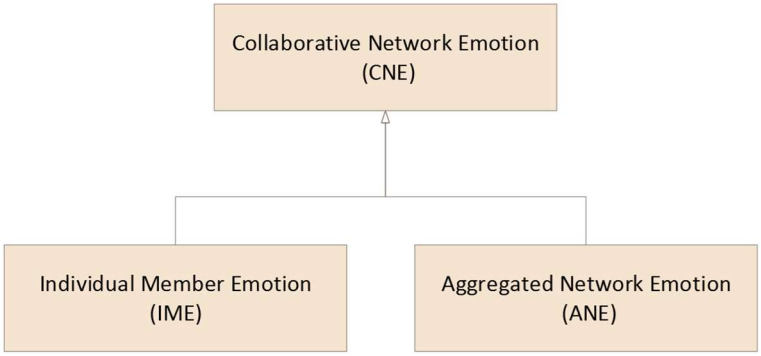



**Figure 3.2. CNE taxonomy.**

From this point forward, whenever the term ***emotion*** is referred, it should be interpreted as a CNE or any of its two types: IME and ANE, depending on the context.

### 3.1.1 CNE Typology

Having in mind that the involved players in a CN are organizations and not humans, the types of considered emotions should be adequate in order to be reasonable thinking about "emotions" in a CN. In this sense the typology that is proposed consists of two positive and two negative CNEs, plus a neutral emotional state as depicted in Figure 3.3.

The suggested CNEs independently of being positive or negative, are adopted with the assumption that they are the more appropriate ones for characterizing emotions

both for the CN and the involved organizations. In this line, the *excitement* and *contentment* emotions characterize the positive CNEs while the *frustration* and *depression* characterize the negative ones.

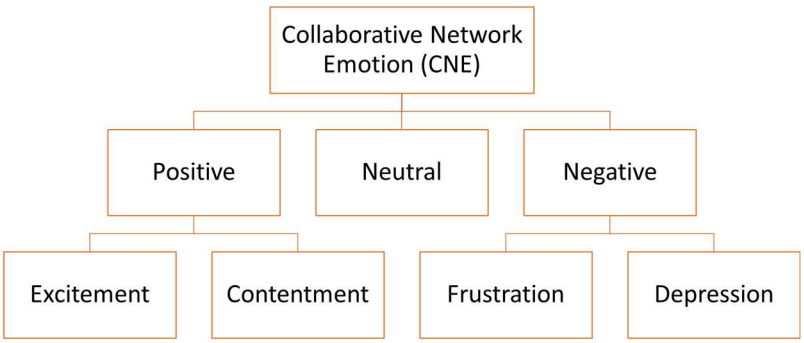



**Figure 3.3. CNE typology.**

Table 3.1, describes in detail the nature of each proposed CNE. Including a description of the associated "feeling", the elicitation mechanisms and the potential emotional responses both for the IME and the ANE.

**Table 3.1. Description of CNEs.**

| *CNE* | *IME Description* | *ANE Description* |
|---|---|---|
| **Excitement** | Excitement is a positive emotion, experienced when the CN member "feels" thrilled and electrified. It might be triggered when its most challenging objectives, expectations and desires are ***fully*** achieved. As a positive emotion it contributes to maintain the member extremely active and willing to continue interacting and promoting the success of future collaboration within the CN. | Excitement is a positive emotion experienced when the CN as a whole "feels" excited, thrilled or electrified. It might be triggered when most of its members feel emotionally excited and the CN objectives are ***fully*** achieved. As a positive emotion it reflects that the CN is **perfectly healthy**, influencing in a very positive way the emotional states of the members. |
| **Contentment** | Contentment, like excitement, is a positive emotion, experienced when the CN member "feels" content, comfortable and satisfied. It might be elicited when the objectives, expectations and desires are ***partially*** achieved. As a positive emotion it indicates a successful achievement and a relaxed sensation of well-being. The CN member keeps its interactions with the CN in a moderated way. | Contentment, like excitement, is a positive emotion, experienced when the CN as a whole "feels" content, comfortable and satisfied. It might be elicited when most of its members feel emotionally content and the CN objectives are ***partially*** achieved. As a positive emotion it indicates that the CN is in **good health**, influencing in a moderate positive way the emotional states of the members. |

| | | |
|---|---|---|
| **Frustration** | Frustration is a negative emotion, experienced when the CN member "feels" frustrated, angry or unsatisfied. It might be triggered when the objectives, expectations and desires are ***mostly not*** achieved. As a negative emotion it inhibits the member from accomplishing its goals and as a consequence a disturbing sensation of irritability takes over. The CN member tends to assume controversial actions towards the CN and its members. | Frustration is a negative emotion, experienced when the CN as whole "feels" frustrated, angry or unsatisfied. It might be triggered when most of its members feel emotionally frustrated and the CN objectives are ***mostly not*** achieved. As a negative emotion it indicates that the CN is suffering from **stress and anxiety**, influencing in a moderate negative way the emotional states of the members. |
| **Depression** | Depression, like frustration, is a negative emotion, experienced when the CN member "feels" depressed, hopeless and uninterested. It might be elicited when the objectives, expectations and desires are a ***complete failure***. As a negative emotion, it incapacitates the member to focus on collaboration activities. As a consequence, the CN member puts in jeopardy its position in the community, compromises the interactions and may provoke conflicts. | Depression, like frustration, is a negative emotion, experienced when the CN as a whole "feels" depressed, hopeless and uninterested. It might be elicited when most of its members feel emotionally depressed and the CN objectives are a ***complete failure***. As a negative emotion it indicates that the CN is **unhealthy**, influencing in a negative way the emotional states of its members. |

### 3.1.2 CNE Theory

Many different theories of human **emotion** have been proposed and followed by a great amount of **emotion** theorists over the last decades, as seen in chapter 2.2.2.1. Among the vast panoply of theories, the most common ones were described, the physiological or somatic, the basic **emotion**, the appraisal and the dimensional theories of **emotion**, as shown in Table 2.7. The first two, are mainly focused of human physiology, therefore are out of the scope of this work. Nevertheless, both the Scherer's (2009) components of **emotion** model, most widely known as CPM (Component Process Modeling) of the appraisal theory and the Russell's (1980) circumplex model of the dimensional theory are adopted and combined as the underlying theories of CNE. The next sub-sections will detail the adopted aspects from these two theories.

**The Dimensional Model of CNE.** Dimensional theories provide a suitable framework for representing **emotions** from a structural perspective, defining **emotions** as states that can be represented on a common multidimensional space. Furthermore, they establish that **emotions** can be differentiated on the basis of dimensional parameters. J. A. Russell

(1980), proposes a bi-dimensional space organized along the axes of valence, measuring the pleasure related to the **emotion**, and arousal, i.e. the degree of activity associated with the **emotion**, as illustrated in Figure 3.4. a). In this model, also known as the circumplex model of **emotion**, each **emotion** can be understood as a linear combination of these two dimensions, or as varying degrees of both valence and arousal (Posner et al., 2005).

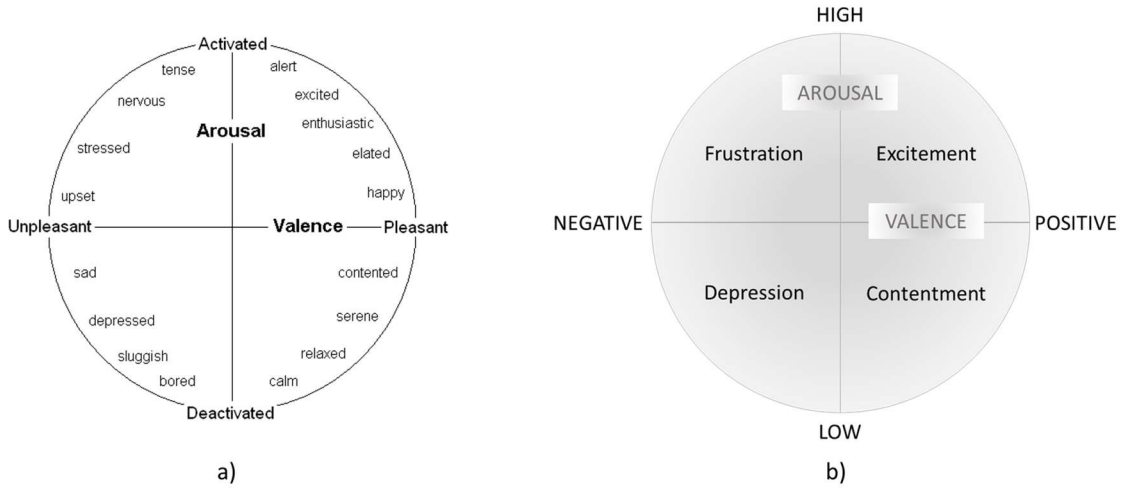



**Figure 3.4. a) Russell's circumplex model of affect. b) The adapted dimensional model of CNE states.**

In this context, the model proposed for the representation of CNEs is based on the Russell's model, essentially because it facilitates a good adaption from the human model to the organizational model, through its well-defined structure for representing **emotions**. Furthermore, the circumplex model offers a way of describing **emotional** states, which are more tractable than using words, such as in the other studied models. By adapting these **emotional** states, the four CNE states that are proposed to describe the "feelings" of the CN players mirror those of the Russell's circumplex model and are illustrated in Figure 3.4b). In the adapted dimensional model, it can be seen that the CNE also follows the two dimensional components: the valence and arousal. In this work, they are defined as follows:

Definition 5. ***Valence***

*Valence is a dimension of the CNE emotional state and represents the pleasure-displeasure continuum.*

Definition 6. ***Arousal***

*Arousal is a dimension of the CNE emotional state and represents the level of activation, uncertainty, novelty, expectation and complexity of the emotional stimuli.*

In this sense, the CNEs can be differentiated according to their positive or negative valence and their high or low arousal. Accordingly, *excitement* is defined as positive valence and high arousal; *contentment* as positive valence and low arousal; *frustration* as negative valence and high arousal; and finally *depression* as negative valence and low arousal. Table 3.2, resumes the CNEs dimensional placement.

**Table 3.2. The adopted CNE emotional states and their dimensional placement.**

| *CNEs* | *Synonyms* | *Dimensions* |
|---|---|---|
| **Excitement** | Active, enthusiastic, thrilled, electrified | Valence >0; Arousal >0 |
| **Contentment** | Comfortable, relaxed, satisfied | Valence >0; Arousal<0 |
| **Frustration** | Afraid, nervous, angry, unsatisfied | Valence <0; Arousal >0 |
| **Depression** | Hopeless, miserable, uninterested | Valence<0; Arousal<0 |

**The Four Components of CNE.** In the last decades, the concept of **emotion** has been evolving to be approached in a broader and holistic perspective. Theorists such as Scherer (1982, 2009) or Moors (2010), on their research, consider **emotion** as a process rather than as a simply affective state that influences cognition. The term emotional episode is then used to indicate any process starting from the stimulus to the later components of **emotion** as presented in section 2.2.2.2. In this sense, and making a kind of analogy, the CNE concept should also be seen in a comprehensive perspective and its constituent components identified.

In spite of the various disagreements amongst psychologists, regarding the number of components of an emotional episode (see Moors (2009)), Scherer proposed five components to define the **emotion** process. They are the cognitive, somatic, motivational, motor, and feeling components (the reader is invited to see Table 2.8). This research work is strongly based on the Scherer's components, nevertheless not all components are included when performing the analogy between **emotions** and emotions "felt" by organizations. It is the case of the component that is directly related to the human body and the **emotions** that are accompanied by the autonomic nervous system activity, i.e. the somatic component. The other components, are adjusted and adapted and are considered in the CNE process as follows:

- The *cognitive or appraisal component* mirrors the Scherer's homonym component and consists of evaluating the events and stimulus that are significant according to each CN player appraisal criteria. This component is considered as a multilevel process, which causes changes in all the other three components.

- The *feeling component*, is based on the Scherer's subjective feeling component, and consists of categorizing the appraisal results with the corresponding emotional responses or CNE states. These can be positive or negative, pleasant or unpleasant, and calm or aroused, as seen previously.
- The *motivational component*, is in charge of understanding the behavioral intentions that the CNEs carry and the different response actions. This component is founded on the Scherer's homonym component.
- The *expression component*, on its turn, follows the motor expression component and consists basically in the way the CN emotions are transmitted/communicated to the outside, i.e. to the CN environment and its players. In this specific case, the communication might be done through an abstract representation using emoticons or resorting to different colors representing the different CNEs.

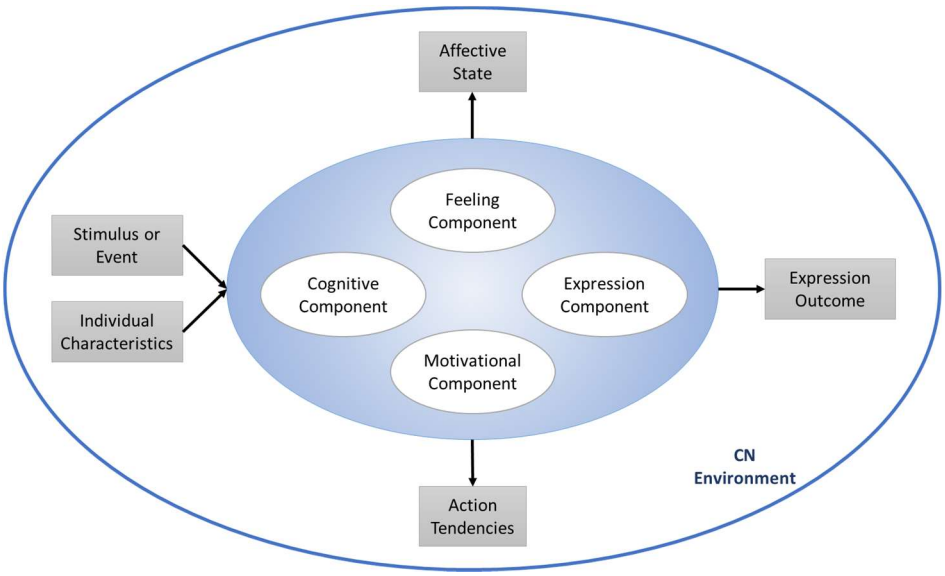



**Figure 3.5. The four components of CNE.**

In this context, four components composing the "CNE episode" or process are proposed as illustrated in Figure 3.5. In this figure, the ellipses represent the above components while the rectangles represent the inputs and outputs of the CNE episode. As inputs it is considered the *Stimulus or Events* that occur in the CN environment and the *Individual Characteristics* of each CN player. On its turn, the outputs are composed of the *Affective State*, representing the value of the appraised CNE, the *Expression Outcome*, that is the graphical representation of the affective state, and the *Action*

*Tendencies*, that represent the potential behavioral actions of the CN player when it is "feeling" the appraised CNE.

## 3.2 Individual Member Emotion Model

The individual member emotion model (IME model) represents the dynamically changing emotions of individual members of a CN. Human emotions involve feelings, experience, behavior, physiology and cognition. As known, members of a CN are organizations that might be dispersed geographically with different purposes and competences, and not humans, although ultimately organizations involve people. Yet they are managed and operated by humans. Emotions are unquestionably related to humans and it is evident that organizations cannot feel emotions in the same way humans do. Nevertheless, the author believes that a kind of IME state of an organization can be appraised when it belongs to a virtual environment that presupposes interaction and collaboration among its members.

In this context, the main modelling challenges are threefold. The first one is related to the aspects of the human-emotion theories that can be applicable to organizations, namely the cognitive and behavioral aspects. The second one, consists in determining how the stimulus, events and IME evidences should be used in order to conceive a model inspired, in one hand, on human-related emotional theories and on the other hand applied to organizations preserving at the same time their privacy. The final challenge deals with the selection of proper mechanisms, which can be borrowed from the computational models of emotion, for the evaluation of IME stimuli, for the estimation of IMEs and the generation of IME responses. Please note that many more challenges might be identified, nevertheless they are out of the boundaries of the model proposed in this PhD work.

Having this in mind and in order to cope with the CNE theory, the individual member emotion part of the C-EMO framework is composed of four main building blocks: *Perception*, *Internal Knowledge*, *Emotion*, and *Behavior*. The perception and internal knowledge elements are the ones that give support to the IME elicitation, i.e. that provide all the necessary information for the emotion module. The other two, the emotion and the behavior are the core elements of the IME model. An overview of the IME model context is depicted in Figure 3.6.

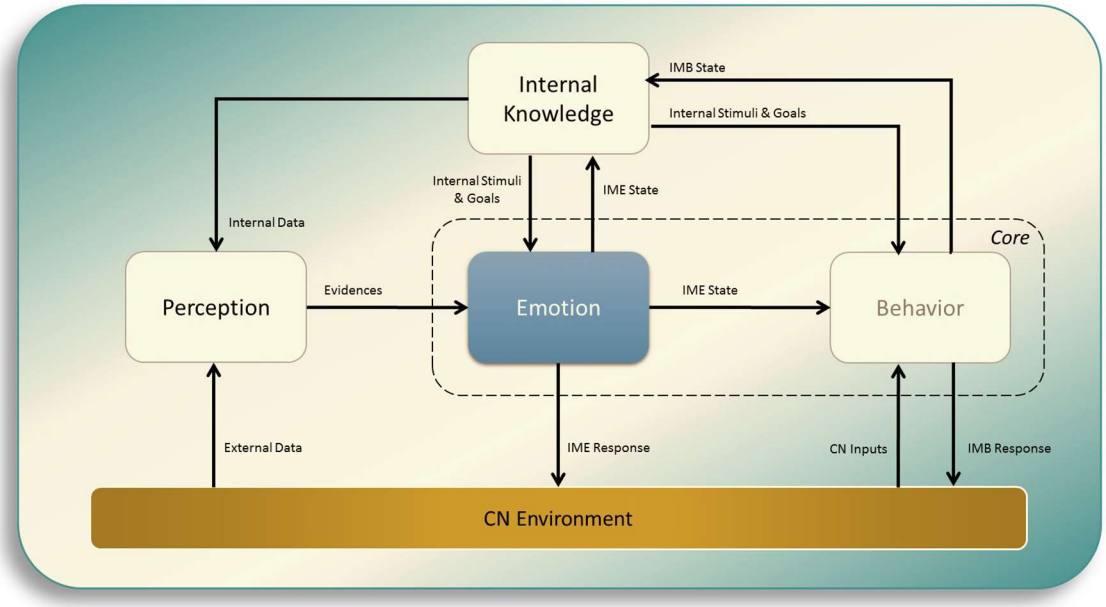



**Figure 3.6. Overview of the IME model.**

In more details:

- The *Internal Knowledge* module, keeps the individual member information and knowledge updated. Its main objective is to provide the perception and emotion modules with data and knowledge about the individual member.
- The *Perception* module, is in charge of collecting the necessary data from the CN environment (external data) and from the individual (internal data) with the aim to prepare an evidences information vector that will be later appraised in the emotion module.
- The *Emotion* module, is the core element and is devoted to the IME appraisal and elicitation. Its purpose is to appraise the evidences information and generate/estimate and later activate the corresponding IME state. It is also responsible for making the IME state manifesto to the CN.
- The *Behavior* module, also makes part of the core element, and is responsible for the preparation of the action tendencies or the behavioral responses after an IME is activated. This module's objective is to infer the actions (emotional and behavioral responses) that correspond to the activated IME. This module is out of the scope of this PhD work. Nevertheless, and in order to give a comprehensive idea of the IME model, a simplified version of this module is presented. A comprehensive development will remain as future work.

This model is based on the conceptual views from CATHEXIS (Velásquez, 1996), KISMET (Breazeal, 2003) and WASABI (Becker-Asano, 2008) as it will be further pointed out in the remainder of this dissertation. The following sections will describe in detail each one of the building blocks of the IME model and their context.

### 3.2.1 Context Elements of the IME Model

The context elements provide to the core elements of the IME model the necessary information relative to the state of the individual member and the CN environment. The next sub-sections give details about these elements.

#### 3.2.1.1 Internal Knowledge

The internal knowledge module is in charge of managing the information about the CN member, maintaining it updated. It comprises two main blocks as depicted in Figure 3.7: the *Internal State* and the *Internal Stimuli*.

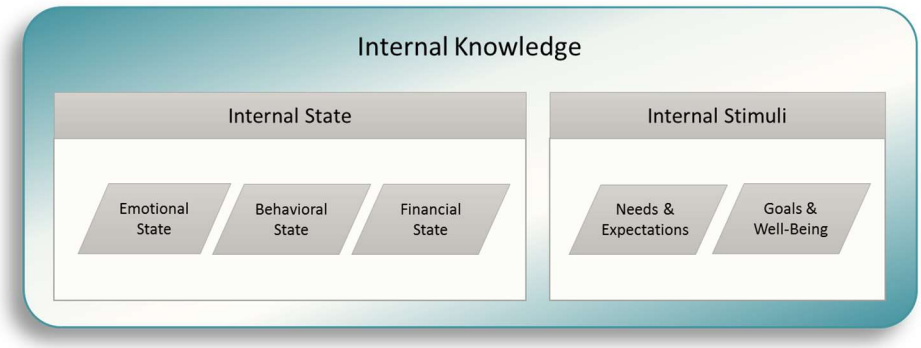



**Figure 3.7. IME internal knowledge components.**

The Internal State component manages information related to the CN member inner states, namely the emotional state, the behavior state and the financial state as described in Table 3.3.

**Table 3.3. Description of the internal state elements of the IME internal knowledge component.**

| *Element* | *Description* |
|---|---|
| **Emotional State** | Keeps the IME state of the CN member updated. This information is provided by the emotion module. |

| | |
|---|---|
| **Behavioral State** | Maintains the behavioral state of the CN member updated. This information is provided by the behavior module. |
| **Financial State** | Upholds a record of the financial state of the CN member. This is provided by the CN member itself. |

The Internal Stimuli component comprises the intrinsic information relative to the motivations of the CN member. It is in this component that a record expressing the individual member's needs and expectations and goals towards its involvement in CN are present. Table 3.4 describes in more detail these elements.

**Table 3.4. Description of the internal stimuli elements of the IME internal knowledge component.**

| *Element* | *Description* |
|---|---|
| **Needs & Expectations** | This element keeps a record with an update of the needs and expectations of the individual member. The needs might be proposed depending on two kinds: the rational needs, where statements such as "I need money" or "I need competences growth" are included; and the emotional needs, where questions such as "Do I feel good?" or "do I feel valued?" are answered. In what relates to expectations, they reflect the perception the individual member has on the CN itself, the rest of its members, the relationship with the external market, etc. They are formed through personal past experience, and the experience of others with whom the individual member interacts. |
| **Goals & Well-Being** | Possesses an updated manifesto with the goals and well-being aspects of the individual member updated. It includes short-term goals, like participating in VOs, and long-term goals, like being recognized as a good partner. Basically, these are the goals that motivate individual members to be part of a CN and contributing for well-being. For this specific work, the goals and well-being adopted were selected by the author, as described later on. |

The **output** of the internal knowledge module is: a) the Internal Data Vector (IDV) and b) the Internal Stimuli and Goals Vector (ISGV), defined as below:

$$IDV = \langle ES, BS, FS \rangle \quad 3.1$$

where,

$ES$ - is the emotional state
$BS$ - is the behavior state
$FS$ - is the financial state

and,

$$ISGV = \langle NE, GW \rangle \quad 3.2$$

where,

*NE* - is the vector containing the needs and expectations
*GW* - is the vector containing the goals and well-being

#### 3.2.1.2 Perception

The perception module, illustrated in Figure 3.8, is responsible for gathering data from the CN environment and from the CN member internal module, process these data in categories of information and deliver the resulting vector to the emotion module. This module is then composed of two components, the *Data Reception* and the *Data Processing*.

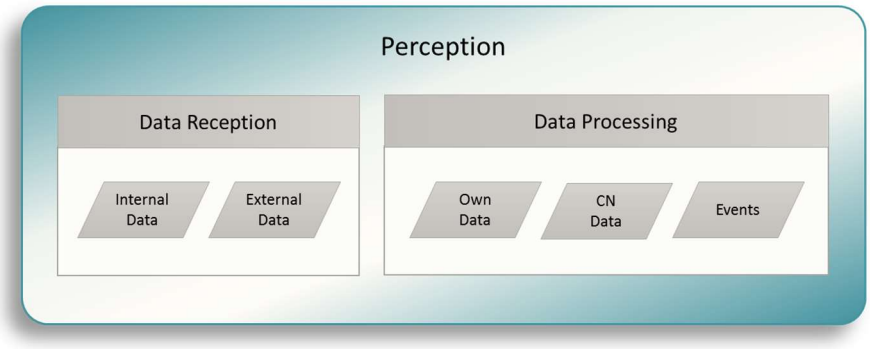



**Figure 3.8. IME perception components.**

The Data Reception component, receives the Internal Data Vector (IDV), expression 3.1, that is being provided by the internal knowledge module and collects member internal data and the data of the CN environment in the *Internal Data* and *External Data* elements, respectively.

The Data Processing component, structures the collected data in three categories of information: *Own Data*, *CN Data*, and *Events*. These categories form the evidences information vector that is provided to the emotion module. Table 3.5 describes these three elements.

**Table 3.5. Description of the categories of information elements of the IME perception component.**

| *Element* | *Description* |
|---|---|
| **Own Data** | The data that correspond to the CN member. This category is composed of the data that are provided from the internal module, i.e. its inner data; and also the data that come from the CN environment and that are related to the CN member, like the performance evaluation or the number of VOs in which the CN member is actively participating. |
| **CN Data** | The data that belong to the CN, like the total number of members, the total number of VOs or the current ANE state. |

| | |
|---|---|
| **Events** | This category is composed of the information about the external events, i.e. the events from the CN environment. These events might be related to one specific CN member, such as for instance, the event that represents that an individual member was invited to form a VO, or to the CN itself such as the event that represents that a violation in the CN social protocol occurred. |

The **output** of this component is the IME Evidences Vector (IEV), which is defined as:

$$IEV = \langle OD, CND, E \rangle \qquad 3.3$$

where,

*OD* - is the vector containing the own data
*CND* - is the vector containing the CN data
*E* - is the vector containing the events.

For a more detailed description about the kind of information that the outputs, related to the expressions 3.1, 3.2, and 3.3), of the context elements of the IME model could have, the reader is invited to consult section 4.1.1.1.1.

## 3.2.2 Core Elements of the IME Model

### 3.2.2.1 Emotion

The emotion module is one of the core components of the IME model. It is responsible for the estimation of the individual member emotions (IMEs). This module is conceived having as basis the CNE typology and CNE theory described in section 3.1. It comprises three main blocks: *Cognitive Appraisal*, *Activation* and *Expression Selection*, as depicted in Figure 3.9.

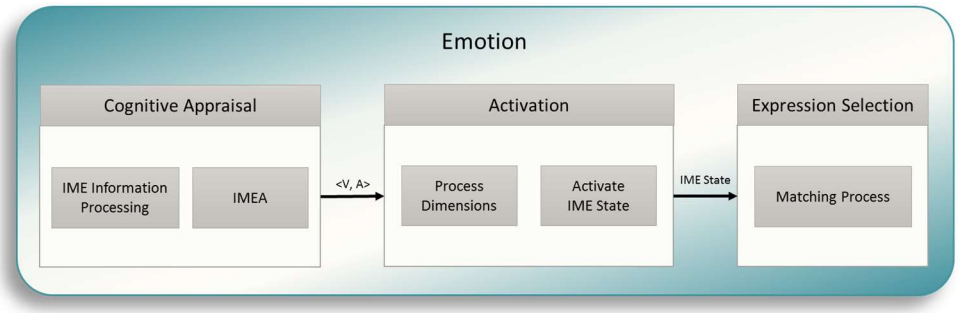



**Figure 3.9. IME emotion components.**

In more details:

- *Cognitive Appraisal*. This component is responsible for appraising the intensity of the pair (valence, arousal) of the IME.
- *Activation*. This component is in charge of performing the intersection of the two IME dimensions <V, A> in the dimensional model (see Figure 3.4 b)), and of activating the corresponding IME.
- *Expression Selection*. This component performs the selection of a graphical presentation for the activated IME.

**Cognitive Appraisal.** The main element of the cognitive appraisal component is the *Individual Member Emotion Appraisal (IMEA)*, which is responsible to calculate the value of the IME dimensions <V, A>, that results from the evidences provided by the perception module (expression (3.3)) and their reasoning having into consideration the goals and motivations of the individual member provided by the internal knowledge module (expression (3.2)). The handling of this information is made by the *IME Information Processing* element, as depicted in Figure 3.9.

In this work, a model based on system dynamics designed to reason about the dynamics of the IME appraisal is suggested, however other model approaches can be developed to infer the IME. The model that is proposed is the *Individual Member Emotion Appraisal System Dynamics - IMEA SD* Model and is described in detail in section 4.1.1.1.

**Activation.** The activation component is composed of two elements: the *Process Dimension* and the *Activate IME State*, as shown in Figure 3.9. The first picks the values of <V, A> generated by the cognitive appraisal component, points their place in the IME bi-dimensional space and delivers the matching quadrant to the activate IME state element. The latter, activates the corresponding IME according to the received information about the quadrant, as illustrated in Figure 3.10.

The **output** of this component is the IME current state (*IMEstate*). This output is delivered to the behavior and internal knowledge modules as can be seen in Figure 3.6 and also to the expression selection element:

$$IMEstate = \langle IMELabel, V, A \rangle \qquad 3.4$$

where,

| | | |
|---|---|---|
| *IMELabel* | - | is the label of the selected IME |
| *V* | - | is the value of valence |
| *A* | - | is the value of arousal |

An example of this output could be:

$$IMEstate = \langle \text{"Contentment"}, 0.75, -0.45 \rangle \quad 3.5$$

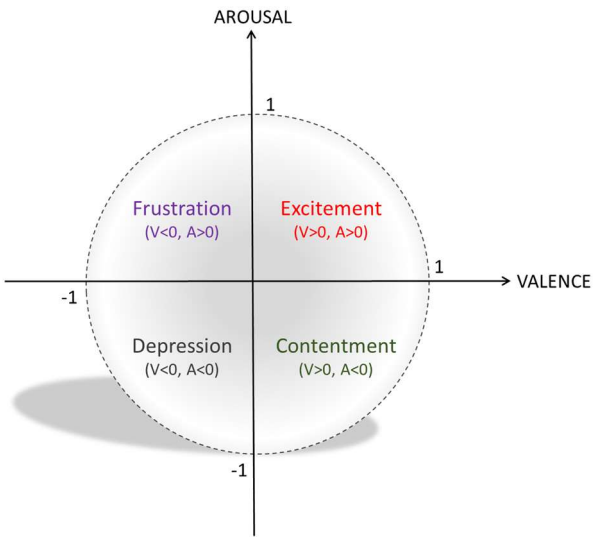



**Figure 3.10. IME activation according to the values of the dimensions <V, A>.**

**Expression Selection.** The expression selection component, is devoted to the graphical matching of the active IME label that is delivered in expression 3.4 with a corresponding figure/picture/emoticon. This matching is performed in the *Matching Process* element. For this work the adopted emoticons are illustrated in Figure 3.11.

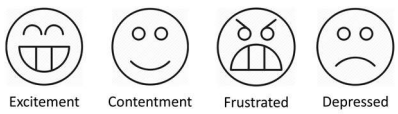



**Figure 3.11. The adopted emoticons for expressing IME.**

The **output** of this component is the complete information about the IME state (*IMEresp*), for the CN environment:

$$IMEresp = \langle IMELabel, V, A, Exp \rangle \quad 3.6$$

where,

| | | |
|---|---|---|
| *IMELabel* | - | is the label of the activated IME |
| *V* | - | is the value of valence |
| *A* | - | is the value of arousal |
| *Exp* | - | is the graphical representation of the IME |

An example of this output could be $IMEresp = \langle \text{"Contentment"}, 0.75, -0.45, ☺ \rangle$.

#### 3.2.2.2 Behavior

In humans, emotions influence adaptive action tendencies and their motivational foundations. In this sense they have a strong effect on emotion-consequent behavior, often interrupting ongoing behavior sequences and generating new goals and plans. In this case, the behavior module intends to give a behavioral response to the elicited IMEs in the form of potential actions that the CN member might perform when "feeling" such IMEs. As previously mentioned, the accurate modeling of the behavior component is out of the scope of this research work. Nevertheless, and for the sake of a holistic view of the IME model component of the C-EMO framework, some initial ideas about the potential components are presented. Therefore, the behavior component is composed of two elements: the *Behavior Inference* and the *Action Generator* as illustrated in Figure 3.12.

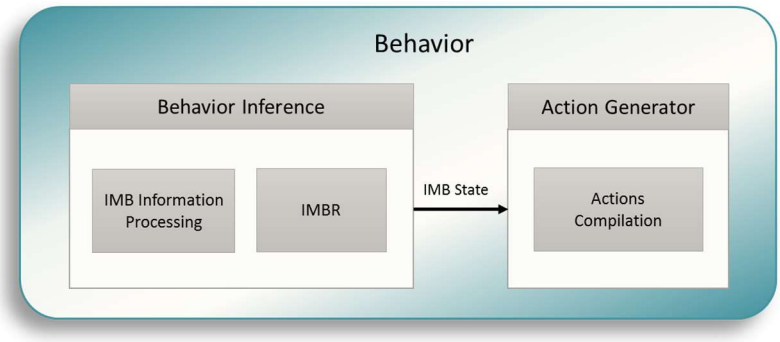



**Figure 3.12. Behavior components.**

The Behavior Inference component is responsible for inferring the individual member behavior (IMB) state taking into account its IME state, its motivations and CN environment. For instance, negative IME states like frustration accompanied by messy CN social protocols could provoke a behavior of complain, while positive ones like contentment complemented with a strong alignment of the member values might incite a behavior of will to engage. This component is composed of two elements: the *IMB Information Processing* for processing the information that is received by this behavior component, such as the IME state; and the *Individual Member Behavior Reasoning (IMBR)*, that is responsible to reason about the behavior. It is the understanding of the author of this research work that behavior is governed by a function that depends on the individual member information, such as the IME state and the goals & motivation and also on the information that comes from the CN environment, such as the feedback from the VOs, the performance of the CN or the aggregated network emotion (ANE).

The Action Generator component is in charge of generating the action or actions tendencies that the CN member might carry out, taking into consideration the IMB state.

This is handled by the *Actions Compilation* element, which could have for instance, a set of "behavior -> action" rules (like complain -> show displeasure and irritability) in a knowledge database with an adaptive machine learning algorithm, such as a behavior decision tree, running in the background.

In this context, the **output** of this component is: a) the IMB state (*IMBstate*) that is delivered to the CN internal knowledge, and b) the IMB response (*IMBresp*) comprising a full information package about the IMB state, defined as below:

$$IMBstate = \langle IMBLabel \rangle \tag{3.7}$$

where,

*IMBLabel* - is the label of the inferred IMB

and,

$$IMBresp = \langle IMBLabel, ActionList \rangle \tag{3.8}$$

where,

*IMBLabel* - is the label of the inferred IMB, e.g. "Complain"
*ActionList* - is a list with all the potential behavioral actions, e.g. "Show displeasure", "Show irritability", …

As previously mentioned, this module is out of the scope of this thesis work. However, an example of how the behavior component could be conceptually imagined is presented. Noticeably a whole world of research in this area is needed to be further studied in order to properly model this component. In this line, the development of this module will be taken as future work.

## 3.3 Aggregated Network Emotion Model

As seen before, the emotional and behavioral states of CN members are influenced by the CN "feeling" as a whole, i.e. the aggregated network emotion - ANE (see Definition 4). Nevertheless, the other way around also happens. This means that the CN itself is also able to "feel" an emotion that is the product of the aggregation of the emotional influence of all its members with its current state of operation, such as its performance evaluation or the total number of VOs running.

Over the last the years, the study of **emotions** in social contexts such as in communities and work contexts (Rafaeli et al., 2010) has been growing (for further reading on this subject, consult Van Kleef, 2016). Empirical studies on sociology provide

results on how **emotions** could affect culture, climate and atmosphere in groups (Bar-Tal et al., 2007); socialization processes (de Rivera, 1992); social structures and collective groups behavioral implications, such as conflicts between groups and societies (Petersen, 2002; Bar-Tal, 2007).

In the context of CNs, and inspired in those sociological aspects of **emotion**, a model that represents the concept of aggregated network emotion is developed, the ANE model. This model, constitutes the second element of the C-EMO framework (see Figure 3.1). The ANE model is composed of four main building blocks: *Perception*, *CN Internal Knowledge*, *Emotion Reasoning* and *Decision Making* as illustrated in Figure 3.13.

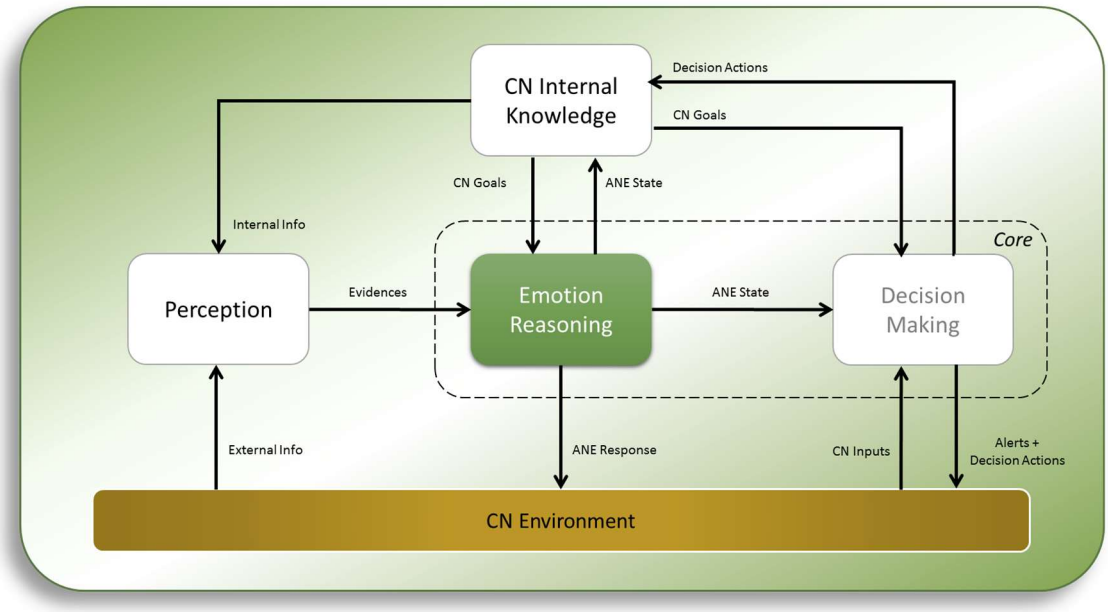



**Figure 3.13. Overview of the ANE model.**

In more details:

- The *CN Internal Knowledge* module, manages the CN information and knowledge, keeping it updated. Its main objective is to deliver the information about the internal info of the CN to the perception module and the inner goals to the emotion reasoning module.
- The *Perception* module is responsible for collecting data relative to the CN environment that is useful for the preparation of the evidences information vector. The evidences vector is then used in the emotion reasoning module for appraising the aggregated emotional state.

- The *Emotion Reasoning* module is one of the core elements of the ANE model and also the focus of this work. It is dedicated to the ANE appraisal and reasoning. The main purpose of this element is to appraise the evidences information and infer and activate the corresponding ANE state. It is also responsible to update the ANE state in the CN environment (for being known to the CN members).
- The *Decision-Making* module is the other core element of the ANE model. It is responsible for assessing the ANE state and, depending on its evaluation and established preferences, decide what actions should be taken in order to preserve a positive or healthy ANE state within the CN environment. This module will not be developed within this PhD work, nevertheless will be roughly conceptually described. The development of this module will be taken as future work.

The following sections describe in detail each one of the ANE model building blocks and context.

## 3.3.1 Context Elements of the ANE Model

The context elements provide the core elements of the ANE model with the necessary information relative to the state and goals of the CN and its environment. The next sub-sections give details about these elements.

### 3.3.1.1 CN Internal Knowledge

This module is in charge of keeping the information and knowledge about the inner aspects of the CN updated. It comprises two main components as depicted in Figure 3.14: the *Internal Information* and the *Internal Goals*.

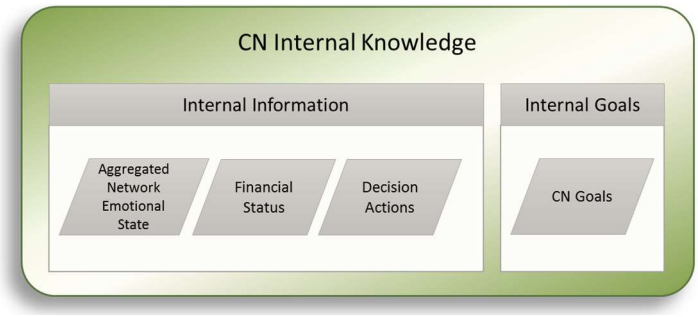



**Figure 3.14. ANE internal knowledge components.**

The Internal Information component manages information about the CN inner situation, namely the aggregated network emotional state, the accounting status and a record with all decision actions that were suggested to the CN administrator, as described in Table 3.6.

**Table 3.6. Description of the internal information elements of ANE internal knowledge component.**

| *Element* | *Description* |
|---|---|
| **Aggregated Network Emotional State** | Maintains the ANE state of the CN updated. This information is refreshed by the emotion reasoning module. |
| **Financial Status** | Upholds a registry of the financial state of the CN. In the case of a CN not for profit, this element can be replaced with information related to the number of attended help/support situations vs. the number of unsolved cases. |
| **Decision Actions Record** | Keeps a record with all decision actions that were suggested to the CN administrator in order to maintain the emotional equilibrium of the CN. This information is provided by the decision making module. |

The Internal Goals component comprises the goals of the CN and it is composed of a single element, the CN goals. It comprises short-term goals like achieving high level of participants' interactions and long-term goals such as innovation and value creation. For this work, a set of goals were adopted as mere examples as described later on section 4.1.1.2.1.

The **output** of the CN internal knowledge module is composed of two results: a) the CN Internal Info Vector (CNIV) and b) the CN Goals Vector (CNGV), defined as below:

$$CNIV = \langle ANES, FS \rangle \qquad 3.9$$

where,

*ANES* - is the aggregated network emotional state
*FS* - is the financial state

and,

$$CNGV = \langle CNG \rangle \qquad 3.10$$

where,

*CNG* - is the goals of the CN

#### 3.3.1.2 Perception

The perception module is in charge of collecting data from the CN internal knowledge and the CN environment, that is present in the CN management system, for the preparation of the evidences information vector. The gathered data is then processed in two categories composing the evidences information vector. The output vector is used in the emotion reasoning module for appraising the aggregated network emotional state (ANE). As illustrated in Figure 3.15, this module is composed of two components: the *Data Reception* and the *Data Processing*.

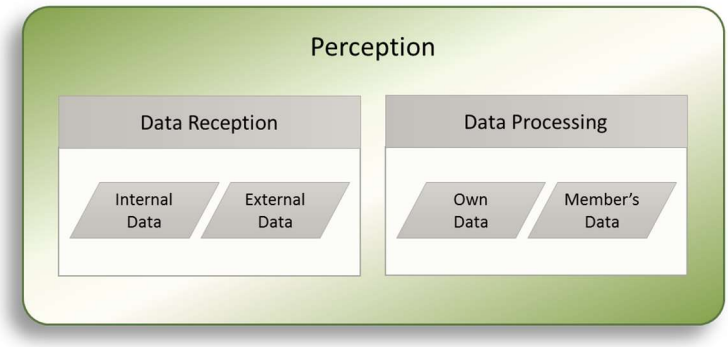



**Figure 3.15. ANE perception components.**

The Data Reception component collects data that comes from the CN management system that is essential for the appraising of the ANE and receives the CN Internal Info Vector (CNIV) that is being provided by the CN internal knowledge.

The Data Processing component structures the received data in two categories of information: *Own Data* and *Member's Data*. These categories form the evidences information vector that is provided to the emotion reasoning module. Table 3.7 describes these two elements.

**Table 3.7. Description of the categories of information elements of the ANE perception component.**

| *Element* | *Description* |
|---|---|
| **Own Data** | The data that corresponds to the internal knowledge and CN environment. It is composed of the data that is delivered from the internal knowledge module and the CN management system that is related to the indicators of the CN performance, sustainability, level of collaboration within the CN, among others. |
| **Member's Data** | The emotional data that belongs to each CN member. In other words it is a dataset comprising the IME state of each CN member. |

The **output** of this component is the ANE Evidences Vector (AEV), which is defined as:

$$AEV = \langle OD, MD \rangle \quad 3.11$$

where,

*OD* - is the vector containing the own data of the CN

*MD* - is the vector containing the members' data

More details regarding the information that the outputs of the context elements of the ANE model (expressions 3.9, 3.10 and 3.11) could have, the reader is invited to consult section 4.1.1.2.1.

## 3.3.2 Core Elements of the ANE Model

### 3.3.2.1 Emotion Reasoning

The emotion reasoning module is one of the core components of the ANE model. It is this module that appraises the aggregated network emotion (ANE). This module is conceived having also as basis the CNE typology and theory described in section 3.1. Figure 3.16 illustrates the three comprising components of the emotion reasoning module: the *Reasoning* and the *Activation* and *Expression Selection*.

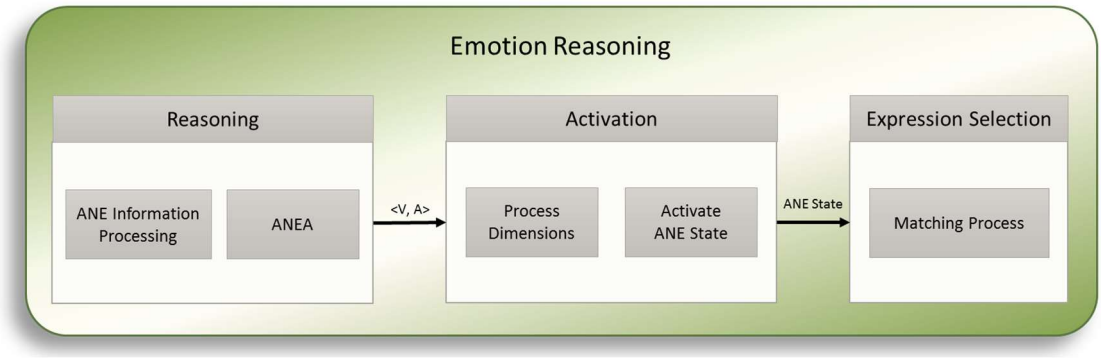



**Figure 3.16. ANE emotion reasoning components.**

In more details:

- *Reasoning*. This component is responsible for reasoning about the intensity of the pair (valence, arousal) of the ANE.

- *Activation*. This component, as its homonym of the IME model, performs the intersection of the two ANE dimensions <V, A>, in the dimensional model (see Figure 3.4 b)), and activates the corresponding ANE.
- *Expression Selection*. This component makes the selection of a graphical presentation for the activated ANE.

**Reasoning.** The main element of the reasoning component is the *Aggregated Network Emotion Appraisal (ANEA)*, which is responsible to estimate the values of the ANE dimensions <V, A>, resulting from the evidences provided by the perception module (expression 3.11) and their reasoning taking into account the goals of the CN, provided by the CN internal knowledge module (expression 3.10). The management of the involved information is performed by the *ANE Information Processing* element, as illustrated in Figure 3.16.

As in the case of the appraisal of the IME, a system dynamics model is suggested in order to understand the dynamics underlying the ANE. It is the *Aggregated Network Emotion Appraisal System Dynamics - ANEA SD* Model and is described in section 4.1.1.2.

**Activation.** The activation component is responsible for the activation of the dominant ANE. This component, is composed of the *Process Dimensions* and *Activate ANE State* elements. Both elements perform the same functions as its homonym from the IME model (see Figure 3.10), however applied to the activation of the ANE state.

The **output** of this component is the ANE current state (*ANEstate*). This output is delivered to the decision making and CN internal knowledge modules, as can be seen in Figure 3.13, and also to the expression selection element:

$$ANEstate = \langle ANELabel, V, A \rangle \qquad 3.12$$

where,

| | | |
|---|---|---|
| *ANELabel* | - | is the label of the activated ANE |
| *V* | - | is the value of valence |
| *A* | - | is the value of arousal |

An example of this output could be:

$$ANEstate = \langle \text{"Frustration"}, -0.35, 0.7 \rangle \qquad 3.13$$

**Expression Selection.** As the previous component, this component's functionality is the same as its homonym in the IME model, nevertheless applied to the matching of the ANE state with the corresponding graphical presentation. The adopted emoticons are the same of the Figure 3.11.

The **output** of this component is the full information about the ANE state (*ANEresp*) for the CN environment.

$$ANEresp = \langle ANELabel, V, A, Exp \rangle \qquad 3.14$$

where,

| | | |
|---|---|---|
| *ANELabel* | - | is the label of the activated ANE |
| *V* | - | is the value of valence |
| *A* | - | is the value of arousal |
| *Exp* | - | is the graphical representation of the ANE |

An example of this output could be $ANEresp = \langle \text{"Frustration"}, -0{,}35, 0.7, ☹ \rangle$.

#### 3.3.2.2 Decision-Making

The decision-making module is the other core element of the ANE model. It is responsible for making decision, either reactive or proactive, in relation to the ANE that is being felt within the CN environment. It is known from the psychology and sociology of emotion that emotions can influence the decisions people make. Moreover, the outcome of the decision can influence the emotions that are experienced. Nevertheless, many researchers in the area state that the interplay of cognition, emotion and decision-making has been paid very limited attention (Norbert Schwarz, 2000; Lerner et al., 2015; George & Dane, 2016).

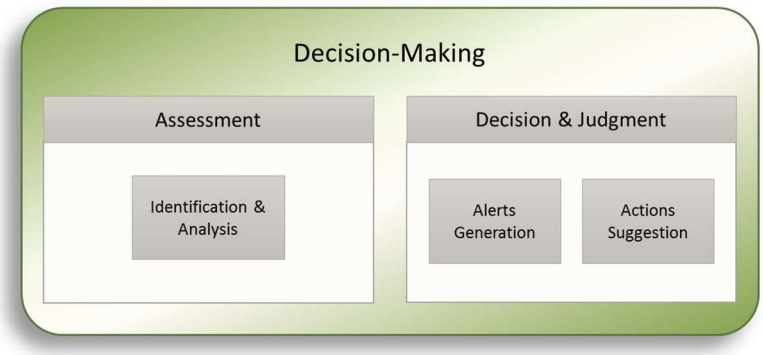



**Figure 3.17. ANE decision-making components.**

In this context, and picking this as basis, the ANE can influence the decisions that the CN administrator might make and the outcome of the decisions can, on its turn, influence the IME of the members and consequently the ANE. These actions are taken in order to preserve a positive and/or healthy state within the CN environment. In this way, the decision-making module is composed of two main components: *Assessment* and *Decision & Judgement*, as illustrated in Figure 3.17.

The Assessment component, performs the identification and analysis of the emotional situation taking into consideration the ANE state and the decision criteria and preferences pre-established for the CN environment. For instance, negative ANE states may signal that the current situation within the CN is problematic being the result of this assessment delivered to the decision and judgment component with high level of priority. In contrast, a positive ANE state may signal a healthy environment, delivering to the decision and judgment component a result with low priority.

The Decision and Judgement component is responsible for the selection of solutions matching the analyzed emotional situation of the network. It is composed of two elements: the *Alerts Generation* and the *Actions Suggestion*. The former is in charge of triggering an alarm to the CN administrator whenever the emotional situation is handled with high priority. The latter element is responsible for creating an actions plan consonant to the priority of the emotional situation. Hence, the actions plan might have a reactive or a predictive nature, depending on the status of the emotional situation.

In this context, the decision-making component delivers two **output** results to the CN environment (CN administrator): a) the *Alerts* and b) the *Decision Actions*, defined as below:

$$Alerts = \langle AlertType, AlertMessage \rangle \quad 3.15$$

where,

*AlertType* - is the type of alert, e.g. warning, danger, etc.
*AlertMessage* - is the message describing the alert situation

and,

$$DecisionActions = \langle ActType, ActPlan \rangle \quad 3.16$$

where,

*ActType* - is the nature of the action (reactive or predictive)
*ActPlan* - is the actions plan suggestion for the current emotional situation.

Please note that, as previously mentioned, this module is not being addressed in this thesis work. Hence, this is merely an example of how the decision-making component could be used in the proposed ANE model. Clearly a whole world of research in this area is needed to be further studied in order to properly model this component. In this line, the development of this module will be taken as future work.

**Brief Summary.** The C-EMO framework, aiming to modeling the concept of emotions in the context of CNs (CNEs), was presented and its components described in detail. This framework contribute to solve the main research question addressed in section 1.2, integrating and adapting the psychological and sociological views of human-emotions and also of some computational views of human-emotion models. It comprises two models, one representing the components for the individual member emotion appraisal and the other expressing the elements for the aggregate network emotion reasoning. These two models contribute to answer the RQ1 and RQ2 addressed in section 1.2. In this context, Figure 3.18, presents an integrated view of the C-EMO modeling framework.

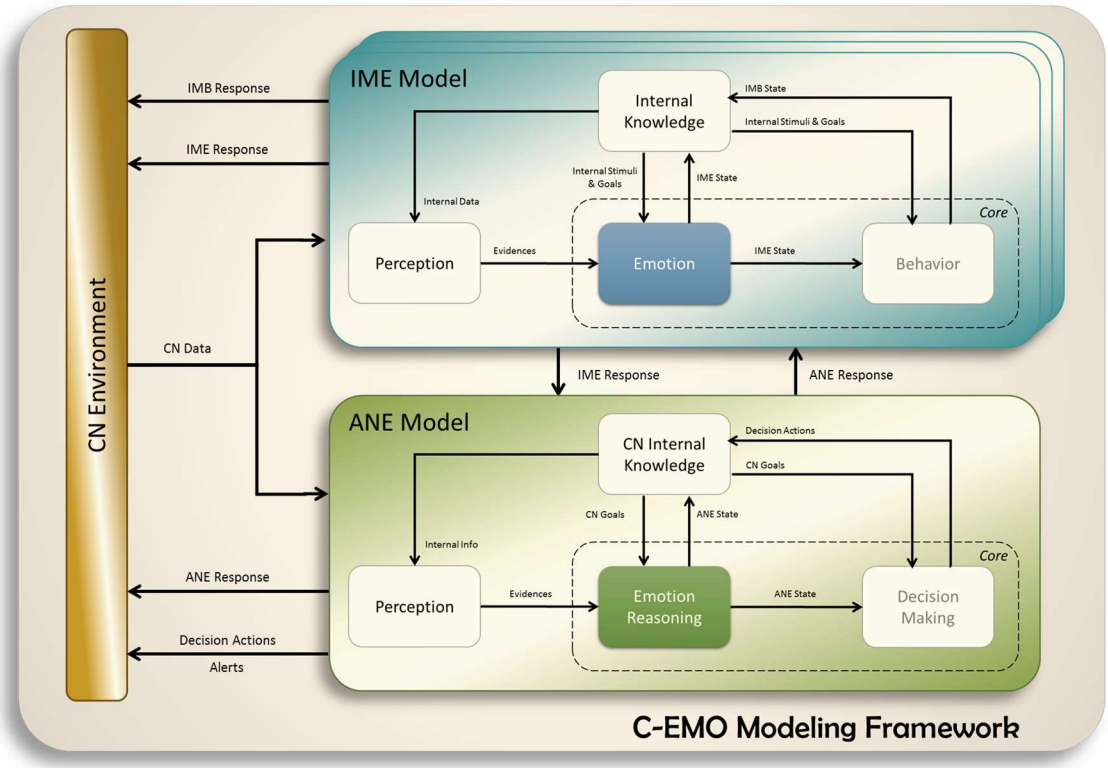



**Figure 3.18. Integrated view of the C-EMO modeling framework.**

## 3.4 Adopted Simulation Modeling Approach

In order to give an insight of the instantiation of the above presented C-EMO modeling framework a simulation modeling approach, for the development of both individual member emotion and aggregated network emotion models, was considered.

As seen in section 2.4, different simulation modelling processes have been introduced by several researchers reflecting their own touch of magic and art (Shannon, 1975; Nance, 1981; Balci, 1990, 1994; Savory & Mackulak, 1994; Shannon, 1998; Robinson, 2013). Yet, the underlying differences of such simulation processes, are sometimes based on the author's background areas. Nevertheless a set of common steps can be considered as illustrated in Figure 2.8 of section 2.4.2.

For this work, the adopted simulation modelling process is another variant of the studied simulation processes. It was designed adapting and integrating some elements from Balci (2015) and Robinson (2014). Therefore, the simulation modeling process for the development of C-EMO is composed of nine steps that together provide a solution with the agent-based and system dynamics modeling techniques, as presented in Figure 3.19.

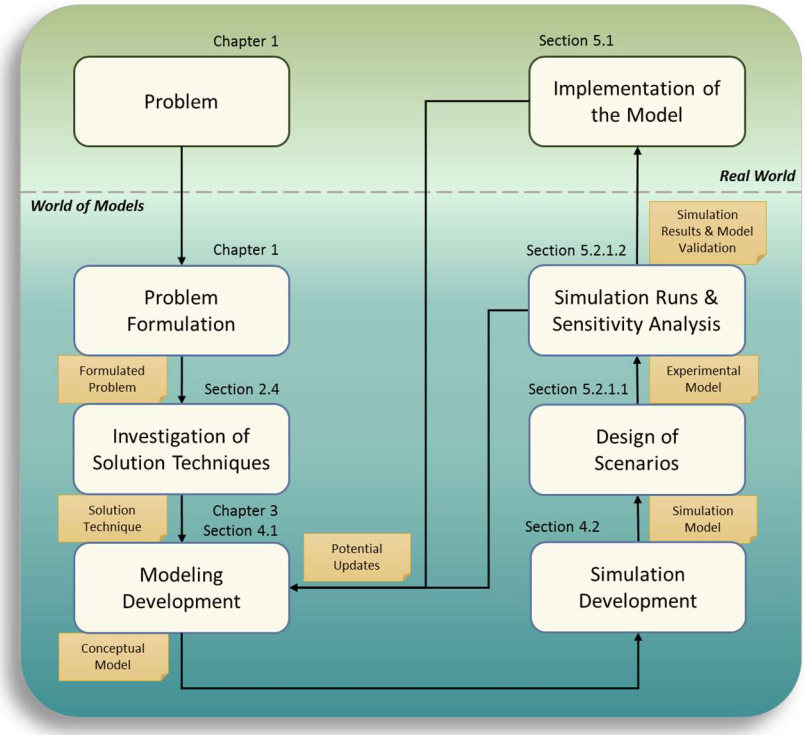



**Figure 3.19. The C-EMO simulation modeling process.**

Each step outcome is a process achievement that can be delivered in the form of a document, executable model or simulation results. This process is further detailed in Table 3.8.

**Table 3.8. C-EMO simulation modeling processes in detail.**

| *Process* | *Description* | *Outcome* |
|---|---|---|
| **Problem** | The real problem that is to be solved in its most elemental sense, i.e. the problem statement. This is presented in chapter 1. | Problem statement |
| **Problem Formulation** | Consisting in clearly defining the goals of the study so that the purpose is well known. In other words why this problem is being studied – the problem motivation, and what questions are envisaged to be answered – the research question(s). The process by which the initial problem is translated into a formulated problem sufficiently well-defined to enable specific research action – hypothesis and research method, is also addressed. This can be found in chapter 1. | Formulated problem |
| **Investigation of Solution Techniques** | Usually this phase consists of determining if a solution can best be derived analytically, by numerical approximation, or simulation and in investigating the more suitable technique for accomplishing it. In this case, the solution is through simulation and the techniques are the ones studied in section 2.4. A combination of Agent-Based and System Dynamics modeling and simulation techniques is adopted. | Solution technique |
| **Modeling Development** | The modeling developmet consists in developing conceptual models to support this thesis problem understanding and offering a systematic approach to problem solving. They reflect organization and information quantification to be further used on simulation development. This phase is sub-divided in two steps, the *Model Formulation* and the *Model Representation*.<br><br>**Model Formulation**. Process by which a conceptual model is envisioned to represent the system under study. It is a non-software specific description of a simulation model describing the model objectives, boundaries, components, descriptive variables and logic interactions. This step is represented by the C-EMO modeling framework described above in this chapter.<br><br>**Model Representation**. Process of translating the conceptual model into a communicative model. In other words, it is the representation which can be communicated to other humans. In this case, the used representation formats are the SD and AB modeling techniques as presented in section 4.1. | Conceptual model |

| | | |
|---|---|---|
| **Simulation Development** | The simulation development is the transformation of the conceptual model into a computer model. It consists mainly in programming and giving quantification to the involved components of the conceptual model. Currently it can be accomplished through Visual Interactive Modeling Systems (VIMS) such as AnyLogic, Vensim, Dynamo, and others (see section 2.4.4). As later seen in section 4.2, the selected VIMS for this work is the AnyLogic. | Simulation model |
| **Design of Scenarios** | Process of formulating a plan to gather the desired information and to enable the drawing of valid conclusions. This is done through the design of experimental models or scenarios. An experimental model (or scenario) is the computer model incorporating an executable description of operations presented in such a plan. The development of this phase is done in chapter 5.2.2.2.1. | Experimental model |
| **Simulation Runs & Sensitivity Analysis** | Consists in executing the simulation (or the computer model) to generate the inferred data and to perform sensitivity analysis. The sensitivity analysis consists of running the various scenarios designed in the previous phase. A constant verification and validation is performed and the models updated accordingly. The simulation runs and sensitivity analysis are further presented in chapter 5.2.2.2.2. | Simulation results Validation and Potential model updates |
| **Implementation of the Model** | This is the phase where the solution is put in practice. In the case of this work the simulation model is implemented and integrated with the GloNet system. This is done in section 5.1. | Model implementation |

The next chapter will focus on this thesis approach for modeling and simulating the C-EMO framework, based on agent-based and system dynamics modeling techniques. It covers the *Model Representation* and *Simulation Development* phases of the above simulation process.

# 4

# C-EMO Simulation Modeling

*This chapter presents the approach that is proposed for modelling the components of the C-EMO framework. It consists of the development of conceptual and simulation models based on the agent-based and system dynamics methodologies. This development, which follows the simulation modeling process presented in the previous chapter, is divided in two parts: one consisting of the design of two system dynamics models for the estimation of the IME and ANE, respectively, and also of the conception of an agent-based model for representing the CN and its players; and other comprising the transformation of these models into a computer model providing in this way a simulation model.*

The approach that is proposed for modeling and simulating the components of the C-EMO framework is presented in this chapter. This approach is based on system dynamics and agent-based modeling and simulation techniques. In this way, and following the simulation process of Figure 3.19, the conceived system dynamics models representing the estimation of the IME and ANE are presented in section 4.1.1. Section 4.1.2 is devoted to the modeling of the CN environment proposing a solution based on agents. Finally, in section 4.2 the simulation model is developed. This simulation model transforms the modeling approach into a computer model by programming and giving quantification to the parameters of the C-EMO models' elements. This is performed using the AnyLogic multi-method simulation tool.

The approach presented in this chapter should not be seen as the solution for the modeling of the C-EMO framework. Many others can be envisaged. This solution takes into consideration that a CN for profit is being modeled and that its implemented CN management system is compliant with the ones developed within the context of the

ECOLEAD and GloNet projects (Afsarmanesh et al., 2008; Camarinha-Matos et al., 2013a; Camarinha-Matos et al., 2013e) .

## 4.1 C-EMO Modeling

The modeling of C-EMO comprises two approaches: a) a system dynamics modelling view to estimate the IME and the ANE, described in section 4.1.1, and b) an agent-based model that represents the abstraction of the CN environment and its participants illustrated in section 4.1.2.

### 4.1.1 System-Dynamics Modeling

The system dynamics modeling approach is used as a potential solution for the *Emotion* and *Emotion Reasoning* modules of the C-EMO framework (see Figure 3.18).

The emotion element is one of the core elements of the IME model, which on its turn is composed of other three components: the *Cognitive Appraisal*, the *Activation* and the *Expression Selection* as illustrated in Figure 3.9. Within the cognitive appraisal component, the IMEA element is responsible to calculate the value of the CNE dimensions <V, A>. It is the modeling development of this element that is proposed to be designed using the system dynamics methodology: the *IMEA SD Model*, presented in section 4.1.1.1.

The emotion reasoning element, on its turn, is one of the core elements of the ANE model, which comprises other three components as well: the *Reasoning*, the *Activation* and the *Expression Selection* as illustrated in Figure 3.16. It is the ANEA element of the reasoning component that is in charge of estimating the values of the <V, A> , thereby in the same line of thought as the previous one, a system dynamics modeling approach is designed for this element: the *ANEA SD Model*, presented in section 4.1.1.2.

#### 4.1.1.1 IMEA SD Model

The principal objective of the cognitive appraisal component of the IME model is to calculate the IME dimensions <V, A>. For that a system dynamics model is proposed, the IMEA (Individual Member Emotion Appraisal) SD model.

IMEA SD models the dynamics of the variables that affect the pair <V, A>, which are given by the evidences that were collected and processed by the perception module and their relationship with the variables that represent the goals and motivations of the individual member. In this context, the IMEA SD model conceptualization consists of defining the relevant variables, mapping relationships between the variables, determining the important causal loop feedback structures and generating dynamic models as proposed solution to the problem.

#### *4.1.1.1.1 Definition of Variables*

According to the C-EMO framework, the variables of the IMEA component are the ones that are provided by the IME evidences vector – *IEV* - defined in expression 3.3 and by the internal stimuli and goals vector – *ISGV* – defined in expression 3.2. The adopted definition of each type of variables for the IMEA SD model is included in the sections below.

**Definition of the IME Evidences Vector Variables**

The IEV is composed of three sets of information, as described in expression 3.3: a vector containing the CN member own data (*OD*), a vector containing the CN related data (*CND*), and a vector containing the events (*E*).

Having this in mind, the variables proposed to compose the OD vector are shown in Table 3.7:

**Table 4.1. Definition of the variables of the OD vector.**

| *OD Vector Variables* | *Definition* |
|---|---|
| **Valence** (***Valence***) | The dimension of the IME that represents the pleasure-displeasure continuum as defined in Definition 5. Valence can be seen as the stable dimension of the IME. In this vector, this variable corresponds to the latest value of the estimated valence, so it represents the initial value of valence before the new estimation. It is a decimal variable that varies between -1 (negative valence) and 1 (positive valence). |
| **Arousal** (***Arousal***) | The dimension of the IME state that represents the level of activation, uncertainty, novelty and complexity of the surrounding stimulus as defined in Definition 6. Arousal can be seen as the unstable and dynamic dimension of the IME. In this vector, this variable corresponds to the latest value of the estimated arousal, so it represents the initial value of arousal before the new estimation. It is a decimal variable that varies between -1 (low arousal) and 1 (high arousal). |

| | |
|---|---|
| **Valence Decay (*ValenceDecay*)** | This variable represents the value of the decay that the valence dimension of IME assumes for the CN member. It is a value that might be different across members and that might vary between 0 (minimum valence decay) and 1 (maximum valence decay). |
| **Arousal Decay (*ArousalDecay*)** | This variable represents the value of the decay that the arousal dimension of IME assumes for the CN member. It is a value that might be different across members and that might vary between 0 (minimum arousal decay) and 1 (maximum arousal decay). |
| **VO Participation as Planner ($VOP_{Planner}$)** | The number of participations in VOs as a VO planner. This represents the number of times a CN member takes the initiative to prepare a new business to the CN environment. In this case the CN member takes the lead in planning the VO and in selecting the most appropriate partners for the job. It is measured using a value greater than or equal to 0. |
| **VO Participation as Partner ($VOP_{Partner}$)** | This represents the number of times the CN member is selected to be part of a VO taking into consideration its competences and soft capabilities. It is measured using a value greater than or equal to 0. |
| **Performance Evaluation (*PerfEval*)** | The performance evaluation value of the CN member. This variable represents the assessment of the performance of the member according to a set of performance indicators. It is a variable using a decimal value between 0 (bad performance) and 1 (excellent performance). |
| **Needs & Expectations Met (*NeedsExpecMet*)** | The value regarding the level of needs and expectations that were accomplished or met in what concerns the member involvement in the CN. This variable is determined after a questionnaire periodically answered by the CN member. It is a variable using a decimal value between 0 (not met) and 1 (totally met). |
| **Income from CN (*IncomeCN*)** | The total earnings of a CN member resulting from its participation in VOs inside the CN environment. It is measured using a decimal value greater than or equal to 0. |
| **Income from Other Sources (*IncomeOther*)** | The total earnings of a CN member resulting from its participation on external activities to the CN. It is measured using a decimal value greater than or equal to 0. |
| **Costs and Expenses (*CostsExpen*)** | This variable represents the amount of costs and expenses a CN member had independently of being inside the CN or outside. It is measured using a decimal value greater than or equal to 0. |
| **Belonging Informal Networks Ratio (*BelongInformalNets*)** | The ratio of the number of informal networks the CN member belongs to in relation to the total active informal networks within the CN environment. Informal networks are ad-hoc networks that might be created within the CN by a small number of CN members with the aim to provide a space for discussions and knowledge and resources sharing around a specific topic of interest. It is a variable using a decimal value between 0 (no belonging) and 1 (belonging to all active informal networks within the CN environment). |

| | |
|---|---|
| **Shared Knowledge & Resources Ratio (*SharedKnowResour*)** | The ratio of the total amount of knowledge and resources a CN member shared in relation to the total knowledge and resources present within the CN environment. It is a variable using a decimal value between 0 (no sharing) and 1 (total sharing). |
| **Communication Frequency (*CommFreq*)** | The rate at which the CN member communicates with others within the CN environment. This variable reflects a result of a social network analysis over the CN environment. It is a variable using a decimal value between 0 (no communication) and 1 (total communication). |
| **Communication Effectiveness (*CommEffect*)** | The measure of the effectiveness of the communication conducted by the CN member. This variable is related to the way the CN member delivers its message to its recipients. It represents the rate of understandability of the CN environment about the messages sent by the member. This variable reflects a result of a social network analysis over the CN environment. It is a variable using a decimal value between 0 (no understandability) and 1 (total understandability). |

The variables proposed to compose the CND vector are shown in Table 4.2.

**Table 4.2. Definition of the variables of the CND vector.**

| *CND Vector Variables* | *Definition* |
|---|---|
| **Total CN Members (*TCNmemb*)** | The total number of registered members in the CN. It is a variable using a value greater than or equal to 0. |
| **Total CN VOs (*TotalCNVOs*)** | The total number of VOs operating within the CN environment. This variable does not filter the different VOs' life cycles. This means that all phases of the VO creation, VO operation and VO dissolution are accounted. It is a variable using a value greater than or equal to 0. |
| **Aggregated Network Emotional State (*ANEState*)** | The last known value of the ANE state. It is a variable using a relative scale (varying from -2 to 2; -2 = depression; -1 = frustration; 0 = neutral; 1 = contentment; 2 = excitement). |
| **CN Trust (*CNTrust*)** | The level of trust that is established between the members involved in the CN environment. This variable represents the value of the trust assessment results that is conducted to all members. It is a variable using a decimal value between 0 (no trust) and 1 (complete trust). |
| **CN Value System Alignment (*CNVSAlign*)** | The measure of the alignment of the core value system of the CN with the core value systems of all CN members. It is a variable using a decimal value between 0 (no alignment) and 1 (total alignment). |

The events (or variables from the E vector) that were chosen are the ones that were considered in this model. This selection was performed having into consideration the sub-systems and CN management system information provided by the CN model that

was adopted, as previously mentioned. Therefore, the variables proposed to constitute the E vector are shown in Table 4.3.

**Table 4.3. Definition of the variables of the E vector.**

| *E Vector Variables* | *Definition* |
|---|---|
| **Invitation to form VOs (*InvitVO*)** | The value that represents the occurrence of the event "invitation to form VO". This event is triggered when the CN member receives an invitation from the VO planner to join the VO. It is a variable using a Boolean scale: 0 - event not active and 1 - event active. |
| **Incentive Reward (*IncentReward*)** | The value that represents the occurrence of the event "selected to earn an incentive reward". This event is triggered when the CN member earns a reward (from any kind, the specification is not important for this model purpose) after being recognized or after achieving a set of goals of the CN incentive program. It is a variable using a Boolean scale: 0 - event not active and 1 - event active. |
| **CN Trust Breach (*CNTrustBreach*)** | The value that represents the occurrence of the event "lack of trust situation". This event is triggered whenever the CN trust level achieves the danger threshold. It is a variable using a Boolean scale: 0 - event not active and 1 - event active. |
| **CN Value System Misalignment (*CNVSMisalign*)** | The value that represents the occurrence of the event "no CN value system alignment". This event is triggered when the result of the assessment of the alignment of the value systems of the CN and the members achieves the misalignment threshold. It is a variable using a Boolean scale: 0 - event not active and 1 - event active. |
| **CN Social Protocols Violation (*CNSocProtViol*)** | The value that represents the occurrence of the event "social protocols violated". This event is triggered when the interactions among a group of CN members become not acceptable according to the established set of social protocols. It is a variable using a Boolean scale: 0 - event not active and 1 - event active. |

### Definition of the Internal Stimuli and Goals Variables

The ISGV is composed of a vector containing the needs and expectations and a vector containing the goals and well-being as defined in expression 3.2. In this case, a merge between the two vectors is performed resulting in only one vector representing the goals and internal stimuli variables. Thereby, the goals and internal stimuli variables are those that represent the inner beliefs, desires and intentions of the member towards its involvement in the CN. Examples could be:

- *Beliefs*: Positive impact of the CN on the external market; Potential growth.

- *Desires*: Profit; reputation; satisfaction/expectations met.
- *Intention*: High participation in VOs; High collaboration interaction with peers.

The variables that are proposed for this IMEA SD model are based on these three aspects and are shown in Table 4.4.

**Table 4.4. Definition of the variables that represent the goals and internal stimuli.**

| *Goals & Internal Stimuli Variables* | *Definition* |
|---|---|
| **Member Satisfaction (*MembSatisf*)** | The degree of satisfaction of the CN Member. Represents the level of approval when comparing the CN member situation with its expectations and needs. It is a variable using a decimal value between 0 (unsatisfied) and 1 (satisfied). |
| **Profitability (*Profitability*)** | It measures the efficiency of the CN member. It differs from profit. Profit has a currency unit to measure while profitability is generally measured as a ratio of profit to revenue. It is a variable using a decimal value between 0 (no profitability) and 1 (total profitability). |
| **Profit (*Profit*)** | The financial benefit that is realized when the amount of revenue gained from the member business activity exceeds the expenses and costs needed to sustain the activity. It is measured using a decimal value greater than or equal to 0. |
| **Reputation and Recognition (*ReputRecog*)** | The potential of recognition and reputation of the CN member by the CN community, i.e. by all CN members. It combines quality of collaboration and competences recognition. It is a variable using a decimal value between 0 (no reputation) and 1 (high reputation). |
| **Participation in VOs (*ParticipVOs*)** | The level of participation in VOs in relation to the total VOs operating in the CN environment. It is a variable using a decimal value between 0 (no participation) and 1 (high participation). |
| **Collaboration Dynamics (*CollabDynam*)** | The dynamism of the CN member within the CN environment. This variable is the reflection of the interactions and communication with the other CN members and the level of willingness to engage with the CN environment. It is a variable using a decimal value between 0 (no dynamics) and 1 (high level of dynamism). |
| **Commitment (*Commitment*)** | The level of attachment, linkage and enthusiasm a member has with the CN environment. This variable reflects the connection, the contentment, the involvement and the effort a member puts in the CN. It is a variable using a decimal value between 0 (no commitment) and 1 (total commitment). |
| **Trust Level (*TrustLevel*)** | The level of trust felt by the CN member on the CN environment. It is a variable using a decimal value between 0 (not trustable) and 1 (completely trustable). |
| **Value System Alignment (*VSAlign*)** | The CN member level of values alignment with the CN environment. This variable represents the need of the member to be lined up with the |

| | |
|---|---|
| | organizational values and vision of the CN environment. It is a variable using a decimal value between 0 (not aligned) and 1 (completely aligned). |
| **Member Motivation (*MembMotiv*)** | The degree of motivation of the CN member. This variable represents the member's goal to keep motivated. The motivation is influenced by the member's performance evaluation, satisfaction and incentive rewards and also by the ANE state of the CN environment. It is a variable using a decimal value between 0 (no motivation) and 1 (high motivation). |
| **Potential Conflicts Creation (*PotenConflictsCreat*)** | The level of creation of potential conflicts by the CN member. This variable might be activated by the lack of felt trust, by the recognition of values system incompatibility and by the emotional state of the CN member. Avoidance of conflicts is one of the member's expectations, so in order to cope with this expectation this variable should remain the more neutral as possible. It is a variable using a decimal value between 0 (no potential conflicts creation) and 1 (high conflicts creation). |
| **Communication (*Communication*)** | The level of communication a CN member has within the CN environment. This variable represents the relationship between the communication effectiveness, the communication frequency and the level of arousal of the member. It is a variable using a decimal value between 0 (no communication) and 1 (high communication). |

The initial values of these goals and internal stimuli variables are initially equal to zero, being then calculated dynamically taking into consideration the influences of the evidences input variables on these variables as it will be further explained in the next sections (4.1.1.1.2 and 4.1.1.1.3).

**Assumptions and Constraints.** For the IMEA SD model the following constraints and assumptions are considered:

- According to the human-emotion theories, emotions have short duration period, but it is not instantaneously that they have a decay period (the reader is invited to see Figure 2.6). This decay period is also considered in the IMEA SD model. This assumption is supported by empirical and theoretical studies that show how emotional states exponentially decay in a stochastic manner (R. W. Picard, 1995; Kuppens et al., 2010; Garcia, 2012b). Furthermore, the decay rates of arousal and valence may be different and even different across CN members.
- The IMEA SD model intends to give a perspective of modelling for IME appraisal within collaborative networked environments, rather than being the exact model for the involving concepts. For instance the concepts of member satisfaction or member's commitment in CNs are areas of a vast research development, and are only partially modeled in this proposal.

- The variables from the *OD* (with exception of the valence and arousal), *CND* and *E* vectors are considered, in a first phase, as exogenous to this system model. They are not directly influenced by any other variables within the model. Nevertheless, it is assumed that in a long term they would be affected by the emotional dynamics of this model. Therefore, in a first phase, and in order to validate the model, they are adjusted manually. In a second phase, their values can be collected from the CN management system of the CN associated.

#### *4.1.1.1.2 IMEA SD Causal Loop Diagram*

The feedback structure of the IMEA SD model can be qualitatively mapped using causal diagrams. As seen in Chapter 2.4.3.1, a causal loop diagram consists of variables connected by causal links, represented by arrows. A positive link (illustrated with a "+" sign on the arrow) implies that if the cause increases (decreases), the effect increases (decreases) above (below) accordingly. A negative link (illustrated with a "-" sign on the arrow) implies that if the cause increases (decreases), the effect decreases (increases) below (above) accordingly (Sterman, 2000). For example, picking an excerpt of the causal loop of the population dynamics of Figure 2.9 (left), the implication of the causal link between *births* and *population* should be interpreted as: "*if the births rate increases (decreases), the amount of population increases (decreases) in the same direction*".

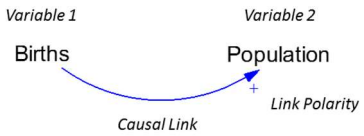



**Figure 4.1. Example of a causal link. Excerpt from the population dynamics of Figure 2.9 (left).**

The IMEA SD causal loop diagram is depicted in Figure 4.2. Positive linkages are presented with blue colored arrows and a "+" sign while negative linkages are presented with red colored arrows and a "-" sign. Variables from the OD vector are written in black. Variables from the CND vector appear in blue. Variables from the E vector are represented in dark orange. Finally, variables representing the goals and motivation are green. As the overall objective is to calculate the two IME dimensions, the valence and arousal variables are in purple and bold, just to highlight them. In addition to these variables, some auxiliary variables are needed in the model and are represented in grey. Table 4.5, illustrates these auxiliary variables.

**Table 4.5. IMEA SD auxiliary variables definition.**

| *Auxiliary Variables* | *Definition* |
|---|---|
| **Total Amount of VOs (*TotalVOs*)** | The total amount of VOs a CN member is or was involved in. It represents the sum of VOs where the member participates as planner with the VOs it participates as partner. It is measured using a decimal value greater than or equal to 0. |
| **Revenue (*Revenue*)** | The total amount of income of the CN member. It represents the sum of the income from its activities within the CN with the income of its activities outside the CN. It is measured using a decimal value greater than or equal to 0. |

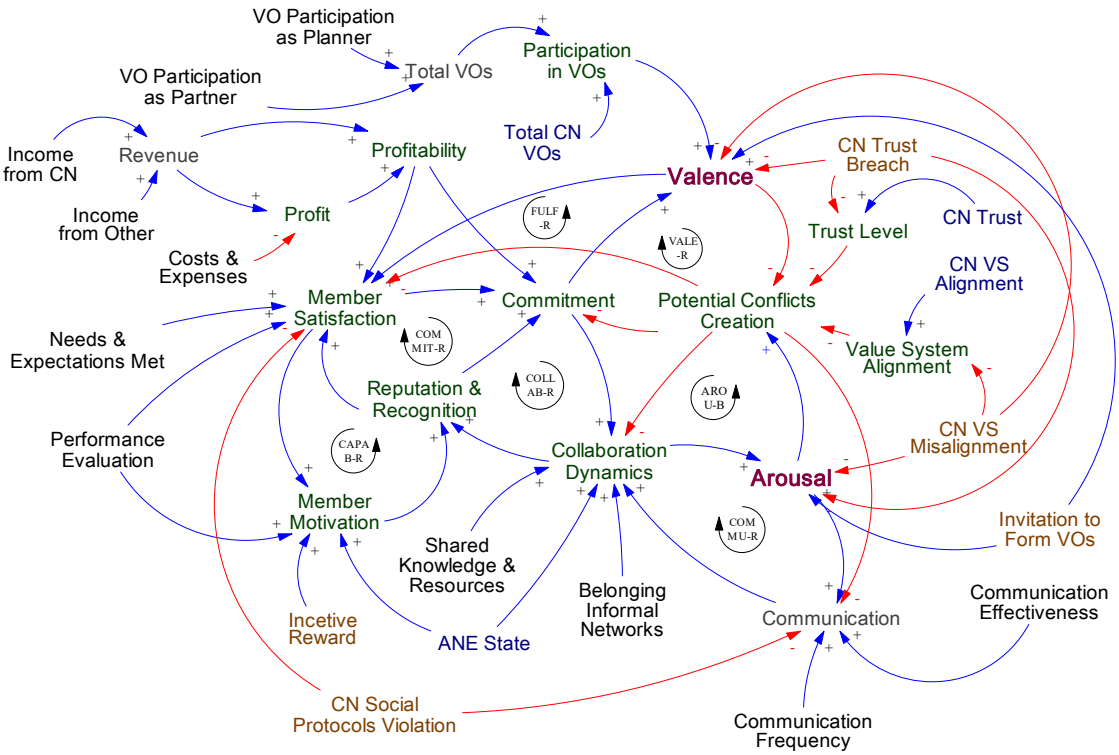



**Figure 4.2. IMEA SD causal loop diagram.**

The main causal loops identified for the IMEA causal model are: *COMMIT-R* (Commitment reinforcing loop); *COLLAB-R* (Collaboration reinforcing loop); *CAPAB-R* (Capability reinforcing loop); *COMMU-R* (Communication reinforcing loop); *FULF-R* (Fulfilment reinforcing loop); *VALE-R* (Valence reinforcement loop); and *AROU-B* (Arousal balancing loop). A detailed description of each identified causal loop is presented below:

- **Commitment Reinforcing Loop (COMMIT-R):** This reinforcing loop models the dynamics among commitment, collaboration dynamics, reputation and member satisfaction. As collaboration dynamics increase (decrease), the potential for reputation and recognition of the member increases (decreases). This in turn results in the increase (decrease) of member's satisfaction. The increase (decrease) of member's satisfaction positively (negatively) influences the level of commitment of the CN member. On its turn, this results in an increase (decrease) of the motivation to collaborate within the CN environment.
- **Collaboration Reinforcing Loop (COLLAB-R):** This reinforcing loop models the dynamics among collaboration, reputation and recognition, and commitment. As the potential to be recognized increases (decreases), the member feels more (less) committed to the CN environment. This in turn results in a strengthening (weakening) of the motivation to collaborate within the CN environment. When the member collaboration increases (decreases) the potential to be recognized and gain reputation also increases (decreases).
- **Capability Reinforcing Loop (CAPAB-R):** This reinforcing loop models the dynamics among reputation and recognition, member satisfaction, and member performance motivation. When the potential to have a good reputation and being recognized by the CN peers increases (decreases), it contributes for the growth (decay) of the member's satisfaction (in terms of self-esteem). As soon as the member's satisfaction increases (decreases) the motivation to achieve high levels of performance is incremented (decremented). A high (low) level of performance motivation concedes an increase (decrease) in the potentiality to be recognized and earn reputation.
- **Communication Reinforcing Loop (COMMU-R):** This reinforcing loop models the dynamics among the collaboration dynamics the arousal, and the communication. As the collaboration dynamics increases (decreases) the arousal is positively (negatively) influenced. As the arousal represents the activation level of the CN member, when it increases (decreases) the communication also tends to increase (decrease) because the member feels with energy to socialize. The effect of this increment (decrement) in communication implies an increase (decrease) in the collaboration forms to put the communication in practice.
- **Fulfilment Reinforcing Loop (FULF-R):** This reinforcing loop models the dynamics among the member's satisfaction, commitment, and valence. When the member's satisfaction grows (decays) it influences positively (negatively)

the level of commitment of the member. In other words, the more (less) satisfied the more (less) committed the member is to its relationship with the CN environment. On its turn with the augmentation (diminishing) of the commitment the member increases (decreases) its valence. As the valence represents the member's pleasantness-unpleasantness mood, when it increases (decreases) it means that its level of satisfaction also increases (decreases) in proportion.

- **Valence Reinforcement Loop (VALE-R):** This reinforcement loop models the dynamics among the member commitment, the valence, and the potential to create conflicts. As the level of commitment of the CN member fortifies (weakens) the valence is positively (negatively) influenced. As the valence means that the member is pleased or not, when it increases (decreases) the probability to the member initiating a conflict situation decreases (increases) in the same direction. As the potential to create conflict situations increases (decreases) the level of commitment of the member decreases (increases) accordingly.
- **Arousal Balancing Loop (AROU-B):** This balancing loop models the dynamics among the potential to create conflicts, the collaboration dynamics, and the arousal. As the potential to initiate a conflict situation increases (decreases) the collaboration dynamics is negatively (positively) affected. A decrease (increase) in the effort to maintain a healthy dynamism in collaboration leads to a drop (rise) in the arousal level. When the level of arousal decreases (increases), it might influence the creation or not of a conflict situation. It depends on the value of valence. In other words, as arousal represents the CN member's level of activity and excitement, when matched with the valence it might provoke or not the creation of a conflict. For instance, if the arousal is negative and the valence is negative it means that the IME is depression. Depression is associated to inactiveness, which might leave the member quiet, without any energy. Consequently, the probability for creating conflicts is reduced.

##### *4.1.1.1.3 IMEA SD Stocks and Flows Diagram*

This modeling phase consists of setting up a complete formal model with equations, parameters and initial conditions that represent the IMEA system.

The IMEA SD causal loop diagram is used to start this modelling process in order to capture the mental models. Although a causal loop diagram shows the relationships

among variables that have the potential to change over time, it does not permit the distinction between the different types of variables. The stocks and flows diagram allows such distinction and maintains the causal relationships of the variables. Therefore, stocks and flows, along with feedback, are the two core concepts of systems dynamics theory.

**Table 4.6. Stocks and flows diagram notation.**

| | *Name* | *Symbol* | *Description* |
|---|---|---|---|
| **Basic Notation** | **Stock** (level, accumulation, or state variable) | (*box*) | ▪ Accumulation of "something" over time.<br>▪ Value of stock changes by accumulating or integrating flows.<br>▪ Physical entities which can accumulate and move around (e.g. people, stocks of money, etc.). |
| | **Flow** (rate, activity, movement) | (*valve*) | ▪ Flow or movement of the "something" from one stock to another.<br>▪ The value of a flow is dependent on the stocks in a system along with exogenous influences. |
| | **Information** | (*curved arrow*) | ▪ Between a stock and a flow.<br>▪ Indicates that information about a stock influences a flow. |
| **Additional Notation** | **Auxiliary** | (*circle*) | ▪ Used when the formulation of a stock's influence on a flow involves one or more intermediate calculations.<br>▪ Often used in formulation of complex flow equations. |
| | **Source and Sink** | (*cloud*) | ▪ Source represents systems of stocks and flows outside the boundary of the model.<br>▪ Sink is where flows terminate outside the system. |

Stocks are accumulations of "something" over time, that result from the difference of the input and output flow rates to a process or component in a system. Stocks provide inertia and memory, based on which decisions and actions are taken. They also originate delays in the system and generate disequilibria (Sterman, 2000). On its turn, a flow is the movement of the "something" from one stock to another. There are two types of flows: inflows and outflows. Inflows are perceived as the *rate* at which the stock is increasing over time. Outflow is the *rate* at which the stock is decreasing. Table 4.6, illustrates the stocks and flows notation that is used to build our model.

In this context, the general structure of a stock and flow is composed of stocks, inflows, outflows, valves, and sources and sinks as illustrated in Figure 4.3.

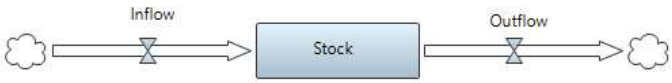



**Figure 4.3. General structure of a stock and flow.**

In this way, a stock is the integral of the net flow added to the initial value of the stock, which mathematically is represented by equation 4.1.

$$Stock(t) = Stock(t_0) + \int [Inflow(t) - Outflow(t)]dt \qquad 4.1$$

Stocks are also considered the state variables of the system. Flows are all variables that are rates or derivatives. If at any moment a snapshot of the system is taken, what would be seen is the state of different processes or components of the system. These are the stocks that compose the modelling of the system. The inflows and outflows cannot be identified.

The IMEA SD stocks and flows diagram is presented in Figure 4.4. This diagram is based on the IMEA SD causal loop diagram of Figure 4.2. Thereby, the IMEA SD stocks and flows diagram is a more detailed graphic representation where the quantification of what was modeled with the causal loop diagram is performed. Besides the output state variables *Valence* and *Arousal*, five other state variables are identified, they are the *MembSatisf*, *Commitment*, *Communication*, *PotenConflictsCreat* and *CollabDynam*. In this way, there are seven structures of stocks-and-flows in the IMEA SD stocks and flows diagram. These are modeled with the quantification of its structures as shown below. This quantification is formalized with a set of equations that should not be interpreted as the only solution for the IMEA SD modeling approach, but rather as examples of how it could be realized. Furthermore, the values of the given weights will also depend on the requirements and objectives of each CN environment to be modeled and have to be calibrated accordingly.

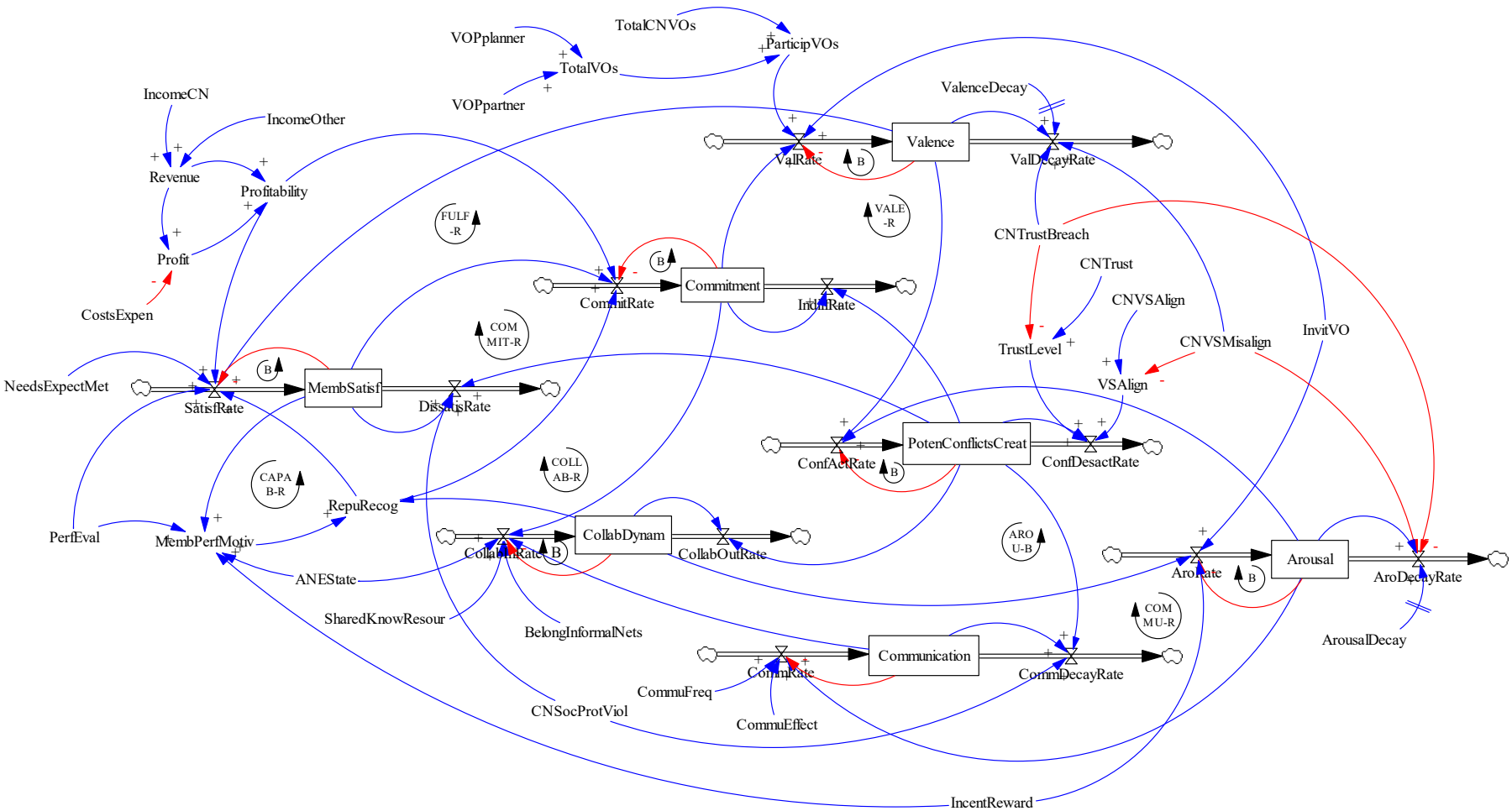



**Figure 4.4. IMEA SD stocks and flows diagram.**

### Stock and Flow Structure of Member Satisfaction

The *MembSatisf* (member's satisfaction) stock is fed by the *SatisfRate* (satisfaction rate) inflow and is drained out by the *DissatisRate* (dissatisfaction rate) outflow as illustrated in Figure 4.5.

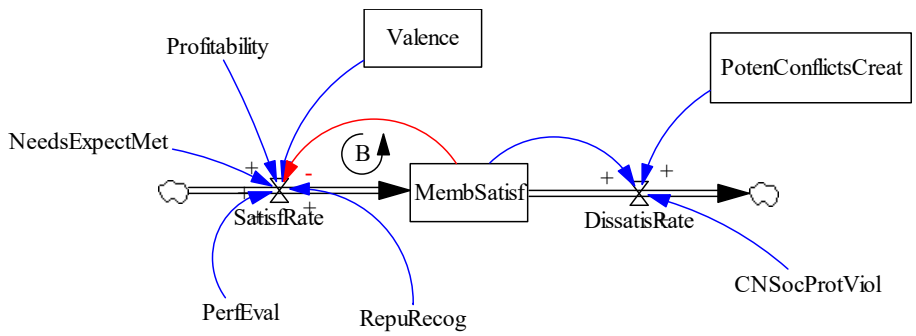



**Figure 4.5. Stock and flow structure of member's satisfaction.**

The *MembSatisf* stock variable is then the integral of the difference of *SatisfRate* and *DissatisRate* added to the initial value of the stock, and is represented in the equation 4.2.

$$MembSatisf(t) = MembSatisf(0) + \int [SatisfRate(t) - DissatisRate(t)]dt \qquad 4.2$$

where, $MembSatisf \in \Re \wedge \{0 \leq MembSatisf \leq 1\}$

The *SatisfRate* inflow is considered to be primarily driven by the needs and expectations met (*NeedsExpectMet*) and the performance evaluation (*PerfEval*) values at time *t*. Therefore, due to their importance both parameters should have a multiplicative factor of $w_i$ that is supposed to be superior in relation to the other involved parameters. The other parameters are the *Profitability*, *RepuRecog* (reputation and recognition) and the *Valence* values at time *t*, and have as multiplicative factor the weight $w_j$.

Taking into consideration that Valence varies between -1 and 1 and all the other variables between 0 and 1, it is needed to be adjusted accordingly. The adopted criterion was to reference the Valence parameter between 0 and 1. Therefore, a linear function (of the form $y = mx + c$) was fitted in order to reference the range of values. The analytical expression that captures this adjustment is described in equation 4.3.

$$ValAdj(t) = 0.5 \times Valence(t) + 0.5 \qquad 4.3$$

Equation 4.4, represents the *SatisfRate* inflow.

$$SatisfRate(t) = [w_i \times (NeedsExpectMet + PerfEval) + w_j \times (ValAdj(t) + Profitability + RepuRecog)]/(2 \times w_i + 3 \times w_j) - MembSatisf(t) \quad 4.4$$

where, $SatisfRate, w_i, w_j \in \Re \wedge w_i > w_j$

The *DissatisRate* outflow is considered to be primarily driven by the occurrence of the CN social protocol violation event (*CNSocProtViol*), and secondly by the potential conflicts creation (*PotenConflictCreat*) accumulation. Thus, whenever *CNSocProtViol* event is triggered the *DissatisRate* diminishes with a multiplicative factor, $w_i$, the total accumulated member's satisfaction (*MembSatisf*). The higher (lower) the *PotenConflictCreat* is the more (less) the *MembSatisf* diminishes, with an order of magnitude of $w_j$. The overall equation to describe the relationship is shown in equation 4.5.

$$DissatisRate\ (t) = MembSatisf(t) \times \left(w_i \times CNSocProtViol + w_j \times ConfPoten(t)\right)/(w_i + w_j) \quad 4.5$$

where, $\{DissatisRate, w_i, w_j \in \Re \wedge w_i > w_j\}$

### Stock and Flow Structure of Commitment

The *Commitment* stock is fed by the *CommitRate* (commitment rate) inflow and is drained out by the *IndiffRate* (indifference rate) outflow as depicted in Figure 4.6.

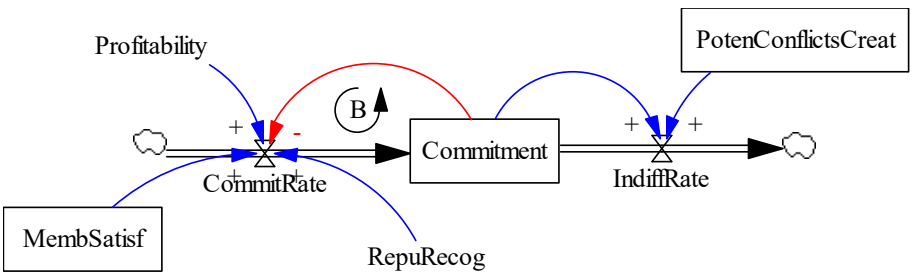



**Figure 4.6. Stock and flow structure of commitment.**

The *Commitment* stock variable is then the integral of the difference of *CommitRate* and *IndiffRate* added to the initial value of the stock, and is represented in equation 4.6.

$$Commitment(t) = Commitment(0) + \int [CommitRate(t) - IndiffRate(t)]dt \quad 4.6$$

where, $Commitment \in \Re \wedge \{0 \leq Commitment \leq 1\}$

The *CommitRate* inflow is driven by the weighted average of *Profitability*, *MembSatisf* and *RepuRecog* subtracted by the current value of *Commitment* as represented in equation 4.7.

$$CommitRate(t) = \left(\frac{w_i \times MembSatisf(t) + w_j \times Profitability + w_k \times RepuRecog}{w_i + w_j + w_k}\right) - Commitment(t) \quad 4.7$$

where, $CommitRate, w_i, w_j, w_k \in \Re \wedge w_i, w_j > w_k$

The *IndiffRate* outflow is driven by the potential conflicts creation (*PotenConflictCreat*) accumulation. In this way, the level *Commitment* diminishes if the level of conflict potential (*PotenConflictCreat*) augments and does not diminish if the level of conflict potential is null. In order to formalize this behavior, a quadratic curve (of the form $y = ax^2 + bx + c$) was used in order to capture the *IndiffRate* as described in equation 4.8.

$$IndiffRate(t) = (A \times PotenConflictCreat(t)^2 + B \times PotenConflictCreat(t) + C) \times Commitment(t) \quad 4.8$$

where, $IndiffRate, A, B, C \in \Re$

In order to better understand what is being said, consider that the modeler wishes that the values of *IndiffRate* vary according to the following table (i.e. when the value of *PotenConflictCreat* is 1.0 then the *Commitment* should be decreased with an *IndiffRate* of 0.8):

| | | | |
|---|---|---|---|
| *PotenConflictCreat* | 1.0 | 0.5 | 0 |
| *IndiffRate* | 0.8 | 0.6 | 0 |

In this case, the values of A, B and C are -0.8, 1.6 and 0.0 respectively, as shown in equation 4.9.

$$IndiffRate(t) = \left(-0.8 \times PotenConflictCreat(t)^2 + 1.6 \times PotenConflictCreat(t)\right) \times Commitment(t) \quad 4.9$$

### Potential Conflicts Creation Stock and Flow Structure

The *ConfPoten* stock is fed by the *ConfActRate* (conflict activation rate) inflow and is emptied by the *ConfDesactRate* (conflict desactivation rate) outflow as illustrated in Figure 4.7.

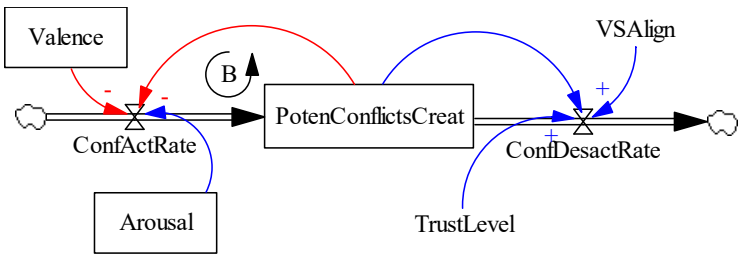



**Figure 4.7. Stock and flow structure of potential conflicts creation.**

The *PotenConflictsCreat* stock variable is then the integral of the difference of *ConfActRate* and *ConfDesactRate* added to the initial value of the stock, and is represented in equation 4.10.

$$\begin{aligned} PotenConflictsCreat(t) \\ &= PotenConflictsCreat(0) \\ &+ \int [ConfActRate(t) - ConfDesactRate(t)]dt \end{aligned} \qquad 4.10$$

where, $PotenConflictsCreat \in \Re \wedge \{0 \leq PotenConflictsCreat \leq 1\}$

According to Mayer (2000), conflicts may be composed of three dimensions: perception, feeling, and action. Having this as base, the potential for a conflict situation, involves the perception of a CN member's trust, needs or values being incompatible with those of the CN environment. Conflict also involves feelings, such as depression and frustration. And finally, conflicts are manifested through the CN member' actions, from commitment to quality of collaboration (i.e. the result of conflicts affect, among others, the *MembSatisf* and *Commitment* variables as seen before). Each of these dimensions are considered in the modeling of the conflicts potential, and although independent from each other, they do affect each other.

In this context, the *ConfActRate* inflow is driven by the CN member's automatic IME reaction or spontaneous feeling to the CN environment, which is given by the levels of *Arousal* and *Valence*. The analytical expression that captures the *ConfActRate* is described in equation 4.11.

$$ConfActRate(t) = SpontConfFeeling\big(Valence(t), Arousal(t)\big) - PotenConflictsCreat(t) \quad 4.11$$

where, $ConfActRate \in \Re$

The *SpontConfFeeling* function captures the spontaneous feeling of the CN member that represents the feeling dimension of the conflict. The function is given by equation 4.12. For depression and frustration the function returns 0.3 and 0.5, respectively, meaning that for these IMEs there is a considerable possibility to create conflicts (more in the frustration emotion). For excitement and contentment it returns 0 meaning that the possibility to create conflict is null. Finally, for the neutral state it returns 0.5, as described in equation 4.12.

$$SpontConfFeeling(V(t), A(t)) = \begin{cases} 0.3, & (V < 0 \cap A \leq 0) \\ 0.5, & (V \leq 0 \cap A > 0) \\ 0, & (V = 0 \cap A = 0) \\ 0, & (V \geq 0 \cap A < 0) \\ 0, & (V > 0 \cap A \geq 0) \end{cases} \quad 4.12$$

The *ConfDesactRate* outflow is driven by the average of *TrustLevel* and *VSAlign* (Value System Alignment) giving the perceptional dimension of the conflict. Thus, the more (less) the trust and value system is aligned with the CN, the more (less) the conflict deactivation rate values. The analytical expression that captures the *ConfDesactRate* is described in equation 4.13.

$$ConfDesactRate(t) = \left(\frac{TrustLevel + VSAlign}{2}\right) \times PotenConflictsCreat(t) \quad 4.13$$

where, $ConfDesactRate \in \Re$

**Stock and Flow Structure of Communication**

The *Communication* stock is fed by the *CommRate* (communication rate) inflow and is drained out by the *CommDecayRate* (communication decay rate) outflow as depicted in Figure 4.8.

The *Communication* stock variable is then the integral of the difference of *CommRate* and *CommDecayRate* added to the initial value of the stock, and is represented in the equation 4.14.

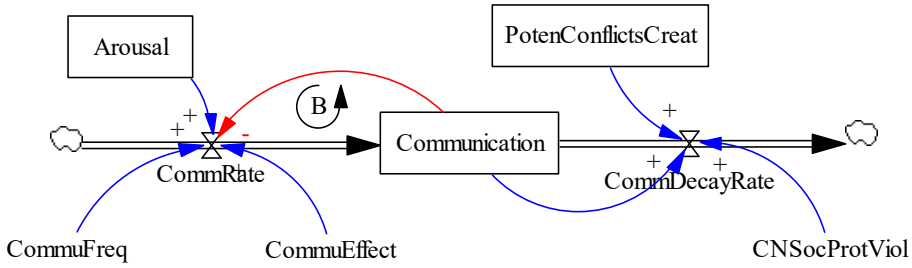



**Figure 4.8. Stock and flow structure of communication.**

$$Communication(t) = Communication(0) + \int [CommRate(t) - CommDecayRate(t)]dt \quad 4.14$$

where, $Communication \in \Re \wedge \{0 \leq Communication \leq 1\}$

The *CommRate* inflow is driven by the relation between *CommFreq*, *CommEffect* and *Arousal* considering the communication effects and also the level of activation for the increase of the communication level. In this way, the more (less) the communication effects multiplied by factors $w_i$, $w_k$ and the level of activation (*Arousal*) multiplied by a factor $w_j$, the more (less) the level of communication of the member.

Taking into consideration that *Arousal* varies between -1 and 1 and that the order of magnitude of the other involving parameters is between 0 and 1, it needs to be adjusted (like the case of *Valence* in equation 4.3). Hence, a linear function (of the form $y = mx + c$) was fitted in order to reference *Arousal* between 0 and 1. The analytical expression that captures this adjustment is described in equation 4.15.

$$AroAdj(t) = 0.5 \times Arousal(t) + 0.5 \quad 4.15$$

The analytical expression that captures the *CommRate* is described in equation 4.16.

$$CommRate(t) = \frac{(w_i \times CommFreq + w_j \times AroAdj(t) + w_k \times CommEffect)}{w_i + w_j + w_k} - Communication(t) \quad 4.16$$

where, $CommRate, w_i, w_j, w_k \in \Re \wedge w_i > w_j, w_k$

The *CommDecayRate* outflow is considered to be primarily driven by the event *CNSocProtViol*, i.e. by the event that is triggered when the social protocols within the CN

environment are violated and go against the CN member's beliefs. Whenever this event is triggered the *Communication* level decreases to its lowest value. If the event does not occur, the *CommDecayRate* depends on the value of potential conflicts multiplied by a factor $w$, with the premise the higher (lower) the level of potential conflicts the lower (higher) the communication. The analytical expression that captures the *CommDecayRate* is described in equation 4.17.

$$CommDecayRate(t) = \begin{cases} Communication(t), & CNSPV = 1 \\ w \times PotenConflictsCreat(t) \times Communication(t), & CNSPV = 0 \end{cases} \quad 4.17$$

where, $CommDecayRate, w \in \Re \wedge 0 \leq w \leq 1$

### Stock and Flow Structure of Collaboration Dynamics

The *CollabDynam* stock is fed by the *CollabInRate* (collaboration inflow rate) inflow and is emptied by the *CollabOutRate* (collaboration outflow rate) outflow as depicted in Figure 4.9.

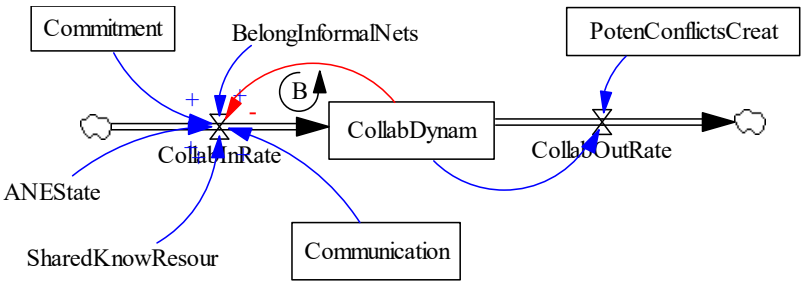



**Figure 4.9. Stock and flow structure of collaboration dynamics.**

The *CollabDynam* stock variable is then the integral of the difference of *CollabInRate* and *CollabOutRate* added to the initial value of the stock, and is represented in the equation 4.18.

$$CollabDynam(t) = CollabDynam(0) + \int [CollabInRate(t) - CollabOutRate(t)]dt \quad 4.18$$

where, $CollabDynam \in \Re \wedge \{0 \leq CollabDynam \leq 1\}$

*CollabDynam* measures the dynamism of the CN member within the CN environment. It is a reflection of the collaborative interactions and the communication level with the CN and with the other peers. It is also an image of the level of commitment and the potential to create conflict situations. The ANE state also contributes for the willingness of the CN member to be effectively dynamic within the CN environment.

Taking into consideration that the values of *ANEState* use a relative scale varying from 2 = excitement to -2 = depression, and that the other variable's interval is between 0 and 1, it was considered a correspondence of values as presented below:

| | | | | | |
|---|---|---|---|---|---|
| *ANEState* | -2 | -1 | 0 | 1 | 2 |
| *ANEStateAdj* | 0 | 0.25 | 0.5 | 0.75 | 1.0 |

This correspondence is formalized in the equation of the form $y = mx + c$) as described in equation 4.19.

$$ANEStateAdj = 0.25 \times ANEState + 0.5 \qquad 4.19$$

In this way, an increase (decrease) of the level of *Commitment*, the *ANEStateAdj*, the shared knowledge and resource ratio (*SharedKnowResour*), the belonging informal networks (*BelongInformalNets*) and the *Communication* level leads to and increase (decrease) of the collaboration inflow rate (*CollabInRate*). Thus, the equation that governs this *CollabInRate* inflow is the weighted arithmetic mean of these variables. In this particular case, it is considered that the weights of *Communication*, *BelongInformalNets* and *SharedKnowResour* would be superior to the others, as presented in equation 4.20.

$$\begin{aligned} CollabInRate(t) = \big(\big(&w_i \times Communication + w_j \\ &\times (SharedKnowResour + BelongInformalNets) + w_k \\ &\times Commitment + w_y \times ANEStateAdj\big)/(w_i + 2 \times w_j + w_k \\ &+ w_y)\big) - CollabDynam(t) \end{aligned} \qquad 4.20$$

where, $\{CollabInRate, w_i, w_j, w_k, w_y \in \Re \ \wedge \ w_i, w_j > \ w_k, w_y\}$

On the other hand, an increase (decrease) of the potential conflicts level (*PotenConflcitsCreat*) leads to a decrease (increase) of the *CollabDynam*. Therefore, the *CollabOutRate* is primarily driven by the conflicts level as presented in 4.24.

$$CollabOutRate(t) = PotenConflictsCreat \times CollabDynam(t) \quad 4.21$$

where, $CollabOutRate \in \Re$

### Stock and Flow Structure of Valence

The *Valence* stock is nurtured by the *ValRate* (valence rate) inflow and is emptied by the *ValDecayRate* (valence decay rate) outflow as illustrated in Figure 4.10.

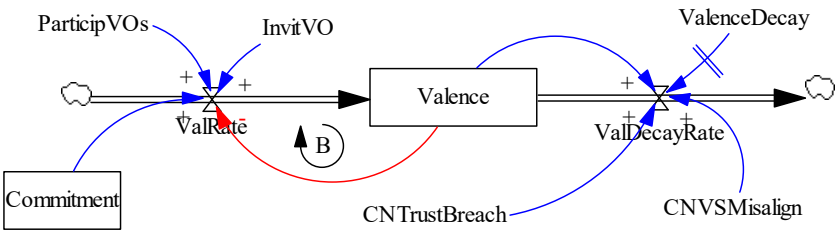



**Figure 4.10. Stock and flow structure of valence.**

The *Valence* stock variable is then the integral of the difference of *ValRate* and *ValDecayRate* added to the initial value of the stock, and is represented in equation 4.22.

$$Valence(t) = Valence(0) + \int [ValRate(t) - ValDecayRate(t)]dt \quad 4.22$$

where, $Valence \in \Re \wedge \{-1 \leq Valence \leq 1\}$

The *ValRate* inflow is considered to be primarily driven by the level of *Commitment* of the CN member and by the *ParticipVOs* and *InvitVO* with a lower influence respectively. Since the commitment level is the variable that most contributes for the level of pleasure (i.e. valence) of the CN member it is multiplied by a factor $w_i$. The relation of participating VOs, also contributing for the level of enjoyment of the member, is multiplied by a factor of $w_j$, which is supposed to be inferior to the previous one. Finally, the occurrence of an event inviting the member to participate in a VO is also a contributor for pleasure. Nevertheless with lower effect than in the previous two ($w_k$). In this way, the mathematical expression that rules this rate is given by the weighted average of the three inputs as presented in equation 4.23.

$$ValRate_{int}(t) = \frac{(w_i \times Commitment(t) + w_j \times ParticipVOs + w_k \times InvitVO)}{w_i + w_j + w_k} \quad 4.23$$

where, $ValRate_{int}, w_i, w_j, w_k \in \Re \wedge \{0 \leq ValRate_{int} \leq 1\} \wedge \{w_i > w_j > w_k\}$

Nevertheless, it is not the final expression for *ValRate*. This is due to the fact that the *Valence* level varies between -1 and 1. Therefore $ValRate_{int}$ that varies between 0 and 1 has to be adjusted. This is made using once again the linear function (of the form $y = mx + c$). And so, the analytical expression that captures the *ValRate* is described in equation 4.24.

$$ValRate(t) = (2 \times ValRate_{int} - 1) - Valence(t) \qquad 4.24$$

where, $ValRate \in \Re$

The *ValDecayRate* outflow is considered to be primarily driven by the events *CNTrustBreach and CNVSMisalign*, i.e. by the events that are triggered when a trust breach (*CNTB*) occurs or when a misalignment of the value system (*CNVSM*) is identified. Whenever one of these events are triggered, the *Valence* level decreases accordingly. If these events do not occur, the *ValDecayRate* is governed by the *ValenceDecay* of the CN member, and independently of the IME that is active it tends to "push" it to its neutral position. Please note that the *ValenceDecay* is a constant value that can be different across members. The analytical expression of the *ValDecayRate* is described in equation 4.25.

$$ValDecayRate(t) = \begin{cases} Valence(t) \times ValenceDecay, & (CNTB = 0 \cap CNVSM = 0) \\ |Valence(t)|, & (CNTB = 1 \cup CNVSM = 1) \cap (-0.5 < Valence(t) \leq 1) \\ 0, & (Valence(t) \leq -0.5) \end{cases} \qquad 4.25$$

where, $ValDecayRate \in \Re$

### Stock and Flow Structure of Arousal

The *Arousal* stock is fed by the *AroRate* (arousal rate) inflow and is drained out by the *AroDecayRate* (arousal decay rate) outflow, as illustrated in Figure 4.11.

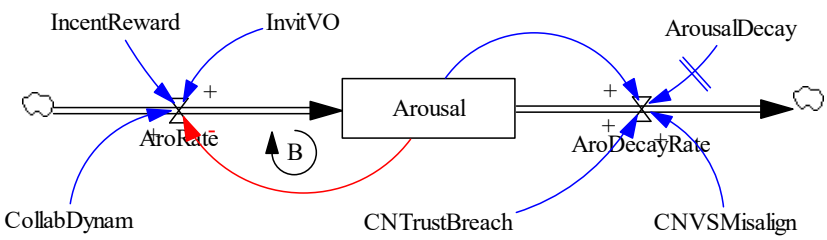



**Figure 4.11. Stock and flow structure of arousal.**

The *Arousal* stock variable is then the integral of the difference of *AroRate* and *AroDecayRate* added to the initial value of the stock, and is represented in equation 4.26.

$$Arousal(t) = Arousal(0) + \int [AroRate(t) - AroDecayRate(t)]dt \qquad 4.26$$

where, $Arousal \in \Re \wedge \{-1 \leq Arousal \leq 1\}$

The *AroRate* inflow is considered to be driven by the occurrence of the *InvitVO* (invitation to form VOs) and *IncentReward* (incentive reward) events and also by the collaboration dynamics (*CollabDynam*). As the arousal represents the level of activation of the CN member, it is assumed that when an invitation to form a VO is made or an incentive reward attributed, it increases substantially the activation of the member. Thus, the *CollabDynam* event has a multiplier factor $\boldsymbol{w_i}$, *InvitVO* a multiplier factor of, $\boldsymbol{w_j}$ and *IncentReward* a multiplier factor of $\boldsymbol{w_k}$. In this way the mathematical expression that rules this rate is given by the weighted average of the two inputs as presented in 4.27.

$$AroRate_{int}(t) = \frac{(w_i \times CollabDynam + w_j \times InvitVO + w_k \times IncentReward)}{w_i + w_j + w_k} \qquad 4.27$$

where, $AroRate_{int}, w_i, w_j, w_k \in \Re \wedge \{0 \leq AroRate_{int} \leq 1\}$

Nevertheless, as in the case of *Valence*, the above equation is not the *AroRate* final expression. Again there is the case of the adjustment of intervals. Therefore, in order to transform the output interval of $AroRate_{int}$ (which is between 0 and 1) into the *Arousal's* interval a linear function is used. Therefore, the analytical expression that captures the *AroRate* is described in equation 4.28.

$$AroRate(t) = (2 \times AroRate_{int} - 1) - Arousal(t) \qquad 4.28$$

where, $AroRate \in \Re$

The *AroDecayRate* outflow is considered to be primarily driven by the events *CNTrustBreach and CNVSMisalign*, i.e. by the events that are triggered when a trust breach occurs or when a misalignment of the value system is identified. Whenever one of these events are triggered the *Arousal* level decreases accordingly. If these events do not occur, the *AroDecayRate* is governed by the *ArousalDecay* of the CN member, and independently of the IME that is active it tends to "push" it to its neutral position. Please note that as in the case of the valence, the *ArousalDecay* is a constant value that can be different across members.

The analytical expression of the *AroDecayRate* is described in equation 4.29.

$$AroDecayRate(t) = \begin{cases} Arousal(t) \times ArousalDecay, & (CNTB = 0 \cap CNVSM = 0) \\ |Arousal(t)|, & (CNTB = 1 \cup CNVSM = 1) \cap (-0.5 < Arousal(t) \leq 1) \\ 0, & (Arousal(t) \leq -0.5) \end{cases} \quad 4.29$$

where, $AroDecayRate \in \Re$

**Participation in VOs Structure**

The *ParticipVOs* is a variable that measures the level of participation in VOs a CN member holds. It corresponds to the relation between the total VOs operating in the CN environment with the total amount of VOs a member is/was participating, either as VO planner or as VO partner as illustrated in Figure 4.12.

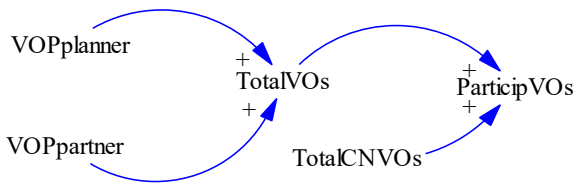



**Figure 4.12. Participation in VOs structure.**

In this way, the *ParticipVO* is driven by the *TotalCNVOs* and the *TotalVOs*. The analytical expression of *ParticipVOs* is described in equation 4.30.

$$ParticipVOs = \frac{TotalVOs}{TotalCNVOs} \quad 4.30$$

*TotalVOs* measures the total amount of VOs a member participate. Either as promoter and organizer of the creation and operation of the VO or as an invited partner. The expression that rules this measure is given by equation 4.31.

$$TotalVOs = VOPplanner + VOPpartner \quad 4.31$$

**Profitability Structure**

*Profitability* indicates the potential of the CN member's profit in relation to its overall revenue, which results in profit generation. It is generally measured as a ratio of *Profit* to *Revenue*. Figure 4.13 presents the structure of profitability.

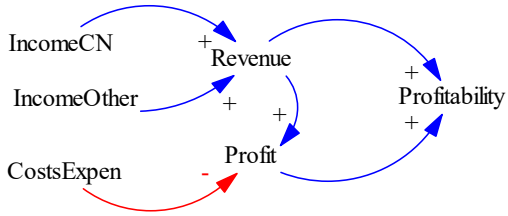



**Figure 4.13. Profitability structure.**

Therefore, the analytical expression that governs this measure is given by the equation 4.32.

$$Profitability = \frac{Profit}{Revenue} \qquad 4.32$$

*Profit* is the financial benefit that is realized by the CN member. It corresponds to the net income, where the amount of revenue gained exceeds the costs and expenses of the member. The expression that describes this relationship is given by equation 4.33.

$$Profit = Revenue - CostsExpen \qquad 4.33$$

*Revenue* is the total amount of income of the CN member. It represents the sum of the incomes from its activities. These activities may be inside the CN environment or from the business that the CN member externally to the CN. The analytical expression that represents this sum is given by equation 4.34.

$$Revenue = IncomeCN + IncomeOther \qquad 4.34$$

### Member Motivation Structure

*MembMotiv* indicates the degree of performance motivation of the CN member. In other words, it measures the member's motivation to keep achieving high levels of performance. Figure 4.14 shows its structure.

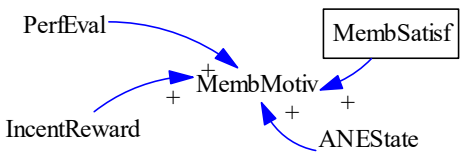



**Figure 4.14. Member motivation structure.**

In this line, the motivation is considered to be primarily driven by the average of the performance evaluation value (*PerfEval*), the member's satisfaction level (*MembSatisf*) and the aggregated network emotion state (*ANEState*), and secondly driven by the occurrence of an incentive reward event, i.e., the motivation also increases (decreases) whenever an event of incentive rewards occurs (does not occur).

As previously presented, the values of *ANEState* in order to correspond to the same order of magnitude of the other involving variables need to be adjusted. This adjustment is given by equation 4.19– *ANEStateAdj*.

Therefore, the expression that governs the *MembMotiv* is the weighted arithmetic mean of the variables *PerfEval*, *MembSatisf*, *ANEStateAdj* and the *IncentReward* as given by the equation 4.35.

$$MembMotiv = \frac{w_i \times (PerfEval + MembSatisf) + w_j \times ANEStateAdj + w_k \times IncentReward}{2 \times w_i + w_j + w_k} \quad 4.35$$

where, $MembMotiv, w_i, w_j \in \Re \wedge \{0 \leq MembMotiv \leq 1\} \wedge \{w_i > w_j > w_k\}$

**Reputation and Recognition Structure**

*RepuRecog* measures the potential of reputation and recognition of the CN member by the CN environment. It combines the dynamics of collaboration and the competences of the member evaluated in terms of motivation to achieve high performance. In this way, an increase (decrease) in *MembMotiv* and an increase (decrease) in the *CollabDynam* leads to an increase (decrease) of the potential of reputation and recognition as shown in Figure 4.15.

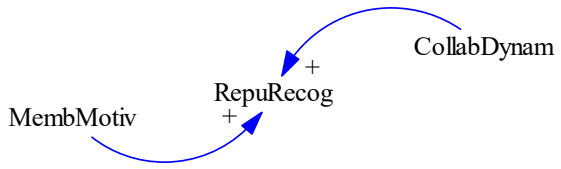



**Figure 4.15. Reputation and recognition structure.**

Taking into consideration the nature of this variable, it is considered that a simple sum expression of *MembMotiv* with *CollabDynam* would not express its correct behavior. Rather, it is more probable to be recognized and by consequence gain reputation with higher values of the sum of *MembPerf* with *CollabDynam* than with the lower ones.

Therefore, a quadratic curve (of the form $y = ax^2 + bx + c$) was considered in order to better fit the nature of *RepuRecog*. This analytical expression is described in equation 4.36.

$$RepuRecog = A \times (MembPerfMotiv + CollabDynam)^2 + B \times (MembPerfMotiv + CollabDynam) + C \quad 4.36$$

where, $RepuRecog, A, B, C \in \Re \wedge \{0 \leq RepuRecog \leq 1\}$

In order to better understand what is being said, consider that the modeler wishes that the values of *RepuRecog* vary according to an exponential function, i.e. when the values of the sum of *MembPerf* with *CollabDynam* are low the *RepuRecog* returns lower values, when they are higher the value that is returned increases exponentially as shown in the table below:

| | | | |
|---|---|---|---|
| *MembPerf* + *CollabDynam* | 0 | 1.3 | 2 |
| *RepuRecog* | 0 | 0.4 | 1 |

In this case, the values of A, B and C are 0.28, -0.06 and 0.03 respectively, as shown in equation 4.37.

$$RepuRecog = 0.28 \times (MembPerfMotiv + CollabDynam)^2 - 0.06 \times (MembPerfMotiv + CollabDynam) + 0.03 \quad 4.37$$

where, $RepuRecog \in \Re \wedge \{0 \leq RepuRecog \leq 1\}$

**Trust Level Structure**

The *TrustLevel* measures the level of trust that a CN member senses from the CN environment. In fact it represents the level of trustworthiness of the CN environment and how it affects the trust level of the member. It is driven by the *CNTrust*, which stands for the trust assessment that is made to the involved members of the CN, and by the *CNTrustBreach*, which represents the event whenever a breach in the CN trust occurs, as illustrated in Figure 4.16.

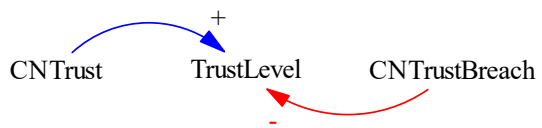



**Figure 4.16. Trust level structure.**

In this way, the *TrustLevel* increases (decreases) as the *CNTrust* increases (decreases). On the other hand, the trust level sensed by the CN member is penalized with a multiplier factor $w$, whenever a trust breach event (*CNTrustBreach*) occurs within the CN environment. Therefore the analytical expression that describes the *TrustLevel* variable is given by the equation 4.38.

$$TrustLevel = CNTrust - w \times CNTrustBreach$$
$$\text{where,} \quad TrustLevel, w \in \Re \ \wedge \{-1 \leq TrustLevel \leq 1\} \wedge \{0 \leq w \leq 1\} \qquad 4.38$$

As the *TrustLevel* scale was defined to vary between 0 and 1 (see Table 4.4), it is necessary to adjust the resulting values of the equation 4.38. As this equation might return negative values, which should be interpreted as 0, a ramp function was applied. The ramp function may be defined analytically in several ways, such as a system of equations, a max function, the mean of a straight line with unity gradient and its modulus, among others. For this case, the ramp function that describes the adjustment of the trust level (*TrustLevelAdj*) is given by the max function as shown in equation 4.39.

$$TrustLevelAdj = \max(TrustLevel, 0)$$
$$\text{where,} \quad TrustLevelAdj \in \Re \ \wedge \{0 \leq TrustLevelAdj \leq 1\} \qquad 4.39$$

**Value System Alignment Structure**

The *VSAlign* measures the level of values alignment of the CN environment. It denotes the need of the member to be lined up with the organizational values and CN vision. It is driven by the *CNVSAlign*, which is the measure of the alignment of the core values of the CN with the core values of all the CN members, and by the CNVSMisalign, which represents the event whenever a value system misalignment within the CN occurs, as illustrated in Figure 4.17.


**Figure 4.17. Value system alignment structure.**

In this way, an increase (decrease) in the *CNVSAlign* leads to an increase (decrease) in the *VSAlign*. On its turn, the *VSAlign* variable is penalized with a multiplier factor $w$,

whenever a values misalignment (*CNVSMisalign*) is detected. In this way, the analytical expression that describes the *VSAlign* is given by the equation 4.40.

$$VSAlign = CNVSAlign - w \times CNVSMisalign$$
$$\text{where,} \quad VSAlign, w \in \Re \ \wedge \{-1 \leq VSAlign \leq 1\} \wedge \{0 \leq w \leq 1\} \qquad 4.40$$

As in the *TrustLevel* seen above, the *VSAlign* scale was defined to vary between 0 and 1 (see Table 4.4), therefore it is also necessary to adjust the resulting values of the equation 4.40. As this equation might return negative values, which should be interpreted as 0, a ramp function was applied and is given by the max function resulting in the *VSAlignAdj* expression as shown in equation 4.41.

$$VSAlignAdj = \max(VSAlign, 0)$$
$$\text{where,} \quad VSAlignAdj \in \Re \ \wedge \{0 \leq VSAlignAdj \leq 1\} \qquad 4.41$$

In order to conclude this section, the IMEA SD stocks and flows diagram is modeled with the quantification of its structures. This quantification (i.e. the set of equations that were formalized above) should not be interpreted as the only solution for the IMEA SD modeling approach, but they are just examples of how it could be realized. Furthermore, the values of the given weights will also depend on the requirements and objectives of each CN environment to be modeled and have to be calibrated accordingly. For the specific case of this IMEA SD model that is being proposed, the values of the weights are not the focus, instead the proof that this modeling framework and simulation approaches are promising to this work hypotheses.

#### 4.1.1.2 ANEA SD Model

The main goal of the reasoning component of the ANE model of the C-EMO framework (see Figure 3.18) is to determine the ANE dimensions <V, A>. For that, a system dynamics model is proposed, the ANEA (Aggregated Network Emotion Appraisal) SD model.

ANEA SD models the dynamics of the variables that influence the tuple <V, A>, which are given by the evidences that are delivered by the perception module and their relationship with the variables that represent the goals of the CN. In this sense, the ANEA SD model conceptualization consists of defining the relevant variables, mapping

relationships between the variables, determining the important causal loop feedback structures and generating dynamic models as solution to the problem.

The ANEA SD model, like the IMEA SD model, is built on top of the concept of CNE as defined in section 3.1. In addition, some inspiration comes also from the social psychological and sociological theories like the social-constructivist perspective on the social nature of **emotions** from Averill (1980). According to Averill's theory, **emotion** derives from the social context, because it is in this social context that **emotions** have functioning and meaning. Furthermore, some inspiration from the sustainability mechanisms are also considered in what concerns the goals of the CN. These goals are aligned with the three pillars of sustainability (economic, social and environment) aiming at keeping the CN emotionally equilibrated.

In the case of this ANEA SD model, it is assumed that the ANE state (seen as the social context) influence the individual emotional states (IMEs) of the CN members, being their IME states also responsible, in part, for the overall emotion felt within the CN (the ANE) and consequently the CN sustainability.

#### *4.1.1.2.1 Definition of Variables*

According to the C-EMO framework, the variables of the ANEA component are the ones provided by the ANE evidences vector – *AEV* – defined in expression 3.11 by the CN goals vector – *CNGV* – defined in expression 3.10. The adopted definition of each type of variables for the ANEA SD model is given in the sections below.

**Definition of the ANE Evidences Vector Variables**

The AEV is composed of two sets of information, as described in expression 3.11: a vector containing the CN own data (OD) and a vector containing the CN members' data (MD).

In this context, the variables proposed to comprise the OD vector are shown in Table 4.8.

**Table 4.7. Definition of the variables of the OD vector.**

| *OD Vector Variables* | *Definition* |
|---|---|
| **Valence** (***Valence***) | The dimension of the ANE that represents the pleasure-displeasure continuum as defined in Definition 5. In this vector, this variable corresponds to the latest value of the estimated valence, so it represents the initial value of |

| | |
|---|---|
| | valence before the new estimation. It is a decimal variable that varies between -1 (negative valence) and 1 (positive valence). |
| **Arousal** (***Arousal***) | The dimension of the ANE state that represents the level of activation, uncertainty, novelty and complexity of the surrounding stimulus as defined in Definition 6. Arousal can be seen as the unstable dimension of the ANE. In this vector, this variable corresponds to the latest value of the estimated arousal, so it represents the initial value of arousal before the new estimation. It is a decimal variable that varies between -1 (low arousal) and 1 (high arousal). |
| **Valence Decay** (***ValenceDecay***) | This variable represents the value of the decay that the valence dimension of ANE assumes for the CN environment. It is a value that might vary between 0 (minimum valence decay) and 1 (maximum valence decay). |
| **Arousal Decay** (***ArousalDecay***) | This variable represents the value of the decay that the arousal dimension of ANE assumes for the CN environment. It is a value that might vary between 0 (minimum arousal decay) and 1 (maximum arousal decay). |
| **Total CN Members** (***TCNmemb***) | The total number of registered members in the CN. It is a variable using a value greater than or equal to 0. |
| **Active Members** (***ActiveMembs***) | The number of the active members within the CN. It is a variable using a value greater than or equal to 0. |
| **Total CN VOs** (***TotalCNVOs***) | The total number of VOs of CN environment. This variable includes the VOs that successfully finished, the VOs that are under operation, the VOs that are in the formation phase and also the ones that failed. It is a variable using a value greater than or equal to 0. |
| **VOs Successfully Finished** (***VOsSuccess***) | The total number of VOs that have successfully finished within the CN environment. It is a variable using a value greater than or equal to 0. |
| **VOs Under Operation** (***VOsOperation***) | The total number of VOs that are in the phase of operation within the CN environment. It is a variable using a value greater than or equal to 0. |
| **VOs Failed** (***VOsFailed***) | The total number of VOs that have failed either in the creation or the operation phase within the CN environment. It is a variable using a value greater than or equal to 0. |
| **VOs Being Created** (***VOsCreation***) | The total number of VOs that are in the phase of creation within the CN environment. It is a variable using a value greater than or equal to 0. |
| **CN Performance Evaluation** (***CNPerfEval***) | The performance evaluation value of the CN. This variable represents the assessment of the performance of the CN according to a set of performance indicators. It is a variable using a decimal value between 0 (bad performance) and 1 (excellent performance). |
| **CN Trust** (***CNTrust***) | The level of trust that is established among the members involved in the CN environment according to a pre-defined set of trust criteria. These trust criteria are managed by the CN administrator. This variable represents the value of |

| | |
|---|---|
| | the trust assessment of all CN members. It is a variable using a decimal value between 0 (no trust) and 1 (complete trust). |
| **CN Value System Alignment (*CNVSAlign*)** | The measure of the alignment of the value system of the CN with the value systems of all CN members. It is a variable using a decimal value between 0 (no alignment) and 1 (total alignment). |
| **CN Sharing Ratio (*CNSharingRatio*)** | The ratio of knowledge and resources sharing within the CN. This variable results from the (sum of shares per CN members divided by the total CN shares) divided by (the total CN members). It is a variable using a decimal value between 0 (no CN sharing) and 1 (high CN sharing). |
| **CN Informal Networks Ratio (*CNInformalNetsRatio*)** | The ratio of informal networks within the CN per CN member. This variable results from (the sum of informal networks that a member belongs to divided by the total amount of informal networks) divided by the (total CN members). It is a variable using a decimal value between 0 (no networks) and 1 (all networks). |
| **Communication Intensity (*CommIntensity*)** | The measure of the overall frequency of interactions amongst members of the CN. This variable represents the dynamics of communication within the CN. It is a variable using a decimal value between 0 (no communications) and 1 (max level of communication). |
| **CN Income (*CNIncome*)** | The total earnings of the CN resulting for instance, both from the members' fees and the pre-established percentage of the VOs' overheads. It is a variable using a value greater than or equal to 0. |
| **CN Costs and Expenses (*CNCostsExpen*)** | The total costs and expenses of the CN. Costs and expenses represent the amount that has to be paid in order to get something, such as specific software or the expenses of insurance, taxes, etc. It is a variable using a value greater than or equal to 0. |

The variables proposed to constitute the MD vector are shown in Table 4.8.

**Table 4.8. Definition of the variables of the MD vector.**

| *MD* | *Definition* |
|---|---|
| **Excitement Frequency (*ExcitFreq*)** | The total amount of excitement present amongst the CN members. In other words, it is the total number of members that have the excitement IME state within the universe of the CN. It is a variable using a value greater than or equal to 0. |
| **Contentment Frequency (*ContFreq*)** | The total amount of contentment present amongst the CN members. In other words, it is the total number of members that have the contentment IME state within the universe of the CN. It is a variable using a value greater than or equal to 0. |

| | |
|---|---|
| **Frustration Frequency (*FrustFreq*)** | The total amount of frustration present amongst the CN members. In other words, it is the total number of members that have the frustration IME state within the universe of the CN. It is a variable using a value greater than or equal to 0. |
| **Depression Frequency (*DepreFreq*)** | The total amount of depression present amongst the CN members. In other words, it is the total number of members that have the depression IME state within the universe of the CN. It is a variable using a value greater than or equal to 0. |
| **Neutral Frequency (*NeutralFreq*)** | The total amount of neutral IME present amongst the CN members. In other words, it is the total number of members that have the neutral IME state within the universe of the CN. It is a variable using a value greater than or equal to 0. |

### Definition of the CN Goals Variables

The CN goals variables that are being assumed for the ANEA SD model, are those that represent the inner aspirations of the CN in order to be successful and sustainable.

According to Camarinha-Matos et al. (2010a) the areas of Collaborative Networks (CN) and Sustainability are creating synergies that bring benefits for both scientific domains. These synergies are leading to novel areas of application like the collaborative agribusiness ecosystems (Volpentesta & Ammirato, 2008) or the collaborative networks and ageing (del Cura et al., 2009; Camarinha-Matos et al., 2010b). Furthermore, mechanisms inspired in the biological ecosystems like the business ecosystems have demonstrated that some models, systems and processes may mimic the Nature in order to apply them to human situations. These mechanisms are being studied in the emerging discipline of biomimicry or biomimetic (Camarinha-Matos et al., 2010a).

According to Adams (2006), sustainability is divided into three pillars: economic, social, and environmental/ecological. Taking into consideration the biomimetic nature of this work, the identified CN goals lay on the knowledge and mechanisms that lead to sustainable and successful collaboration environments. Hence, the proposed CN goals are compliant with the three pillars of sustainability leading to the core goal of this work that relies on the collaborative network emotional health and wellbeing. Table 4.9 defines the variables that represent the CN goals.

**Table 4.9. Definition of the variables that represent the CN goals.**

| *CN Goals* | *Definition* | *Sust. Pillars* |
|---|---|---|
| **Collective Performance (*CollectivePerf*)** | The collective contribution to the performance of the CN. This variable reflects the dynamics of the organizational, | Economic<br>Social |

| | | |
|---|---|---|
| | business and social practices relating the results of the CN against the intended goals and objectives. It is a decimal variable using a decimal value between 0 (null collective performance) and 1 (high collective performance). | |
| **Financial Health (*FinacialHealth*)** | The financial health or monetary situation of the CN. It measures the overall financial aspect of the CN that includes the amount of net income and a prediction of the short-term expenses. It is a decimal variable using a decimal value between 0 (bad financial health) and 1 (excellent financial health). | Economic |
| **Innovation & Value Creation (*InnovValueCreation*)** | The measure of the successful innovation and value creation actions within the CN. It represents the degree of new concepts, services or products and knowledge development that deliver value to the CN as a whole. It is a decimal variable using a decimal value between 0 (null) and 1 (high innovation and value creation). | Economic |
| **Conflict Risks (*ConfRisks*)** | The level of risk of conflict situations within the CN environment. Avoidance or low level risk of conflicts is one of the CN goals for keeping sustainability. This variable might be activated whenever the other CN goals are put in jeopardy like for instance in case low level of trustworthiness or problems in community building. The consequence is then reflected in the CN performance and value creation. It is a variable using a decimal value between 0 (no conflicts) and 1 (high level of risks for conflict situations). | Economic<br>Social |
| **Level of Interactions (*InteractLevel*)** | The level of connections and relations among CN members. This variable reflects the communication exchanges and collaboration dynamics across the CN environment. It is a variable using a decimal value between 0 (no interactions) and 1 (high level of interactions). | Social |
| **Community Building (*CommuBuild*)** | The level of community availability (or sense of community, or constructed linkages) within the CN environment. It also reflects the extent to which CN members can work together effectively by means of creating communities around a specific purpose. It is a variable using a decimal value between 0 (no community building) and 1 (high community building). | Social |
| **Knowledge Creation Potential (*KnowCreatPoten*)** | The potential level for generating new knowledge within the CN environment. Represents the degree of information, knowledge and resources made available for the CN either by CN members individually or by informal networks created within the CN acting as communities or groups of | Economic<br>Social<br>Environmental |

| | | |
|---|---|---|
| | interest. The availability of resources and the exchange of knowledge/information contribute indirectly for the social cohesion and ecological sustainability. The potential of knowledge creation influences the economic pillar. It is a variable using a decimal value between 0 (potential to create new knowledge is null) and 1 (high potential to generate knowledge). | |

As in the case of the IMEA SD model, the initial values of these CN goals are initially equal to zero, being then generated dynamically taking in account the influences of the evidences input variables on these variables. This is further explained in sections 4.1.1.2.2 and 4.1.1.2.3.

**Assumptions and Constraints.** For the ANEA SD model the following constraints and assumptions are considered:

- In the same line as IMEs, the ANE have a specific duration period or decay period. In the case of ANE, it is considered that the decay period should be longer than the decay period of IMEs. This is due to the fact that it is assumed that the ANE is characterized by a collection of several emotional states in a certain duration time, therefore, it represents more a mood than an emotion (the reader is invited to see Figure 2.6). Anyway, both arousal and valence have a decay rate which can be different form each other.
- It should also be assumed that the ANEA model intends to give a perspective of modeling for ANE estimation within collaborative networked environments, rather than being the accurate model for the involving concepts. For instance, the concept of innovation and value creation or business performance in CNs are per se areas of intense research and development, and are only partially modeled in this proposal.
- The variables from the OD (with exception of the valence and arousal) vector are considered, in a first phase, as exogenous to this system model. They are not directly influenced by any other variable within the model. Nevertheless, it is assumed that in a long term they would be affected by the emotional dynamics of this model. In a first phase they are adjusted manually. In a second phase, they are collected from the CN management system of the corresponding CN.

#### 4.1.1.2.2 *ANEA Causal Loop Diagram*

Similar to the IMEA SD model, the feedback structure of the ANEA SD model is qualitatively mapped using a causal loop diagram, as depicted in Figure 4.18.

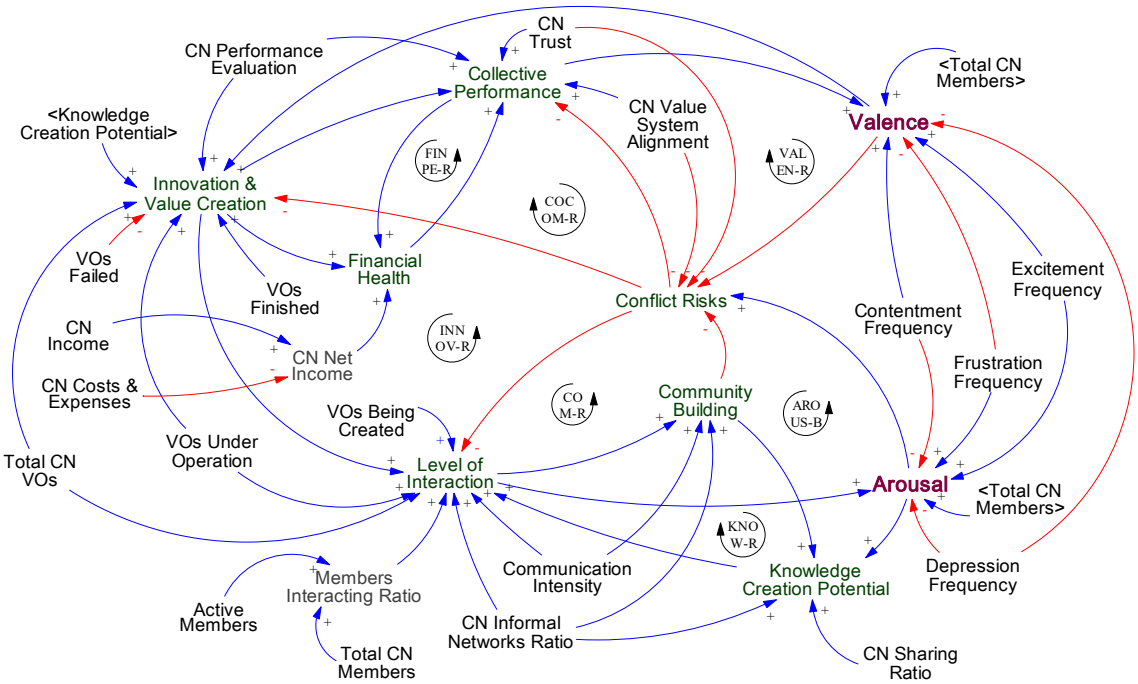



**Figure 4.18. ANEA SD causal loop diagram.**

Positive linkages are represented in blue colored arrows with a "+" sign, while negative linkages are represented in red colored arrows with a "-" sign. The variables from the OD vector are written in black (with exception of valence and arousal that are highlighted in purple color). The variables representing the CN goals are presented in green. In addition, some auxiliary variables are created for model simplification sake. These are written in grey and defined in Table 4.10.

**Table 4.10. ANEA SD auxiliary variables definition.**

| *Auxiliary Variables* | *Definition* |
|---|---|
| **CN Net Income (*CNNetIncome*)** | The measure of the amount of total CN incomes that exceed total expenses. It other words, it shows how much income is left over after all expenses have been paid. This is the amount of money that the CN can save for its own that can be used to invest in marketing strategies for new business opportunities, to distribute to CN members or even to keep for just in case. It is a variable using a value greater than or equal to 0. |

| | |
|---|---|
| **Members Interacting Ratio (*MembsInteractRatio*)** | The relationship of active members and the total of members in a CN. This variable reflects the percentage of actively interacting members in the whole universe of existing members of the CN. It is a variable using a decimal value between 0 (no members interacting) and 1 (all CN members are interacting with each other). |

As it can be identified in the causal loop diagram of Figure 4.18, the main causal loops for the ANEA causal model are: *COCOM-R* (Collective commitment reinforcing loop); *FINPE-R* (Financial performance reinforcing loop); *INNOV-R* (Innovation reinforcing loop); *COM-R* (Community reinforcing loop); *KNOW-R* (Knowledge generation reinforcing loop); *VALEN-R* (Valence reinforcement loop); and *AROUS-B* (Arousal balancing loop). A detailed description of each identified causal loop is presented below:

- **Collective Commitment Reinforcing Loop (COCOM -R):** This reinforcement loop models the dynamics between collective performance, valence, conflict risks, and innovation & value creation, reflecting the notion of collective commitment. As innovation & value creation increase (decrease), a boost (blow) in collective performance potentially happens within the CN. On its turn, with the improvement (worsening) of the collective performance, the valence dimension of the ANE tends to augment (diminish) due to being directly connected with the level of the collective pleasantness. Having a good (bad) valence the risks of conflict situations within the CN environment diminish (augment). As the risks of conflict conditions decreases (increases) the CN environment gets healthier (sicker) leveraging (not leveraging) innovation and value creation.
- **Financial Performance Reinforcing Loop (FINPE -R):** This loop reinforces the dynamics between financial health and collective performance. Having into account that financial health is a major objective of the CN that is being modeled, the better (worse) it is the better (worse) the mechanisms for motivation and control of collective performance are achieved. On its turn, the higher (lower) the collective performance is, the healthier (sicker) is the financial situation.
- **Innovation Reinforcing Loop (INNOV-R):** This reinforcing loop models the dynamics among the interactions level within the CN, community building, conflict risks, and innovation and values creation, reflecting the notion that without a healthier atmosphere among CN members, innovation and value

creation suffer some consequences. As the level of interactions inside the CN increases (decreases) the potential of community building also increases (decreases), basically due to the strengthening (weakening) of bonds among members. Whenever the level of community building is high (low), the potential of conflicts within the CN diminishes (augments). On its turn, as the risks of conflict situation decreases (increases), the atmosphere means for innovation and value creation within the CN increases (decreases). With an increase (decrease) in innovation and value creation, there is the necessity for more (less) interaction among members in order to pursuit the innovation requirements.

- **Community Reinforcing Loop (COM-R):** This reinforcement loop models the dynamics among community building, conflict risks, and level of interaction, reflecting in this way the conditions that are important for community strengthening within the CN environment. Thus, as the level of interactions among CN members increases (decreases) the potential for the community to get stronger ties also increases (decreases). As the community gets stronger (weaker) the risk to conflicts diminish (augment). On its turn, as the conflictual risks decrease (increase), the interactions and relationships among members are strengthened (weakened) accordingly.
- **Knowledge Generation Reinforcing Loop (KNOW-R):** This reinforcement loop models the dynamics among the level of interactions, community building and knowledge creation potential, reflecting the conditions to reinforce the generation of knowledge. In this way, as the quality and intensity of interactions increases (decreases) the potential for strengthening (weakening) community ties increases (decreases). With the increase (decrease) of the community sense and tied linkages, the likelihood to generate knowledge also increases (decreases). On its turn, the augmentation (diminishing) of knowledge creation leads to more (less) interactions among members.
- **Valence Reinforcement Loop (VALEN-R):** This reinforcement loop models the dynamics among collective performance, valence, and risks of situations of conflict, reflecting the conditions that influence (positively or negatively) the valence dimension, i.e. the pleased-unpleased level of the aggregated networked emotion. In this sense, as the collective performance gets higher (lower) the CN valence augments (diminishes). By lowering (raising) the risks of conflict the collective performance actions tend to increase (decrease) accordingly.

- **Arousal balancing loop (AROUS-B):** This balancing loop models the dynamics among the interactions level, arousal and conflict risks, reflecting the tendency of the dynamic dimension of the aggregated network emotion. As the potential for conflict risks increases (decreases) the level of interaction among members is negatively (positively) affected. On its turn, with the interactions level diminishing (increasing), the arousal is influenced negatively (positively). When the level of arousal decreases (increases), it might influence the risks of conflicts either positively or negatively depending on the value of the valence. In other words, as arousal represents the aggregated level of excitement or enthusiasm of the CN, when matched with the valence it might leverage or not the risk of conflicts that may arise. For instance, if the arousal is positive but the valence is negative it means that the ANE of the collaborative environment is frustration. Meaning that the probability of conflicts situations is high.

#### *4.1.1.2.3 ANEA SD Stocks and Flows Diagram*

This modeling phase consists of setting up a complete formal model with equations, parameters and initial conditions that represent the ANEA SD system. As the ANEA SD causal loop diagram only captures the mental models through the relationships among the different identified variables but does not permit the distinction between the different types of variables, it is necessary to develop a stocks and flows diagram. This diagram follows the same line of thought used for the IMEA SD models previously presented.

In this context, the ANEA stocks and flows diagram is presented in Figure 4.19. This diagram is build based on the ANEA SD causal loop diagram of Figure 4.18. It consists of two output state variables *Valence* and *Arousal* and four other state variables: *InnovValueCreation*, *CollectivePerf*, *ConfRisks* and *InteractLevel*. In this way, there are six structures of stocks-and-flows in the ANEA SD stocks and flows diagram. These are modeled with the quantification of its structures as shown in the following sub-sections. This quantification is formalized with a set of equations that should not be seen as the only quantitative solutions, but rather as examples of how it could be performed. Furthermore, the values of each weight and the intervals of action of each variable will also depend on the requirements, data availability and objectives of each CN environment to be modeled and have to be calibrated accordingly.

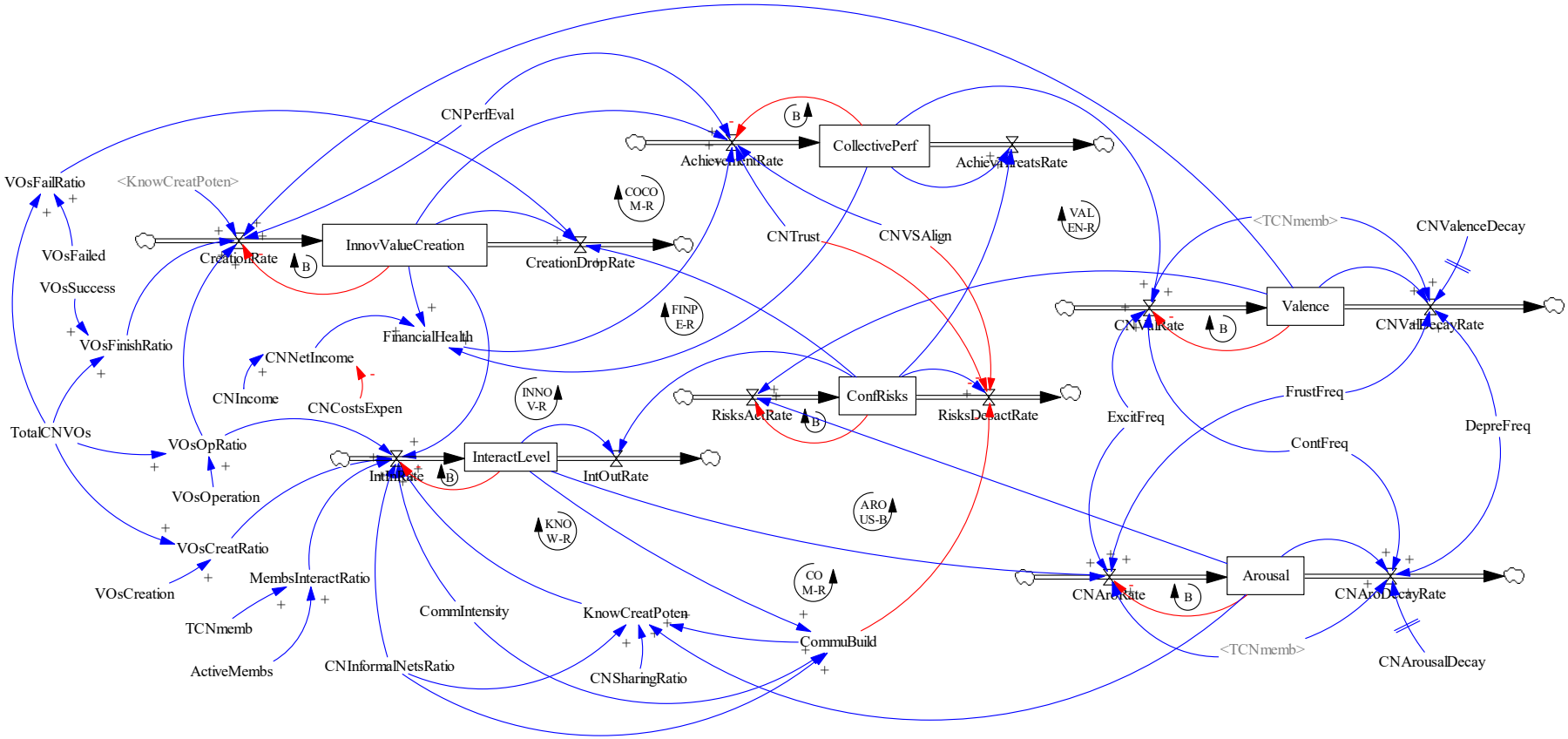



**Figure 4.19. ANEA stocks and flows diagram**

### Stock and Flow Structure of Innovation and Value Creation

The *InnovValueCreation* (innovation and value creation) stock is fed by the *CreationRate* inflow and is deflated by the *CreationDropRate* outflow as illustrated in Figure 4.20.

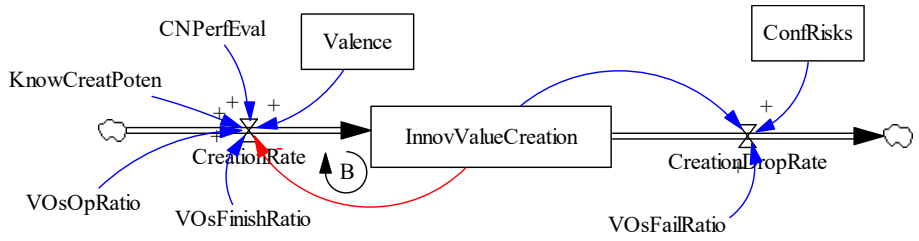



**Figure 4.20. Stock and flow structure of innovation and value creation.**

The *InnovValueCreation* stock variable is then the integral of the difference of *CreationRate* and *CreationDropRate* added to the initial value of the stock, represented below in equation 4.42.

$$\begin{aligned} InnovValueCreation(t) \\ &= InnovValueCreation(0) \\ &+ \int [CreationRate\ (t) - CreationDropRate\ (t)]dt \end{aligned} \qquad 4.42$$

where, $InnovValueCreation \in \Re \wedge \{0 \leq InnovValueCreation \leq 1\}$

The *CreationRate* inflow is governed by the contributing factors of innovation and value creation. The main contributing factors for innovation pass by forming solid teams of organizations capable of bringing more and diverse knowledge and experience and also of breaking down knowledge silos. As a consequence fresh new ideas arise that need to be put forward in order to create value for both the members of the CN and the customers. Therefore, the creation of value is given by the sum of the value added from existing products or services and the creation of new ones. Having this in background, the *CreationRate* inflow is divided into two main perspectives: *i)* the generation and implementation of new ideas collaboratively and, *ii)* the creation of value. Equation 4.43 formalizes the *CreationRate* inflow.

$$\begin{aligned} CreationRate(t) \\ &= \big(IdeaGenerator(t) + ValueCreat(t)\big)/2 \\ &- InnovValueCreation(t) \end{aligned} \qquad 4.43$$

where, $CreationRate \in \Re$

The *IdeaGenerator* term captures the collaborative generation and implementation of new ideas. It is determined by the weighted average of the potential of knowledge creation (*KnowCreatPoten*) value, of the ratio of VOs under operation (*VOsOpRatio*) and of the level of the aggregated pleasure of the CN (*Valence*), adjusted in order to fit within the order of magnitude of the other variables (see equation 4.3). Furthermore, for this model it is considered that the weights of the *KnowCreatPoten* and the *VOsOpRatio* are superior to the *ValenceAdj* as described in equation 4.44.

$$IdeaGenerator(t) = \frac{\left(w_i \times KnowCreatPoten + w_j \times VOsOpRatio + w_k \times ValenceAdj\ (t)\right)}{w_i + w_j + w_k} \qquad 4.44$$

where, $IdeaGenerator, w_i, w_j, w_k \in \Re\ \wedge\ \{0 \leq IdeaGenerator \leq 1\} \wedge \{w_i, w_j > w_k\}$

The *ValueCreat* term captures the value created inside the CN. It is determined by the weighted arithmetic mean of the existing products and services, represented by the rate of VOs that have already terminated (*VOsFinishRatio*), the ongoing creation of new products and services, represented by the VOs under operation (*VOsOpRatio*), the overall performance evaluation of the CN (*CNPerfEval*) and of the level of aggregated pleasure of the CN adjusted (*ValenceAdj*). Furthermore, for this model it is considered that the weights of the *VOsFinishRatio* and the *VOsOpRatio* are superior to the others as described in equation 4.45.

$$ValueCreat(t) = \left(w_i \times VOsFinishRatio + w_j \times VOsOpRatio + w_k \times CNPerfEval + w_y \times ValenceAdj\ (t)\right) / w_i + w_j + w_k + w_y \qquad 4.45$$

where, $ValueCreat, w_i, w_j, w_k, w_y \in \Re\ \wedge\ \{0 \leq ValueCreat \leq 1\} \wedge \{w_i, w_j > w_{k,} w_y\}$

The *CreationDropRate* outflow is driven by the costs of VOs failing (*VOsFailRatio*) and by the conflict risks (*ConfRisks*) influencing negatively the creation of value and innovation. The higher (lower) the *ConfRisks* and the *VOsFailRatio* are, the more (less) the *InnovValueCreation* diminishes. In this case it was considered that the weight of *ConfRisks* would be superior to the *VOsFailRatio*, as represented in equation 4.46.

$$CreationDropRate(t) = \left(w_i \times ConfRisks(t) + w_j \times VOsFailRatio\right) / w_i + w_j \times InnovValueCreation(t) \qquad 4.46$$

where, $CreationDropRate, w_i, w_j \in \Re\ \wedge\ \{w_i > w_j\}$

### Stock and Flow Structure of Collective Performance

The *CollectivePerf* (collective performance) stock is fed by the *AchievementRate* inflow and is consumed by the *AchievThreatsRate* (achievement threats rate) outflow as depicted in Figure 4.21.

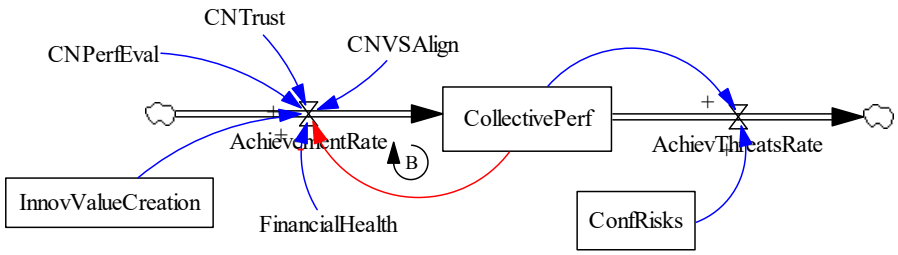



**Figure 4.21. Stock and flow structure of collective performance.**

The *CollectivePerf* stock variable is then the integral of the difference of *AchievementRate* and *AchievThreatsRate* added to the initial value of the stock, represented below in the equation 4.47.

$$CollectivePerf(t) = CollectivePerf(0) + \int[AchievementRate(t) - AchievThreatsRate(t)]dt \quad 4.47$$

where, $CollectivePerf \in \Re \wedge \{0 \leq CollectivePerf \leq 1\}$

The *AchievementRate* inflow is ruled according to the factors that influence and contribute to the collective performance. It is considered to be primarily driven by the financial performance (*FinancialHealth*), the CN performance (*CNPerfEval*) and the CN members return (*InnovValueCreation*). The trust environment among CN members (*CNTrust*) and the alignment of the members' values with the CN (*CNVSAlign*) are also contributing factors for the success of collective performance, playing and important background role, therefore with a secondary weight. In this context, the *AchievementRate* inflow increases (decreases) if all the input variables increase (decrease). It is determined by the weighted average of the sum average of *FinancialHealth, CNPerfEval* and *InnovValueCreation*, and of the sum average of *CNTrust* and *CNVSAlign*. The analytical expression that captures the *AchievementRate* inflow is represented in equation 4.48.

$$\begin{aligned} AchievementRate(t) &= \big(w_i \times (FinancialHealth \\ &+ CNPerfEval + InnovValueCreation(t)) + w_j \times (CNTrust \\ &+ CNVSAlign)\big)/(3 \times w_i + 2 \times w_j) - CollectivePerf(t) \end{aligned} \quad 4.48$$

where, $AchievementRate, w_i, w_j \in \Re \wedge \{w_i > w_j\}$

The *AchievThreatsRate* outflow is primarily driven by the level of risk conflicts (*ConfRisks*). In this way, the *CollectivePerf* tends to diminish if *ConfRisks* augments and is not affected if the risk conflicts level is null. A quadratic curve (of the form $y = ax^2 + bx + c$) was considered in order to describe this response. The analytical expression that captures the *AchievThreatsRate* is described in equation 4.49.

$$AchievThreatsRate(t) = ConfRisks(t) \times CollectivePerf(t) \qquad 4.49$$

where, $AchievThreatsRate \in \Re$

**Stock and Flow Structure of Conflict Risks**

The *ConfRisks* stock is fed by the *RisksActRate* (risks activation rate) inflow and is drained out by the *RisksDesactRate* (risks deactivation rate) outflow as illustrated in Figure 4.22.

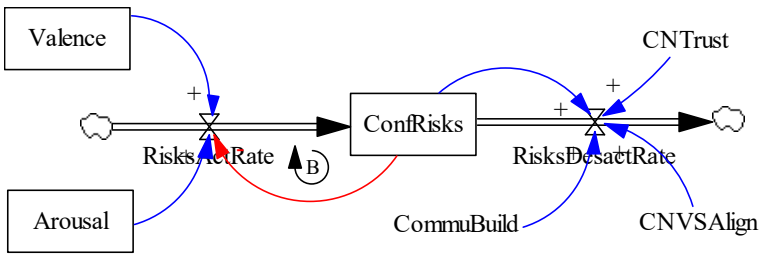



**Figure 4.22. Stock and flow structure of conflict risks.**

The *ConfRisks* stock variable is then the integral of the difference of *RisksActRate* and *RisksDesactRate* added to the initial value of the stock, and is represented in equation 4.50.

$$ConfRisks(t) = ConfRisks(0) + \int [RisksActRate(t) - RisksDesactRate(t)]dt \qquad 4.50$$

where, $ConfRisks \in \Re \wedge \{0 \leq ConfRisks \leq 1\}$

The risks of a conflictual situation within the CN environment involve the Mayer's (2000) three dimensions of conflict. Namely perception, feeling and action. In this context, perception is directly connected to the CN sensitivity to trust (*CNTrust*), shared and aligned values (*CNVSAlign*) and community building (*CommuBuild*), and is used as

the outflow rate (*RisksDesactRate*) for the conflict risks level, i.e., the higher (lower) theses values the higher (lower) is the rate that drains out the level of conflicts. On its turn, feeling influences the conflict risks taking into consideration the aggregated networked emotion, the ANE. This is used as the inflow rate (*RisksActRate*) for the conflict risks level. Finally, the result of conflicts are manifested by CN environment actions, such as the influence it has on the creation of value and innovation or in the quality of members' interactions.

The *RisksActRate* inflow is driven by the aggregated feeling of the CN that is translated by the aggregated values from *Valence* and *Arousal* and by the value of *ConfRisks* at time *t*. The analytical expression that captures this dynamics is described in equation 4.51.

$$\begin{aligned} RisksActRate(t) \\ &= SpontConfFeeling\big(Valence(t), Arousal(t)\big) \\ &- ConfRisks(t) \end{aligned} \qquad 4.51$$

where, $RisksActRate \in \Re$

The *SpontConfFeeling* is the function represented in equation 4.12 and captures the spontaneous aggregated feeling of the CN. In this way the feeling dimension of conflict is represented.

The *RisksDesactRate* outflow is driven by the perceptual dimension that is defined by the average of level of trust of the CN (*CNTrust*), of the values alignment of the CN with all members (*CNVSAlign*) and of the level of community building (*CommuBuild*). Thus, the more (less) the trust, the alignment of values and the community building, the more (less) the conflicts risks deactivation rate. The analytical expression that captures the *RisksDesactRate* is described in equation 4.52.

$$\begin{aligned} RisksDesactRate\ (t) \\ &= \left(\frac{CNTrust + CNVSAlign + CommuBuild}{3}\right) \times ConfRisks(t) \end{aligned} \qquad 4.52$$

where, $RisksDesactRate \in \Re$

**Stock and Flow Structure of Level of Interactions**

The *InteractLevel* stock is fed by the *IntInRate* (interactions inflow rate) inflow and is drained out by the *IntOutRate* (interactions outflow rate) outflow as illustrated in Figure 4.23.

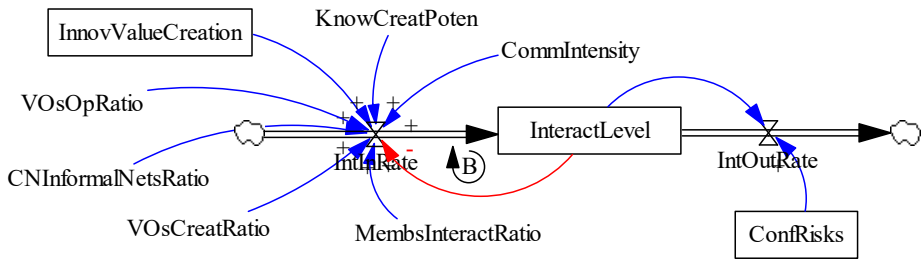



**Figure 4.23. Stock and flow structure of level of interactions.**

The *InteractLevel* stock variable is then the integral of the difference of *IntInRate* and *IntOutRate* added to the initial value of the stock, and is represented in equation 4.53.

$$\begin{aligned} InteractLevel\ (t) \\ &= InteractLevel\ (0) \\ &+ \int [IntInRate\ (t) - IntOutRate\ (t)]dt \end{aligned} \qquad 4.53$$

where, $InteractLevel\ \in \Re\ \wedge\ \{0 \leq InteractLevel\ \leq 1\}$

The *InteractLevel* is a variable that reveals the communication exchanges and the collaboration dynamics across the CN environment. Therefore, the contributing factors of this stock rely on variables that represent on one hand, the communication aspects among CN members like the overall communication intensity and the relation of members that are actively interacting and, on the other hand, the variables that leverage the interaction among members like the creation of value and innovation, the proportion of active informal networks within the CN, the potential to generate knowledge, and the operation and creation of VOs ratios. As a negative influencing variable for the high level of interaction is the existence of conflictual risks (*ConfRisks*) within the CN environment.

Therefore, the *IntInRate* inflow is given by the weighted arithmetic mean of the communications aspects with the variables that leverage interaction. The communications aspects are given by the sum of *CommIntensity* and *MembsInteractRatio*. On its turn, the interaction aspects are given by the sum of *InnovValueCreation*, *CNInformalNetsRatio*, *KnowCreatPoten*, and the average of *VOsOpRatio* and *VOsCreatRatio*. The analytical expression is defined in equation 4.54.

$$\begin{aligned} IntInRate\ (t) = \big(w_i \times (CommIntensity\ + MembsInteractRatio) + w_j \\ \times (InnovValueCreation + CNInformalNetsRatio \\ + KnowCreatPoten + (VOsOpRatio + VOsCreatRatio)/2)\big) \\ /(2 \times w_i + 3 \times w_j) - InteractLevel\ (t) \end{aligned} \qquad 4.54$$

where, $IntInRate, w_i, w_j \in \Re\ \wedge \{w_i > w_j\}$

The *IntOutRate* outflow is given by the level of conflict risks (*ConfRisks*). The higher (lower) the conflict risks are, the higher (lower) the outflow rate of the *InteracLevel* stock which means a decrease (increase) in the interaction levels. The analytical expression of the *IntOutRate* is described in equation 4.55.

$$IntOutRate(t) = ConfRisks(t) \times InteractLevel(t)$$

where, $IntOutRate \in \Re$ 4.55

### Stock and Flow Structure of Valence

The *Valence* stock is fed by the *CNValRate* (CN valence rate) inflow and is emptied by the *CNValDecayRate* (CN valence decay rate) outflow as illustrated in Figure 4.24.

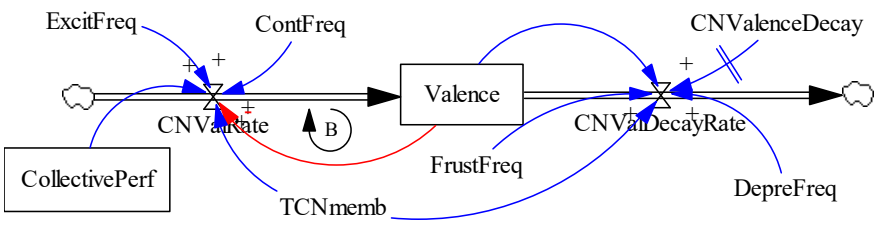



**Figure 4.24. Stock and flow structure of valence.**

The *Valence* stock variable is an integral of the difference of *CNValRate* and *CNValDecayRate* added to the initial value of the stock as represented in equation 4.56.

$$Valence(t) = Valence(0) + \int [CNValRate(t) - CNValDecayRate(t)]dt$$

where, $Valence \in \Re \wedge \{-1 \leq Valence \leq 1\}$ 4.56

The *CNValRate* inflow is driven by the *CollectivePerf* and by the CN member's individual emotions that have positive valences, which is the case of excitement and contentment (*ExcitFreq* and *ContFreq* respectively). In this way, the expression that rules an intermediary value of *CNValRate* is given by the average of the collective performance (*CollectivePerf*) and the ratio of existing positive valenced IMEs within the CN ($ExcitFreq + ContFreq/TCNmemb$) as presented in equation 4.57.

$$CNValRate_{int} = \left( \frac{\frac{ExcitFreq + ContFreq}{TCNmemb} + CollectivePerf(t)}{2} \right)$$

where, $CNValRate_{int} \in \Re \wedge \{0 \leq CNValRate \leq 1\}$ 4.57

As stated, the previous equation is an intermediary value, i.e., it is not the final expression for *CNValRate*. This is due to the fact that the *Valence* level varies between -1 and 1 and the result of the intermediary value varies between 0 and 1. Therefore, in order to adjust these values a linear function (of the form $y = mx + c$) was used. The analytical expression that captures the *CNValRate* is described in equation 4.58.

$$CNValRate(t) = (2 \times CNValRate_{int} - 1) - Valence(t) \qquad 4.58$$

where, $CNValRate(t) \in \Re$

The *CNValDecayRate* outflow is driven by the *CNValenceDecay* which is a constant value determined by the CN administrator, and by the CN member's individual emotions that have negative valences, which is the case of frustration and depression (*FrustFreq* and *DepreFreq* respectively). Therefore, the *CNValenceDecay* is given by the average of these variables. The analytical expression of the *CNValDecayRate* is described in equation 4.59.

$$CNValDecayRate(t) = \left( \frac{\left(\frac{FrustFreq + DepreFreq}{TCNmemb}\right) + CNValenceDecay}{2} \right) \times Valence(t) \qquad 4.59$$

where, $CNValDecayRate(t) \in \Re$

### Stock and Flow Structure of Arousal

The *Arousal* stock is fed by the *CNAroRate* (CN arousal rate) inflow and is drained by the *CNAroDecayRate* (CN arousal decay rate) outflow in Figure 4.25.

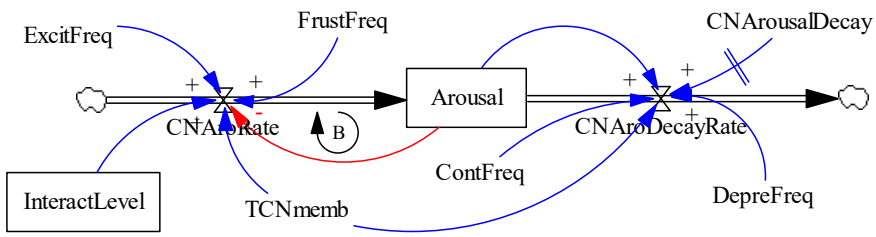



**Figure 4.25. Stock and flow structure of arousal.**

The *Arousal* stock variable is an integral of the difference of *CNAroRate* and *CNAroDecayRate* added to the initial value of the stock, as represented in equation 4.60.

$$Arousal(t) = Arousal(0) + \int [CNAroRate(t) - CNAroDecayRate(t)]dt \quad 4.60$$

where, $Arousal \in \Re \wedge \{-1 \leq Arousal \leq 1\}$

The *CNAroRate* inflow is driven by the *InteractLevel* and by the CN member's IMEs that have positive arousals, which is the case of excitement and frustration (*ExcitFreq* and *FrustFreq* respectively). In this way, the expression that rules an intermediary value of the *CNAroRate* is given by the average of the level of interaction (*InteractLevel)* and the ratio of existing positive aroused IMEs within the CN ($ExcitFreq + FrustFreq/TCNmemb$), as presented in equation 4.61.

$$CNAroRate_{int} = \left( \frac{\frac{ExcitFreq + FrustFreq}{TCNmemb} + InteractLevel(t)}{2} \right) \quad 4.61$$

where, $CNAroRate_{int} \in \Re \wedge \{0 \leq CNAroRate \leq 1\}$

The previous equation is an intermediary value, i.e., it is not the final expression for *CNAroRate*. This is due to the fact that the *Arousal* level varies between -1 and 1 and the result of the intermediary value varies between 0 and 1. Therefore, in order to adjust these values a linear function (of the form $y = mx + c$) was used, as described in equation 4.62.

$$CNAroRate(t) = (2 \times CNAroRate_{int} - 1) - Arousal(t) \quad 4.62$$

where, $CNAroRate(t) \in \Re$

The *CNAroDecayRate* outflow is driven by the *CNArousalDecay* which is a constant value determined by the CN administrator, and by the CN member's IMEs that have negative arousals, which is the case of contentment and depression (*ContFreq* and *DepreFreq* respectively). Therefore, the *CNAroDecayRate* is given by the average of these variables as described in equation 4.63.

$$CNAroDecayRate(t) = \left( \frac{\left(\frac{ContFreq + DepreFreq}{TCNmemb}\right) + CNArousalDecay}{2} \right) \times Arousal(t) \quad 4.63$$

where, $CNAroDecayRate(t) \in \Re$

### Community Building Structure

The *CommuBuild* is a variable that indicates if the CN members are being effective by means of creating communities within the CN environment. It is driven by the level of interactions among members (*InteractLevel*), the frequency of communications (*CommuIntensity*) and the ratio of the active informal networks (*CNInformalNets*), as illustrated in Figure 4.26

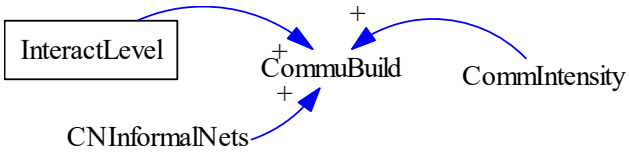



**Figure 4.26. Community structure.**

In this way, the *CommuBuild* increases (decreases) as the *InteractLevel*, *CommIntensity* and *CNInformalNets* increase (decrease). Considering that the *CNInformalNets* indicates the ratio of active informal networks within the CN, and that to some extent, it can be viewed as community clusters, it should have a higher influencing multiplicative factor, $w_i$. On its turn, the interaction level (*InteractLevel*) due to its function for creating strong ties, should have multiplicative factor $w_j$, which should be superior to the communication intensity (*CommIntensity*) multiplicative factor, $w_k$. Therefore, a weighted average function is the expression that governs the *CommuBuild* variable as described in equation 4.64.

$$CommuBuild = \left(w_i \times CNInformalNets + w_j \times InteractLevel(t) + w_k \times CommIntensity\right)/w_i + w_j + w_k \qquad 4.64$$

where, $CommuBuild, w_i, w_j, w_k \in \Re \wedge \{0 \leq CommuBuild \leq 1\} \wedge \{w_i > w_j > w_k\}$

### Financial Health Structure

The *FinancialHealth* measures the overall financial health aspect of the CN. It includes a physical part, given by the CN profitability and a wellbeing (soft) part that is provided by the creation of value and innovation (the purpose of innovation is to create business value) and the collective performance of the network as depicted in Figure 4.27.

The CN profitability is given by the relation between the *CNNetIncome* and the *CNIncome* while the wellbeing part is given by the *InnovValueCreation* and *CollectivePerf*. The expression that describes the *FinancialHealth* is given by the average of the above involved variables as described in equation 4.65.

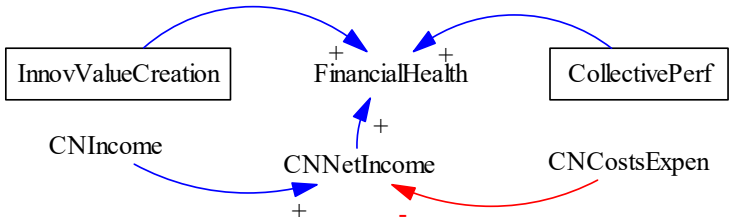



**Figure 4.27. Financial health structure.**

$$FinancialHealth = \frac{\frac{CNNetIncome}{CNIncome} + InnovValueCreation + CollectivePerf}{3} \qquad 4.65$$

where, $FinancialHealth \in \Re \wedge \{0 \leq FinancialHealth \leq 1\}$

and,

$$CNNetIncome = CNIncome - CNCostsExpen \qquad 4.66$$

### Knowledge Creation Potential Structure

The *KnowCreatPoten* measures the CN potential to generate knowledge and is positively influenced by the ratio of shared knowledge and resources (*CNSharingRatio*), the ratio of active informal groups (*CNInformalNets*), the level of aggregated arousal (*Arousal*) and the community building state (*CommuBuild*), as illustrated in Figure 4.28.

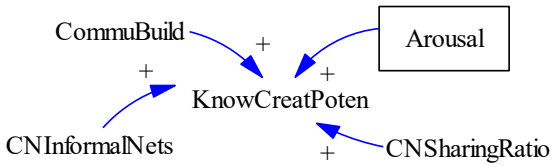



**Figure 4.28. Knowledge creation potential structure.**

The *KnowCreatPoten* is considered to be primarily given by the ratio of shared knowledge and resources (*CNSharingRatio*) and the ratio of active informal groups (*CNInformalNets*), and secondly by the level of aggregated arousal (*Arousal*) and the community building state (*CommuBuild*), which also contribute for the development of knowledge giving an extra motivation force. As previously seen and justified, the value of *Arousal* should be adjusted in order to fit in with the order of magnitude of the other variables, therefore the *AroAdj* described in equation 4.15 is used for the adjustment of the *Arousal*. In this way, the analytical expression for the *KnowCreatPotent* is given by the weighted arithmetic mean as described in equation 4.67.

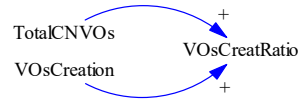
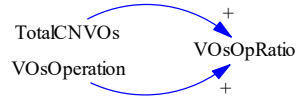
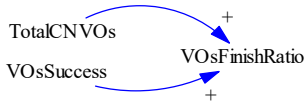
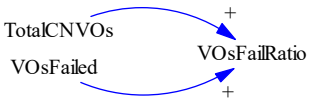
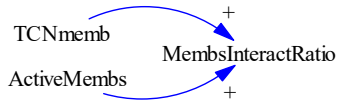
$$KnowCreatPotent = w_i \times (CNSharingRatio + CNInformalNets) + w_j \times \big(CommuBuild + AroAdj(t)\big)/(2 \times w_i + 2 \times w_j) \quad 4.67$$

where, $KnowCreatPotent, w_i, w_j \in \Re \wedge \{0 \leq KnowCreatPotent \leq 1\} \wedge \{w_i > w_j\}$

### Other Auxiliary Variables Structures

As illustrated in the ANEA stocks and flows diagram of Figure 4.19, other auxiliary variables aiming at calculating the some ratios are used. These are the *VOsCreatRatio* (equation 4.68), *VOsOpRatio* (equation 4.69), *VOsFinishRatio* (equation 4.70), *VOsFailRatio* (equation 4.71) and *MembsInteractRatio* (equation 4.72) as expressed in Table 4.11.

**Table 4.11. Other auxiliary variables structures.**

| *Structure* | *Analytical Expression* | |
|---|---|---|
|  | $VOsCreatRatio = \frac{VOsCreation}{TotalCNVOs}$ | 4.68 |
|  | $VOsOpRatio = \frac{VOsOperation}{TotalCNVOs}$ | 4.69 |
|  | $VOsFinishRatio = \frac{VOsSuccess}{TotalCNVOs}$ | 4.70 |
|  | $VOsFailRatio = \frac{VOsFailed}{TotalCNVOs}$ | 4.71 |
|  | $MembsInteractRatio = \frac{ActiveMembs}{TCNmemb}$ | 4.72 |

In summary, the ANEA SD stocks and flows diagram is quantitatively modeled. This quantification, i.e. the equations that are being proposed along this section, should not be seen as the only quantitative solutions. Rather, they are examples of how this modeling approach could be performed. In addition, the values of each weight and the intervals of action of each variable will also depend on the requirements, data availability and objectives of the CN to be modeled. For the specific case of this ANEA SD model, the values of the weights are not the focus, instead the guarantee that this modeling framework and simulation approaches are valid and promising.

### 4.1.2 Agent-Based Modeling

The agent-based modeling approach is used as a potential solution for representing the abstraction of the considered CN and its involved players.

In *Agent-Based Modeling (ABM)*, a complex system is modeled as a collection of autonomous decision-making entities called agents (either individual or collective entities such as organizations or groups). Each agent individually evaluates its situation and makes decisions on the basis of a set of rules. According to Siebers et al. (2010), an ABM system should be used when the problem has a natural representation of agents, i.e., when the goal is modeling the behavior and interactions of individual entities in a diverse population in the form of a range of alternatives or futures. In this work, the ABM is used to reproduce the CN environment proposed in the C-EMO framework (see Figure 3.18) with focus on the individual member's emotional influence on the overall emotional health of the CN and vice-versa.

In this context, using the ABM methodology is adequate because it allows (based on (Marreiros et al., 2005a)):

- *Individual modelling* – each participant of the CN can be represented by an agent that has the characteristics (attributes and behaviors) needed to appraise the IME state (in the case of members) and the ANE state (in the case of the CN), the potential behavior, and the interactions with the other agents.
- *Flexibility* – meaning that it is possible to add or remove entities from the CN, or even change some features and characteristics of the network in order to help in simulation of a variety of scenarios.
- *Data distribution* – CNs are by nature distributed entities, containing distributed members with distributed data.

In this line, individual entities are the CN members and the entity that represents the emotion management system within the CN (which, for simplification is normally denominated as CN), and the population is the collection of individual entities that belong to the collaborative network. Thus, each CN individual member is represented by an agent, the CN by another agent, and the CN and the collection of members are represented by a population of agents that "live" inside the agent that represents the collaborative environment as illustrated below.

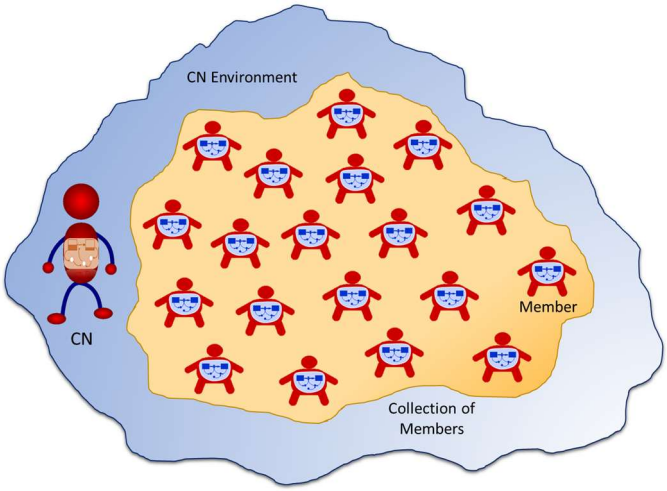



**Figure 4.29. Agent-based illustrative view of the CN environment.**

The model is then composed of three different types of agents:

- The *Individual Member Agent (IMAgent)*, which represents each participating individual member of the CN,
- The *CN Agent (CNAgent)*, which represents the CN's emotion management system, and
- The *CN Environment (CNEnvironment)*, which represents the CN itself, the CN agent and the collection of IMA agents that belong to the CN.

In this proposed model, the IMA agents embeds the IME model with the IMEA SD model presented in section 4.1.1.1, and on its turn, the CNA agent embeds the ANE model with the ANEA SD model presented in section 4.1.1.2. In this way, both agents comprise the different building blocks of the C-EMO framework.

The IMA agent is modeled using two sub-agents:

- The *Individual Perception Agent (IPerceptionAgent)* which is the agent that represents the perception module of the IME model component of the C-EMO framework, i.e., it is the agent that is in charge of interacting with the CN environment and of collecting the data from the internal knowledge database and that creates the IEV vector (see section 3.2.1.2).
- The *Individual Emotion Agent (IEmotionAgent)* which is the agent that represents the emotion module of the IME model component of the C-EMO framework, i.e., the agent that is responsible for the IME appraisal. As it will be seen in section 4.1.2.1, it is in this agent that the IMEA SD model is embedded.

On its turn, and following the same thought of the IMA agent, the CNA agent is modeled using also two sub-agents:

- The *CN Perception Agent (CPerceptionAgent)* which is the agent that represents the perception module of the ANE model component of the C-EMO framework, i.e., it is the agent that is in charge of interacting with the CN environment and of collecting the data from the internal knowledge database and that creates the AEV vector (see section 3.3.1.2).
- The *Aggregated Emotion Agent (AEmotionAgent)* which is the agent that represents the emotion reasoning module of the ANE model component of the C-EMO framework, i.e., it is the agent that is responsible for the ANE estimation. As it will be seen in section 4.1.2.2, it is in this agent that the ANEA SD model is embedded.

Furthermore, and in order to represent the population of agents that are embedded in the CN environment, there is also the *CNEnvironment* agent.

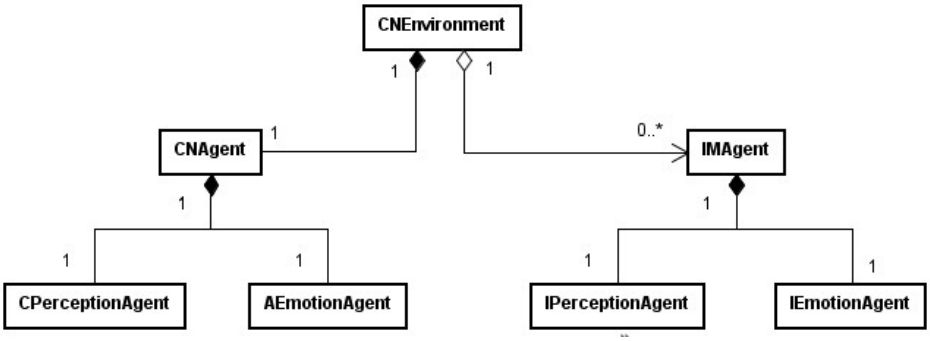



**Figure 4.30. UML class diagram of the C-EMO agent-based model.**

In this context, a UML diagram of the overall model structure is depicted in Figure 4.30. The *CNAgent* type (class) aggregates the *CPerceptionAgent* and the *AEmotionAgent* types. On its turn, the *IMAgent* type aggregates the *IPerceptionAgent* and the *IEmotionAgent* types. The *CNEnvironment* is the top-level agent representing the environment where the agents are embedded. Each agent class is represented by a set of attributes and methods (behaviors, behaviors that modify behaviors, and update rules for dynamic attributes) that operate on the agent class (Macal & North, 2013).

In the literature different types of agents are defined, mostly in the robotics field (S. Russell & Norvig, 2003), such as classical vs. behavior-based; reflex/goal-based, planning, learning, knowledge-based, etc. Nevertheless, due to its widely open field nature there is no accepted theory of agent architectures or architecture design.

According to S. Russell and Norvig (2003), the architecture of an agent defines how the job of generating *actions*, i.e. ways for the agent to influence the environment from *percepts*, i.e. observations about the state of the world, is organized.

In this work a particular agent architecture is applied. The proposed architecture consists of an *Interaction Module*, *Knowledge & Database Module*, *Reasoning Module* and *Response Module* as represented in Figure 4.31.

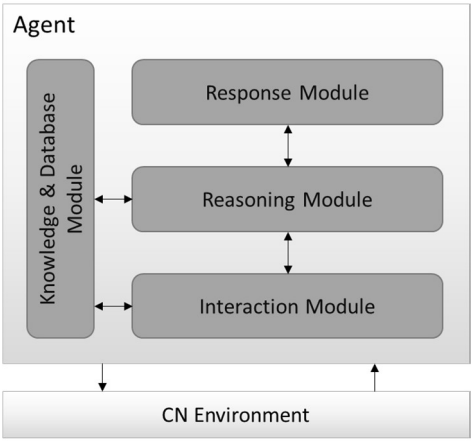



**Figure 4.31. C-EMO agent's generic architecture.**

The *Interaction Module* handles the agent's interactions with external entities, namely the environment perception and the communication (with other agents) interactions. The *Knowledge and Database Module* deals with the management of the CN environment and the internal knowledge and data model. The *Reasoning Module* serves as the core module of the agent. It is used to plan and execute the methods that deal with the agent's specific tasks. Tasks can be simply creating a message or running the emotion appraisal models. Finally, the *Response Module* manages the response actions of the agent. It can be for instance, a specific message acknowledging that its tasks are done, or a specific value, like the value of the collaborative emotional state.

The detailed implementation model of the C-EMO agents is discussed in the following sections.

#### 4.1.2.1 Individual Member Agent

As abovementioned, the IMA agent represents an individual member of the CN, therefore it expresses each individual member emotional state. The IMA agent dynamics is then based on the IME model of the C-EMO framework as presented previously.

Figure 4.32, presents the structure of the IMA agent. It is based on the generic architecture presented in Figure 4.31, and on the modeling approach expressed in the UML class diagram of Figure 4.30, as follows: the *Perception* represents the interaction module and is implemented by the IPerceptionAgent, the *Emotion Appraisal* characterizes the reasoning module and is implemented by the IEmotionAgent , the *Emotion Response* represents the response module and, finally, the *Knowledge & Database* is the database that characterizes the knowledge and database module.

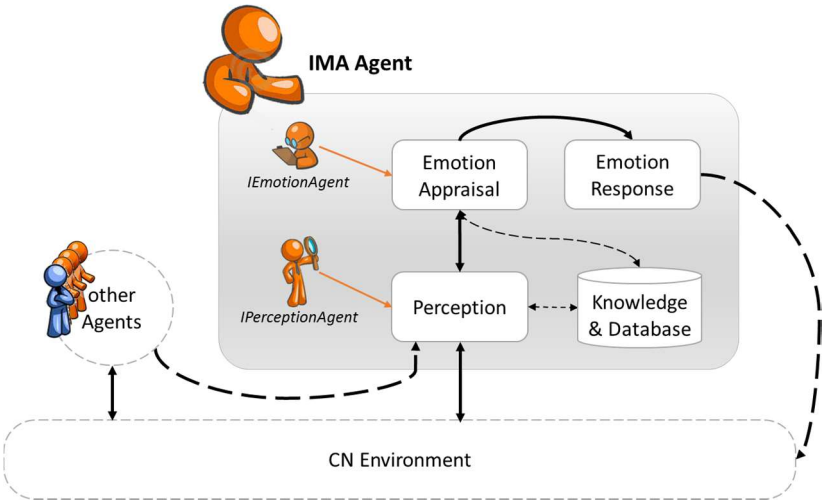



**Figure 4.32. IMA agent structure.**

#### *4.1.2.1.1 Agent Attributes and Behavior*

Each agent class is represented by a set of attributes and behaviors. Figure 4.33, is an excerpt of the class diagram of Figure 4.30, describing in detail the attributes and the behavioral methods of the individual member agents.

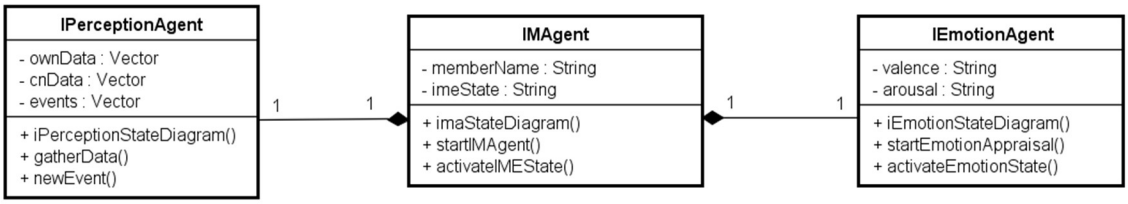



**Figure 4.33. UML class diagram of the IMAgent and sub-agents.**

The following sections describe in detail each one of the individual member agents.

**IMAgent**

The IMAgent is represented by the following attributes: the name of the individual member (memberName) that the agent represents and the corresponding IME state (imeState). The *memberName* is a static attribute while the *imeState* is dynamically updated according to the agent's behavior. This behavior is conceptualized in the state diagram of Figure 4.34. The IMAgent state diagram, which represents the *imaStateDiagram()* method, can be described as follows:

1. The IMAgent waits for a request for starting its actions.
2. When it receives the "Time to start" message, it asks the IPerceptionAgent to start gathering the data necessary to construct the evidences vector. And it stays waiting for a response from the IPerceptionAgent acknowledging that either the data or the events that compose the evidences vector were handled.
3. As soon as one of the messages from the IPerceptionAgent are delivered, a message is sent to the IEmotionAgent in order to start the emotion appraisal. Then, it remains in the "evaluating emotion" state until a message acknowledging that the emotion has been activated arrives.
4. Finally, the IME state (*imeState*) of the IMAgent is updated and it returns to the state of collecting data.

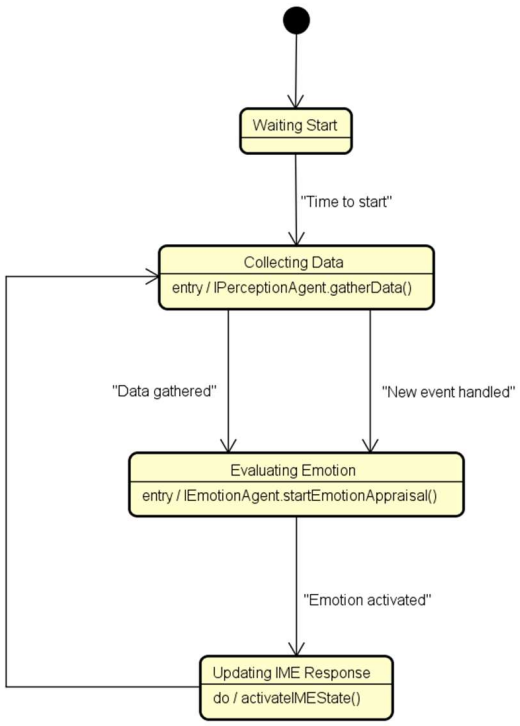



**Figure 4.34. State diagram of the IMAgent.**

**IPerceptionAgent**

The IPerceptionAgent is characterized by the following attributes: a vector containing the individual member data (ownData), the data that is gathered from the CN (cnData) and the information about the state of the events (events). The constant update of these agent's variables is done via the agent's behavior. This behavior is conceptualized in the state diagram of Figure 4.35.

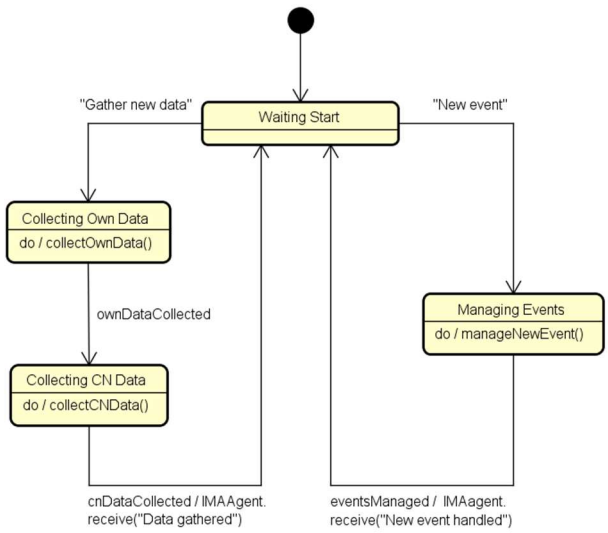



**Figure 4.35. State diagram of the IPerceptionAgent.**

The IPerceptionAgent state diagram, which represents the *iPerceptionStateDiagram()* method, can be described as follows:

1. The IPerceptionAgent waits for starting the perception actions. These actions might follow two directions depending on the triggering message that is sent by the IMAgent. One is related to the normal gathering of data (steps 2, 3 and 4) and the other to the events (steps 5 and 6). Being the events a priority when the two are triggered at the same time.

2. If a message for gathering data arrives, then it starts collecting the actual values of the individual member own data. This is done resorting to the last updated information from the database (see section 4.2.1). When it finishes, it triggers the condition *ownDataCollected*.

3. Then the agent enters in the state of collecting all the data relative to the CN, that is also kept in the database, and that represents the overall state of the CN.

4. When the agent finishes, it triggers the condition *cnDataCollected* and sends the message "Data gathered" to the IMAgent acknowledging that the data

perception has finished. Then it returns to the waiting state until new messages arrive.

5. If a message with a new event arrives, the agent has to activate the corresponding event or events (in the case of the occurrence of more than one event) in the events vector.
6. After that, it triggers the condition *eventsManaged* and sends the message "New event handled" to the IMAgent acknowledging that the events were activated. Finally, it returns to the waiting state until new messages arrive.

**IEmotionAgent**

The IEmotionAgent is characterized by the following attributes: valence and arousal. Its behavior is conceptualized in the state diagram of Figure 4.36.

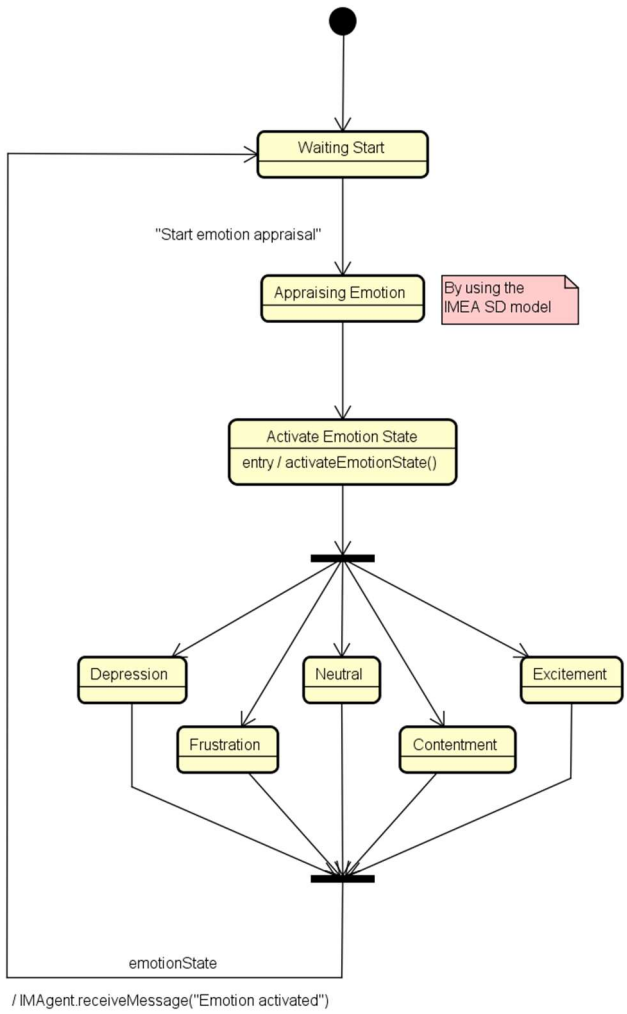



**Figure 4.36. State diagram of the IEmotionAgent.**

The IEmotionAgent state diagram, which represents the *iEmotionStateDiagram()* method, can be described as follows:

1. The IEmotionAgent remains in the "waiting" state until receiving the triggering message "Start emotion appraisal".
2. Then the IEmotionAgent starts the emotion appraisal by using the IMEA SD model (see section 4.1.1.1). As described in the IMEA SD model, the resulting variables are the tuple (valence, arousal), which are updated accordingly.
3. These variables are then used in the *activateEmotionState()* in order to select and activate the corresponding emotion state. This is done using the action chart described in Figure 4.37.
4. Finally, the IEmotion agent sends the message "Emotion activated" to the IMAgent, acknowledging that the current emotion has been estimated and activated and returns to the initial state.

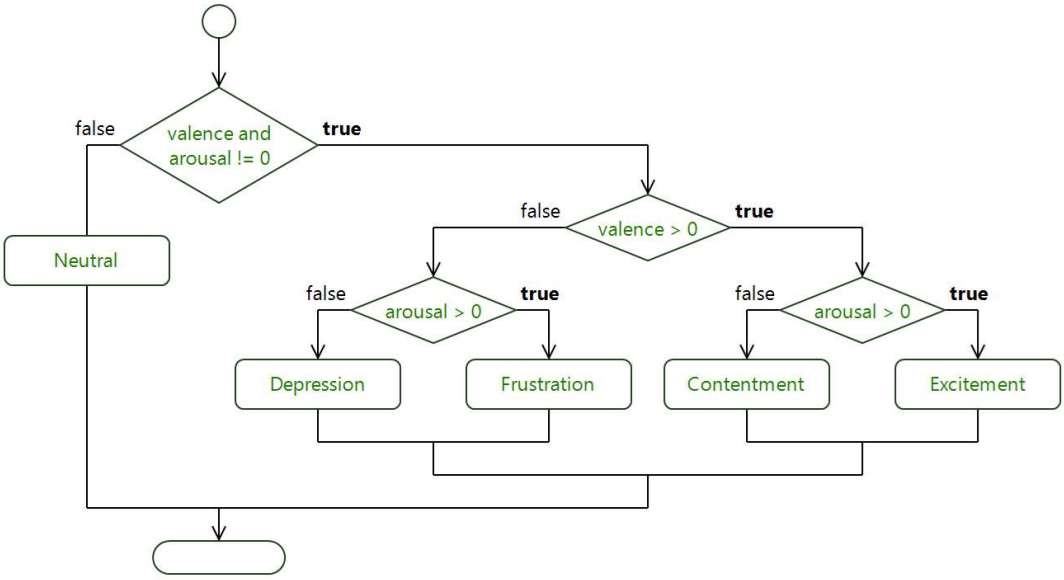



**Figure 4.37. *activateEmotionState()* action chart.**

#### *4.1.2.1.2 Agent's Interactions*

An overall view of the agent's interactions is given using the sequence diagram of Figure 4.38. In this work interaction is seen as the ongoing exchange of data among the participants (agents and the CN environment). The sequence begins with the CNEnvironment requesting the IMAgent to start its activities. Then a loop sequence is initiated. The IMAgent interacts with its IPerceptionAgent requesting to start gathering

data. In the meanwhile, as soon as an event is triggered, either in the CN context or in the individual member's context, a request to manage the new event or events is sent to the IPerceptionAgent. The IPerceptionAgent then acknowledges that the requests were handled. Afterwards, the IMAgent requests the emotion appraisal from its sub-agent IEmotionAgent. After executing its tasks, the IEmotionAgent confirms that the emotion has already been activated and consequently, the IMAgent informs the CN environment of its new IME state.

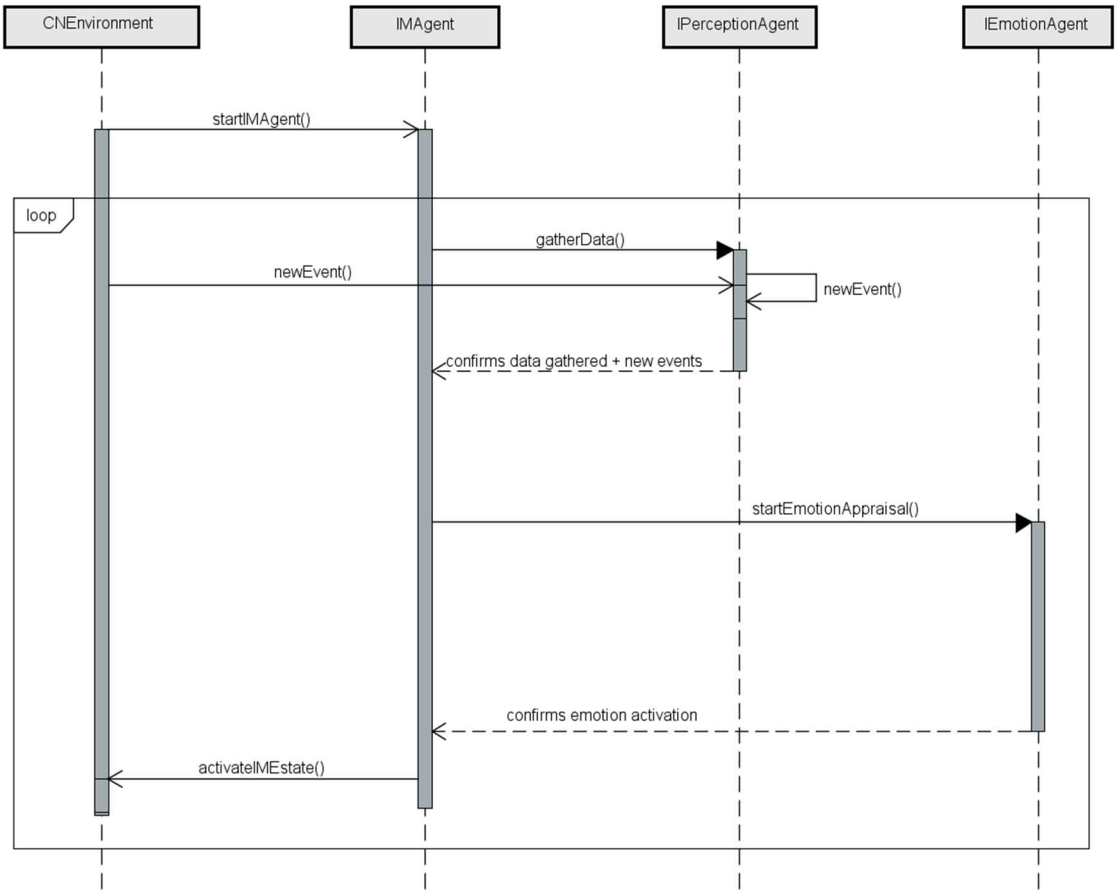



**Figure 4.38. UML sequence diagram illustrating the individual member agent's interactions.**

#### 4.1.2.2 Collaborative Network Agent

The CNA agent represents the CN's emotion management system and expresses the aggregated network emotion. The CNA agent dynamics is based on the ANE model of the C-EMO framework as presented previously. Figure 4.39 presents the implemented structure of the CNA agent. As in the case of the IMA agent, it is based on the generic architecture of Figure 4.31, and on the modeling approach expressed in the UML class

diagram of Figure 4.30 as follows: the *Perception* represents the interaction module and is implemented by the CPerceptionAgent, the *Emotion Reasoning* characterizes the reasoning module and is implemented by the AEmotionAgent , the *Emotion Response* represents the response module and, finally, the *Knowledge & Database* is the database that characterizes the knowledge and database module.

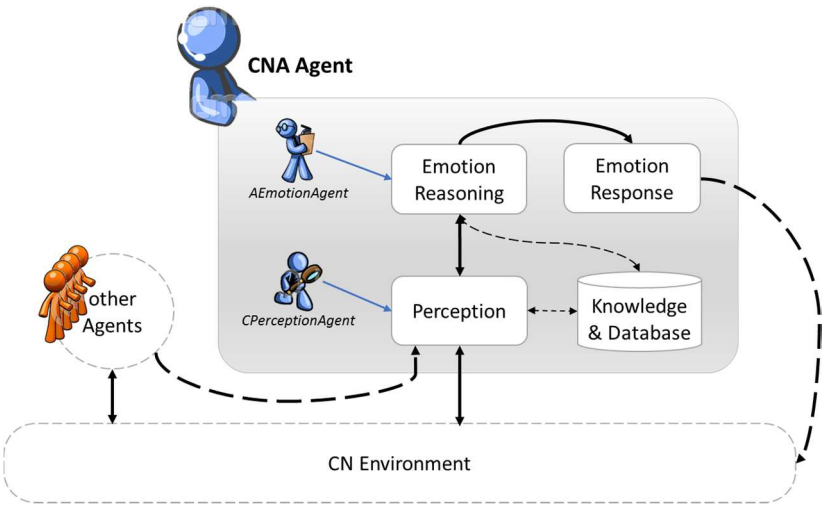



**Figure 4.39. CNAgent structure.**

#### *4.1.2.2.1 Agent Attributes and Behavior*

As mentioned before, each agent class is represented by a set of attributes and behaviors that run on the agent class. Figure 4.40, which is an excerpt of the class diagram of Figure 4.30, describes the CNAgent classes in detail showing their attributes and behavioral methods.

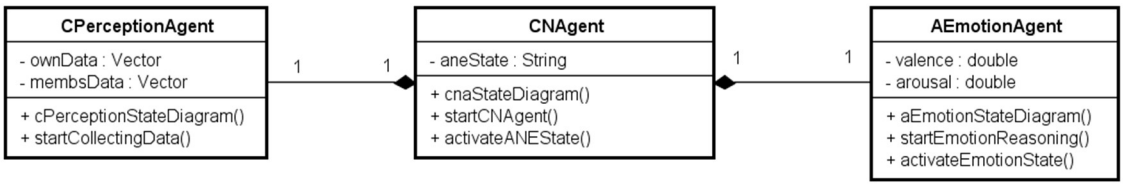



**Figure 4.40. UML class diagram of the CNAgents and sub-agents.**

### CNAgent

The CNAgent is characterized by the attribute representing the ANE state of the CN (aneState). This variable is dynamically updated according to the agent's behavior. This behavior is described in the state diagram of Figure 4.41.

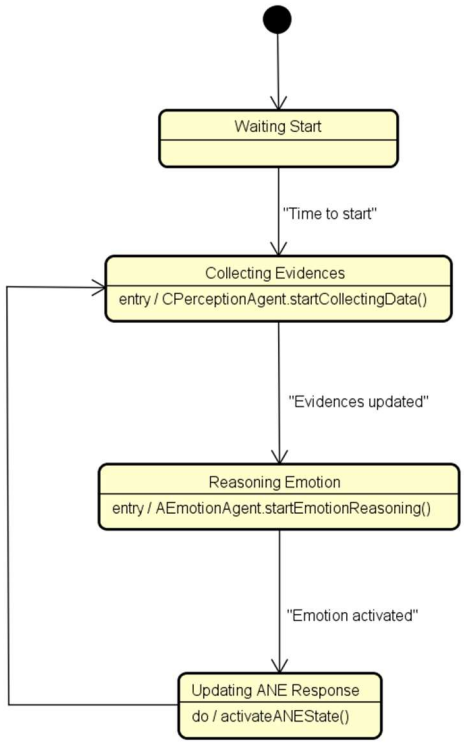



**Figure 4.41. State diagram of the CNAgent.**

The CNAgent's state diagram, which represents the *cnaStateDiagram()* method, can be described as follows:

1. The CNAgent waits for a request for starting its activity.
2. When it receives the "Time to start" triggering message, it informs the CPerceptionAgent to start collecting data for the evidences vector. Then, it remains in the state of collecting evidences until receiving an acknowledgement of "evidences updated" from the CPerceptionAgent.
3. Subsequently, it enters in the state of the emotion reasoning and informs the AEmotionAgent that it is time to start its activity. It remains in this state until receiving a message informing that the aggregated emotion has been activated.
4. Finally, the ANE state (*aneState*) of the CNAgent is updated and the agent returns to the state of collecting evidences.

**CPerceptionAgent**

The CPerceptionAgent is characterized by the following attributes: a vector containing the data that is collected from the CN (ownData) and a vector that includes the data related to the actual information about the CN member's IMEs (membsData).

The continuous update of these variables is done via the agent's behavior. This behavior is represented in the state diagram of Figure 4.42.

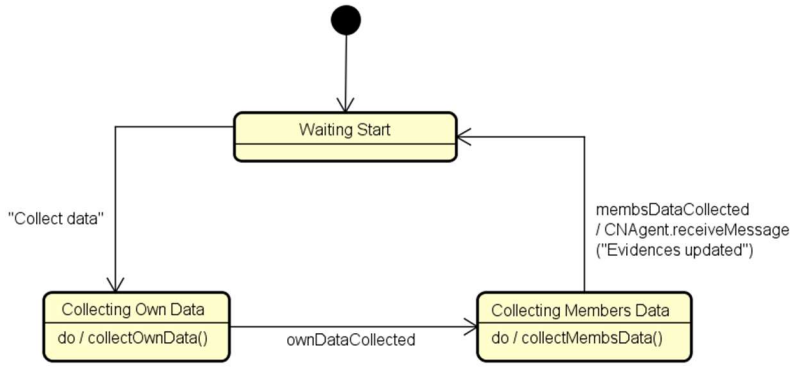



**Figure 4.42. State diagram of the CPerceptionAgent.**

The CPerceptionAgent's state diagram, which represents the *cPerceptionStateDiagram()* method, can be described as follows:

1. The initial state of the CPerceptionAgent is waiting to start the perception actions.
2. When it receives a message to collect data, it enters in the collecting own data state which main task is to update the own data vector with the latest information present in the database (see section 4.2.1). At the end, it triggers the condition *ownDataCollected*.
3. Then the agent enters in the state of collecting the IME states of all individual members. When it finishes, the agent triggers the condition *membsDataCollected* and informs the CNAgent sending the message "Evidences updated".
4. Finally, it returns to the initial state and waits for further execution messages.

**AEmotionAgent**

The AEmotionAgent is the "brain" agent and is characterized by the following attributes: valence and arousal. Its behavior is described in the state diagram of Figure 4.43.

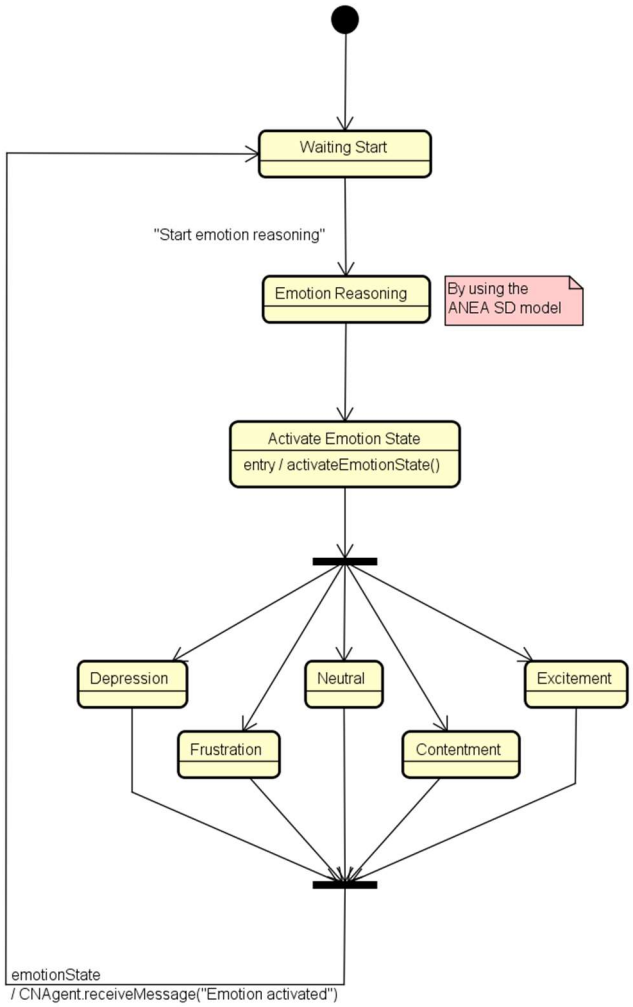



**Figure 4.43. State diagram of the AEmotionAgent.**

The AEmotionAgent's state diagram, which represents the *aEmotionStateDiagram()* method, can be described as follows:

1. The AEmotionAgent initial state is waiting for the trigger message to start.
2. Then the agent enters in the emotion reasoning state and starts executing the ANEA SD model (see section 4.1.1.2). The ANEA SD model result is the update of the agent's state variables valence and arousal.
3. These variables are then used in the *activateEmotionState()*, which is described in Figure 4.37, in order to select and activate the corresponding aggregated emotion state.
4. Finally, the AEmotionAgent sends the message "Emotion activated" to the CNAgent, acknowledging that the current aggregated emotion has been estimated and activated, and returns to the initial state.

#### 4.1.2.2.2 *Agent's Interactions*

The overall view about the agent's interactions is given in the sequence diagram of Figure 4.44.

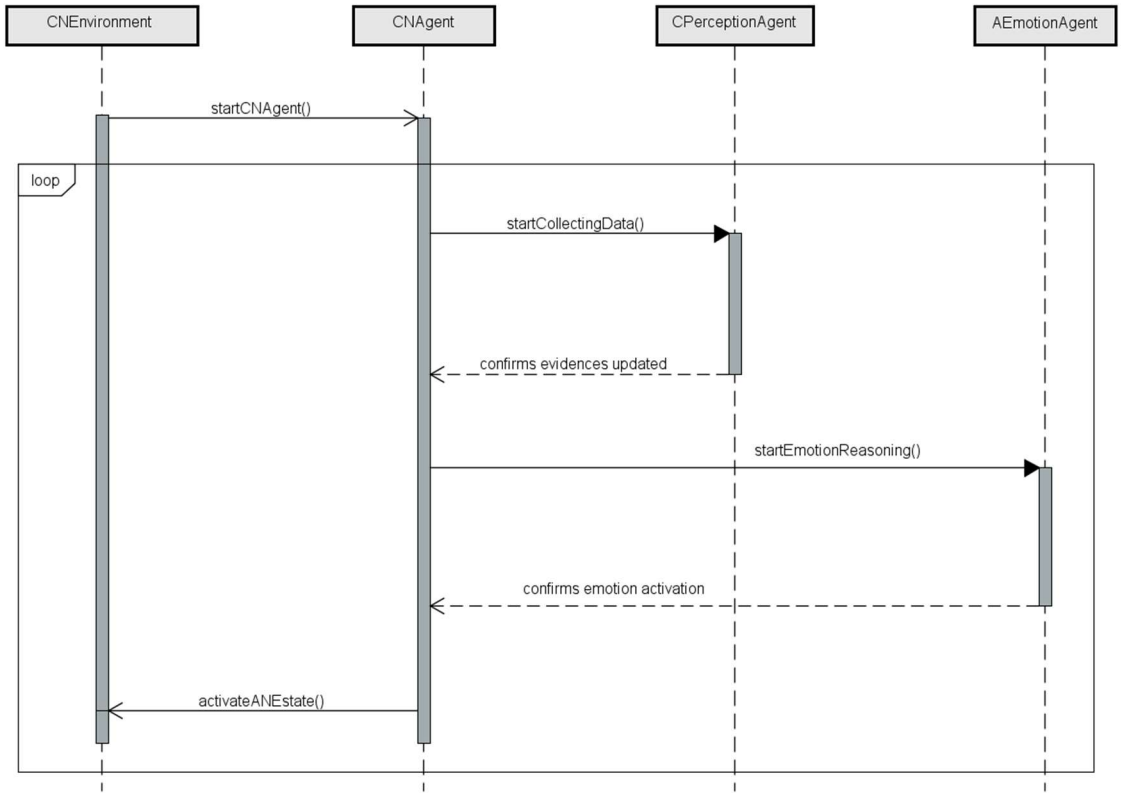



**Figure 4.44. UML sequence diagram illustrating the CN agent's interactions.**

The sequence begins with the CNEnvironment requesting the CNAgent to start running. Then a loop sequence is initiated. The CNA agent interacts with the CPerceptionAgent, requesting to start collecting the data and waits for the confirmation that the data were updated. Once the confirmation is received, the CNA agent requests the start of the emotion reasoning to the AEmotionAgent and waits for the confirmation of the emotion activation. Finally, after receiving that confirmation, the CNA agent informs the CN environment of its new ANE state.

## 4.2 C-EMO Implementation

The simulation model is implemented using the AnyLogic modeling software. This simulator intends to execute the C-EMO agent-based model and to mimic a CN

environment comprising several individual members geographically distributed. In addition, AnyLogic allows a graphical interface-based construction of hybrid simulation models which can be enriched by Java code blocks. It supports the development of component based simulation frameworks, such as the components of the C-EMO framework. E.g., the ANEA SD and IMEA SD models, and the involving agent's behaviors. It approaches software and model development from an object-oriented perspective and includes facilities for implementing models based on UML conventions, such as state charts, inheritance, and transition diagrams (Borshchev, 2013).

The implementation of the framework features generic interfaces and abstract classes with pre-implemented basic functionality. Any agent based model in Anylogic, is hierarchical and has at least two classes: the top-level class (that in our case is the CNEnvironment class) that contains the collection of *members* (from IMAgent class) and the *CN* (from the *CNAgent* class). Agents might exist as single instances, such as the CNAgent, or a replicated object (a collection of multiple objects of the same type – i.e. the collection of IMAgents representing the members), which are embedded, in this case, into the CNEnvironment class as depicted in Figure 4.45. C-EMO agent classes do not inherit directly from the AnyLogic's *ActiveObject* class; they are subclasses of the class *Agent*, which extends *ActiveObject* with features specific for ABM.

Another interesting feature, which fits the purpose of this work, is that these AnyLogic models can be reusable and/or customizable in accordance to the specificities of each CN. This means that both the IMEA SD and ANEA SD models might be easily adjustable and customized, taking into consideration the nature of the specific CN to be simulated.

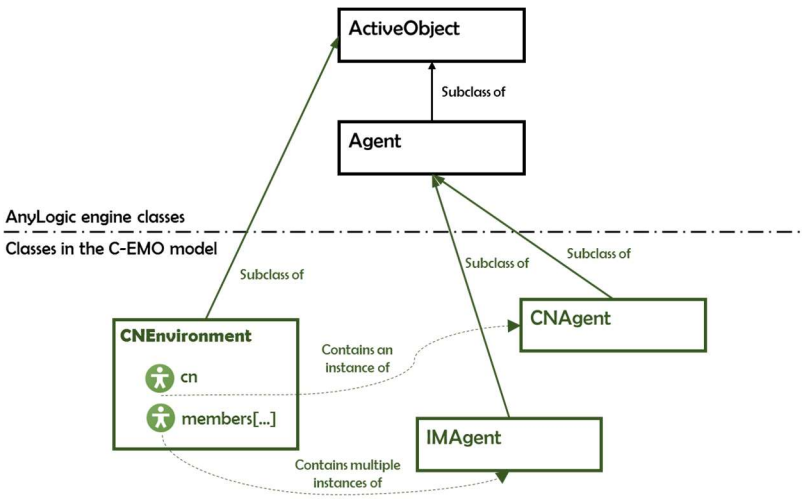



**Figure 4.45. UML diagram of the C-EMO agent-based model in AnyLogic. (Based on (Borshchev, 2013)).**

In summary, the implementation of the simulation model is based on a set of technologies that are described in Table 4.12.

**Table 4.12. Technologies used in the C-EMO simulation model.**

| *Technology* | *Purpose* |
|---|---|
| **AnyLogic 7.0** | Graphical interface-based multimethod simulation tool |
| **Java** | Programming language |
| **MySQL Workbench 6.0** | Workbench for object-relational database management system (ORDBMS) |

### 4.2.1 Database Tables

The information tables designed for supporting the database schema for the C-EMO simulation model are based on the information specified in the C-EMO framework. Figure 4.46 illustrates the corresponding enhanced entity-relationship (EER) model of the designed database.

The data can be categorized into eight groups:

- **CN related data**. Information necessary to identify the CN and the members/organizations that make part of it. In this case only the information that regards the emotion part is considered, nevertheless it is possible to add or remove more data fields. This information is reflected in the *collaborative_network* and *member* tables respectively.
- **VO related data**. Information about the VOs that are available in the CN environment and their involved members. Similar to the previous category, the information that is considered here is the one related to the emotional perspective. This information is stored in the tables *vo* and *vo_has_member*.
- **CNE related data**. Contains information about the collaborative network emotional (CNE) state. It includes the type of CNE and also the specific values for the tuple (valence, arousal). The tables containing this information are: *cne_state* and *cne*.
- **Events related data**. Refers to the events that might occur in the CN environment. Some events happen at the CN level and other events are specific to each member. This information is stored in the tables: *cn_event* and *member_events*.

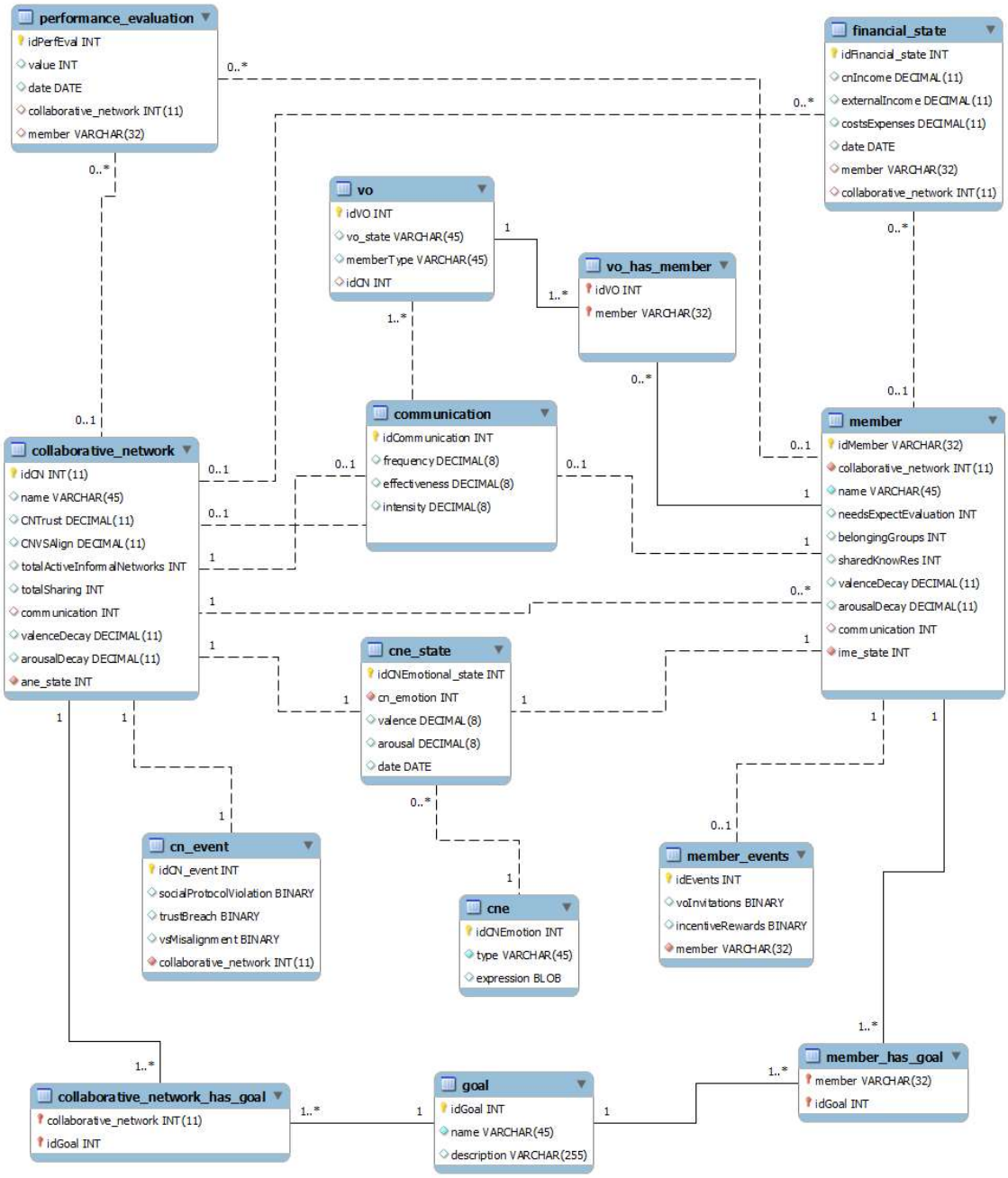



**Figure 4.46. EER diagram for the C-EMO simulation model DB.**

- **Goals & motivation related data**. Information provided by each intervenient regarding the objectives that are strived to achieve. This represents the goals that are used in the design of the ANEA SD model and the IMEA SD model. This information is stored in the following tables: *goal*, *member_has_goal* and *cn_has_goal*.

- **Financial data**. Refers to the information that is related to the financial state both from the CN and from each member. These data are stored in the *financial_state* table. In the case of a not for profit network, this table is not instantiated.
- **Communication related data**. Stores data related to the communication indicators within the CN. These data is kept in the *communication* table.
- **Performance related data.** Contains the information regarding the evaluation conducted both to the CN and its members. This information is stored in the *performance_evaluation* table.

### 4.2.2 Setting the CN Environment

The initial implementation step is performed by embedding the CNAgent as a single instance (represented by the agent variable *cn*) and the IMAgent as multiple instances (represented by the population of agents *members[..]*) creating in this way the CN environment, as illustrated in the top left corner of Figure 4.47. Whenever an agent type is embedded, its presentation properties might become visible in the upper level class (in this case in the CN Environment) if the modeler wishes. In the case of our agents the presentation properties that are allowed to be visible are icons that were considered to express their emotional state. In Figure 4.47, the big icon of the right side of the CN "bubble" represents the CN agent, while the other icons within the CN represent the IMA agents. As can be seen in the same figure, there are an agglomerate of different icons in the same position, at this point they only represent one IMA agent. As it will be seen later, the different icons (which have different colors as well) represent the different IME states that the agent might have. This means that when running the simulation, only one colored icon (the one corresponding to the current IME state of the agent) is active, i.e. visible.

The population of members is dynamically created in runtime. This is done according to the number of members that are present in the database. Their "location" is also calculated in runtime and randomly, with the constraint of being located inside the CN "bubble", for visual reasons. At the beginning the colored icon of each individual member corresponds to the last updated IME state in the database as illustrated in Figure 4.48.

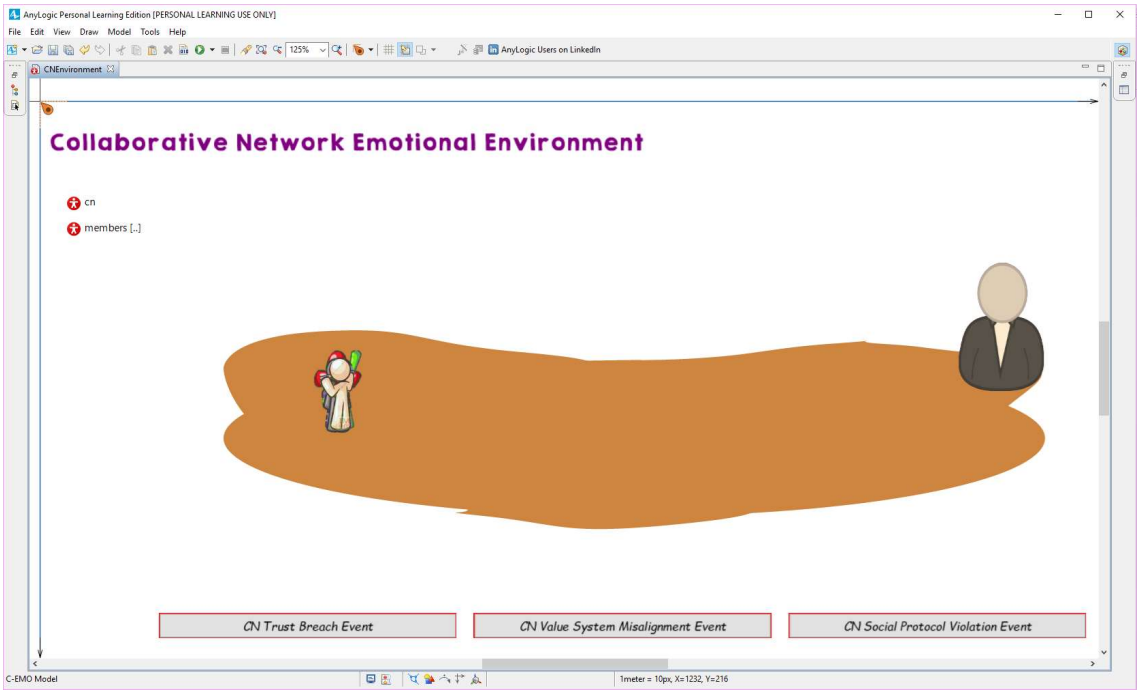



**Figure 4.47. Graphical interface of the implementation of the CNEnvironment in AnyLogic.**

The three buttons located at the bottom of the figure emulate the different events that might occur within the CN. They are the CN trust breach, the CN value system misalignment and the CN social protocol violation events. These events were described earlier on section 4.1.1.1.

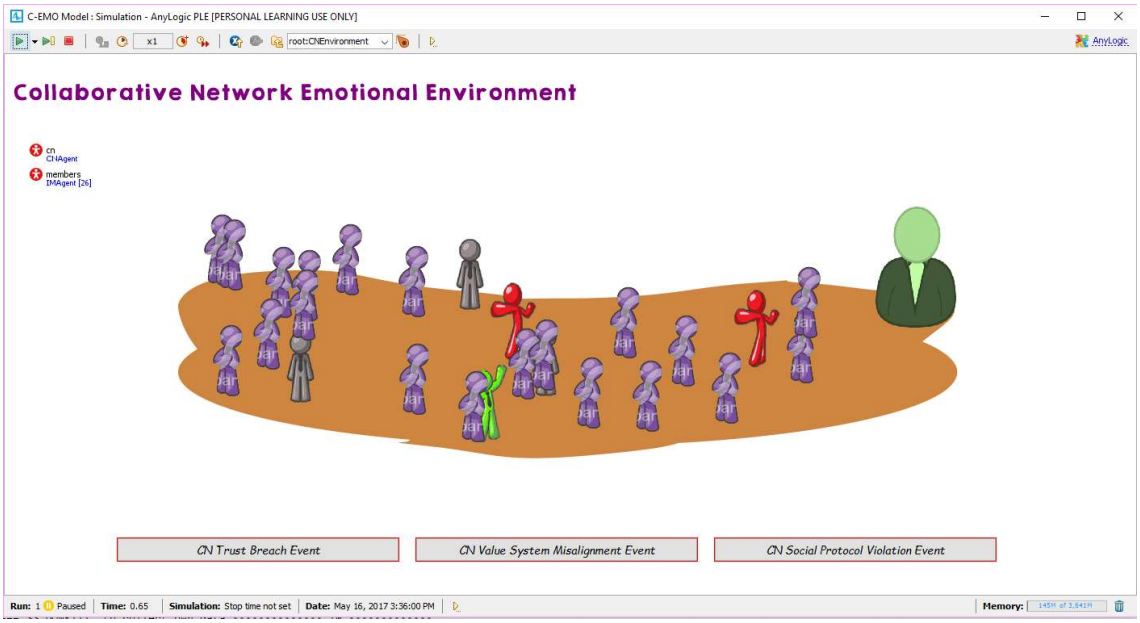



**Figure 4.48. Screenshot of the CN environment in simulation run.**

### 4.2.3 Implementation of the IMAgent

Figure 4.49 illustrates the graphical interface of the implementation of the IMAgent. On the top left corner, are placed the agent colored icons (the ones that are visible in the CN environment) that represent the individual member's different IME states. The IMAgent variables are situated on the left side. Some of these represent the IMAgent attributes (*memberName* and *imeState*), others represent the agent location, by defining its coordinates ($x$, $y$), and the member ID that is assigned to this member in the database (*memberID*). As the IMAgent aggregates the IPerceptionAgent and the IEmotionAgent, their classes are also embedded here and represented by *iPerceptionAgent* and *iEmotionAgent*, respectively. In the center of the figure it is placed the state diagram that rules the behavior of the IMAgent. The interactions of the IMAgent with the IPerceptionAgent and the IEmotionAgent are emphasized with the graphical icons of each one.

The IMAgent is created in runtime and its variables are affected with the corresponding member's latest information available in the database. Figure 4.50, illustrates the screenshot of two IMAgents. One represents the "Quality Company" and the other the "Larsen & Toubro Limited" members of the CN. There, it is visible that the agent variables are distinct for each IMA agent. For instance, besides the *memberName* being different, the *imeState* of the first is frustration, while the second is contentment. In runtime agent state is also visible. The active state is highlighted in bold with the red color. In this case both agents are in the evaluating emotion state.

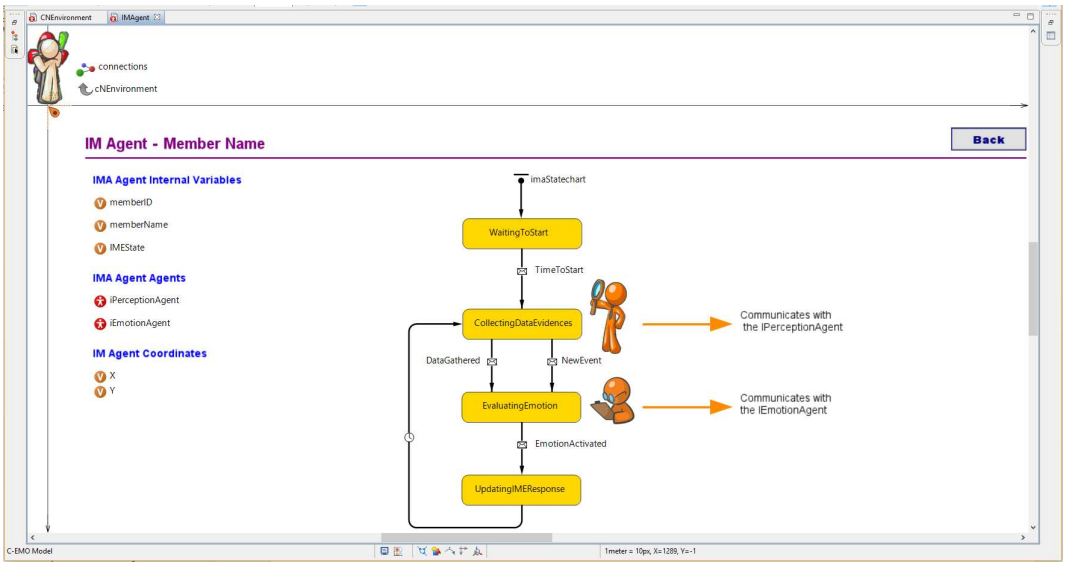



**Figure 4.49. Graphical interface of the implementation of the IMAgent in AnyLogic.**

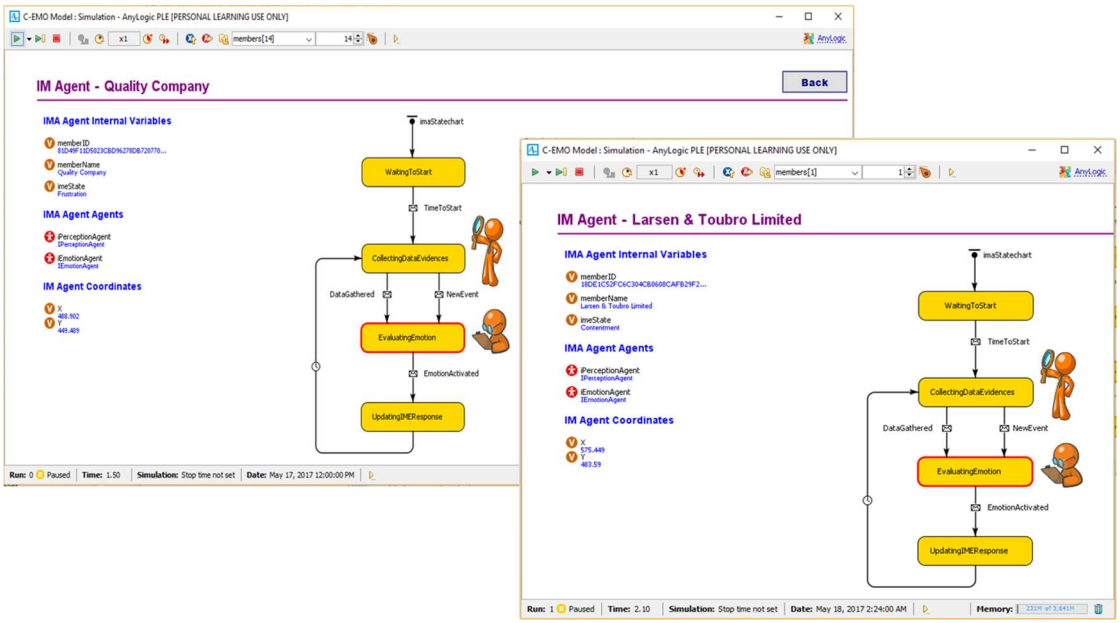



**Figure 4.50. Screenshot of two IMAgents in simulation run.**

Figure 4.51 illustrates the graphical interface of the implementation of the IPerceptionAgent. On the top left corner, it can be found the agent icon that represents the IPerceptionAgent. The IPerceptionAgent parameters that represent the agent attributes, are situated at the bottom. On the top left side of the figure it is placed the state diagram that rules the behavior of the IPerceptionAgent. On the top right side, there are two buttons that emulate the events that occur specifically in this agent. They are the invitation to form VOs and the incentive reward events. These events were described earlier in section 4.1.1.1.

Figure 4.52 illustrates the IPerceptionAgent from the IMAgent that represents the "Quality Company" in runtime. At the time this snapshot was taken, the IPerceptionAgent state was "waiting to start". The values of its attributes are shown in the evidences vector.

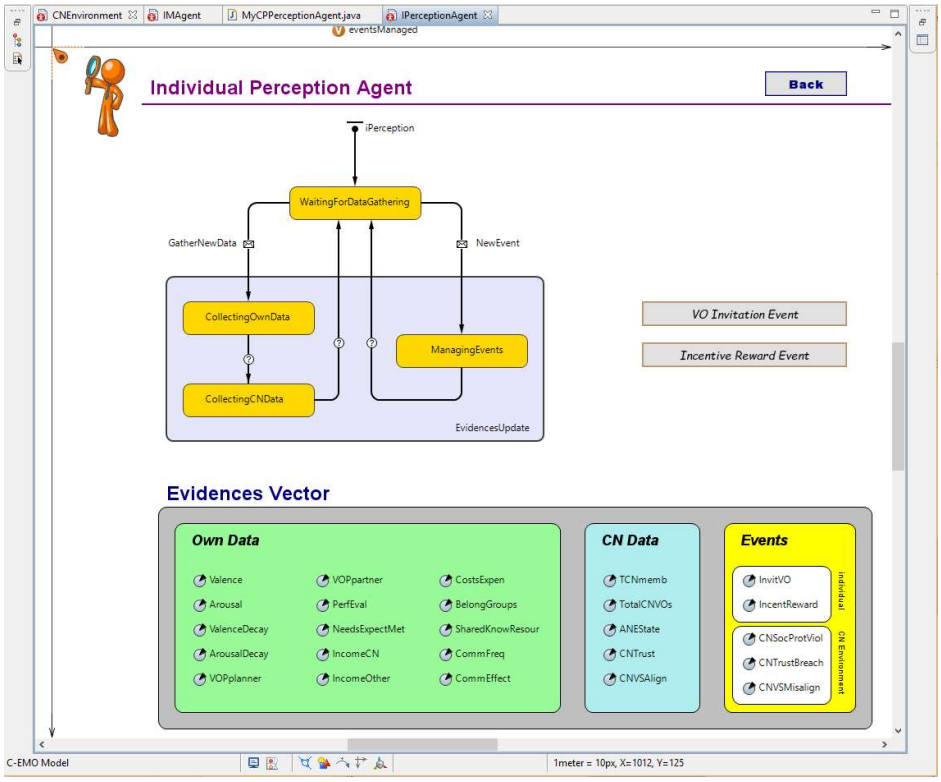



**Figure 4.51. Graphical interface of the implementation of the IPerception agent in AnyLogic.**

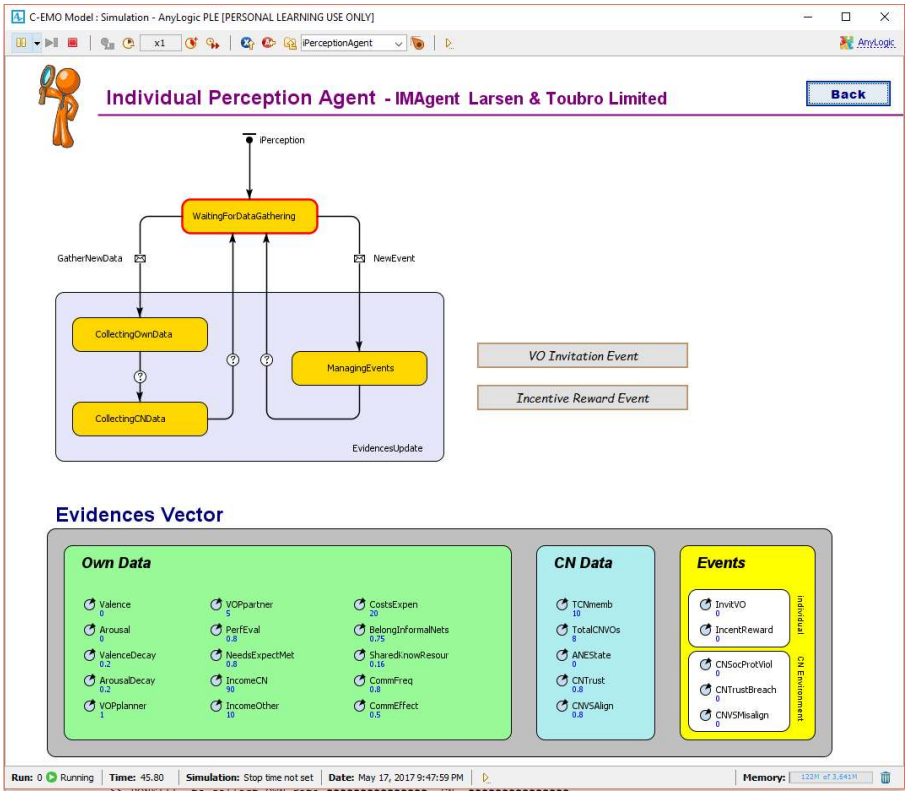



**Figure 4.52. Screenshot of the IPerceptionAgent in simulation run.**

Figure 4.53 illustrates the graphical interface of the implementation of the IEmotionAgent. On the top left corner, it can be found the agent's icon that represents the IEmotionAgent. The IEmotionAgent variables constitute the agent attributes *valence* and *arousal* and also the *emotionState* variable that represents the current emotional state taking into consideration the valence and arousal dimensions. On the left side of the figure, it is placed the state diagram that rules the behavior of the IEmotionAgent. At the bottom, a button with a link to the visualization of the IMEA SD model is available. This means that in runtime the user is allowed to visualize the IMEA SD model dynamics as it will be seen below. On the right side there is the implementation of the *activateEmotionState()* action chart (see Figure 4.37). The arrows illustrate the flow of activity on each agent state. When the IEmotionAgent is in the state of "appraising emotion" it is in fact running the IMEA SD model. Whereas in the state of "activating the emotional" state it is applying the corresponding action chart in order to enter in the right state of emotion expression.

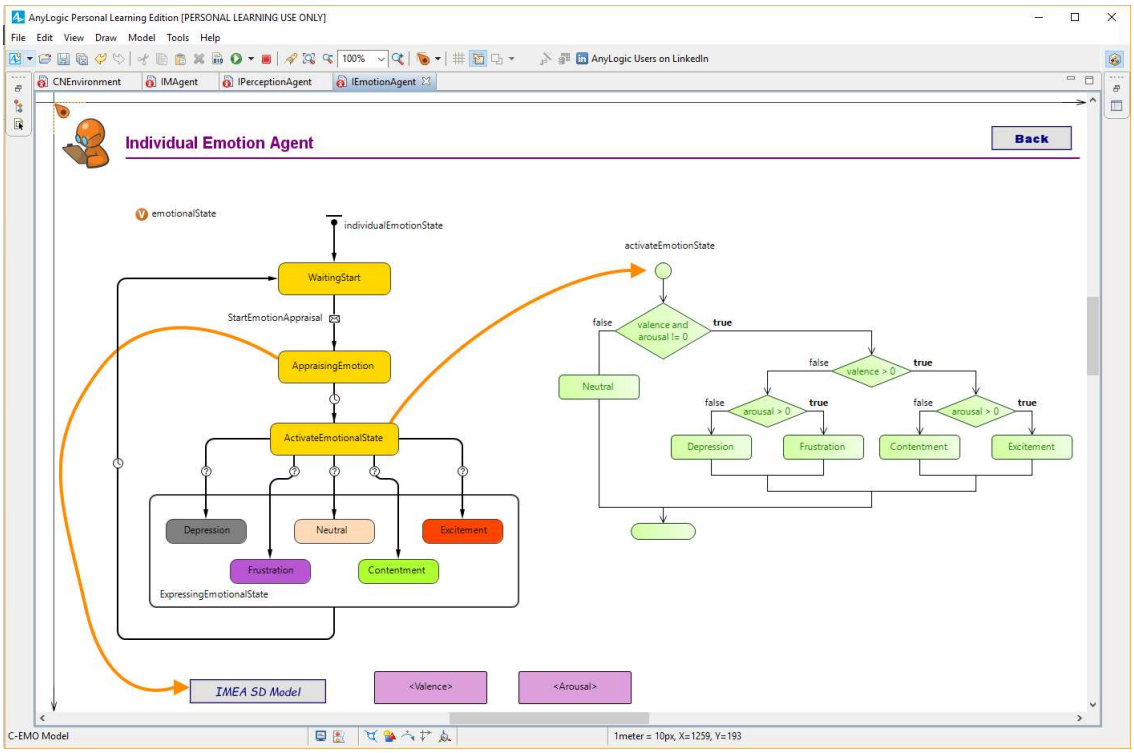



**Figure 4.53. Graphical interface of the implementation of the IEmotionAgent in AnyLogic.**

Figure 4.54 shows the IEmotionAgent of the IMAgent that represents the "Larsen & Toubro Limited" in runtime. At the moment of this snapshot, the IEmotionAgent state was "appraising the emotional state" of the member. The values of the variables

*emotionalState*, *valence* and *arousal* indicate the emotion appraisal that was done before the current state of the agent. In other words, taking into consideration that the agent's state at the current moment is "appraising emotion" this means that at this moment the new values of the variables are being determined. Thus the values that the user sees correspond to the previous emotion appraisal.

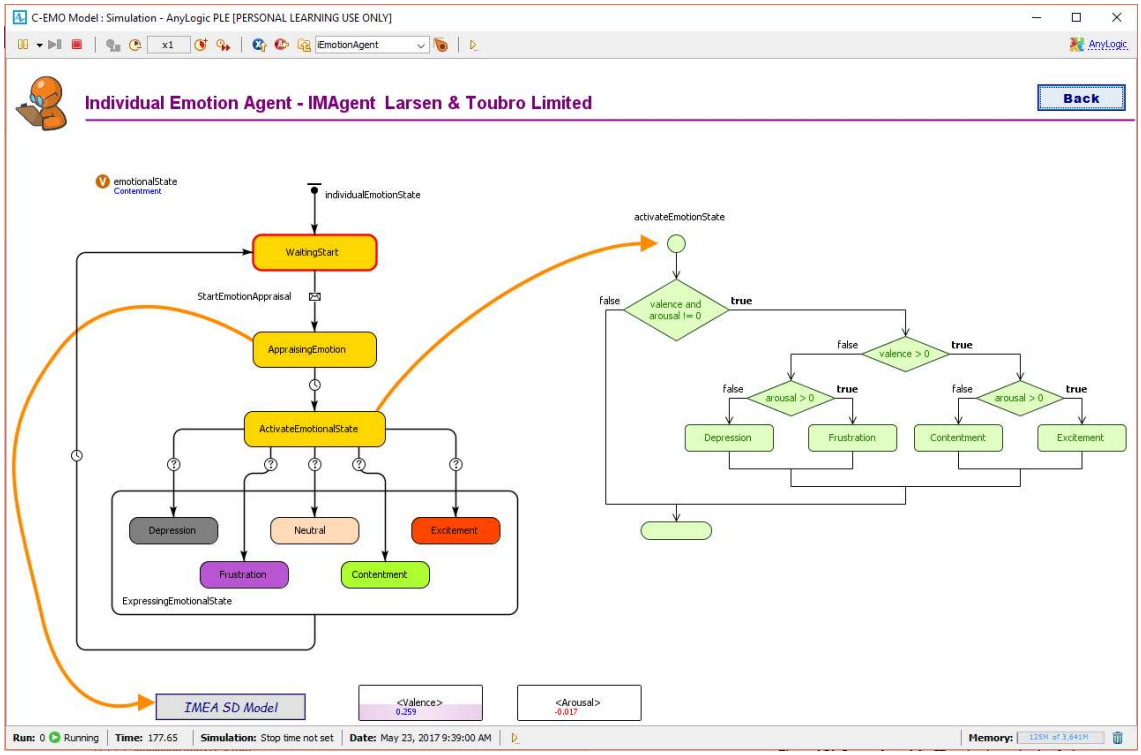



**Figure 4.54. Screenshot of the IEmotionAgent in simulation run.**

Finally, Figure 4.55 and Figure 4.56 illustrate the implemented IMEA SD model and the screenshot of the model in runtime, respectively.

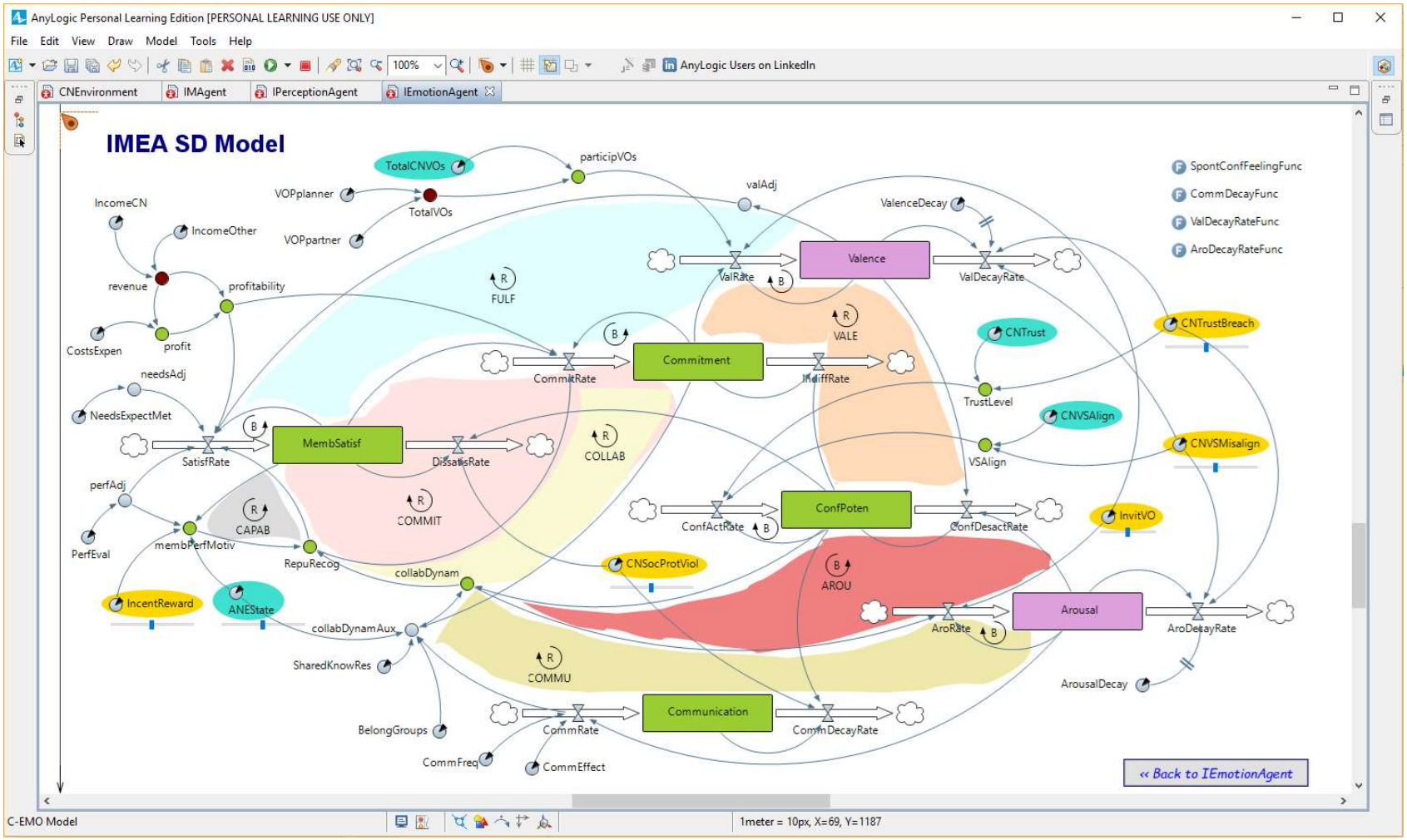



**Figure 4.55. Graphical interface of the implementation of the IMEA SD model.**

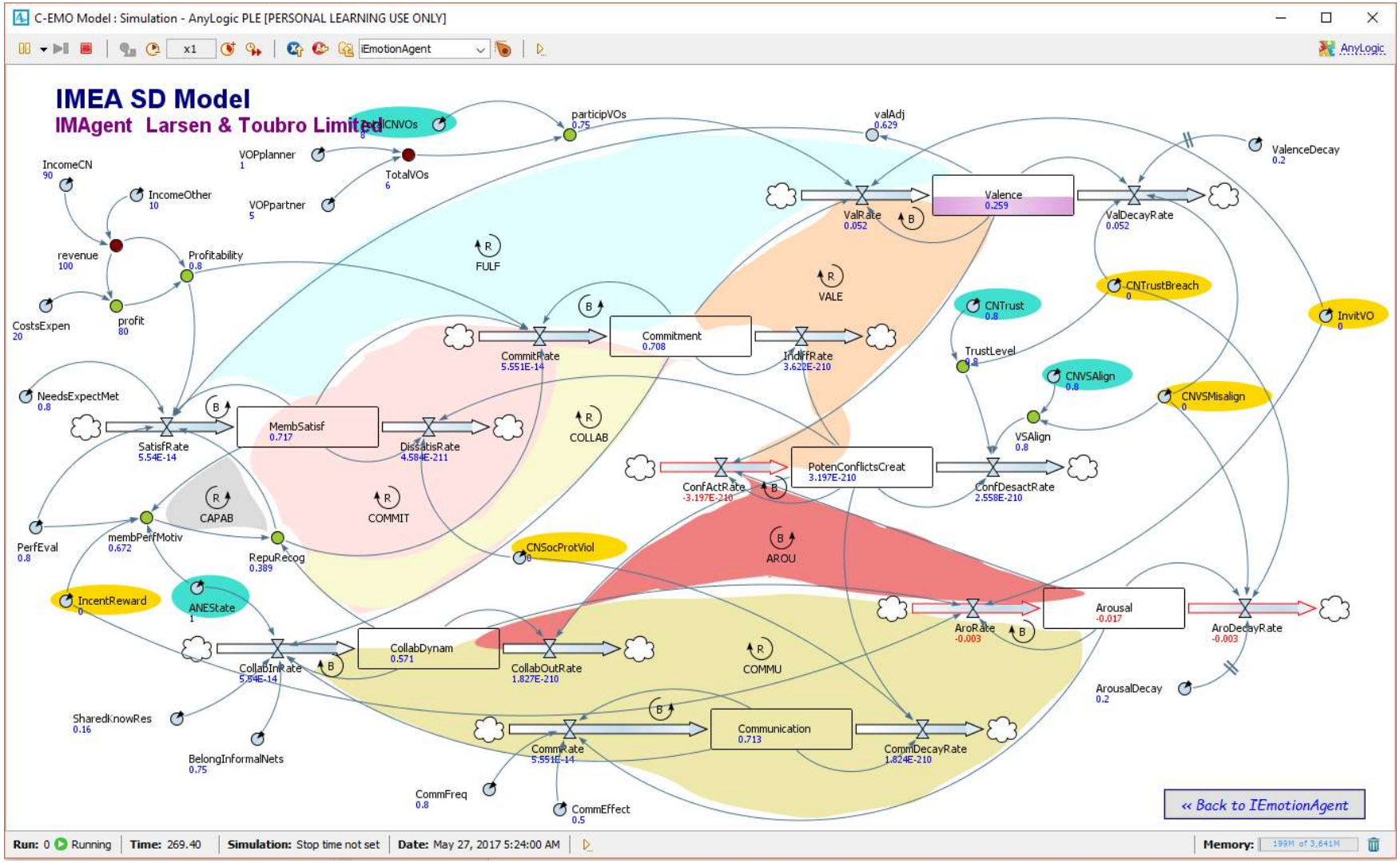



**Figure 4.56. Screenshot of the IMEA SD Model in simulation run.**

### 4.2.4 Implementation of the CNAgent

Figure 4.57 shows the graphical interface of the implementation of the CNA agent. On the top left corner, is placed the graphical icon that represent the CNAgent. This icon might have different colors taking into consideration the different ANE states. The CNAgent variables are situated on the left side. One of them represents the CNAgent's attribute (*aneState*), and the others represent the agent's location by defining its coordinates (*x*, *y*). As the CNAgent aggregates the CPerceptionAgent and AEmotionAagent, their classes are also embedded in this agent's class and are represented by *cPerceptionAgent* and *aEmotionAgent*, respectively. In the center of the figure it is placed the state diagram of the CNAgent behavior. The interactions of the CNAgent with the CPerceptionAgent and the AEmotionAgent are emphasized with the corresponding graphical icons.

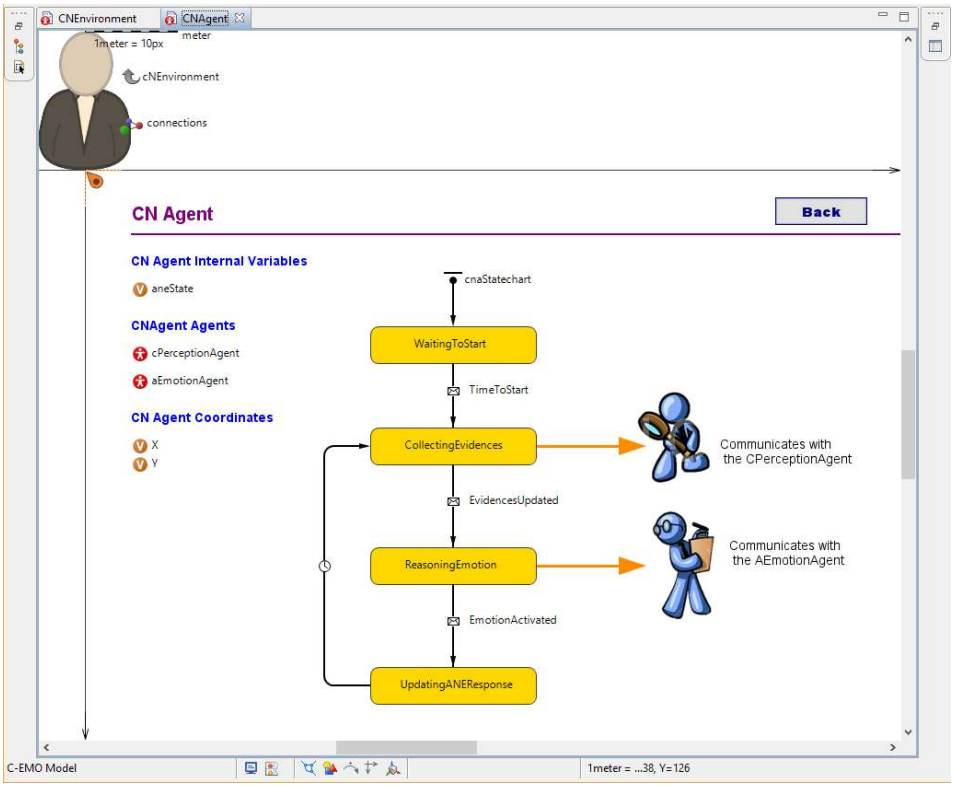



**Figure 4.57. Graphical interface of the implementation of the CNAgent in AnyLogic.**

The CNAgent is created at the start of the runtime and its variables are affected with the corresponding CN's latest information available in the database. Figure 4.58, illustrates a screenshot of the CNAgent. The agent variables are affected with their

current values and the CNAgent state, at the moment of the screenshot, is "collecting evidences" because it is the state that is in bold and with a red color.

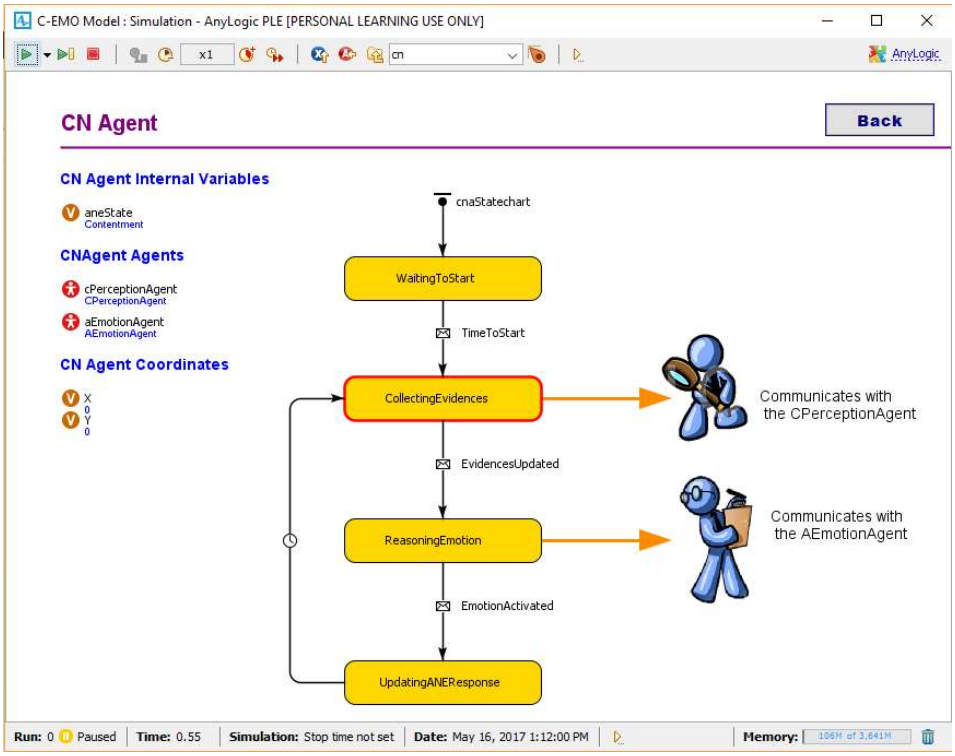



**Figure 4.58. Screenshot of the CNAgent in simulation run.**

Figure 4.59 illustrates the graphical interface of the implementation of the CPerceptionAgent. On the top left corner, it can be found the agent icon that represents the CPerceptionAgent. The CPerceptionAgent parameters, that represent the agent attributes, are situated at the bottom. On the top of the figure it is placed the state diagram of the CPerceptionAgent's behavior.

Figure 4.60 illustrates the CPerceptionAgent of the CNAgent in runtime. At the time this snapshot was taken, the CPerceptionAgent state was "collecting members' data". The values of its attributes are shown in the evidences vector.

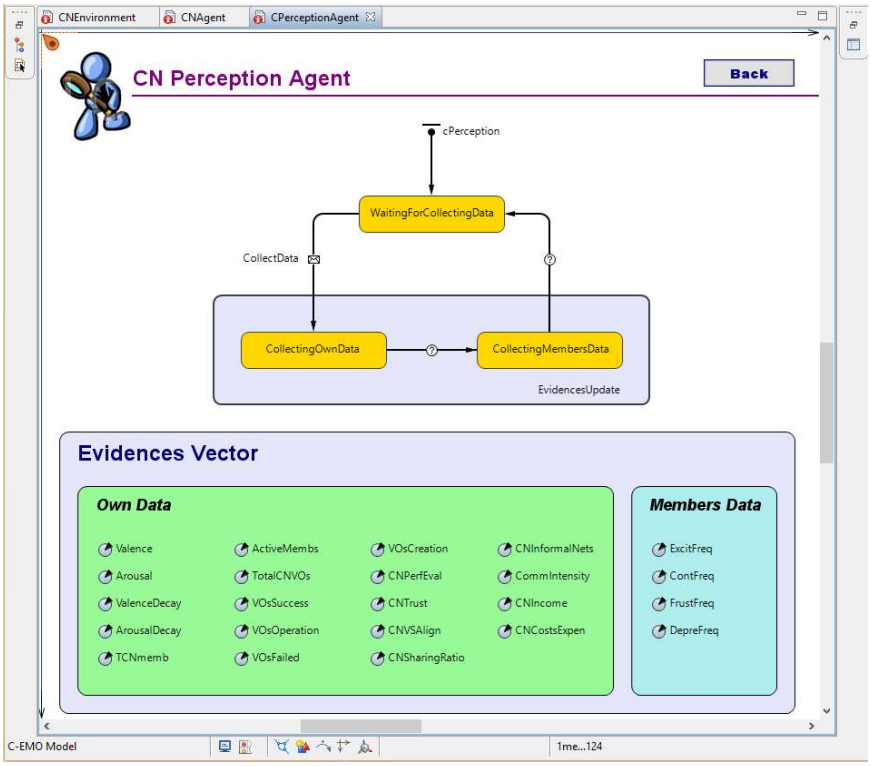



**Figure 4.59. Graphical interface of the implementation of the CPerceptionAgent in AnyLogic.**

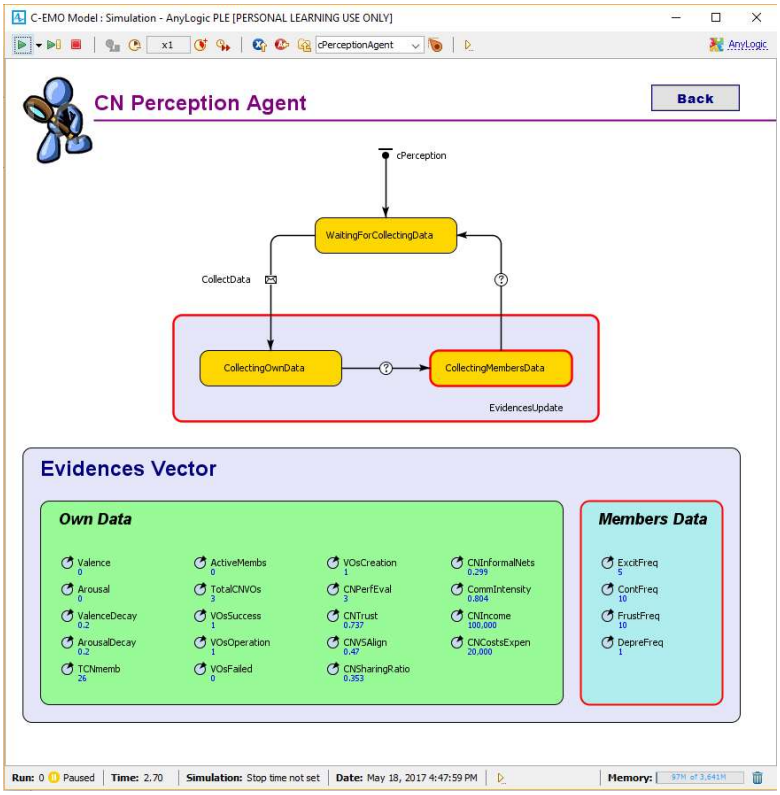



**Figure 4.60. Screenshot of the CPerceptionAgent in simulation run.**

Figure 4.61 shows the graphical interface of the implementation of the AEmotionAgent. On the top left corner, it can be found the graphical icon that represents the AEMotionAgent. The AEmotionAgent's variables constitute the agent's attributes *valence* and *arousal*, and also the *emotionState* variable that represents the current aggregated emotional state taking into consideration the valence and arousal dimensions. On the left side of the figure, it is placed the AEmotionAgent's state diagram. At the bottom, a button with a link to the visualization of the ANEA SD model is available. This means that in runtime the user is allowed to visualize the ANEA SD model dynamics as it will be seen below. On the right side there is the implementation of the *activateEmotionState()* action chart (see Figure 4.37). The arrows illustrate the flow of activity on each agent's state. When the AEmotionAgent is in the state of "reasoning the aggregated emotion" it is in fact running the ANEA SD model. When it is in the state of "activating the aggregated emotional state" it is applying the corresponding action chart in order to enter in the right state of aggregated emotion expression.

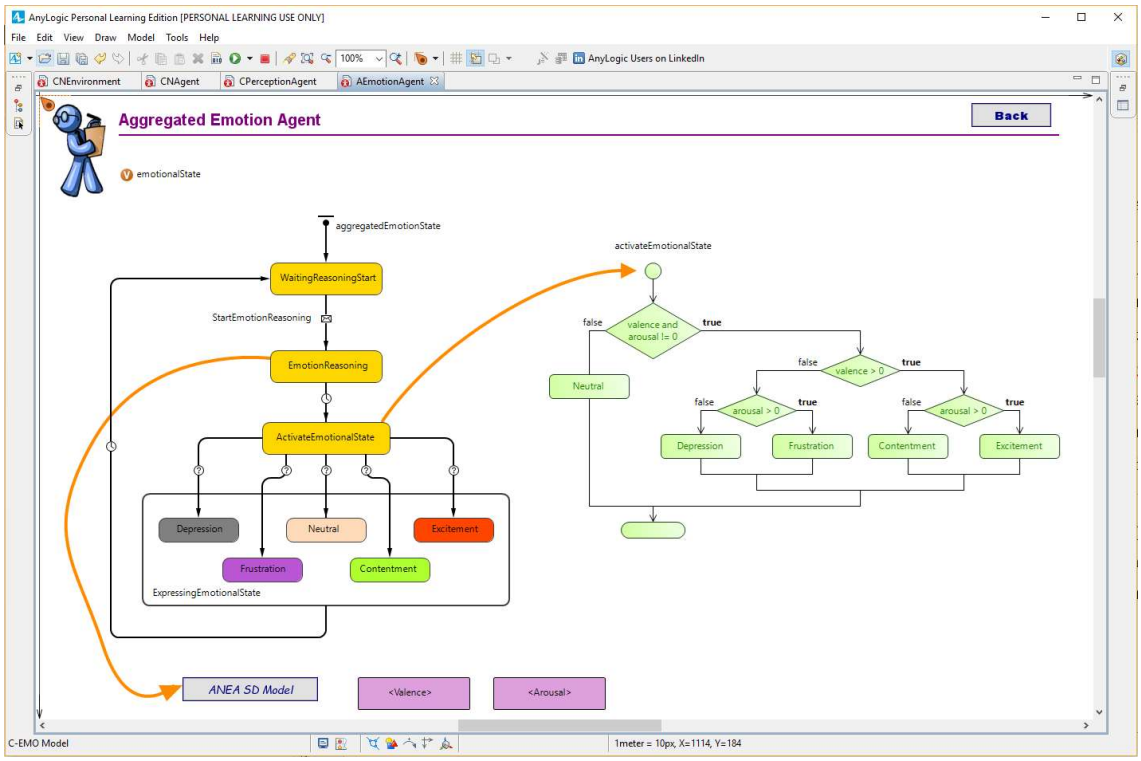



**Figure 4.61. Graphical interface of the implementation of the AEmotionAgent in AnyLogic.**

Figure 4.62 shows the AEmotionAgent of the CNAgent in runtime. At the moment of the snapshot, the AEmotionAgent was in the state "waiting to start".

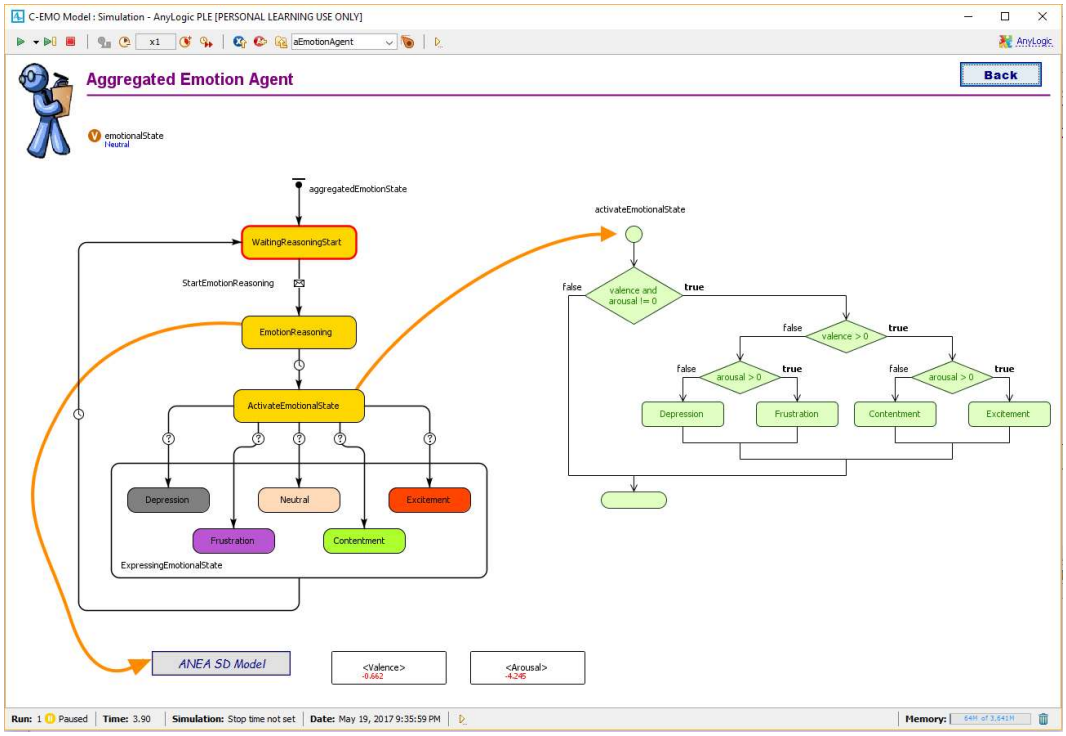



**Figure 4.62. Screenshot of the AEmotionAgent in simulation run.**

Figure 4.63 and Figure 4.64 illustrate the implemented ANEA SD model and the screenshot of the model in runtime, respectively.

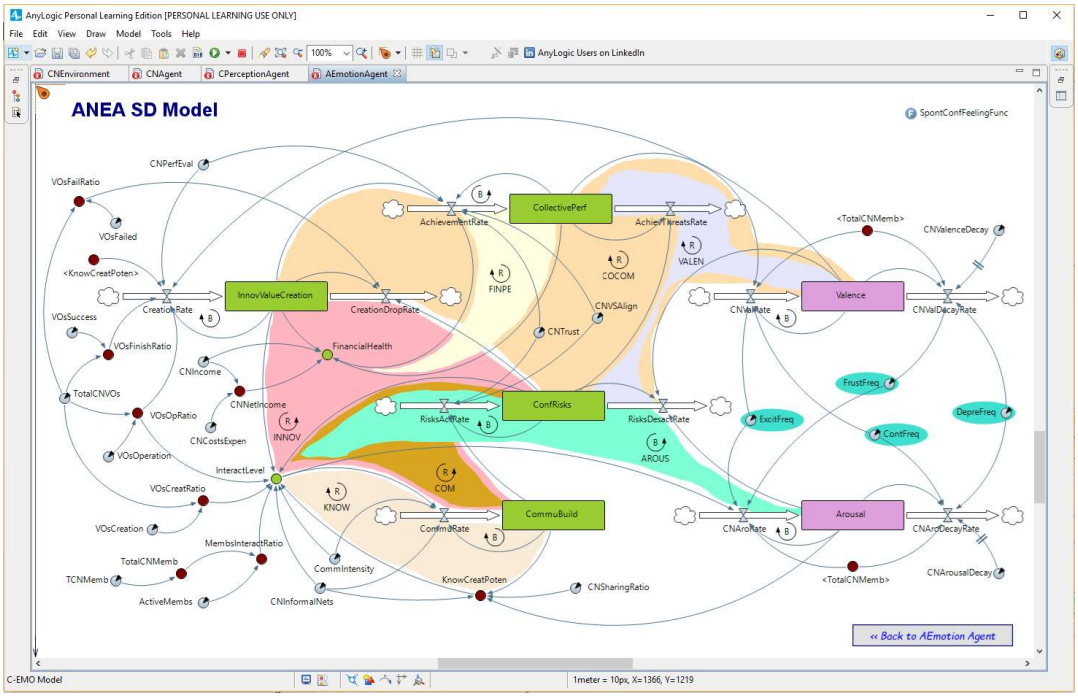



**Figure 4.63. Graphical interface of the implementation of the ANEA SD model.**

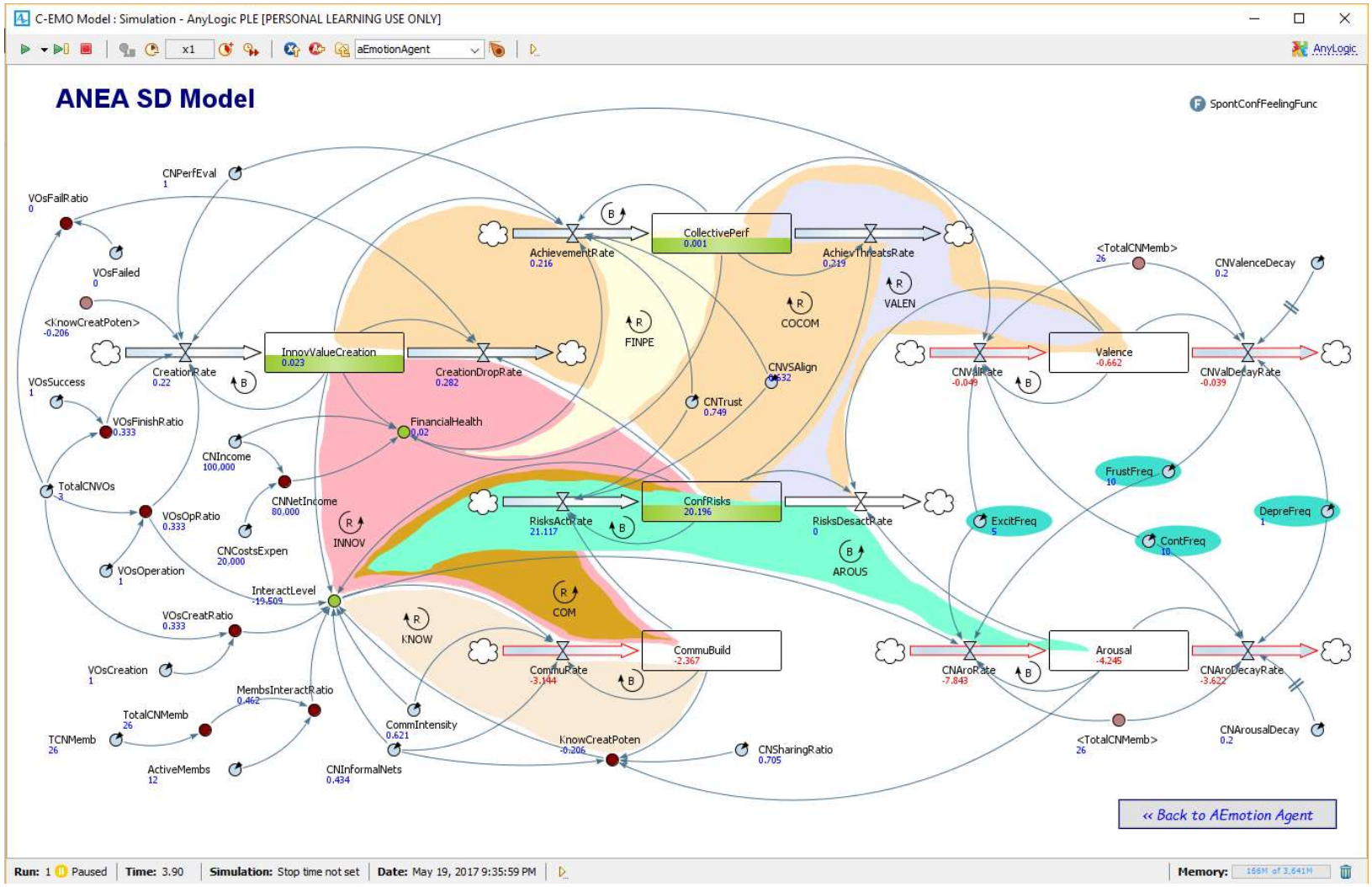



**Figure 4.64. Screenshot of the ANEA SD model in simulation run.**

## 4.3 Brief Summary

This chapter introduced the C-EMO simulation model, which is the proposed modeling approach to materialize the C-EMO framework. In this line, it is a way to validate the proposed hypotheses of the RQ2. The development of this simulation model allows an assessment of the usability of the proposed C-EMO modeling framework and a verification that the conceptual models proposed might be applied in future works.

The adopted simulation modeling process for the development of the C-EMO simulation model was the one presented earlier on section 3.4. This simulation model was modeled and implement with the system dynamics and agent-based modeling and simulation techniques.

The system dynamics methodology was the one used to model the IMEA and ANEA components of C-EMO framework (see Figure 3.18), designing the IMEA SD and ANEA SD models, respectively. An exhaustive description of these models was performed and is present in sections 4.1.1.1 and 4.1.1.2, correspondingly.

The agent-based methodology, on its turn, was used to model the abstraction of the CN environment and its players. A comprehensive description of the involved agents and the way they were modeled is present in section 4.1.2.

Finally, the implementation aspects of the C-EMO simulation model are presented (section 4.2). This implementation uses the AnyLogic multi-method modeling software. Moreover, the first set of simulation verifications is conducted during the execution of the implemented models, and the first calibrations are done.

In the next chapter a more structured validation process is presented (section 5.2.2.2), with the development of validation scenarios and the sensitivity analysis of the simulation results.

# 5

# Prototype Development and Validation

*This chapter presents the developed emotion support system prototype and the validation processes for both the emotion support prototype and the C-EMO modeling framework. It, starts with an overview of the methodological approach that was taken in the context of the GloNet project and the description of the different implementation phases. Then, the validation strategy for this research work is presented. It comprises four validation aspects: a) validation of the C-EMO modeling framework; b) validation of the C-EMO simulation modeling approach; c) validation of this work by the research community; and d) validation of the underlying concepts and prototype in the solar energy industry area.*

The concept of emotions within CNs was firstly introduced in the developments of the GloNet project (GloNet, 2011-2015) , with the intention of being a complementary solution for risks reduction in CNs. The idea behind the development of an emotion support system, besides being a mechanism to understand the relationship between the CN emotional status and the potential conflicts that might arise within the CN environment, is also to introduce the concept of collaborative emotions and assess its acceptance by the GloNet projects' end-users. The development of the emotion support system was carried out through three distinct iterations being the C-EMO framework, through the C-EMO simulation model, part of the solution of the improvement results of the first iteration. Section 5.1 is devoted to the description of this prototyping methodology.

The main challenge of this research work is that, due to its novelty, there is no substantial available information from collaborative networks and their respective

members that could be used to validate the proposed emotion modelling approaches. Furthermore, and concerning the awareness of this thesis author, there are not until now, other proposals concerning the study of emotions in a collaborative networked environment aiming at being non-intrusive. Therefore, the adopted validation process is twofold: (1) it passes from validating the concepts and the developed prototype in terms of its fitness-for purpose from the research community and feedback from a solar industry network and, (2) from evaluating the appropriateness of the C-EMO modeling framework through the deployment of the C-EMO simulation model and the simulation modeling approach with the elaboration of simulation scenarios.

## 5.1 Prototype Development Methodology

The first prototype of the collaborative emotional system was developed within the GloNet project and was presented to end-users with the aim to present the idea, validate its usefulness and feasibility, get some feedback, and find alternative approaches. As a result of this initial stage, the concept was well accepted by the potential end-users. Then the enhancement of the underlying emotional model (which in the first phase was modeled with basic linear rules) was a must. Having this in mind, a methodology based on the spiral approach from Boehm (1988) was adopted to proceed with the developments of the emotion support prototype as illustrated in Figure 5.1.

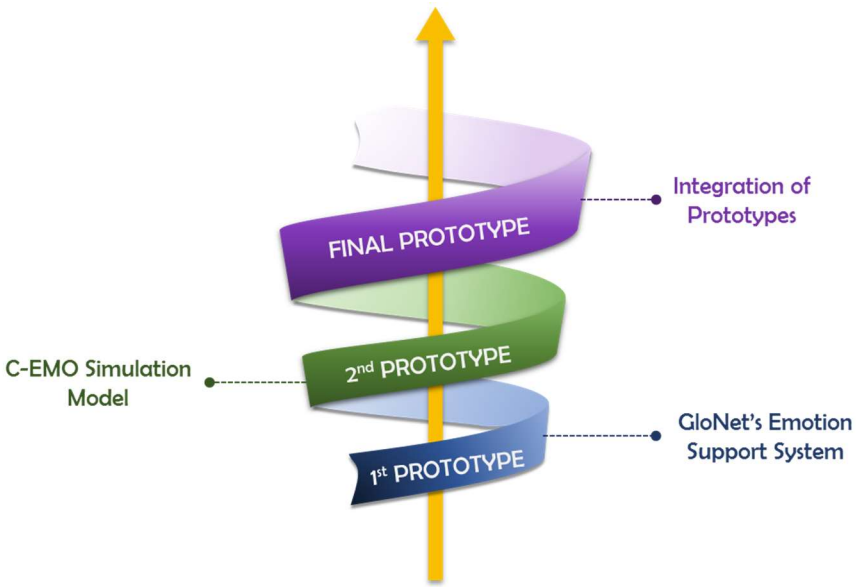



**Figure 5.1. Adopted spiral process development methodology.**

The approach comprises three iterations, corresponding to developing different prototype versions, adding in each iteration new planning and requirements, new or improved design of models, implementation of new or enhanced functionalities and finally new tests and validation processes. The first iteration is relative to the development of the initial emotion support system within the context of the GloNet project and is detailed in section 5.1.1. The second iteration corresponds to the development of the C-EMO simulation model, which is in fact, the core of this thesis work (section 5.1.2). Finally, the third iteration concerns the integration of the two previous prototypes and is presented in section 5.1.3.

### 5.1.1 Initial Prototype: GloNet Prototype

One of the requirements of the GloNet project was the creation of services to support risk reduction in collaborative consortia. In this line, an *Emotion Support System* was developed aiming at assessing the collaborative emotional state of the VBE/CN and thus creating a way to help in reducing risks in collaboration (Camarinha-Matos et al., 2015b; Ferrada & Camarinha-Matos, 2015; Camarinha-Matos et al., 2017). The emotion support system is divided in two components:

- *Member Emotion State Support* – which estimates the individual member's emotion (IME). It includes the management of relevant information of the member, such as its profile, and information from the VBE/CN, such as the events that occurred in the network or the aggregated network emotion state. This system also keeps a record with the past emotional states of the member.
- *Aggregated Emotion State Support* – which estimates the aggregated network emotion (ANE) of the VBE/CN. It includes the management of relevant information of the CN, such as its profile, and information from the participating members' emotional states. This system also keeps a record of the past aggregated network emotions.

Figure 5.2, shows the strategic rationale model of the member emotion state support component in i*. It shows the most relevant dependencies among the involving actors consisting of their goals, and details the internal tasks of the member's emotion state support element. For instance, the member's emotion state support depends on the VBE/CN management system to get information from the members' profile. This dependency is illustrated in the goal: *Get Member Profile*. On its turn, this information is requested by the member emotion state support's task: *Manage Member Profile*.

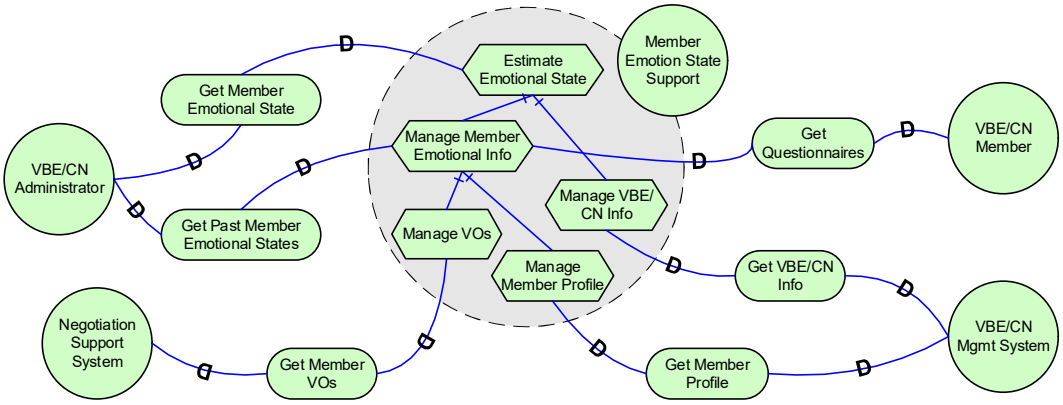



**Figure 5.2. i* Strategic rationale model for the member's emotion state support.**

Figure 5.3, presents the strategic rationale model of the aggregated emotion state support component. It shows the most relevant dependencies among the involving actors consisting of their goals, and details the internal tasks of the aggregated emotion state support element. For instance, the VBE/CN administrator depends on the aggregated emotion state support, via its task *Estimate Aggregated Emotional State*, to get the current status of the aggregated network emotion. This is illustrated in the goal-dependency: *Get Aggregated Emotional State*.

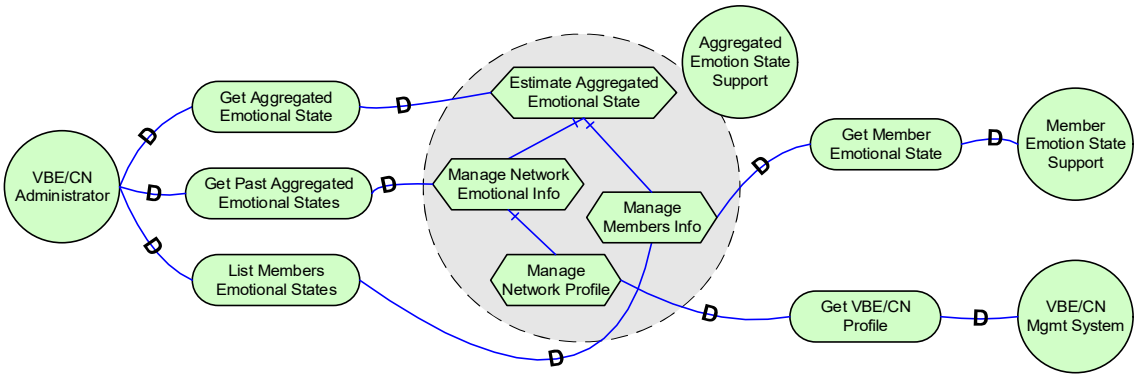



**Figure 5.3. i* Strategic rationale model for the aggregated emotion state support.**

#### 5.1.1.1 Emotion Support System - Overview of Functionalities

As seen above, in order to have the emotion support system properly implemented, it is necessary to have access to two main sub-systems of GloNet. They are the *VBE management system* and the *negotiation support system*. The VBE management system was developed to cover both the *VBE Base Management* and *VBE Advanced Management* components of the GloNet's architecture, while the negotiation support

system was developed in the context of the *Dynamic Consortia Creation* element of the *VO Advanced Management* component as shown in Figure 5.4.

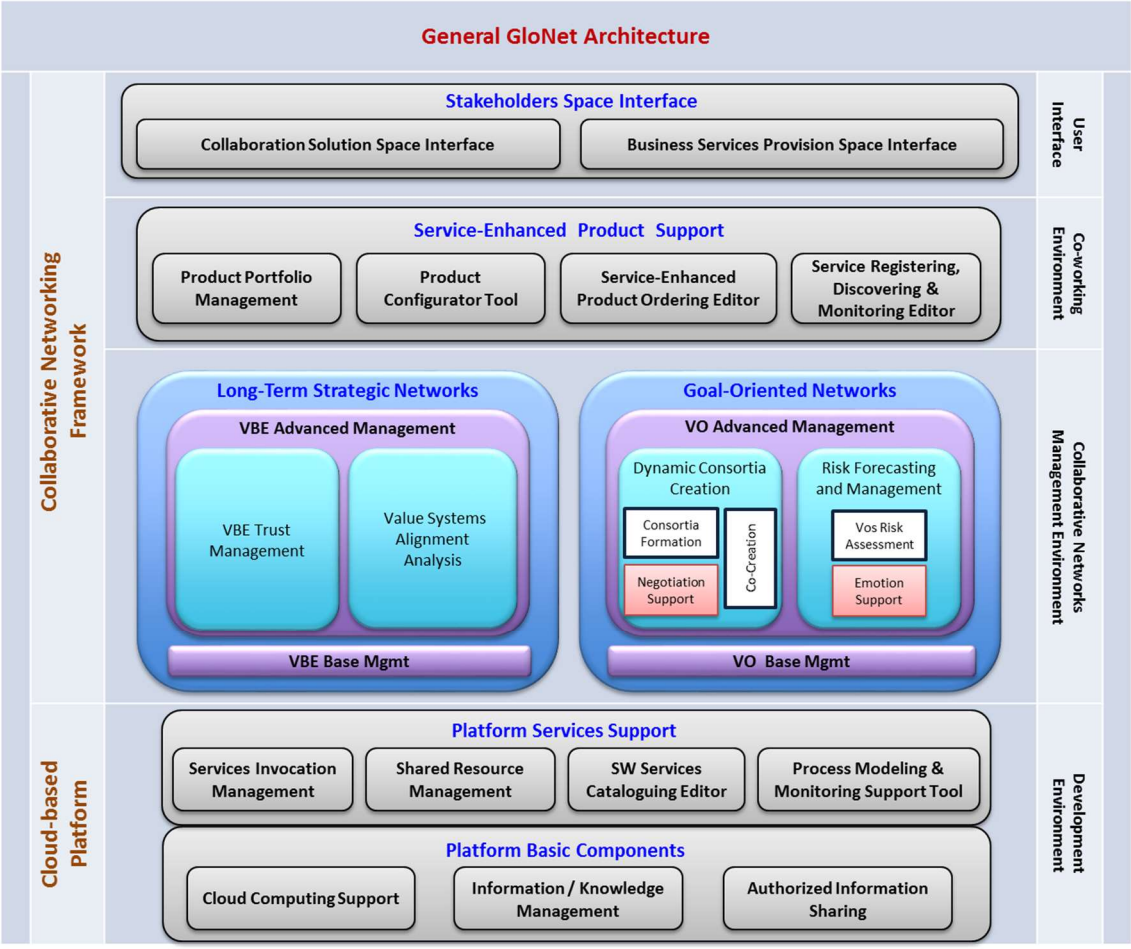



**Figure 5.4. GloNet system architecture. Adapted from (Camarinha-Matos et al., 2013a).**

The VBE management system is the core of the VBE well-functioning. Without this system, services such as the management of member's admission and withdrawal, management of members' and VBE profiles and competencies, management of performance and the facilitation of trust building among members would not be possible (Camarinha-Matos et al., 2013a; Camarinha-Matos et al., 2013e; Camarinha-Matos et al., 2015a; Camarinha-Matos et al., 2015b). Furthermore, this system is the base for the creation of goal-oriented networks (typically Virtual Organizations – VOs) and also the base for this emotional support system. The access to the VBE management system provides information that is necessary in order to estimate the collaborative network emotions (both IMEs and ANE, see Figure 3.2). Such information relies mainly on members' profile, where data such as the performance evaluation can be found. The access to the product portfolio provides information about the VOs that are in operation

and the ones that have already finished. The advanced management system provides the information about the value system analysis and also about the level of trustworthiness within the CN.

On its turn, the negotiation support system facilitates the negotiation of a new VO, in the VO creation process (Oliveira & Camarinha-Matos, 2012, 2013, 2015). The access to this system provides the necessary information about the VOs that are being created, namely who are the planner and the potential partners, and which members are being invited to form VOs. Figure 5.5, illustrates the conceptual architecture of the emotion support system with the representation of the involved systems and their support modules and databases.

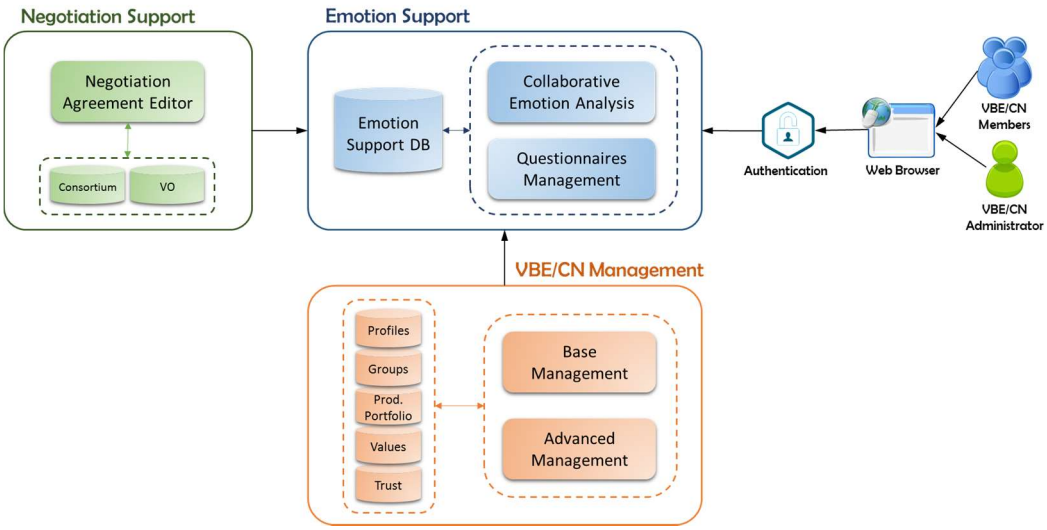



**Figure 5.5. Overview of the conceptual architecture of the GloNet's emotion support system.**

In this prototype, the emotion support system, was developed comprising two main functionalities: the analysis of collaborative emotions (*Collaborative Emotion Analysis*), where the corresponding IMEs and ANE are evaluated, and the functionality devoted to manage both the members' needs and expectations towards the VBE/CN (*Questionnaires Management*). A brief description of these functionalities is summarized in Table 5.1.

**Table 5.1. Main functionalities of the emotion support system.**

| *Functionality* | *Description* |
|---|---|
| **Collaborative Emotion Analysis** | This module, through the interaction with the VBE/CN management system and with the negotiation support system provides support to the assessment of members' emotions and the CN aggregated emotion. |

| | |
|---|---|
| **Questionnaires Management** | This module is in charge of the management of the questionnaires that are available to members in order to collect their needs and expectations. It is with this module that it is possible to evaluate if the needs and expectations of members are being met regarding their involvement in the VBE/CN. The *needs and expectations met* variable is one of the emotional evidences that is also used in the C-EMO model. |

#### 5.1.1.2 Requirements

The requirements of the emotion support system are defined taking into consideration the system stakeholders or involved actors. These requirements are presented as UML *use case diagrams*, which define the interactions between actors and the system. The involved actor's types are:

- **VBE/CN Administrator** – as the stakeholder that uses the system in order to analyze the network aggregated emotion (ANE). It may also request the assessment of the VBE/CN member's emotions (IMEs) and reason about the current emotional status of the network.
- **VBE/CN Member** – each of the stakeholders that use the system in order to manifest their needs and expectations, and also to check their estimated emotional state.

The use case diagram presented in Figure 5.6 specifies the sub-systems that can be accessed by each actor.

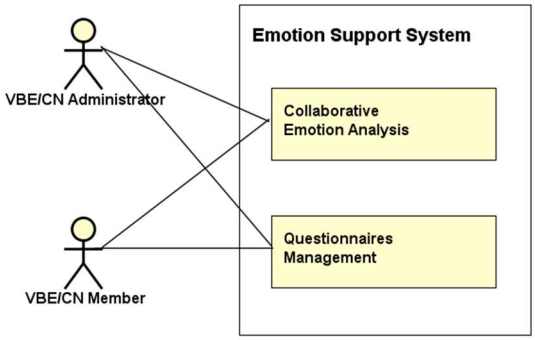



**Figure 5.6. Emotion support system and sub-systems diagram.**

Figure 5.7 shows the use case diagram for the collaborative emotion analysis functionalities with its main requirements and actors.

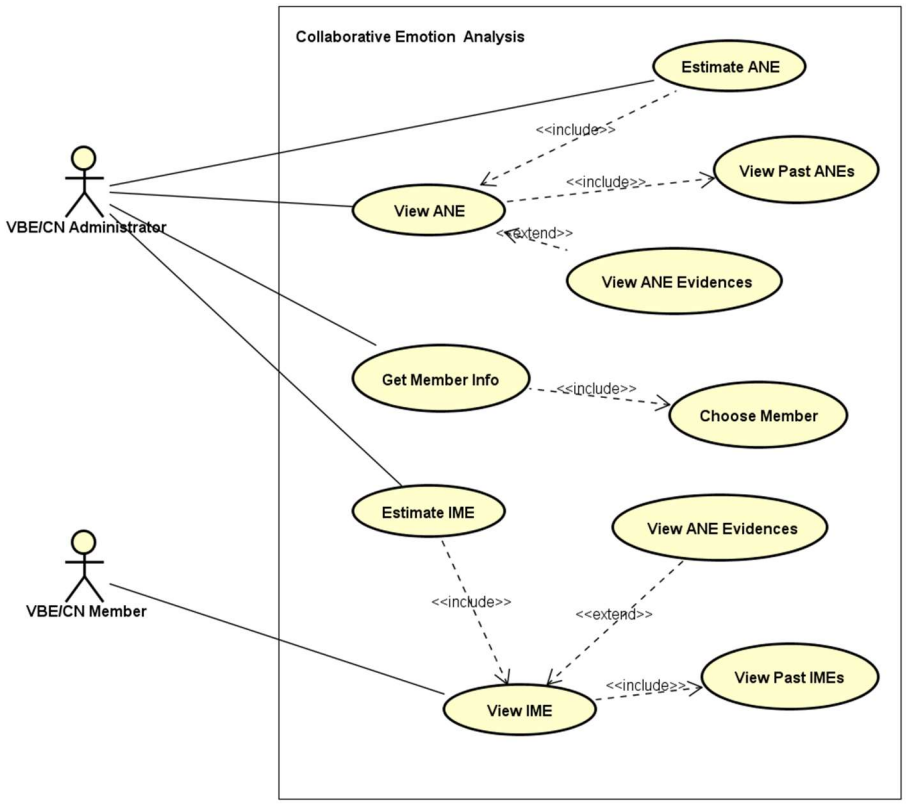



**Figure 5.7. Use case diagram of the collaborative emotion analysis sub-system.**

Figure 5.8 shows the use case diagram for the questionnaires management functionalities with its main requirements and actors.

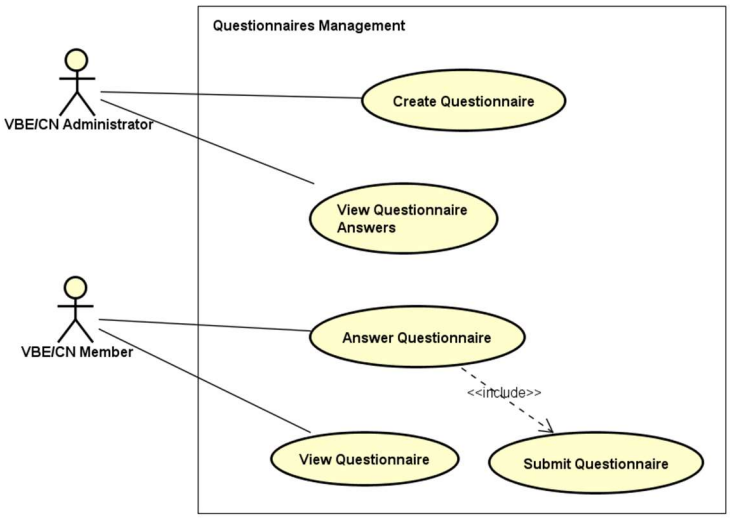



**Figure 5.8. Questionnaire management sub-system use case diagram.**

#### 5.1.1.3 Implementation Approach

The followed implementation approach relied on a 3-tier architecture with a backend database (*data tier*), a middle tier of application services, being the core of the system (*application tier*), and a web browser as the front-end to the user (*presentation tier*). In this way, the emotion support system can be easily reusable. It can be used either as a standalone system, or as a component of the GloNet system. As a GloNet component, the emotion support system can use the services provided by the GloNet platform, namely from the login system, the VBE management system, and the negotiation support system. This integration is done via the available web-services on the GloNet platform. The interactions with the GloNet platform are implemented using a client service of the interface layer (*EimInterface*) as illustrated in Figure 5.9.

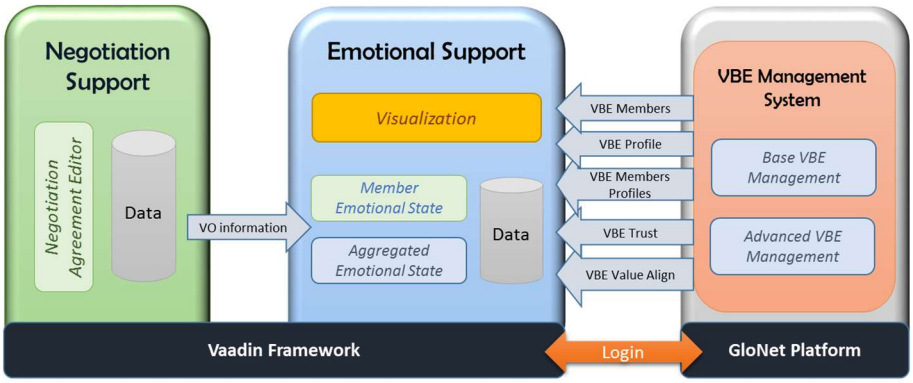



**Figure 5.9. Emotion support system data interaction.**

The technologies that were used for the implementation of the initial emotion support system prototype are described in Table 5.2.

**Table 5.2. Technologies used in the emotion support system prototype.**

| *Technology* | *Purpose* |
|---|---|
| **Java** | Programming language |
| **Java JDK 1.7** | The software development environment used for developing Java applications and applets. |
| **MySQL Workbench 6.0** | The workbench for object-related MySQL database management system |
| **Eclipse Java EE IDE - Kepler** | The integrated development environment (IDE) tool used for developing the system prototype. |

| | |
|---|---|
| **Vaadin Framework (7.2.0)** | Open-source framework for Java that includes user interface components (*widgets*) and tools for the development of web applications. |
| **Glassfish (4.0)** | Open-source Java EE application server. |

Figure 5.10, depicts the relationships among the technologies described above.

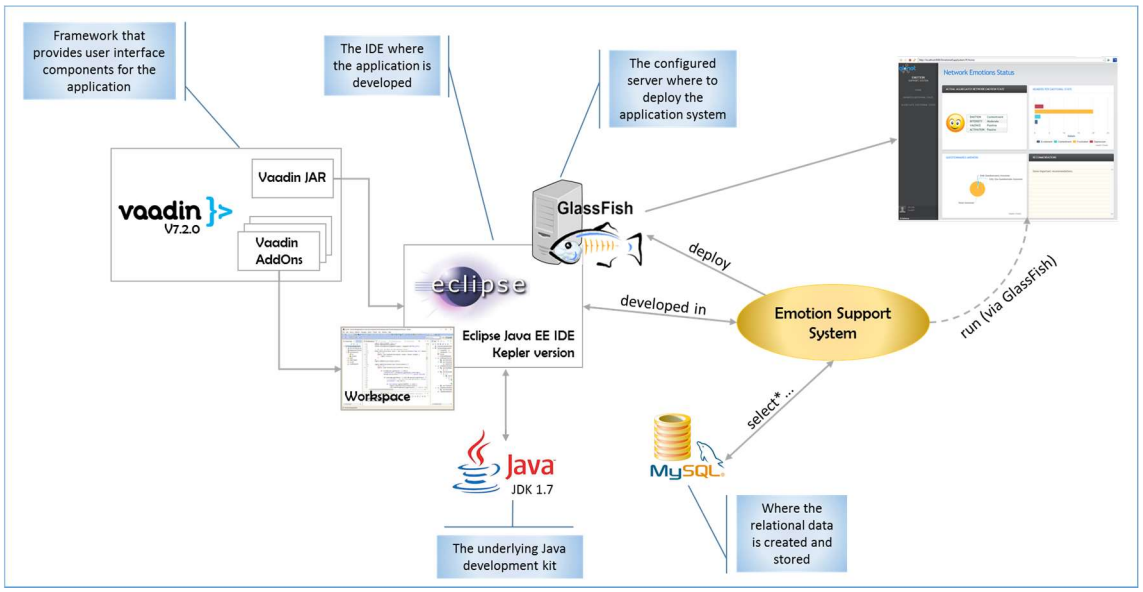



**Figure 5.10. Interactions among the technologies used to implement the emotion support prototype.**

#### 5.1.1.4 Information Tables

As previously seen, the emotion support system uses the open-source MySQL database server for the management of its data. The information tables designed for supporting the database schema of the emotion system were modeled taking into consideration the requirements presented previously in this section. Figure 5.11 illustrates the corresponding EER model of the designed database.

The supporting data of the emotion support system can be categorized into five groups:

- **VBE/CN related data**. Information necessary to identify the VBE/CN, the members of the VBE/CN and the VOs that were formed within the VBE/CN, independently of their life-cycle status. This information is gathered from the GloNet platform and only the information that is essential to the emotion part is considered. Yet, it is possible to add or remove other data fields if necessary.

This category is reflected in the *network_emotional_info*, *member_emotional_info* and *vo* tables respectively.

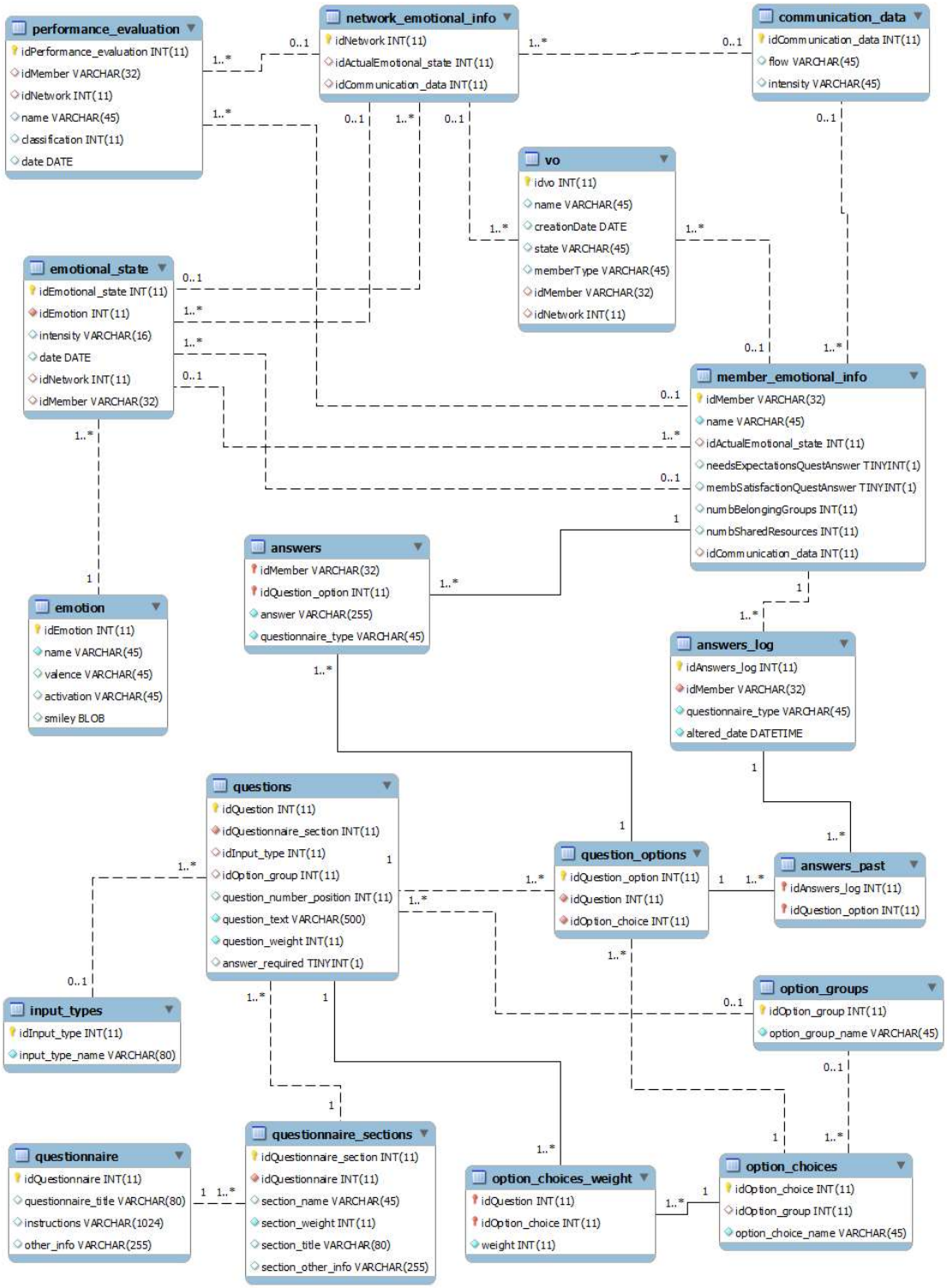



**Figure 5.11. EER diagram for the emotion support system DB.**

- **Performance related data**. Contains information about the performance evaluation of both the VBE/CN and its members. This information is also retrieved from the GloNet platform and stored in the *performance_evaluation* table.
- **Communication related data**. Includes data related to the communication among the different "nodes" of the VBE/CN. These data are stored in the *communication_data* table. The communication data is not directly available in the GloNet platform, but it might be gathered resorting to network analysis tools. For this prototype purposes, the information was got randomly using a triangular distribution function.
- **Emotion related data**. Refers to the information about the emotional state of both the VBE/CN and its members. In this first prototype, the concept of emotion was defined by its name, valence, and activation. The tables containing this information are: *emotional_state* and *emotion*.
- **Questionnaire data**. Stores the information relative to a questionnaire. With this category both the creation and management of questionnaires is possible (for instance adding or removing questions), as well as the management of the respective answers. The VBE/CN administrator can create the number of questionnaire types that it wishes, giving different weights to the different questions or option choices. This information is stored in the following tables: *questionnaire*, *questionnaire_sections*, *questions*, *question_options*, *option_groups*, *options_choices*, *option_choices_weight*, *input_types*, *answers_past*, and *answers_log*.

#### 5.1.1.5 Prototype System

The emotion support system aims to assist essentially the network administrator in evaluating the emotional health of the VBE/CN. Yet, it also includes a component directed to the network members, essentially to collect the information that is necessary to estimate the emotional state of each member. Therefore, the prototype provides different functionalities with different permission/visibility access rights to information, based on the user roles. Figure 5.12 illustrates the different views, for the VBE administrator and member, taking into consideration the different login types.

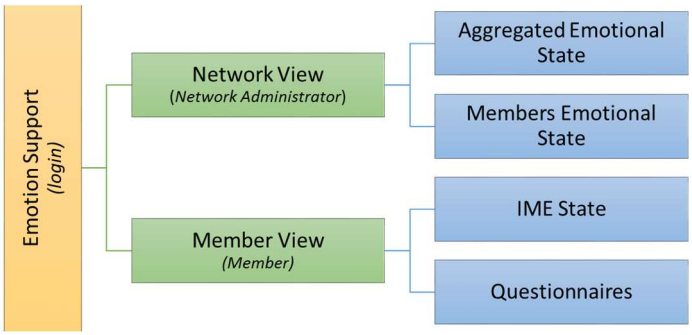



**Figure 5.12. Emotion support prototype navigation map.**

**Network Administrator Side.** After logging in, the network administrator visualizes the overall emotional status of the network by viewing the current aggregated network emotion state and also a graphical representation of the member's emotion state. Then the user has the possibility to choose between viewing each member's emotion or the aggregated emotion states in detail. Furthermore, the user has always the possibility to estimate the current emotional states from both the network and its members. In Figure 5.13 a detailed navigation map for the network administrator role is illustrated.

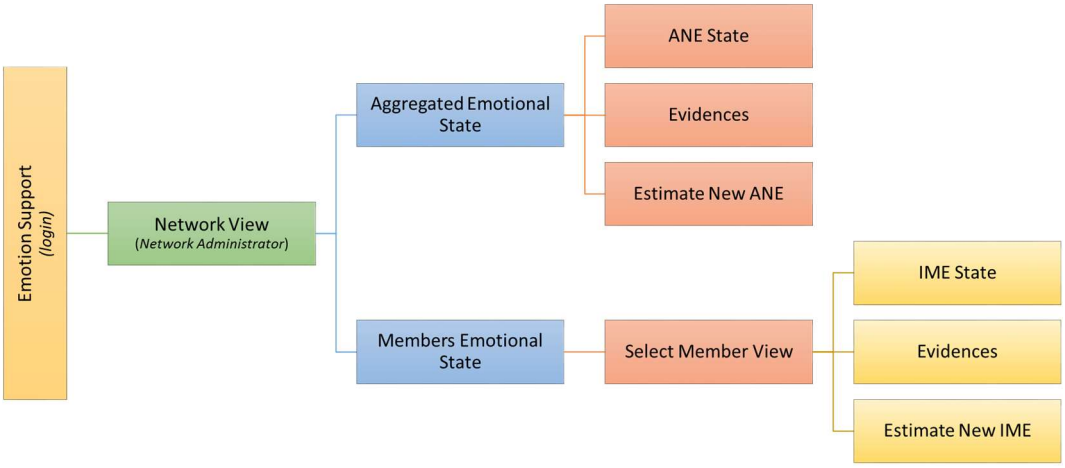



**Figure 5.13. Navigation map for the network administrator's side.**

**Member Side.** After logging in, a member has the possibility to visualize its emotion status (that is estimated by the network administrator) and to select a questionnaire to view. Then the user has the possibility to answer a new questionnaire (save or submit it), or to change the last saved one. Figure 5.14 shows the navigation map relative to the member's role.

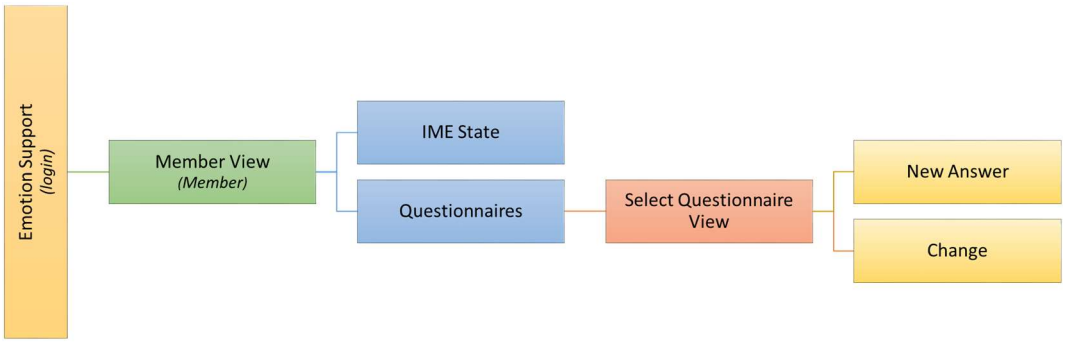



**Figure 5.14. Navigation map for the member's side.**

The user interface layout of this prototype was designed to allow access to all abovementioned functionalities for both user roles. It is composed of two main areas: a sidebar and a main view. Figure 5.15, illustrates the cse of the administrator's role view. The side bar is used to navigate between the *Aggregated Emotional State* and the *Member Emotional State*, while the main view presents all related functionalities.

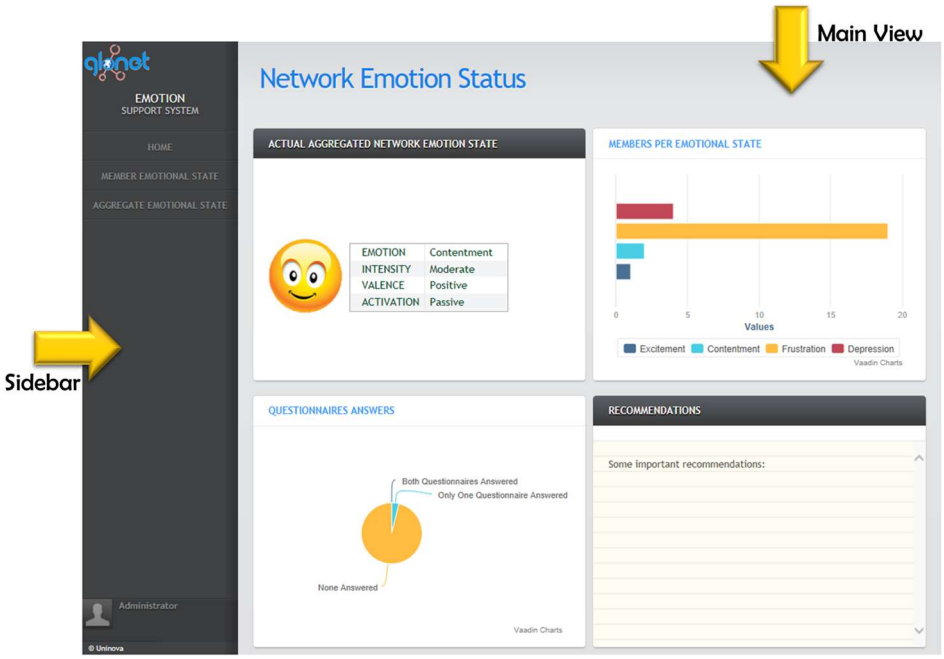



**Figure 5.15. User interface layout (network administrator's view).**

### 5.1.1.6 Examples of Use

Having into consideration the emotion support system requirements and the implementation approach, this section is devoted to the illustration of some examples of use of the developed prototype in the context of the GloNet project. The following

figures show some screenshots of the system for both the administrator and the member views.

**Administrator View.** Figure 5.16 illustrates an example of the information view about the aggregated network emotion. It is shown the last estimated ANE state of the network and also the record of all past ANE states. If the administrator wishes to verify the new ANE state, it can be done by clicking the *Estimate Aggregated Network Emotion* button at the bottom of the window.

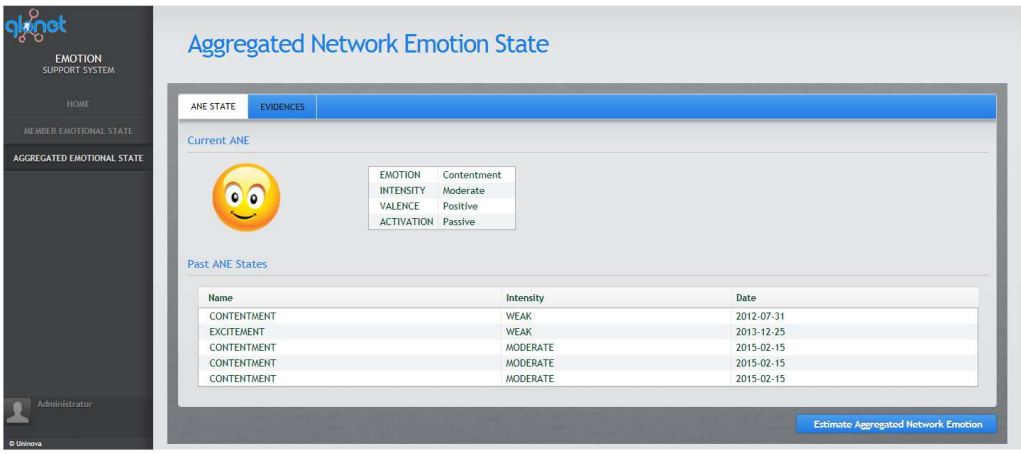



**Figure 5.16. View of the aggregated network emotion state information details.**

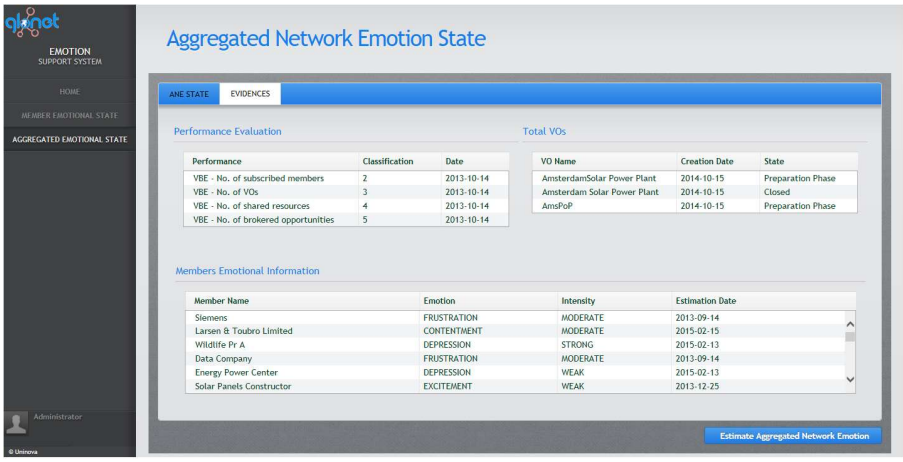



**Figure 5.17. View of the network evidences used to estimate the ANE.**

In the ANE evidences view of Figure 5.17, the administrator has access to the emotional evidences whose values were used to calculate the aggregated network emotion. Please note that the model that was used in this first prototype for estimating

the ANE was based on linear mathematical rules. The main objective with this initial prototype was to investigate if the underlying concepts were well accepted by the GloNet users and not focused on the accuracy of the model. Later on, in this chapter a more detailed discussion about this is presented.

In order to access the information related to a specific member or even to estimate the current emotion of a particular member, the administrator can choose the member out of the list of the members comprising the VBE/CN. Figure 5.18 illustrates the view of such selection.

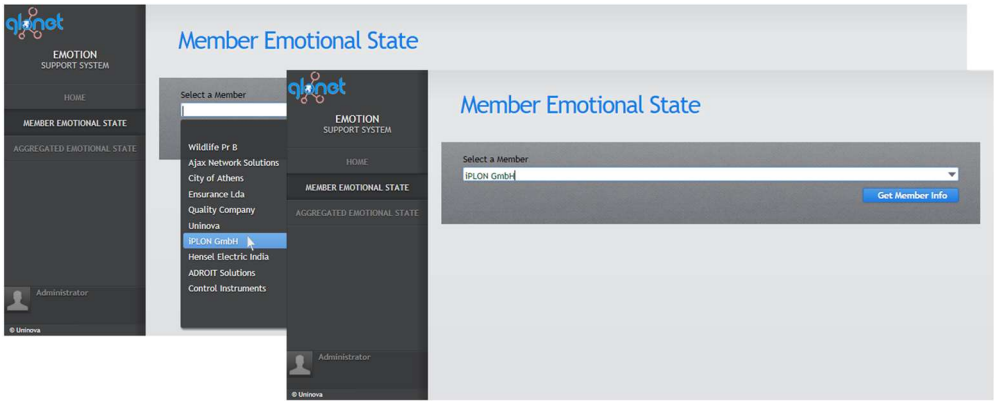



**Figure 5.18. View of the member's selection.**

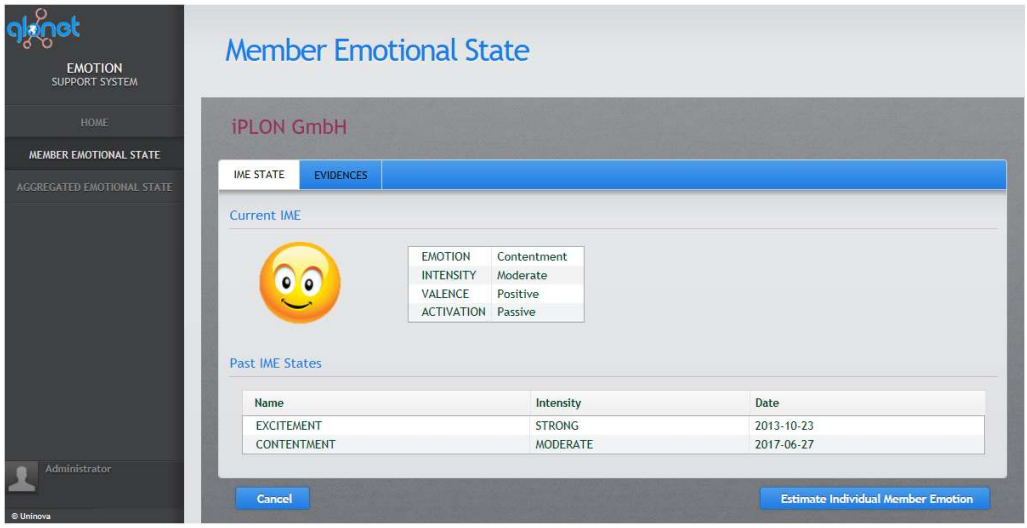



**Figure 5.19. View of the selected member IME state.**

After selecting a member, the administrator enters in the member's emotion state view. There it is shown the last estimated IME state and also a list with all past IME states. In a similar way to the ANE view, if the administrator wishes to validate the new

IME state, it can be done by clicking the *Estimate Individual Member Emotion* button at the bottom of the window as illustrated in Figure 5.19.

**Members View.** Figure 5.20 illustrates an example of the home view of the emotion support system when logged in as a member. This view is divided into two distinct parts, one is related to the information of the last estimated emotional state (previously estimated by the network administrator, see previous figure), and the second to the questionnaires that are available to be answered by the member. These questionnaires are part of the evidences that help in the calculation of the member's emotion state.


**Figure 5.20. View of the individual emotion state information details and questionnaire management.**

These questionnaires, as previously mentioned, are created and managed by the network administrator. For this prototype two questionnaires were conceived, one to assess the member's needs and expectations regarding the VBE/CN and another concerning the evaluation of the member's satisfaction. The sections, questions, options, and weights considered in each questionnaire are merely illustrative, functioning only as an example of implementation and a mechanism to assess the feasibility and usability of them in the estimation of the collaborative emotions. In a real network, these questionnaires have to be created taking into consideration the specific nature and principles of the network. Figure 5.21, shows the views of these illustrative questionnaires.

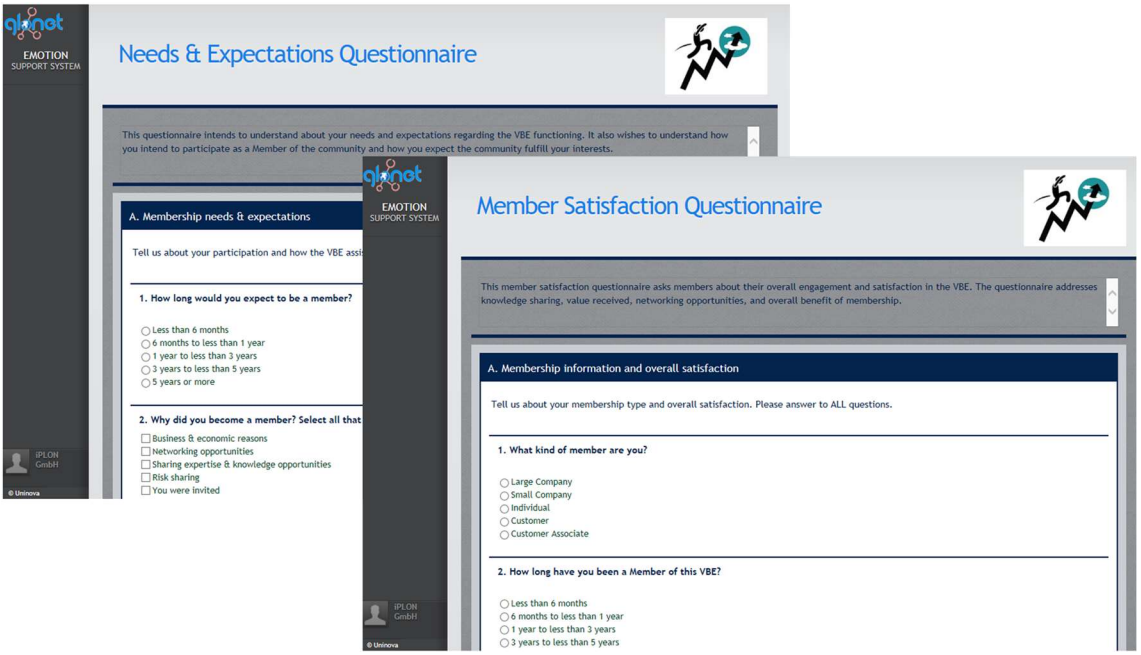



**Figure 5.21. View of the available questionnaires for the member.**

#### 5.1.1.7 Brief Summary

The GloNet's emotion support system prototype was developed in order to cope with the requirements that resulted from the analysis of the models and system functionalities presented at the beginning of sections 5.1.1 and 5.1.1.1.

As stated before, the prototype is based on simple models of emotion (linear rules based) and served as an intermediate validation instrument, to check if the overall approach is promising and interesting for the users, giving a broad understanding of the system as a whole. With this prototype, a first reaction to the concept was evaluated and the necessity to design a comprehensive model of collaborative emotions, with a solid foundational theory, was the main outcome of this validation phase.

### 5.1.2 Second Prototype: C-EMO Simulation Model

The second prototype is the main focus of this PhD work and reflects requirements identified in the previous iteration: a more realistic and accurate model of collaborative network emotions. As such, the approach presented in the context of this work goes towards the design and development of a modelling framework for collaborative emotions and the development of a simulation model as presented in chapters 3 and 4, respectively.

The C-EMO modeling framework is inspired on a comprehensive literature review on human emotions, namely on the knowledge of psychologists and sociologists in the area (see section 2.2). The proposed models are based on the dimensional and appraisal theories of emotion and adapted to organizations within a collaborative environment. They were modeled using the system dynamics methodology as presented in sections 4.1.1.1 and 4.1.1.2. Some computational models of emotions were also reviewed and studied, as presented in section 2.3. The computational models that served as inspiration for the development of the C-EMO framework were the KISMET (Breazeal, 2003), WASABI (Becker-Asano, 2008), and CATHEXIS (Velásquez, 1996). These three computational models of emotion have as basis one or a combination of various theoretical models and are implemented using software agents. In this context, the approach taken for the development of the C-EMO simulation model was the agent-based methodology as presented in section 4.1.2.

With the C-EMO simulation model it is possible to estimate the aggregated network emotion and the individual member emotions resorting to the emotional evidences that are provided by the CN environment. Further on this chapter, in section 5.2.2.2., several simulation of scenarios involving the C-EMO simulation model will be presented. One of the scenarios is designed with the GloNet's environment.

### 5.1.3 Final Prototype: Integration of Prototypes

The final iteration of the collaborative emotional system consists in the integration of the C-EMO simulation model (the 2nd prototype) in the GloNet's emotion support system (the 1st prototype). This integration is performed through the interaction of the database management systems of both prototypes. Basically the interaction among the two systems consists in an exchange of information between them as illustrated in Figure 5.22.

Whenever the GloNet administrator requests for estimating the ANE or estimating an IME (see Figure 5.16 and Figure 5.19), the information related to the VBE, in the first case, and the information related to the individual member, in the second case, is sent to the C-EMO simulation model database. In other words, the information from the VBE/CN environment that is necessary to construct the evidences vector for both the ANEA SD model and the IMEA SD model is sent from the emotion support system to the C-EMO simulator. On its turn, the C-EMO delivers the estimated emotion to the emotion support system.

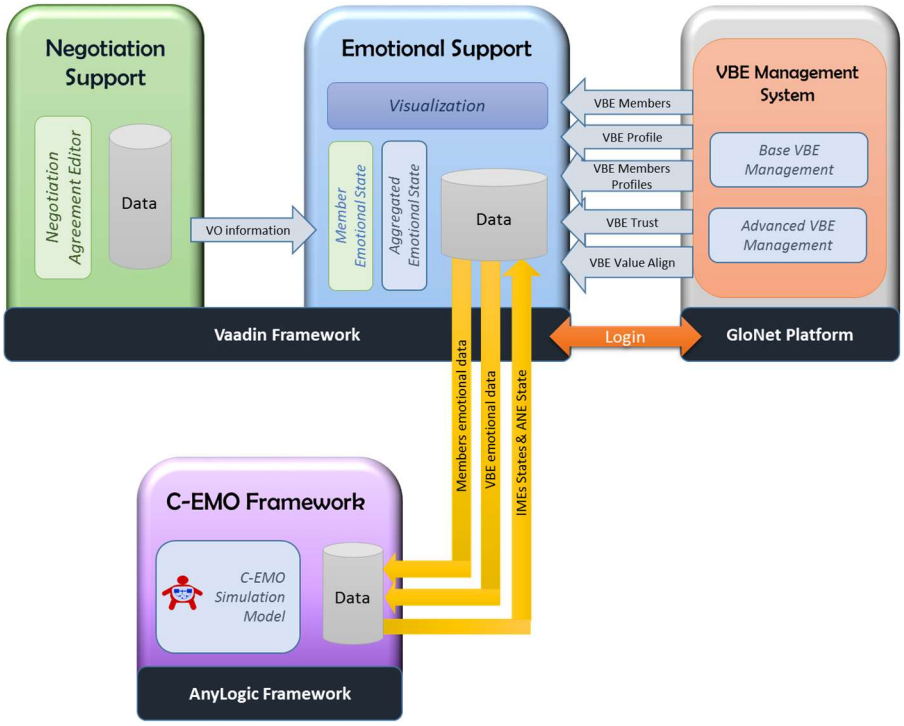



**Figure 5.22. Integration of the C-EMO simulation model and the GloNet's emotion support system.**

## 5.2 Validation

Validation is commonly defined as the process that ensures (or that gives confidence) that the creation of a new model or system has captured all the important aspects of a stated problem. In the case of this research work, with no established comparison benchmarks and without the possibility to implement the developments in a real case scenario, validation depends on the feasibility and acceptability of the proposed framework modeling concepts and the achieved development level. Furthermore, this work is not intended to show the most accurate or the most adequate model of emotions in CNs, instead it intends to provide a modeling approach to the identified problem. In this sense, the purpose of the validation relies on assessing the *appropriateness* of this research proposal within the domain of collaborative networks.

In this context, the validation approach passes by evaluating the functionalities and features of, on one hand, the C-EMO framework and simulation modelling approaches and, on the other hand of the emotion support system prototype. Regarding the former, besides some validation by the research community, some criteria evaluation based on Thalheim's (2009, 2012a) model evaluation and assessment is considered, and a series of simulation experiments are conducted to evaluate the proposed approach. In what concerns the emotion support system, the main purpose of the validation passes

by assessing the feasibility and usefulness of the underlying concepts within the research community and also by gathering feedback about the general fitness-for-purpose of the proposed solution in a network of enterprises from the solar energy industry.

Figure 5.23, depicts the followed validation approach. It comprises the formulated research questions, the respective hypotheses and the proposed solutions for validating the hypotheses. Finally, it shows the evaluation approach that is considered for each solution of this work.

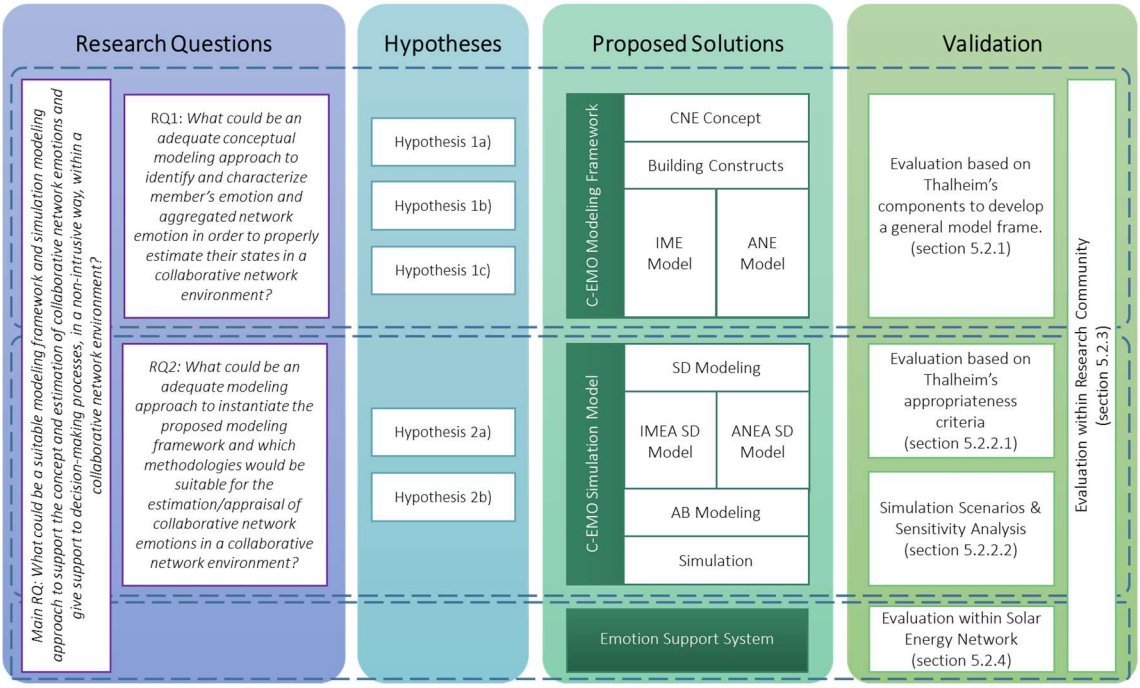



**Figure 5.23. Validation approach.**

In this context, the next sections are devoted to the description and discussion of each evaluation aspect.

## 5.2.1 Evaluation of the C-EMO Modeling Framework

The main evaluation purpose regarding the proposed C-EMO modeling framework is to verify the quality of the modeling pieces, not the quality of the model itself. Furthermore, this assessment relies on the assumption that this framework would serve as a reference to construct models on top of it. In this context, the criteria that is adopted to evaluate the C-EMO modeling framework is an adaptation of Thalheim's (2012a) components to develop a *general model frame*, and consists of five evaluation

aspects: *Founding Concepts*; *Structure and Behavior*; *Application Domain Context*; *Generality*; and *Potentiality*. Each one of these aspects will be described below.

**Founding Concepts.** A modeling framework should be based on paradigms, background theories, assumptions and guiding principles (Thalheim, 2012a). The proposed C-EMO modeling framework is grounded on the paradigm of collaborative networks and also on the background theories of human-emotion found in psychology and sociology. Furthermore, it is composed of base conceptions/concepts such as the defined concept of collaborative network emotion (CNE) or the concept of CN sustainability. The C-EMO framework presupposes that any organizational form, i.e. typology of CN could be modeled and its CNEs estimated accordingly.

**Structure and Behavior.** The structure in a modeling framework should capture the static features of the system, being the place where all components exist. The C-EMO modeling framework is built using object-oriented models which are the two main constructs (IME and ANE building blocks), each comprising its attributes/elements and their relationships as presented in Figure 3.18. The behavior should describe the interaction in the system. It represents the interaction among the structural diagrams. According to Kronlöf (1993), understanding the behavior of a system as a whole requires: *i)* knowledge of the individual parts and their behavior; *ii)* the interfaces between the parts; *iii)* the traffic that passes along the interfaces; and *iv)* the system environment. These requirements are expressed in sections 3.2 and 3.3 of the C-EMO modeling framework where the process-oriented models are presented.

**Application Domain Context.** According to Thalheim (2012a), the domain forms the empirical scope of the modeling framework, and that "each application domain is based on general laws one might have to consider for the model as well". In what regards the C-EMO framework, it is developed in the context domain of the GloNet's solar energy and intelligent buildings networks. Its modeling components are constructed having as basis the CN management approaches and are compliant with their governing rules.

**Generality.** According to Costanza et al. (1993), generality describes the degree to which a single model can represent a broad range of systems' behaviors. The C-EMO framework is developed aiming at being as generic as possible in order to be possible the instantiation or realization of different models on top of it. One example of such generality is the C-EMO simulation model presented in chapter 4, which materializes with system dynamics and agent-based modeling techniques the C-EMO framework.

However, other modeling techniques might be used, such as for instance, qualitative reasoning modeling approaches (Bredeweg & Struss, 2004). This reveals that this framework is constructed with the most elementary building blocks and that more specific ones might be developed having these as basis.

**Potentiality.** Potentially may be seen as the capacity to make a better solution and a chance that in the future new modeling aspects might be explored. Taking into consideration that this C-EMO framework proposal is open and with modular characteristics, new modeling aspects can be added in the future. Two aspects were already identified in the course of the C-EMO framework development which are the modeling of the behavior component of the IME building block (section 3.2.2.2) and the decision-making component of the ANE building block (section 3.3.2.2). They were briefly characterized in this solution, however the underlying concepts need to be further explored as well as the modeling of their behavior in a CN environment.

In overall conclusion, it can be stated that the C-EMO modeling framework applies the foundational concepts adequately, providing elementary structural components and working in an integrated way in the CN domain of applicability. Furthermore, this framework allows the construction of models containing more modeling details on top of it and due to its modular characteristic, allows that further modeling concepts could be explored.

## 5.2.2 Evaluation of the C-EMO Simulation Modeling Approach

As previously mentioned, the C-EMO simulation model is just one example of many models that could be built on top of the C-EMO framework. In this line, the C-EMO simulation model evaluation that is performed here is primarily focused on assessing the viability and facility to build models on top of C-EMO framework and in a second plan focused on the simulation model aspects.

### 5.2.2.1 Qualitative Evaluation

Assessment of quality depends always on the purposes of the model, thereby different quality criteria apply to a model depending on its goal. In the case of this work, the purpose of C-EMO simulation is to validate the appropriateness of the C-EMO framework, as previously stated. Therefore, an evaluation based on the Thalheim's

(2012b) criteria for appropriateness is performed. These criteria are built having into consideration the separation into goal, purpose and deployment functions for models, as shown in Table 5.3 below.

**Table 5.3. Criteria for modelling appropriateness (based on Thalheim (2012b)).**

| *Criterion* | *Definition* | *Underlying Aspects* |
|---|---|---|
| **Adequacy** | The adequacy of a model defines its potential for the goals. It is given by: | *Similarity* with its origin in dependence on its goals. |
| | | *Consistency* of the application domain (within a well-founded system). |
| | | *Fruitfulness* (or capacity) in achieving the goals. |
| | | *Simplicity* through the reduction to the essential and relevant properties in dependence of the goal. |
| **Fit-for-Purpose** | If the model fits its purpose through being: | *Usable* for the purpose. |
| | | *Suitable* within the given context. |
| | | *Robust* against small changes in the parameters. |
| | | *Compliant* with the founding concepts, structure & behavior, and application context. |
| **Usefulness** | The usefulness for deploying is given by: | *Effectiveness* in terms of achieving the proposed goals. |
| | | *Understandability* for specific deployment of the model by users (developers and modelers). |
| | | *Learnability* for characterizing how easy it is for users (stakeholders) to use the model. |
| | | *Reliability* of the model. |
| | | *Efficiency* of the model in what respect the utilization of the available resources. |

**Adequacy.** The primordial goal of the C-EMO modeling framework is providing a modeling approach for representing the CN environment with its involving players, in which the estimation of their collaborative emotions is done in a non-intrusive way. The C-EMO model is an abstraction of a generic CN environment, thus similar to its origin, and it reasons about its player's emotions, satisfying the needed goals (it is fruitful). It is built on top of a well-defined foundation in what concerns the involved paradigms and base concepts, showing its consistency in the solar energy industry application domain. Furthermore, it is known that simplicity of a model is a vague notion and difficult to measure, especially when there are no other models to compare as in this case. Nevertheless, an evaluation taking into consideration some aspects such as the way the

C-EMO framework is conceived, might help in showing that there is an effort for relative simplicity. One aspect has to do with the way the two main building blocks of the framework are designed: they are modeled aiming at separating the contextual elements from the core elements isolating in this way, the data collection and storage from the reasoning processes. Other aspects, are related to the effort put in conceiving a simplified model of collaborative network emotions (inspired in the complex human-emotion theories) and the use of system dynamics modeling approach with causal inductive reasoning for better understanding of the involving entities and underlying concepts. In conclusion it can be said that the C-EMO modeling framework, through the evaluation of the C-EMO simulation model is adequate.

**Fit-for-Purpose.** As said before, the evaluation of a model depends on its purpose. In this case it is a two-in-one purpose: validating the C-EMO modeling framework, and evaluating the modeling approach used for building the C-EMO simulation model. In this context it can be stated that the purpose fits because the model is usable and suited in the CN context as seen with its integration in the third prototype of the emotion support system developed within the GloNet project (section 5.1.3). In addition, the modeling approach could be seen as robust in terms of the easiness of performing small changes in the parameters without putting in jeopardy the purpose of the model (it is easy to add or to remove some parameters). For instance, if the CN instead of being business oriented is not-for-profit, the elements relative to the financial parts can be easily removed and substituted by others. Of course with some minor adjustments in the causal models, nevertheless the purpose of the model remains untouchable. Finally, the modeling approach is compliant with the founding concepts, structure and behavior and also application domain that are inherited from the C-EMO modeling framework.

**Usefulness.** The usefulness of the C-EMO framework is evaluated in terms of the deployment of the C-EMO simulation model. In terms of effectiveness and reliability it can be said that the goals are achieved and that the modeling approach is quite trustworthy as it can be confirmed by the series of complex scenarios that are simulated in section 5.2.2.2. In terms of usability (i.e. understandability and learnability), it is understandable by model developers, at least in our case it was a straightforward process. In what concerns learnability from stakeholders, at this point some preliminary evaluation was conducted with the GloNet project's stakeholders, as presented at the end of this section (5.2.4), and some indirect evaluation has been performed through informal interactions with potential users of the system. The feedback from both is quite positive, nevertheless some issues regarding cultural barriers are pointed out as seen

later on. Finally, the modelling approach is efficient in what respects the utilization of the resources that are provided by the GloNet's CN environment platform, namely the data management system.

In conclusion, it can be stated that both the C-EMO modeling framework and the C-EMO simulation modeling approaches are appropriate, as a first contribution approach to this area, taking into consideration the evaluation performed in conformity with the goals, purpose and deployment of the before mentioned approaches.

#### 5.2.2.2 Simulation Experiments

As mentioned, one main difficulty in the process of testing the C-EMO simulation modeling approach is the lack of a real data for performing benchmarking and tuning the model accordingly with the real case. Therefore, the validation process depends on computational simulations of different scenarios and a kind of benchmarking is done against some pre-defined assumptions and expectations based on the theoretical foundation of the model. In this context, the model validity decision relies on the Sargent's (2014) first basic approach: "*The model developer or development team decide themselves if the simulation model is valid. This decision is based on the results of the various experiments and results evaluation conducted as part of the model development process*".

Having this in mind, a number of simulation experiments are undertaken to analyze the C-EMO simulation model in different scenarios, and through this evaluating both the appropriateness of the C-EMO framework and also the modeling approach adopted to build the C-EMO simulation model, as also mentioned in the previous section. For that, a plan was initially formulated to gather the desired information and also to enable the drawing of valid conclusions. This was done through the design of experimental models or scenarios. Then the scenarios are executed in the C-EMO simulation model and sensitivity analysis and discussion of their results is performed.

##### *5.2.2.2.1 Design of Scenarios*

This section is devoted to the design of experiments on the C-EMO simulation model. In this line, two sets of experiments are considered: one concerning the CN individual members, in order to verify and validate the IMEA SD model (which is the model that materializes the IMEA element of the framework), and the other related to the CN environment, aiming to verify and validate the ANEA SD model (which on its

turn materializes the ANEA element of the framework). In addition, with these set of experiments it will be possible to identify the quality of the proposed the C-EMO agent-based model.

**Individual Member Experiments**

These first experiments focus on the individual member's emotion model. Thus, several scenarios representing the potential conditions of CN members are proposed for evaluating their emotional behavior. For that, some assumptions are considered, taking into consideration the modeling design of the IME component of the C-EMO framework of Figure 3.6. These experiments comprises three distinct types of members. Table 5.4 describes the member's profiles.

**Table 5.4. Member's profiles.**

| *Member* | *Profile* |
|---|---|
| **Company A** | South America company extremely motivated to participate in knowledge discussions with its fellows within the CN. It has been a motivator of a couple of informal interest networks that are formed in the CN and that counts with the participation of members interested in the topic. At this moment it is leading, for the first time, the creation of a VO, but it has been a partner of other VOs that have successfully terminated. One of its biggest aspiration is to receive a reward for its participation in the activities of the CN, which hasn´t happened yet… |
| **Company B** | Company from India that has recently joined the CN. For the moment this company is getting in touch with the CN activities and trying to enhance its competences in order to be aligned with the CN value system and also to be prepared to get invited to form a VO. In the meanwhile, it has been sharing some resources in an informal network that it initiated. The level of trustworthiness among members of the CN is a very important issue. |
| **Company C** | Founder company of the CN, it has participated in many VOs and informal networks since a long time ago. Nevertheless, its expectations towards the CN are becoming low due to the lack of invitations to form VOs and also because the several attempts to form a new VO failed. In addition its last performance evaluation was not very high… |

Having the member's profiles settled, the corresponding simulation scenarios are designed. Therefore, prior to that, for each company member, the representative IMA agents' initial conditions are created by populating the variables of the evidences vector according to the respective member's profile. Table 5.5, Table 5.6, and Table 5.7 describe the initial conditions for company A, Company B, and Company C respectively.

**Table 5.5. Initial conditions for agent A (representing Company A).**

| *Type* | | *Name* | *Initial Condition* |
|---|---|---|---|
| **Input** | | Agent Initial State | 1 *IMAgent* is instantiated and consequently the two sub-agents *iPerceptionAgent* and *iEmotionAgent*.<br>The initial IMEState is **Neutral** and the memberName is **Company A**. |
| **Output** | | IME State | The activated emotion that is delivered from the *iEmotionAgent* sub-agent, corresponding to the values of the tuple <Valence, Arousal>. |
| **Parameters** | **Own Data** | ValenceDecay | **0.2** |
| | | ArousalDecay | **0.2** |
| | | VOPplanner | **1** (*VO under creation that is being planned by this company*) |
| | | VOPpartner | **3** (*Partner of VOs that have successfully finished*) |
| | | PerfEval | **0.8** |
| | | NeedsExpectMet | **0.8** |
| | | Profitability | **0.8** |
| | | BelongInformalNets | **0.75** *(Belongs to 3 informal nets out of a total of 4 )* |
| | | SharedKnowResour | **0.16** *(Shared 1 resources & knowledge out of a total of 6 )* |
| | | CommFreq | **0.8** *(Is being extremely participative and active )* |
| | | CommEffect | **0.2** |
| | **CN Data** | TCNMemb | **5** |
| | | TotalCNVOs | **6** |
| | | ANEState | **Neutral** |
| | | CNTrust | **0.8** |
| | | CNVSAlign | **0.8** |
| | **Events** | InvitVO | **0** *(event not active)* |
| | | IncentReward | **0** *(event not active)* |
| | | CNSocProtViol | **0** *(event not active)* |
| | | CNTrustBreach | **0** *(event not active)* |
| | | CNVSMisalign | **0** *(event not active)* |

**Table 5.6. Initial conditions for agent B (representing Company B).**

| *Type* | | *Name* | *Initial Condition* |
|---|---|---|---|
| **Input** | | Agent Initial State | 1 *IMAgent* is instantiated and consequently the two sub-agents *iPerceptionAgent* and *iEmotionAgent*.<br>The initial IMEState is **Neutral** and the memberName is **Company B**. |
| **Output** | | IME State | The activated emotion that is delivered from the *iEmotionAgent* sub-agent, corresponding to the values of the tuple <Valence, Arousal>. |
| **Parameters** | **Own Data** | ValenceDecay | **0.2** |
| | | ArousalDecay | **0.2** |
| | | VOPplanner | **0** (*The company is new in the CN*) |
| | | VOPpartner | **0** (*The company is new in the CN*) |
| | | PerfEval | **0.2** (*The company is new in the CN, then it has the default value for evaluation*) |
| | | NeedsExpectMet | **0.4** *(Still with high expectations… not met… )* |
| | | Profitability | **0.4** (*The company is new in the CN*) |
| | | BelongInformalNets | **1** *(Belongs to 4 informal nets out of a total of 4 )* |
| | | SharedKnowResour | **0.66** *(Shared 3 resource & knowledge out of a total of 6)* |
| | | CommFreq | **0.9** *(Is being participative and active, initial energy…)* |
| | | CommEffect | **0.8** |
| | **CN Data** | TCNMemb | **5** |
| | | TotalCNVOs | **6** |
| | | ANEState | **Neutral** |
| | | CNTrust | **0.8** |
| | | CNVSAlign | **0.8** |
| | **Events** | InvitVO | **0** *(event not active)* |
| | | IncentReward | **0** *(event not active)* |
| | | CNSocProtViol | **0** *(event not active)* |
| | | CNTrustBreach | **0** *(event not active)* |
| | | CNVSMisalign | **0** *(event not active)* |

**Table 5.7. Initial conditions for agent C (representing Company C).**

| *Type* | | *Name* | *Initial Condition* |
|---|---|---|---|
| **Input** | | Agent Initial State | 1 *IMAgent* is instantiated and consequently the two sub-agents *iPerceptionAgent* and *iEmotionAgent*.<br>The initial IMEState is **neutral** and the memberName is **Company C**. |
| **Output** | | IME State | The activated emotion that is delivered from the *iEmotionAgent* sub-agent, corresponding to the values of the tuple <Valence, Arousal>. |
| **Parameters** | **Own Data** | ValenceDecay | **0.2** |
| | | ArousalDecay | **0.2** |
| | | VOPplanner | **5** (*Founding member of the CN*) |
| | | VOPpartner | **0** (*Although being a founding member was never invited…*) |
| | | PerfEval | **0.4** (*The last performance evaluation was not very good*) |
| | | NeedsExpectMet | **0.5** |
| | | Profitability | **0.8** |
| | | BelongInformalNets | **0.75** *(Belongs to 3 informal nets out of a total of 4 )* |
| | | SharedKnowResour | **0.16** *(Shared 1 resource & knowledge out of a total of 6 )* |
| | | CommFreq | **0.3** *(Is not being participative neither active )* |
| | | CommEffect | **0.2** |
| | **CN Data** | TCNMemb | **5** |
| | | TotalCNVOs | **6** |
| | | ANEState | **Neutral** |
| | | CNTrust | **0.8** |
| | | CNVSAlign | **0.8** |
| | **Events** | InvitVO | **0** *(event not active)* |
| | | IncentReward | **0** *(event not active)* |
| | | CNSocProtViol | **0** *(event not active)* |
| | | CNTrustBreach | **0** *(event not active)* |
| | | CNVSMisalign | **0** *(event not active)* |

With the initial conditions established, three scenarios are proposed for each involving individual member represented by each agent: IMAgent A, IMAgent B, and IMAgent C respectively, as described in Table 5.8. For each scenario, a sensitivity analysis of the involved variables is defined and the expected IME state outcome for the corresponding scenario/agent is envisaged.

**Table 5.8. Scenarios for the individual member experiments.**

| *Scenario* | *Description* | *Sensitivity Analysis* | *Involved Agents* | *Expected Outcomes* |
|---|---|---|---|---|
| **S.1.1** | This scenario runs the initial condition of the involved agent | Initial conditions from the involved agent | IMAgent A | *Contentment* |
| | | | IMAgent B | *Frustration* |
| | | | IMAgent C | *Depression* |
| **S.1.2** | During the runtime the involved agent receives an incentive reward | *IncentReward* varies from 0 to 1 (deactivated to activated) | IMAgent A | *Excitement* |
| **S.1.3** | During the runtime the involved agent receives an invitation to participate in a VO | *InvitVO* varies from 0 to 1 (deactivated to activated) | IMAgent B | *Excitement* |
| | | | IMAgent C | *Contentment/ Excitement?* |

| | | | | |
|---|---|---|---|---|
| **S.1.4** | Some problems happened among some members of the CN, and a social protocol violation was activated by the CN administrator. | *CNSocProtViol* varies from 0 to 1 (deactivated to activated) | IMAgent A | *Frustration* |
| **S.1.5** | Serious conflicts occurred between partners of a VO and the CN due to lack of transparency in some royalty issues… This activated a trust breach in the CN environment. | *CNTrustBreach* varies from 0 to 1 (deactivated to activated) | IMAgent B | *Depression* |
| **S.1.6** | The assessment of the alignment of the value systems of the CN and members reaches an disturbing value | *CNVSMisalign* varies from 0 to 1 (deactivated to activated) | IMAgent C | *Depression* |

**Collaborative Network Experiments.** These experiments on the collaborative network focus on the aggregated network emotion model. Thus, some scenarios representing the potential conditions of the CN are proposed for evaluating its aggregated emotion behavior. For that, some assumptions are considered, taking into account the modeling design of the ANE component of the C-EMO framework of Figure 3.6. This experiment comprises two distinct collaborative networks. One that includes the members of the previous experiments, the *SimulCN,* and another collaborative network representing the members of the GloNet's solar energy industry denominated *VBESolar*. Table 5.9 describes these two CN profiles.

**Table 5.9. Collaborative network profile or profiles.**

| *CN* | *Profile* |
|---|---|
| **SimulCN** | This collaborative network is formed by 5 members including the three companies presented before (A, B & C) and another two that are extraordinary participating members of this CN (D & E). The SimulCN has a total of 6 VOs, 5 of them have successfully terminated and 1 is being created (by IMAgent A). The participation of these members in the CN activities is quite shy with a pretty reduced number of knowledge sharing and resources. The initial member's emotional states are the same of the previous experiments, and the other two members have the contentment state. |
| **VBESolar** | This collaborative network was formed by two founding members (*iPLON GmbH* and *Ajax Network Solutions*), in the area of solar energy manufacturing. Currently it has 10 members, most of them from India and a total of 8 VOs: 2 successfully finished, 5 under operation and other being created. The performance of this CN until now, has been good. A great number of members are dynamically involved in the activities of |

| | |
|---|---|
| | the CN. Regarding the individual emotion of its members, the overall assessment is positive. The majority of members present the contentment state, especially because they are in a phase of great involvement in the VOs that are currently running. |

Similarly to the individual member's experiments, there is the need to define the initial conditions of the CNA agents that embodies the *SimulCN* and the *VBESolar*. Table 5.10 and Table 5.11 and show those conditions.

**Table 5.10. Initial conditions for the agent representing the SimulCN.**

| *Type* | | *Name* | *Initial Condition* |
|---|---|---|---|
| **Input** | | Agent Initial State | 1 *CNAgent* is instantiated and consequently the two sub-agents c*PerceptionAgent* and a*EmotionAgent*. The initial ANEState is **neutral**. |
| **Output** | | ANE State | The activated aggregated emotion that is delivered from the *aEmotionAgent* sub-agent, corresponding to the values of the tuple <Valence, Arousal>. |
| **Parameters** | **Own Data** | ValenceDecay | **0.2** |
| | | ArousalDecay | **0.2** |
| | | TCNmemb | **5** (*The total number of members*) |
| | | ActiveMembs | **4** (*The IMAgent A, IMAgent B and the other two*) |
| | | TotalCNVOs | **6** |
| | | VOsSuccess | **5** |
| | | VOsOperation | **0** |
| | | VOsFailed | **0** |
| | | VOsCreation | **1** |
| | | CNPerfEval | **0.6** |
| | | CNTrust | **0.8** |
| | | CNVSAlign | **0.8** |
| | | CNSharingRatio | **0.2** *(The total of shared assets is 6)* |
| | | CNInformnalNets | **0.7** *(The total of Informal nets is 4)* |
| | | CommIntensity | **0.5** *(Overall communication )* |
| | | CNProfitability | **0.6** |
| | **Member** | ExcitFreq | **0** |
| | | ContFreq | **3** |
| | | NeutralFreq | **0** |
| | | FrustFreq | **1** |
| | | DepreFreq | **1** |

**Table 5.11. Initial conditions for the agent representing the VBESolar.**

| *Type* | | *Name* | *Initial Condition* |
|---|---|---|---|
| **Input** | | Agent Initial State | 1 *CNAgent* is instantiated and consequently the two sub-agents c*PerceptionAgent* and a*EmotionAgent*. The initial ANEState is **neutral**. |
| **Output** | | ANE State | The activated aggregated emotion that is delivered from the *aEmotionAgent* sub-agent, corresponding to the values of the tuple <Valence, Arousal>. |
| **Parameters** | **Own Data** | ValenceDecay | **0.2** |
| | | ArousalDecay | **0.2** |
| | | TCNmemb | **10** (*The total number of members*) |
| | | ActiveMembs | **8** |
| | | TotalCNVOs | **8** |
| | | VOsSuccess | **2** |
| | | VOsOperation | **5** |
| | | VOsFailed | **0** |
| | | VOsCreation | **1** |
| | | CNPerfEval | **0.7** |

| | | | |
|---|---|---|---|
| | | CNTrust | **0.8** |
| | | CNVSAlign | **0.8** |
| | | CNSharingRatio | **0.6** *(The total of shared assets is 28)* |
| | | CNInformnalNets | **0.8** *(The total of Informal nets is 10)* |
| | | CommIntensity | **0.8** *(Overall communication )* |
| | | CNProfitability | **0.7** |
| | **Member** | ExcitFreq | **0** |
| | | ContFreq | **7** |
| | | NeutralFreq | **0** |
| | | FrustFreq | **1** |
| | | DepreFreq | **2** |

With the initial conditions established, four scenarios are proposed for the two collaborative networks and corresponding agents: CNAgent Simul and CNAgent Solar respectively, as described in Table 5.12. For each scenario, a sensitivity analysis of the involved variables is defined and the expected ANE state outcome for the corresponding scenario/agent is predicted.

**Table 5.12. Scenarios for the collaborative network experiments.**

| *Scenario* | *Description* | *Sensitivity Analysis* | *Involved Agents* | *Expected Outcomes* |
|---|---|---|---|---|
| **S.2.1** | This scenario runs the initial condition of the involved agent | Initial conditions from the involved agent | CNAgent SimulCN | *Contentment* |
| | | | CNAgent VBESolar | *Contentment* |
| **S.2.2** | During the runtime the VO under creation failed thus the level of values alignment and trust decreases substantially | *CNTrust, CNVSAlign* decreases a portion of its current value. *VOsCreation* diminishes 1 and *VOsFailed* augments 1. | CNAgent SimulCN | *Depression/ Contentment?* |
| **S.2.3** | During the runtime there is a shift of members IME states from contentment to depressed | *ContFreq* decreases in the same value that the *DepreFreq* increases | CNAgent SimulCN | *Depression* |
| | | | CNAgent VBESolar | *Depression/ Contentment?* |

| | | | | |
|---|---|---|---|---|
| **S.2.4** | Suddenly one VO under operation is abruptly terminated due to conflicts among members… | The number of *VOsOperation* is reduced by 1, consequently the number of *VOsFailed* increases 1. The values of *CNTrust* and *CNVSAlign* are also updated and the corresponding events are activated (*CNTrustBreach* and *CNVSMisalign*) and sent to members. Members belonging to the failed VO "feel" depressed…. | CNAgent VBESolar | *Depression* |

In addition to these experiments, other scenarios are designed with the intention of perceiving the whole emotion behavior of the CN environment as described in Table 5.13. Those scenarios are applied to the *SimulCN* case, i.e. only to **CNAgent Simul**, and simulate what happens in the CN (as a whole) when external events occur. The main expectation is that some members (the ones that are more volatile) would change their IME states and by consequence it would also affect the ANE state. What is not predicted is the values they would take as in previous controlled experiments. These scenarios intend to demonstrate the dynamics of the CN and justify the usage of this C-EMO simulation model for a real context not only for specific cases, as the ones that were presented before.

**Table 5.13. Scenarios for the CN environment.**

| *Scenario* | *Description* | *Sensitivity Analysis* | *Involved Agents* |
|---|---|---|---|
| **S.3.1** | Serious conflicts occurred in the CN and put in jeopardy the CN established social protocols. | *CNSocProtViol* event is activated | CNAgent SimulCN |
| **S.3.2** | Some disturbing issues were perceived in the operation of a VO regarding the delivery times for sub-products. | *CNTrustBreach* event is activated | CNAgent SimulCN |

#### *5.2.2.2.2 Simulation Runs & Sensitivity Analysis*

Simulation runs consist in executing the simulation (or the computer model) to generate the inferred data and to perform sensitivity analysis. On its turn, sensitivity analysis consists of making changes to the model's inputs (using the scenarios designed in the previous section), running those scenarios, inspecting the results by checking if the results are compliant with the expectations, and learning and discussing the results. Moreover, the time unit selected to run these scenarios is in days.

**Individual Member Scenarios Runs.** The individual members' experiments start with the configuration of the initial values of each member's parameters, as described in Table 5.5, Table 5.6 and Table 5.7 and illustrated in Figure 5.24. Having into account that these experiments presupposes a CN with members and also with some VOs, the scenario relative to the *SimulCN* collaborative network is also initialized, as illustrated in Figure 5.25.

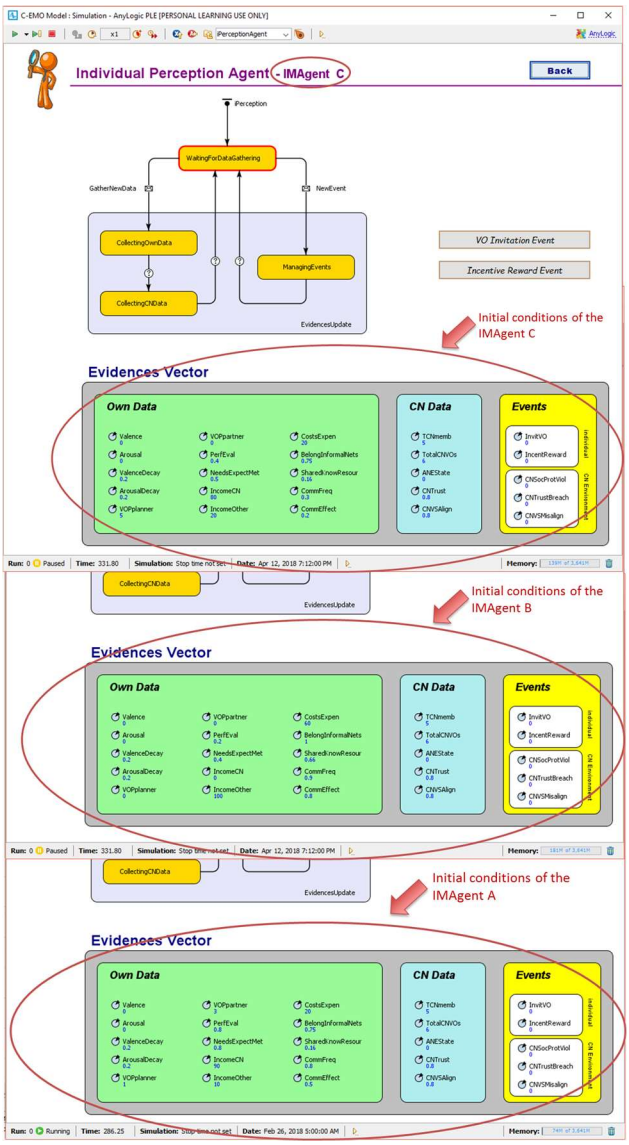



**Figure 5.24. Individual member's initial conditions.**

After the initial configuration, the simulation begins. Figure 5.25 shows a screenshot of the initial moments of the simulation. There it can be seen five IMAgents that represent the different CN members. In this experiment the agents A, B, and C are the ones that are chosen to run the scenarios defined in Table 5.8.

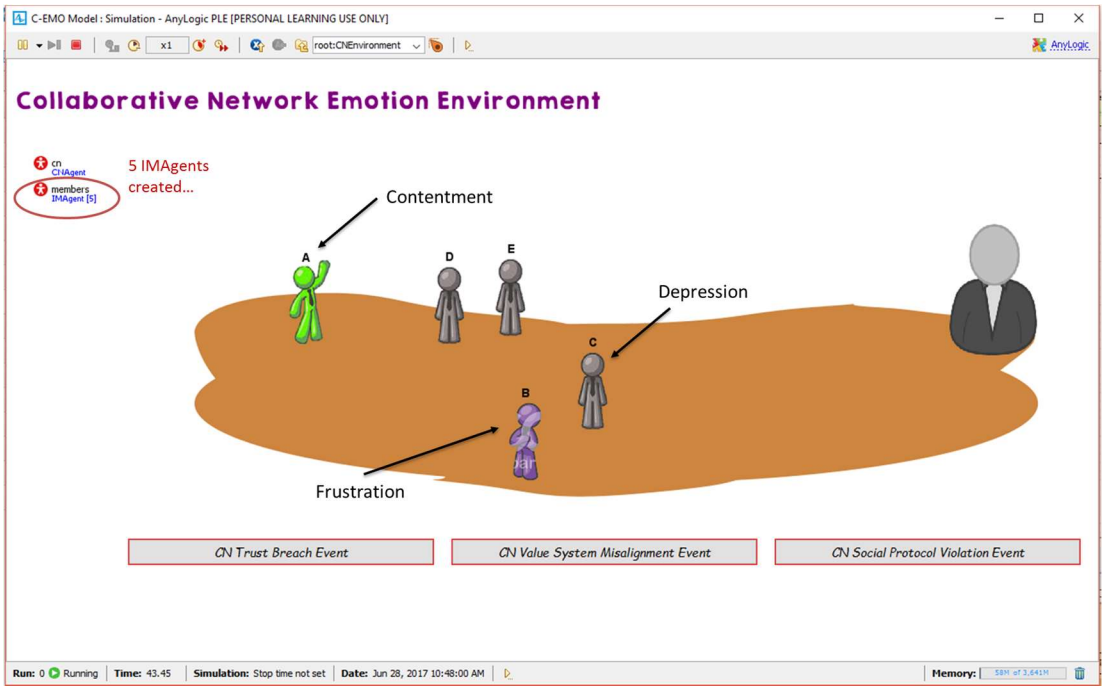



**Figure 5.25. Simulation run of the individual member experiments.**

The initial results of the IME states of the members are in line with what was expected (see Table 5.8) as shown in Figure 5.25. Figure 5.26, demonstrates the IMEA SD models of each IMAgent in runtime, where the values of *Valence* and *Arousal* stocks are highlighted.

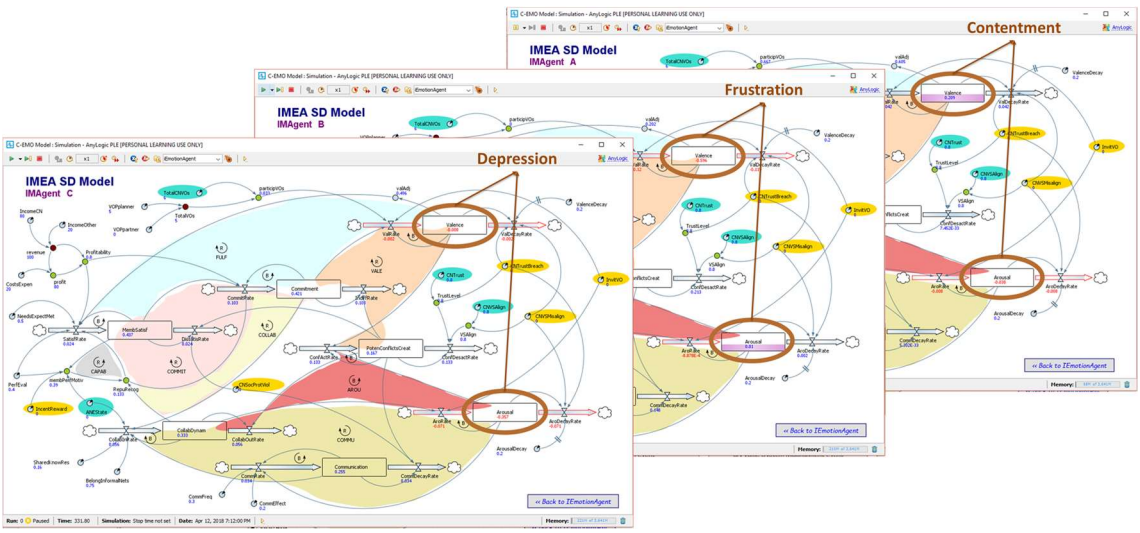



**Figure 5.26. IMEA SD models in runtime.**

The scenarios run and sensitivity analysis is performed for the three IMAgents and are presented below.

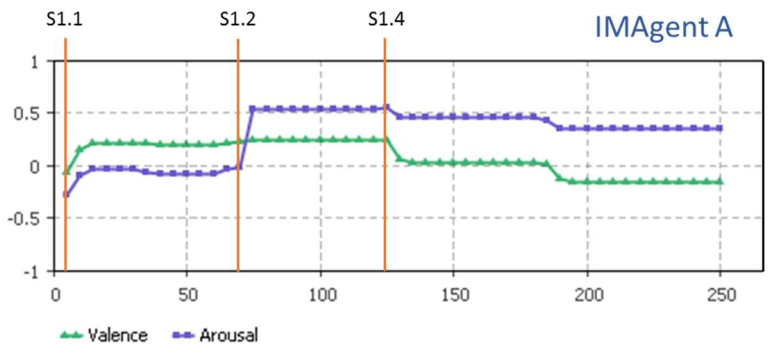



**Figure 5.27. IMAgent A scenarios simulation results.**

Figure 5.27 illustrates the scenarios S1.1, S1.2 and S1.4 that were simulated for IMAgent A. For S1.1, the scenario that runs the initial conditions, the result is what it was expected, i.e. the IME estimated is *contentment*. There is a period where it can be seen that both valence and arousal variables are increasing their values and then they stabilize (approximately at t = 20). After some time company A receives an incentive reward (S1.2), which is something that it was desiring for a long time. Immediately the arousal reacts positively, once it is something that stimulates it. Valence also increases in a small portion and the result is the *excitement* IME state, which goes in the direction of what was initially expected. The scenario S1.4 is put in practice for t = 125. This scenario expresses the dissatisfaction of the members whenever a social protocol violation occurs within the CN. As it can be seen in the same figure, both valence and arousal decrease during a period of time, still in the excitement state but with a very weak value of positive arousal, and after a while stabilizes in the *frustration* IME.

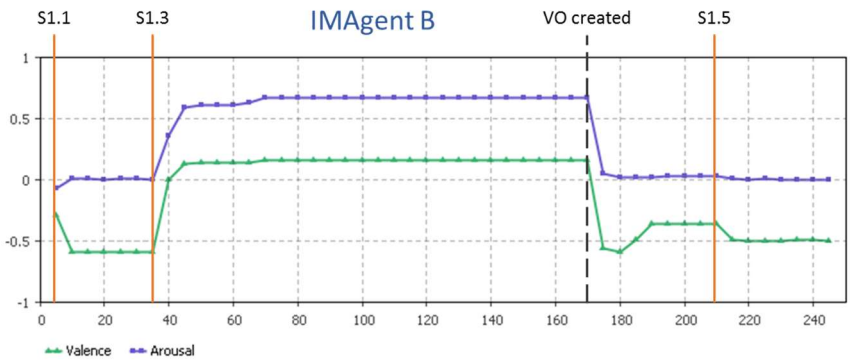



**Figure 5.28. IMAgent B scenarios simulation results.**

Figure 5.28 illustrates the scenarios S1.1, S1.3 and S1.5 for the IMAgent B. As previously seen, at the beginning of the simulation run, which corresponds to the S1.1, the value of the tuple (valence, arousal) corresponds to *frustration*. This agent represents a company that has joined the CN a few days ago so its metrics are still below the average. Nonetheless, following the scenario S1.3, it receives an invitation to form a VO and, as it can be seen in t = ~35, both valence and arousal increases substantially (activating the *excitement* IME) denoting both the satisfaction and the stimulus that this event provoked in company B. Then for a considerable period of days, its IME state remains stable. After a couple of months later, the VO is finally created and with it is reflected in the results with the decrease of the valence and arousal at t =170, activating the *frustration* IME. In the meanwhile some metrics were updated, such as the number of VOs or the CN income, and that is shown in the increase of the valence in t = 180. However, company B is still frustrated, it is still a young company in the CN and its goals are not met yet. Finally, the occurrence of a CN trust breach (S1.5) at t = 210, conducts the IMAgent B state to *depression*, as expected.

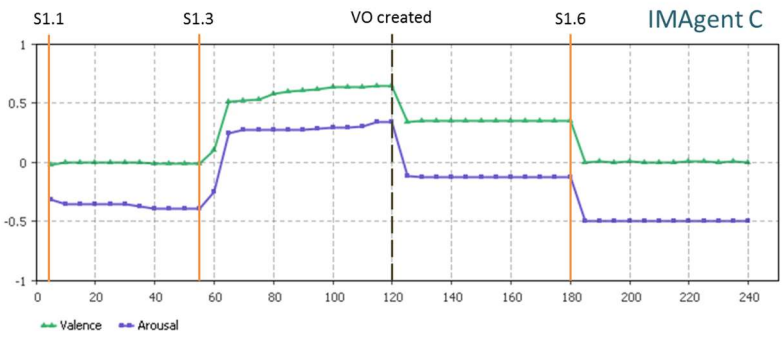



**Figure 5.29. IMAgent C scenarios simulation results.**

Figure 5.29, shows the results of the simulation scenarios S1.1, S1.3 and S1.6 of the IMAgent C. As seen above, this agent initially (S1.1) starts with the *depression* state as expected. This is due to the fact that it is a long time member that is not being active in any activities of the CN. Fortunately, it receives an invitation to form a VO (S1.3) inciting activation and satisfaction in the agent. This is represented with the increase of both arousal and valence and the activation of the *excitement* IME. However when the VO is created, some of the activation is lost and the agent passes to the state of *contentment*. Finally, the occurrence of a CN value system misalignment (S1.6) at t = 180, brings the IMAgent C state to *depression*, as expected.

As a final remark on this analysis, and comparing with what was expected from the experiments design, it can be said that resulting behavior of the IMEA SD model is positively valid. Nevertheless, there are some improvements that are needed to have in mind for future developments in order to transform it into a more accurate model. Some examples are: (*i*) refinements of the IMEA SD model in order to have smoother transitions whenever the events occur; (ii) think about the creation of a new dimension of CNE (collaborative network emotion) that represents intensity of emotion (e.g., strong, moderate and weak). This dimension in conjunction with the other two (arousal and valence) could give more information about the emotion that is being felt. For instance, in the results presented in Figure 5.29, t > 200, the value of valence is in the threshold of negative values but the values of arousal are well established in the negative area, perhaps the IME estimated could be *weak depression*. With this additional information, it is made clear that this emotion could easily pass to the contentment state.

**Collaborative Network Experiments.** These experiments start with the configuration of the initial values of the parameters of the collaborative networks *SimulCN* and *VBESolar*, as described in Table 5.10 and Table 5.11, and illustrated in Figure 5.30.

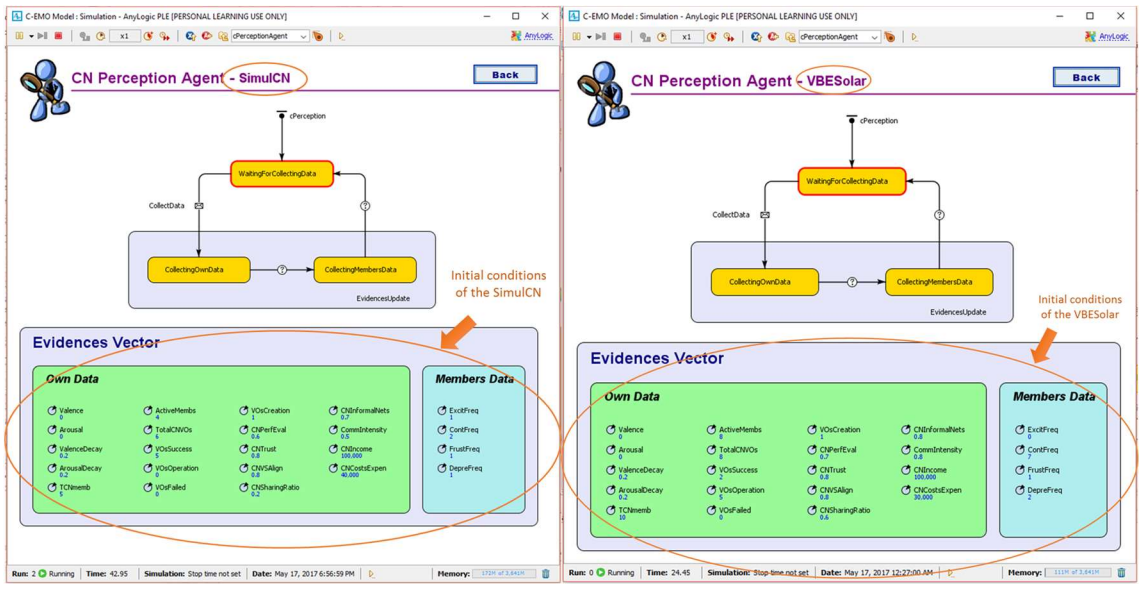



**Figure 5.30. SimulCN and VBESolar initial configuration.**

After the initial configuration, the simulation for each CN begins. The results of these simulations are divided by collaborative network. First with the SimulCN and then with the VBESolar scenarios simulations runs.

**SimulCN.** As previously mentioned, this CN encompasses the company members that were used in the individual member experiments. Figure 5.31 shows a screenshot of the initial moments of the simulation, where the previous five IMAgents and the CNAgent SimulCN can be seen. The initial result of the ANE state of SimulCN (*contentment*) is in line with what was expected from the designed scenarios (see Table 5.12).

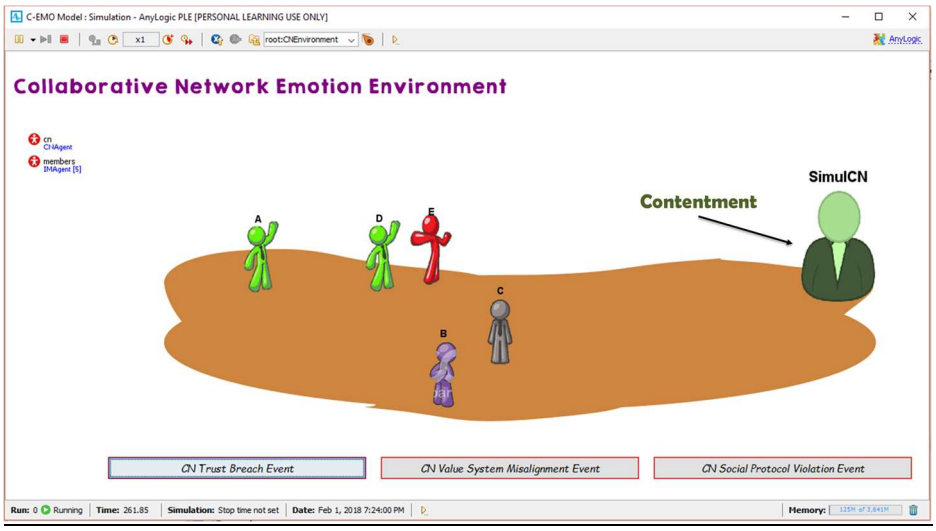



**Figure 5.31. Simulation run of the initial conditions of SimulCN.**

Figure 5.32, shows the ANEA SD model for the CNAgent SimulCN in runtime, with the values of *Valence* and *Arousal* highlighted.

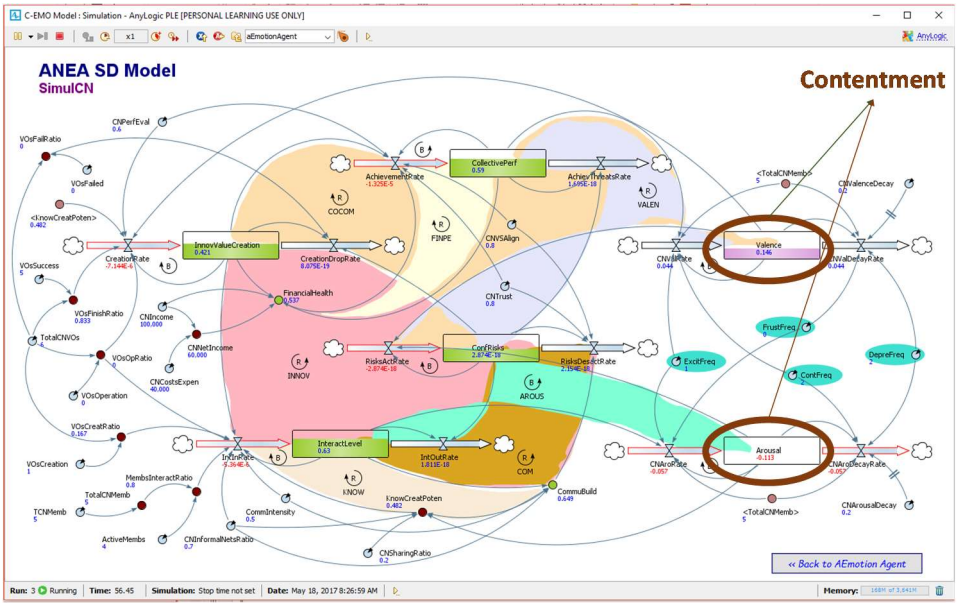



**Figure 5.32. ANEA SD model in runtime in SimulCN.**

Figure 5.33, illustrates the scenarios S2.1, S2.2 and S2.3 that were simulated for the SimulCN agent.

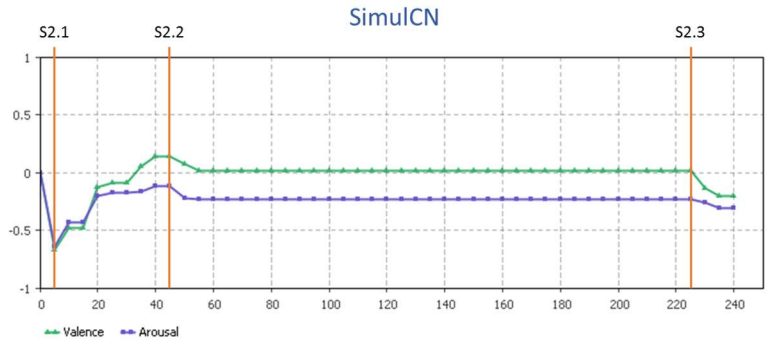



**Figure 5.33. SimulCN CNAgent scenarios simulation results.**

Initially, with the simulation run of the initial conditions (S2.1), it can be seen that both valence and arousal took a period of time before reaching the *contentment* ANE state (as expected) around t = 35. This unstable period has to do with the initial dynamics of the involved members. When the scenario S2.2 is put in practice, i.e. when the only VO under creation fails and the levels of trust and values alignment of the VO decrease substantially, both valence and arousal decrease and the ANE remains in the *contentment* state, although with a reduced value of valence (it can suddenly change to depression, which is what was expected). After a long period of days changes in member's IME affects the dynamics of the ANE as simulated with the S2.3. What happens is a shift from contentment to depression states of two members, which is translated in a negative reaction of both valence and arousal conducting the ANE state of SImulCN to *depression*.

The results of these scenario simulations, denote that both the agent-based model and ANEA SD model implementations go in the direction of what was expected for each scenario. Again, it is noticed that the introduction of a new dimension (intensity) could bring a value-added to the CNE (collaborative network emotion) model.

In addition to these scenarios, other two were previously designed in order to perceive the influence of the ANE state of the SimulCN on its members and vice-versa (see Table 5.13).

The scenario S.3.1, represents the effect that serious conflicts affecting the established social protocols for this CN might have in both the involved members (IMAgents) and the collaborative network as a whole (SimulCN CNAgent). Figure 5.34 shows a screenshot of the state of IMEs and ANE before the simulation of this scenario and another screenshot after the simulation.

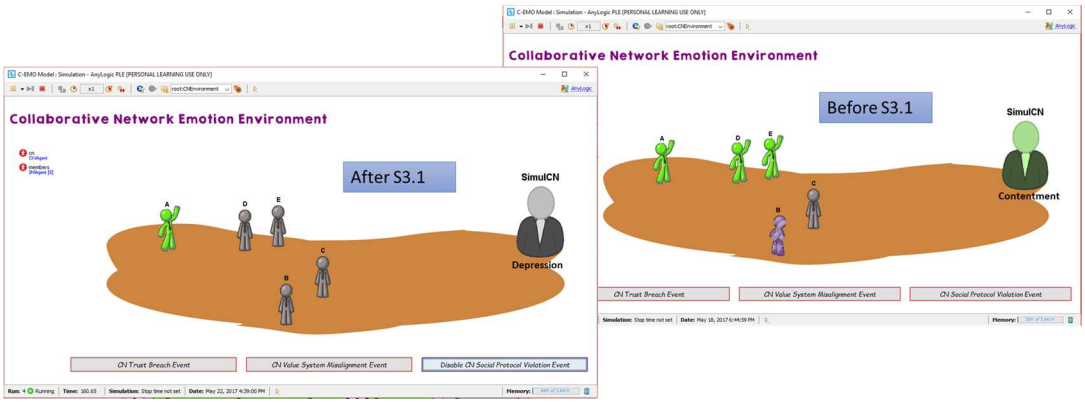



**Figure 5.34. Simulation run of scenario S3.1.**

As it can be seen, the occurrence of the CN social protocol violation event (button on the bottom right corner) influences the IME of three members (B, D and E) and also the ANE of the SimulCN that passes from the contentment state to depression.

On its turn, the scenario S.3.2, represents the effect that the occurrence of a trust breach related to disturbing issues regarding the delivery times of sub-products within a VO might have in both the involved members (IMAgents) and the collaborative network as a whole (SimulCN CNAgent). Figure 5.35 shows a screenshot of the state of IMEs and ANE before the simulation of this scenario and another screenshot after the simulation.

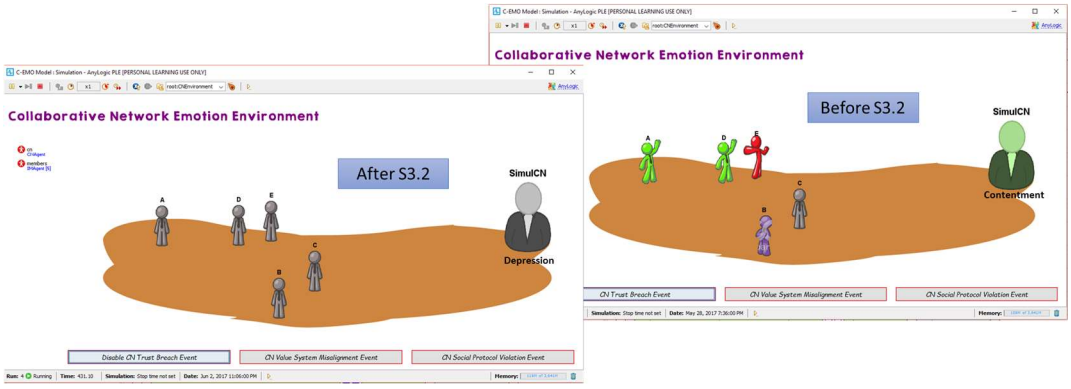



**Figure 5.35. Simulation run of scenario S3.2.**

As it can be seen, the occurrence of the CN trust breach event (button on the bottom left corner) influences the IME of all members and also the ANE of the SimulCN that passes from the contentment state to depression.

**VBESolar.** This CN represents some companies of the solar energy industry that were provided by one of the GloNet's project partner (the iPLON GmbH). This CN was used

for demonstration purposes of the GloNet's developments to companies from the area of solar energy in Chennai, India (as further detailed in section 5.2.4). Therefore, Figure 5.36 shows a screenshot of the initial moments of the simulation, where the 10 companies represented by IMAgents and the VBESolar CNAgent can be seen. The initial result of the ANE state of VBESolar is *contentment* which is in line with what was expected from the designed scenarios (see Table 5.12).

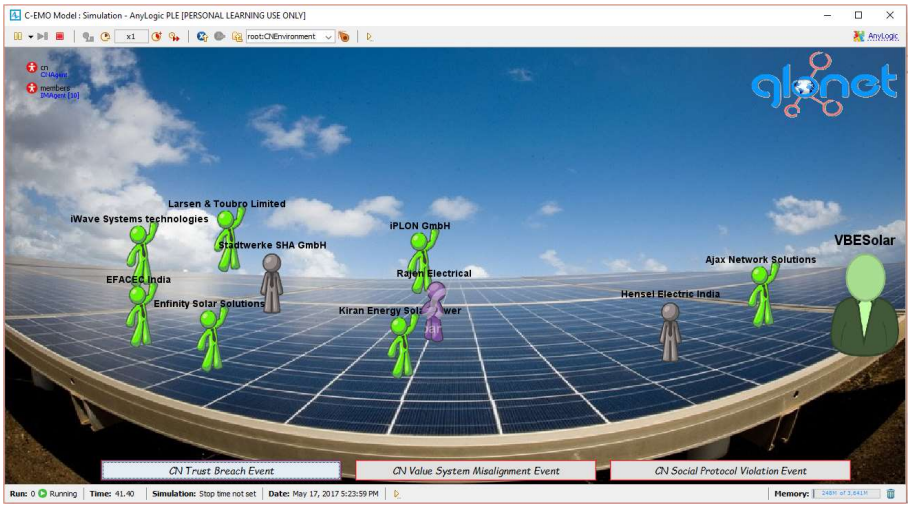



**Figure 5.36. Simulation run of the initial conditions of VBESolar.**

Figure 5.37, shows the ANEA SD model for the VBESolar in runtime, with the values of *Valence* and *Arousal* highlighted.

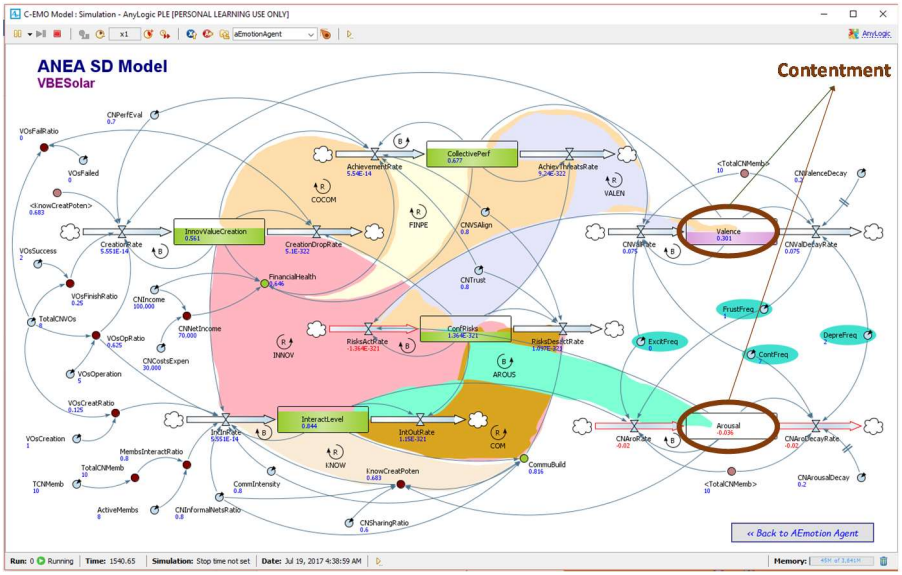



**Figure 5.37. ANEA SD model in runtime in VBESolar.**

Figure 5.33, illustrates the scenarios S2.1, S2.3 and S2.4 that were simulated for the VBESolar agent.

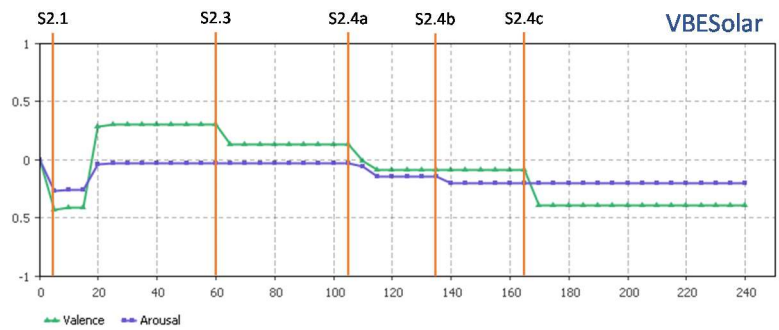



**Figure 5.38. VBESolar CNAgent scenarios simulation results**

As also seen with the SimulCN simulations, at the beginning of the simulation that runs the initial conditions (S2.1), the values of arousal and valence only reach stability after a while (t = 20) with the values that activate the ANE state *contentment*. After some days changes in two member's IME from the state contentment to depression affects the dynamics of the ANE as simulated with the S2.3. In this case, strong decrease in the valence and a slight decrease in arousal happens. Nonetheless, the overall state of the CN continues to be *contentment*, though with a minor strength. When a serious problem occur in one of the VOs that are under operation and this is abruptly terminated, the number of *VOsOperation* and *VOsFailed* are updated immediately (S2.4a). When this happens both valence and arousal decreases and the ANE state of the VBESolar passes to depression. As a consequence the events of trust breach (S2.4b) and values misalignment (S2.4c) are activated which influences the IME states of the members and also the ANE state of the CN, as can be seen with the decrease of the pair (valence, arousal) stabilizing the final ANE in *depression*.

At the end of these experiments it can be said that the both the agent-based model and the system dynamics model implementations of the C-EMO model proposed in this work are adequate to represent the underlying concepts of the C-EMO modelling framework. However, along the various scenarios it has been recognized essentially two improvements for the future: *(i)* a more accurate model for the proposed system dynamics developments in order to have results with more smoothness, and *(ii)* the introduction of a third dimension (intensity) to join the valence and arousal dimensions of the CNE model.

### 5.2.3 Validation in the Research Community

The validation in the research community started with the integration of this research work in the European research project GloNet, where some validation results were obtained. In addition, a close interaction with researchers and stakeholders from the SOCOLNET society (www.socolnet.org), provided some important feedback in the progress of this thesis work. Finally, the validation by peers through scientific publications on peer-reviewed international conferences and journals also contributed for the validation of the proposed research work.

#### 5.2.3.1 Validation in GloNet

The GloNet research project, was assessed by the two project end-users, iPLON (iPLON GmbH The Infranet Company, Germany) in the area of solar energy industry, and PROLON (Prolon Control Systems, Denmark) in the area of intelligent buildings. The end-users assessment relied on two main areas: the *fitness-for-purpose* of the concepts and of the platform and its tools. This assessment consisted of the results of structured questionnaires and on the feedback of the *hands-on* experimentation of the developed prototypes (including the emotion support system).

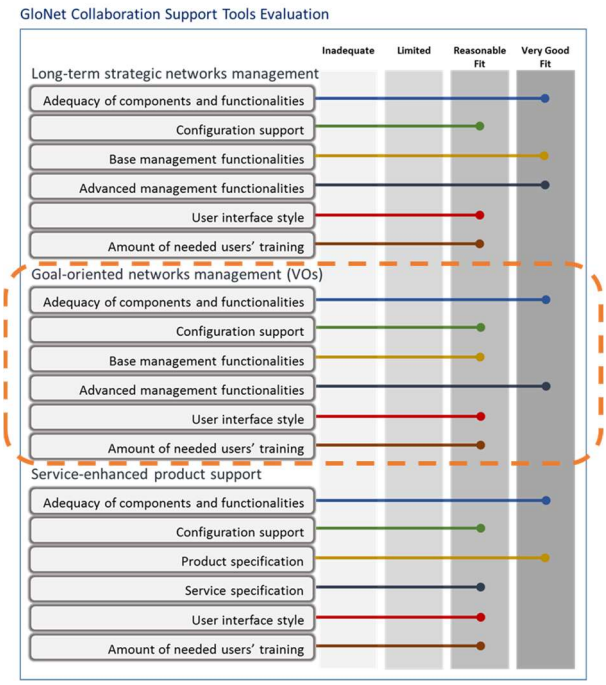



**Figure 5.39. Fit-for-purpose assessment by GloNet's end-users.**

Figure 5.39, summarizes the results of the opinions that were collected through questionnaires, where the emotion support system as part of the *VO advanced management* functionalities of the **goal-oriented networks** component of the GloNet architecture as previously shown in Figure 5.4, is indirectly assessed.

The overall assessment shows that the proposed approach and functionalities provided by the GloNet make a very good fit with the identified collaboration needs. Nevertheless some improvements in the user interface style should be taken into consideration when evolving to a commercial product. Another assessment comprising a solar energy network was sponsored by GloNet as described later in section 5.2.4.

#### 5.2.3.2 Validation by Peers

As stated before, the development of this research work benefited from continuous interaction with various experts and stakeholders from the SOCOLNET society. This interaction was valuable in what respects the feedback on the acceptance of the underlying concepts and of the confirmation of the contribution for the collaborative networks sustainability. Some examples of such informal interactions took place in the form of:

- GloNet's WP5 technical meeting, Amsterdam, 7-10 July 2014.
- GloNet's 3rd review meeting, Brussels, 16 October 2014.
- PRO-VE 2016 Conference – Special Panel Young Researchers Views on Collaboration in a Hyper-connected World (Member of the panel), Porto, 3-5 October 2016.
- DoCEIS 2017 Conference, Caparica, 3-5 May 2017.

Moreover, a number of publications in peer-reviewed conference proceedings and scientific journals (indexed in the WoS), aiming at receiving feedback from the reviewers and also to disseminate the research work, were performed. Figure 5.40, presents the list of publications and the corresponding contributions for this work.

During this research, the author of this dissertation has joined and contributed with research work and publications for another research project (besides GloNet). This project research is also in the context of collaborative networks, applied in ambient assisted living (AAL). With the participation in this project the accumulated knowledge comprising CNs and also the interaction with the project partners' views also contributed for the validation of this thesis work. The project denominated AAL4ALL (Ambient Assisted Living for All), had as main objective the development of a large-

scale ecosystem with products and ambient assisted living services and products to support elderly people and maintaining them at their houses or preferred environments (Camarinha-Matos et al., 2012b).

Previous to this research topic, the author also participated and contributed to other projects that provided relevant background knowledge about the CN context and thus indirect input for this work. They were the TeleCARE - *A multi-agent Tele-supervision system for elderly CARE* - (Castolo et al., 2004), ECOLEAD – *European Collaborative networked Organizations LEADership initiative* – (Camarinha-Matos et al., 2008a), ePAL – *extending the Professional Active Life* – (del Cura et al., 2009) and BRAID – *Bridging Research in Ageing and ICT Development* – (Afsarmanesh et al., 2011).

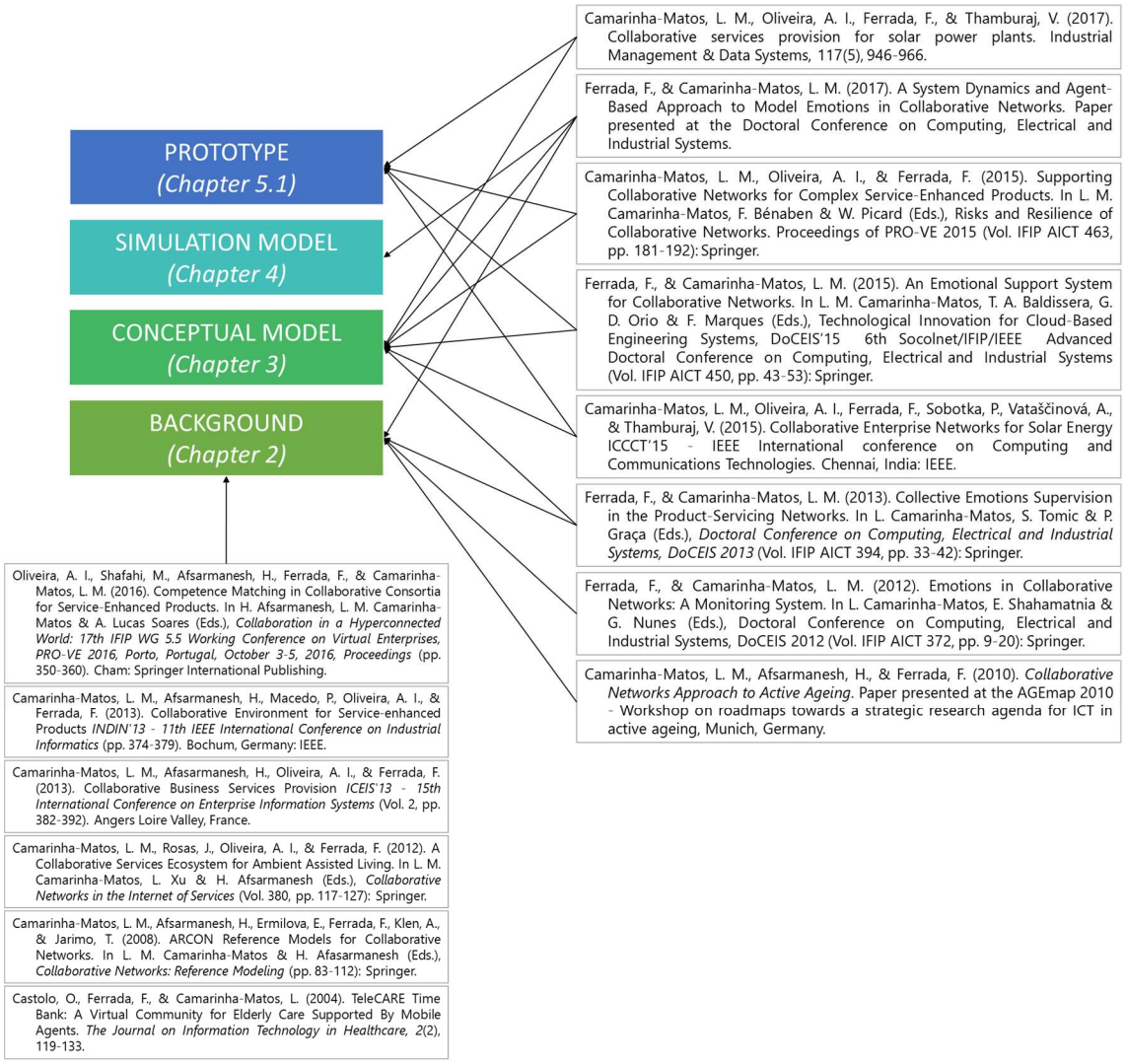



**Figure 5.40. Thesis contributions against list of publications.**

### 5.2.4 Validation by a Solar Energy Industry Network

With the intention of validating the fitness-for-purpose of the GloNet project, including the emotion support system, a pilot demonstrator was implemented in the solar energy application domain. This demonstrator was built based on a case study of the project of the Charanka Solar Park in Gujarat (Figure 5.41), India, a contemporary project in which iPLON GloNet partner participated in the operations and maintenance system.

**Figure 5.41. Charanka solar park, India.**

As the Charanka project started in the initial phase of the GloNet project, its construction did not benefit from the ICT collaborative environment provided by GloNet because it was still being developed. Therefore, the construction of the park followed the traditional methods of this sector, which required face-to-face meetings and manual business processes. Taking this into consideration, the strategy used for taking Charanka as a reference case was by replicating some of the earlier designed business scenarios (Camarinha-Matos et al., 2012a; Camarinha-Matos et al., 2015b), using the GloNet solutions which included also the emotion support system (Ferrada & Camarinha-Matos, 2013).

In this context, two assessment phases of the demonstrator were accomplished:

1. Assessment by a *network of solar energy enterprises*, associated to one of the internal partners of the GloNet project, the iPLON GmbH. This group of companies was not directly involved in the research project or in the pilot implementation so their assessment is from an external perspective, aiming essentially to substantiate or not the fitness of the proposed solutions.

2. Assessment by *lead users* in the solar energy network. In order to obtain a more detailed evaluation, a close interaction with two stakeholders from the iPLON network was conducted.

In addition to the solar energy case, a smaller scale pilot was also developed for the sector of intelligent buildings in Denmark. Nevertheless, the emotion support system was not directly focused on this demonstrator assessment.

#### 5.2.4.1 Network of Solar Energy Enterprises

The assessment conducted by the network of solar energy companies (including 34 participants) took place in Chennai, India in February 2015 (Figure 5.42). It comprised a brief demonstration of the main functionalities of the solutions developed in the GloNet project followed by a hands-on trial. The included functionalities related to this thesis work that were evaluated were: the non-intrusive mechanisms for evidences emotional data collection; the estimation of individual member's and aggregated emotions; and the questionnaires where member's needs and expectations and the member's satisfaction are evaluated. It was also made clear to the audience that this component of GloNet represents an experimental development, still at the level of basic research.

**Figure 5.42. Validation event in Chennai, India in February 2015.**

The feedback of the solar energy network experts was collected through a structured questionnaire (see Annex C). A synthesis of the assessment results is shown in Figure 5.43.

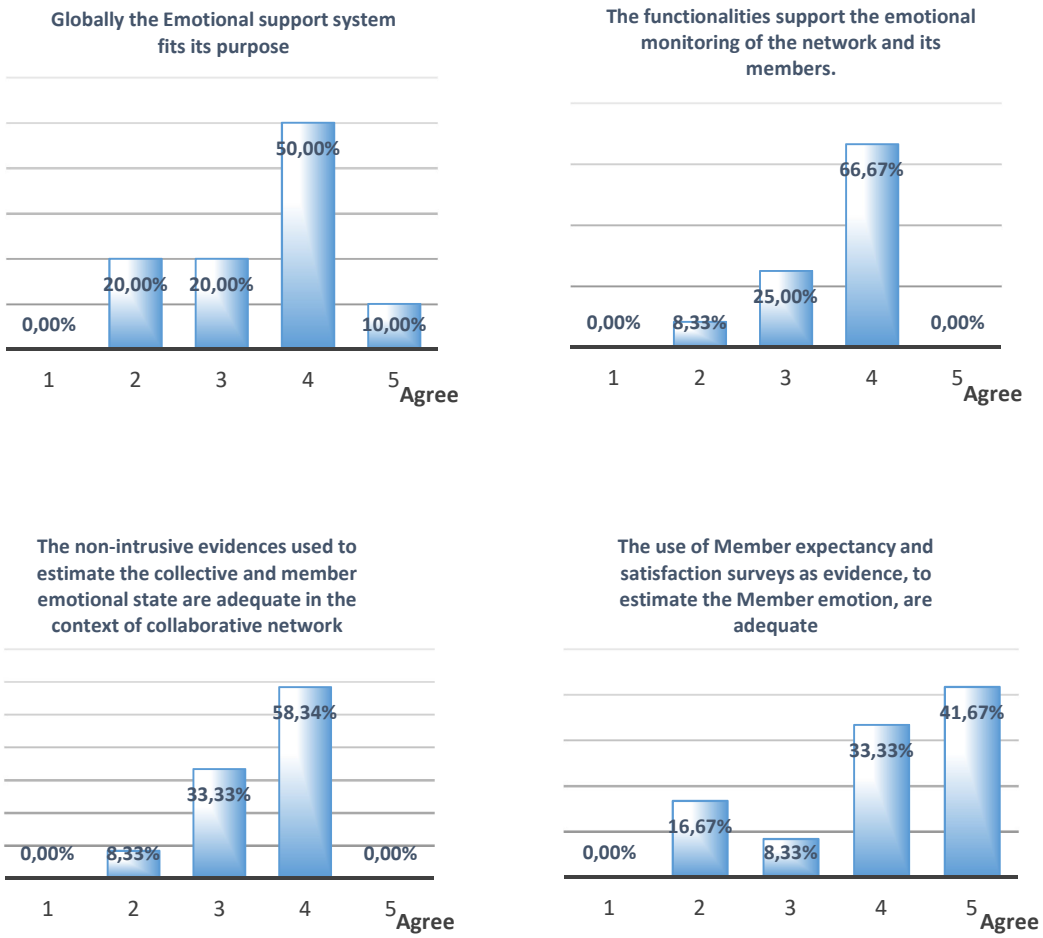



**Figure 5.43. Assessment of emotion support system by the solar energy network.**

The assessment was globally positive although with some dispersion of opinions, which taking into consideration the nature of this work it can be assumed as natural. The inclusion of the questionnaire to evaluate the members' needs and expectations as input for the tool was particularly appreciated by participants. Regarding the fact that this approach does not need sensitive information, through the use of non-intrusive evidences is also an aspect that the participants appreciated.

One participant also expressed doubts about the applicability of this system in the Indian context, due to different cultural and business practices. In fact, this is an issue that needs to be further pursued in future research.

#### 5.2.4.2 Lead Users

The assessment made by a lead user in the solar energy network also took place in Chennai, in February 2015. In order to obtain a more detailed evaluation of the pilot and its solutions, the opinion of the lead user was collected also through extensive structured questionnaires, and comprised five evaluation indicators: effort to acquire information, accessing historical information, design suitability, presentation of the information and, fit for purpose.

Figure 5.44, shows a synthesis of the results of the lead user's assessment. Annex D contains some excerpts of the answers related to the emotion support solution.

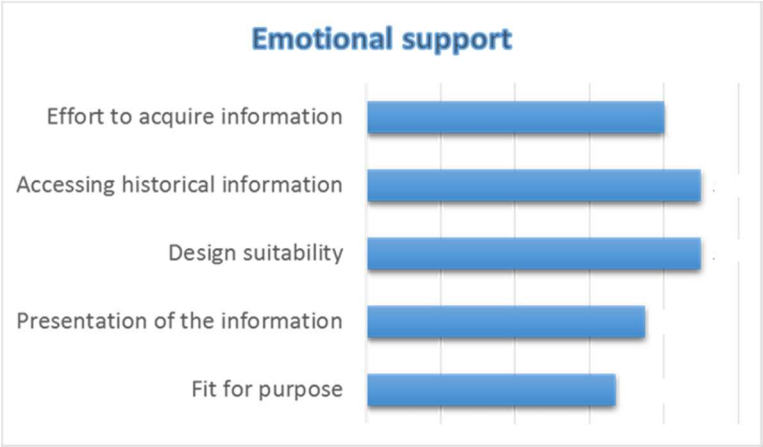



**Figure 5.44. Assessment of the emotion support by lead user in the solar energy.**

While the assessment results were not fully satisfactory, as to some extend expected, they reveal that the concept was moderately accepted. Lead users are naturally biased by their traditional practices. The concept of emotions in organizations and their use for mitigating some potential risks in collaboration is still a hard idea to digest, especially in the Indian context. Nevertheless, it leveraged space for discussions and debate about new business scenarios for the future.

In addition, this assessment was performed with the first prototype (section 5.1.1) of the emotion support, and some of these results and suggestions were extremely important for the following developments. Namely, for the second prototype with the notion that the concept of collaborative network emotions should be well-founded and biased in consistent theories of human-emotion.

A second validation of the full prototype was not possible to conduct due to the fact that the GloNet project, in the meanwhile, ended.

## 5.3 Brief Summary

The followed validation strategy was introduced having into consideration the research questions and the corresponding proposed solutions to validate the hypotheses, as illustrated in Figure 5.23. Therefore, at the end of the evaluation phase, it can be concluded that the hypotheses are positively validated.

The proposed C-EMO modelling framework (chapter 3) supports the estimation of emotions in a non-intrusive way within the context of collaborative networks. It has been qualitatively validated that the founding concepts (the CN paradigm and the notion of CNE – collaborative network emotion) and the structure and behavior (with the two main constructs – IME and ANE models) are appropriate in the domain of collaborative networks. Furthermore, this modeling framework has been validated as generic (with the creation of the C-EMO simulation model) and with potentiality to be explored new modeling aspects in the future (such as the behavior and the decision-making modeling components).

In what concerns the C-EMO simulation modeling approach and the implemented models, either from the qualitative validation perspective and the simulation of the several scenarios it can be concluded that: *(i)* it has been shown the viability and facility of building models on top of the C-EMO framework with the C-EMO simulation modeling approach; *(ii)* it has been shown the appropriateness of the modeling approaches in terms of adequacy, fit-for-purpose and usefulness; *(iii)* it has been shown that with the developed reasoning mechanisms (IMEA SD and ANEA SD) the estimation of both IMEs and ANE are possible and adequate; (*iv*) it has been shown that the proposed agent-based modeling approach was adequate to represent the CN players and their interactions and dynamics (from the emotion related perspective).

The validation conducted within the scientific community is transversal to the different validation aspects, and provided an overall assessment by peers. Some publications dedicated to this work and many others giving background context were published. Furthermore, the participation in EU and national research projects also contributed to the validation of this work namely in terms of direct interaction with potential users of this work. It is highlighted the participation in the GloNet project which provided, through the demonstrator events to end-users and networks, where positive feedback was drawn concerning the acceptance of the concept and the first prototype – emotion support system. The overall assessment of both aspects promoted the development of better foundational concepts and consequently the development of

the C-EMO modeling framework. As a concluding remark, this validation showed that this modeling framework is promising and that a first step in this novel area of research has been approved. Nevertheless we are conscious of the limits of the validation process, constrained by practical limitations. Further developments in this area will certainly require deeper validation.

# 6

# Conclusions and Future Work

*This chapter presents the final considerations stating the novelty of this research area and outlines a series of open issues for future work.*

## 6.1 Summary of the Work

Collaborative networks are being challenged with the necessity to create and provide new socio-technical mechanisms to strengthen their sustainability. This passes by recognizing the social and organizational complexity of the collaboration environments, namely in what concerns the established relationships and the social interactions among the involved participants. One approach is based on supporting CNs with "human-tech" friendly systems capable of "sensing" cognitive aspects such as trust, values alignment, stress or emotion.

This dissertation responds to this challenge presenting a modeling framework to allow defining and estimating collaborative network emotions (C-EMO modeling framework), based on the human psychology and sociology theories of emotion, offering a set of modeling approaches to collect data, via a non-intrusive way, and to reason about the emotions CN participants and the CN itself are "feeling". Based on this, CN administrators are supported with a new mechanism for decision-making and conflicts management contributing in this way to the CN sustainability.

The C-EMO modeling framework has two main building blocks: the IME and the ANE components. With the IME component it is possible to describe the individual member's emotions, i.e. the emotions felt by CN members, and with the ANE component

it is possible to describe the aggregated network emotion, i.e. the emotion felt by the CN as a whole. These components comprise two elements, one devoted to the information system – the context element; and another dedicated to the reasoning mechanisms – the core element. In order to maintain the sensitive information of the CN players preserved, the context element resorts to the "public" information that is available in the CN management system through the profile and competences information systems.

Aiming at validating the appropriateness of the C-EMO modeling framework and also the hypotheses, the development of the C-EMO was made using two modeling research approaches: the agent-based and system dynamics methodologies. The first, uses agents to represent the CN players and their behavior, and the second models the emotion reasoning element of each agent. In other words, the agent-based approach models the C-EMO framework constructs, having embedded in each agent the system dynamics model for the emotion reasoning. In the case of the CN, the ANEA SD model, and in the case of the individual members, the IMEA SD model.

Both the ANEA and IMEA SD models were designed to estimate the pair (valence, arousal) of collaborative networked emotions (CNEs) by modeling the causal influences of the gathered evidences, i.e. the information that is provided by the management system of the collaborative network. These models also reflect the influence of disrupting events in the CN environment, such as the violation of a social protocol, as well as the influence the aggregated network emotion has on each particular member and, on the other hand, the effect that each member emotion has on the overall aggregated emotion.

The implementation of the C-EMO modeling framework, through the C-EMO simulation prototype, has been done in the AnyLogic multi-method simulation software, integrating in this way the proposed concepts and models. Within the scope of the simulation development, the specification of the requirements as well as of the simulation design for the involving agents and IMEA and ANEA was presented.

The validation of the achieved solutions was conducted having into consideration that, as far as the awareness of this thesis author, this is a pioneer research work. Meaning that no other works, concerning the study of emotions applied to organizations (and not to humans) in the context of collaborative networks with a non-pervasive characteristic, were found by the author so far. In addition, there is no substantial available information from collaborative networks and their respective members that could be used to validate the proposed emotion modelling approaches in a real context. Furthermore, this work is not intended to show the most accurate or the most adequate model of emotions in CNs, that would be too ambitious having into account the amount

of knowledge from different scientific areas needed to do that, instead it intended to provide a first step in the research area providing a modeling framework on top of which new models and technologies could be built. In this sense, the purpose of the validation focused on assessing the acceptability, appropriateness and feasibility of the proposed modeling framework, modeling approaches, models and developments within the domain of collaborative networks.

## 6.2 Main Contributions

The main contributions of this research work to scientific knowledge can be separated into three groups, as follows.

**Conceptual Contributions**

- **The CNE concept.** It is a concept introduced as a novel approach to extend the socio-technical mechanisms of collaborative networks. With it the administrator of the collaborative network is able to "sense" the overall emotional health of the network, which helps in decision-making and conflicts resolution management.
- **The CNE Theory.** Complements the CNE concept by categorizing and defining the four CNEs proposed: excitement, contentment, frustration and depression. The dimensional model of CNE, is based on the circumplex model of human-emotions introduced by J.A. Russell, and is where the CNEs are represented from a structural perspective and defined according to two dimensions: valence and arousal. The CNE theory also comprises the conceptual components of CNE that were adopted from the human-emotion theories, and that define the principal constructs of the modeling framework.
- **The C-EMO Modeling Framework.** The major contribution of this PhD work. It draws the CNE concepts and theories in order to estimate the different CN players' CNE states. This framework comprises two novel building blocks, or sub-modeling frameworks:
    - **IME (Individual Member Emotion) Model.** This modeling construct consists of defining the different stimulus (data) both from the CN environment and the individual member itself, and in defining the core IME reasoning and behavior components.

- **ANE (Aggregated Network Emotion) Model.** This modeling construct consists of defining the stimulus from the CN environment (including the emotional information from the members), and in defining the core ANE reasoning and decision-making components.

**Contributions in the form of Modeling Approaches**

- **The IMEA SD Model.** The proposal of a system dynamics modeling approach as a methodology to model the IMEA element of the C-EMO framework is another relevant contribution. The IMEA SD model defines the input variables (from the evidences stimulus) and provides the cognitive appraisal of the IME using the systems dynamics methods: causal loop and stocks and flows diagrams, estimating in this way the two dimensions of the IME: valence and arousal.
- **The ANEA SD Model.** Likewise the previous item, this is another relevant contribution of this work. The ANEA SD model proposes a system dynamics modeling approach as a methodology to model the ANEA element of the C-EMO framework. It defines the input variables (from the evidences stimulus) and provides the reasoning of the ANE using the SD methods: causal loops and stocks and flows diagrams, estimating the two dimensions of the ANE: valence and arousal.
- **The C-EMO Agent-Based Model.** The proposal of an agent-based modeling approach to serve as the abstraction model of the CN environment and the C-EMO modeling framework. This relevant contribution of this PhD, organizes the CN players into three distinct agents: *(i)* the individual member agent (IMAgent), which represents each participating individual member of the CN; *(ii)* the CN agent (CNAgent), which represents the CN's emotion management system; and *(iii)* the CN environment agent, which represents the CN itself, the CN agent and the collection of IMA agents that belong to the CN.

**Technological Contribution**

The technological contributions are not as relevant as the ones outlined previously, nevertheless they demonstrate how the proposed concepts, frameworks and models can be integrated and implemented, serving as important contribution of this PhD work.

- **The C-EMO implementation.** The application of a visual interactive modeling system for the implementation of the C-EMO agent-based model (which

embeds the IMEA SD and ANEA SD model). With this implementation, the C-EMO modeling framework and the designed modeling approaches were validated through the simulation runs of a set of validation scenarios.

- **The Emotion Support System.** The implementation of the final iteration of the prototype which comprised the integration with the C-EMO implementation solution and that was initially conceived within the scope of the GloNet project, also contributed to the verification and validation of the applicability of this research work in different domains.

Figure 6.1, illustrates the relationship of the main contributions of this PhD thesis with the research hypotheses and questions.

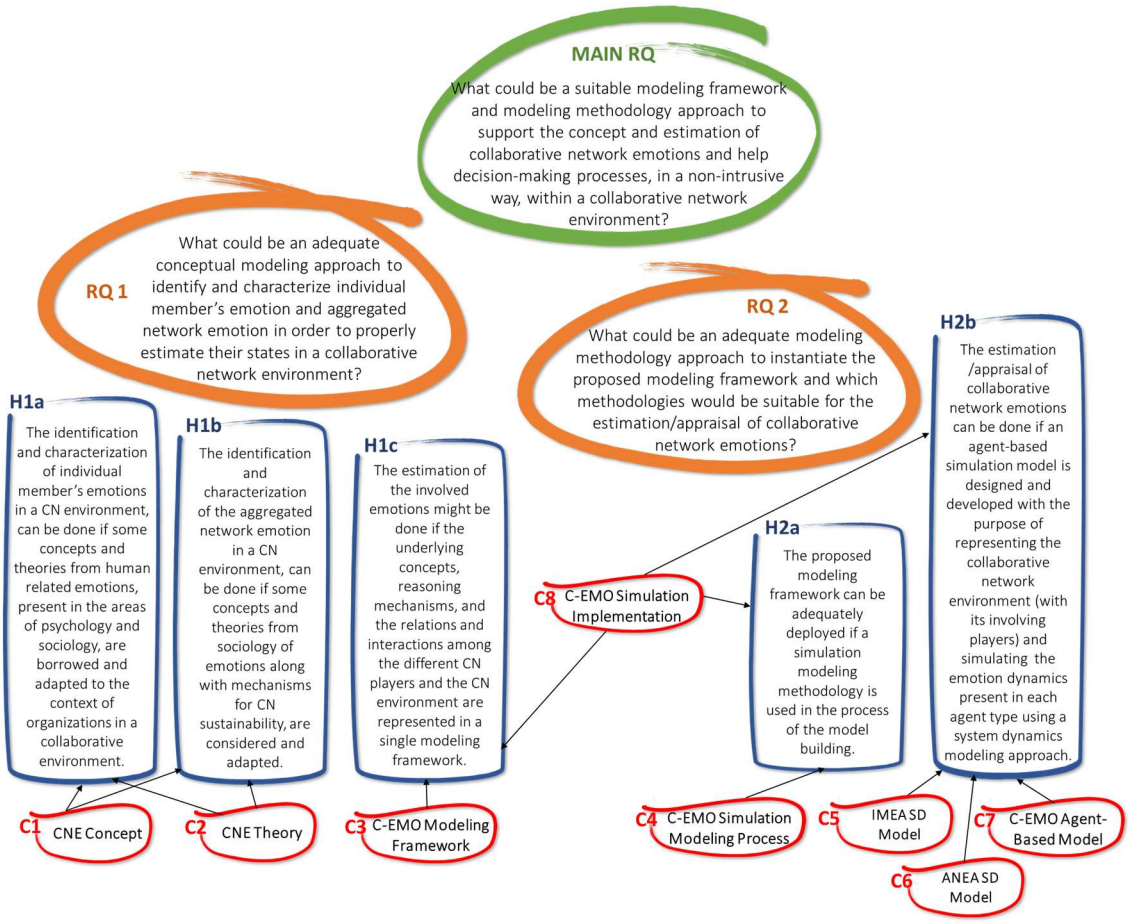



**Figure 6.1. Research contributions relationship with the research questions and hypotheses.**

## 6.3 Future work

Having into consideration the pioneering nature of this research work, it becomes clear that many doors were opened for future research.

The first impression is that the concept of Collaborative Network Emotions is a very promising and complex subject with multiple areas of application. Therefore, some aspects are identified to be improved and others need to be explored. Some of these future research issues are summarized below.

- **Introduce a third dimension to the dimensional model of CNE.** This aspect was observed in the phase of validation of the designed scenarios where the need to understand the intensity of the estimated emotions was perceived. Therefore, the introduction of the *intensity* dimension to the CNE circumplex space would help in detailing if the activated emotion is strong, moderate or weak. This would bring a new analysis aspect to the modelling framework and would refine the future decisions of the CN administrators.
- **Improve and explore the behavior element** of the IME model component of the C-EMO modeling framework. As previously mentioned, although identified and roughly described, the behavior element was out of the scope of this work. Therefore, as future research, a detailed design and modeling of this element would bring new functionality to the C-EMO framework.
- **Improve and explore the decision-making element** of the ANE model component of the C-EMO modeling framework. As previously mentioned, although identified and roughly described, the decision-making element was out of the scope of this work. Therefore, this element could be explored in the future, bringing an added value to the decision management system supporting in a better way the CN administrator.
- **Integration of social network analysis tools.** Although assumed as given in the design and development of the C-EMO models, the information that is expected from the social network analysis to help in the estimation of emotions should be integrated with proper social network analysis tools. An example could be the Pajek tool . Thereby, this issue should be further explored in the future.
- **Overcome cultural barriers.** One participant of the solar industry event conducted within the GloNet project, expressed doubts about the applicability of this system in the Indian context, due to different cultural and business

practices. In fact, this is an issue that needs to be further pursued in future research.

- **Creation of an emotional competences framework.** This framework would abstract the "organizations emotional intelligence", mirroring the human emotional intelligence framework. This framework would help in the characterization of the "emotional maturity" of each CN member and could help in the processes of partner's selection for new VOs by exploring the "emotional alignment" among partners.
- **Self-regulation processes.** Mechanisms for self-regulation of emotions both for members and the CN, could be explored in the future. In this way, new models and tools could be built on top of the C-EMO framework for motivating the CN players and enhancing the current activated CNEs, helping in the overall emotional state of the CN.

As a concluding remark, it is the author's belief that the research conducted and the findings of this work opened a very promising line of research, serving as the initial steps of further research in the area.

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# Annex A Emotion Definitions & Theories

## Emotion Definitions

**Table A.1. Emotion definitions according to several authors.**

| *Author* | *Definition* |
|---|---|
| (James, 1884) | *My theory… is that the bodily changes follow directly the perception of the exciting fact, and that our feeling of the same changes as they occur is the emotion…* |
| (Freud, 1915) | *Ideas are cathexes – ultimately of memory traces – while affects and emotions correspond with process of discharge, the final expression of which is perceived as feeling.* |
| (Watson, 1924) | *An emotion is a hereditary "pattern reaction" involving profound changes of the bodily mechanism as a whole, but particularly of the visceral and glandular systems.* |
| (Cannon, 1929) | *The peculiar quality of the emotion is added to simple sensation when the thalamic processes are aroused.* |
| (Paul T. Young, 1943) | *Emotion is an acute disturbance of the individual as a whole, psychological in origin involving behavior, conscious experience, and visceral functioning.* |
| (Donald O. Hebb, 1958) | *Emotion can be both organizing (making adaptation to the environment more effective) and disorganizing, both energizing and debilitating, both sought after and avoided.* |
| (Arnold, 1960) | *Emotion is felt tendency toward anything intuitively appraised as good (beneficial) or away from anything intuitively appraised as bad (harmful). This attraction or* |

| | |
|---|---|
| | *aversion is accompanied by a pattern of physiological changes, organized toward approach or withdrawal. The patterns differ for different emotions.* |
| (Robert Plutchik, 1962) | *An emotion may be defined as a patterned bodily reaction to either destruction, reproduction, incorporation, orientation, protection, reintegration, rejection or exploration or some combination of these, which is brought about by a stimulus.* |
| (Paul McLean, 1963) | *Emotional feelings guide our behavior with respect to the two basic life principle of self-preservation and preservation of species.* |
| (Bowlby, 1969) | *Emotions are phases of an individual's intuitive appraisals ether of his own organismic states and urges to act or to the succession of environmental situations in which he finds himself…. At the same time, because they are usually accompanied by distinctive facial expressions, bodily postures, and incipient movements, they usually provide valuable information to his companions.* |
| (Charles Brenner, 1974) | *An affect is a sensation of pleasure, unpleasure, or both, plus the ideas, both conscious and unconscious, associated with that sensation.* |
| (Izard, 1977) | *Emotion is a complex process that has neurophysiological, motor-expressive, and phenomenological aspects.* |
| (Lazarus et al., 1980) | *Emotions are complex organized states consisting of cognitive appraisals, action impulses, and patterned somatic reactions.* |
| (Kleinginna & Kleinginna, 1981) | *Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which can (a) give rise to affective experiences such as feelings of arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labeling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed, and adaptive.* |
| (Frijda, 1986) | *Emotions are tendencies to establish, maintain, or disrupt a relationship with the environment…. Emotion might be defined as actions readiness change in response to emergencies or interruptions.* |
| (Lutz & White, 1986) | *Emotions are a primary idiom for defining and negotiating social relations of the self in a moral order.* |
| (Andrew Ortony, C. L. Clore, and A. Coffins, 1988) | *Emotions are valenced reactions to events, agents or objects, with their particular nature being determined by the way in which the eliciting situation is construed.* |
| (Lazarus, 1991a) | *Emotion (is) a complex disturbance that includes three main components: subjective affect, physiological changes related to species-specific forms of mobilization for adapted action, and action impulses having both instrumental and expressive qualities.* |
| (Lazarus & Lazarus, 1994) | *Emotions are organized psycho-physiological reactions to news about ongoing relationships with the environment.* |
| (Frijda & Mesquita, 1994) | *Emotions (…) are, first and foremost, modes of relating to the environment: states of readiness for engaging, or not engaging, in interaction with the environment.* |

| | |
|---|---|
| (J. Campos, D. L. Mumme, R. Kermoian, and R. G. Campos, 1994) | *Emotions are processes that establish, maintain, change, or terminate the relation between the person and the environment o0n matters of significance to the person.* |
| (Joseph M. Jones, 1995) | *Affects are the experiential representation of a non-symbolic information-processing system that can serve as the central control mechanisms for all aspects of human behavior.* |
| (Denys A. de Cantanzaro, 1999) | *Emotions are crude predispositions to react to life events, shaped by an evolutionary heritage, but not always adaptive in the modern context.* |
| (Leda Cosmides and John Tooby, 2000) | *An emotion is a superordinate program whose function is to direct the activities and interactions of the subprograms governing perception; attention; inferences; learning; memory; goal choice; motivational priorities; and physiological reactions, etc.* |
| (Torn Johnston and Klaus Scherer, 2000) | *An emotion is a phylogenetically evolved, adaptive mechanisms that facilitates an organism's attempt to cope with important events affecting its well-being.* |
| (Aaron Ben-Ze'ev, 2000) | *Emotions direct and color our attention by selecting what attracts and holds our attention. They regulate priorities and communicate intentions. Emotions are concerned with issues of survival and social status.* |
| (Plutchik, 2001) | *Emotion is a complex chain of loosely connected events which begins with a stimulus and includes feelings, psychological changes, impulses to action and specific, goal-directed behavior."* |
| (Scherer, 2005) | *[An emotion is] an episode of interrelated, synchronized changes in the states of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus-event as relevant to major concerns of the organism.* |

## Emotion Theories

**James-Lange Theory.** William James (1884) published the first widely accepted theory, known as the James-Lange theory (the same theory was devised independently by James and Lange). James argued that the body reacts to certain situations (like danger) with bodily responses (increase breathing, heart rate, etc.). According to James, different emotions are the result of our body reacting in different ways, so our emotions are just our perception of a bodily response.

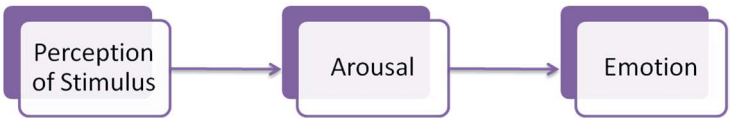


**Figure A.1. James-Lange theory of emotion.**

Thus, James did not think that emotions could be generated in the brain alone, and he disputed the idea of structures in the brain that could produce emotions single-handedly. Several later concepts seemed to dispute the James-Lange Theory, such as the discovery that patients with spinal cord injuries were able to experience a full range of emotions. However, a sound basis to doubt the James-Lange Theory is given when considering how animals experience emotions when all the nerves to and from their body have been cut. In this way, scientists have been able to prove that it is possible to elicit and inhibit certain emotions by stimulating specific areas of the brain, subsequently refuting the James-Lange Theory.

**EXAMPLE:** *You are walking down a dark alley late at night. You hear footsteps behind you and you begin to tremble, your heart beats faster, and your breathing deepens. You notice these physiological changes and interpret them as your body's preparation for a fearful situation. You then experience fear.*

**Cannon-Bard Theory.** In 1929, Walter Cannon refuted James's theory and advanced another one, which was soon modified by Philip Bard and became known as the Cannon-Bard Theory (Cannon, 1929) which states that, when a person faces an event that somehow affects him or her, the nervous impulse travels straight to the thalamus where the message divides. One part goes to the cortex to originate subjective experiences like fear, rage, sadness, joy, etc. The other part goes to the hypothalamus to determine the peripheral physical changes (symptoms). According to this theory emotion can be produced in the brain alone and physiological reactions and emotional experience occur simultaneously.

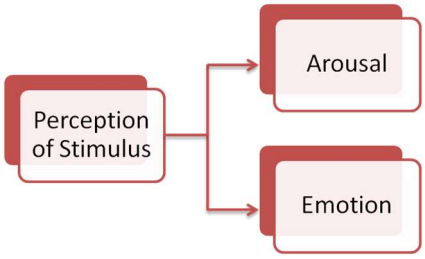


**Figure A.2. Cannon-Bard theory of emotion.**

**EXAMPLE:** *You are walking down a dark alley late at night. You hear footsteps behind you and you begin to tremble, your heart beats faster, and your breathing deepens. At the same time as these physiological changes occur you also experience the emotion of fear.*

The essential error of the Cannon-Bard Theory was to consider the existence of an initial "center" for emotions (the thalamus). Later on, Paul McLean (1970) discovered the limbic system where the hypothalamus and other brain components are involved.

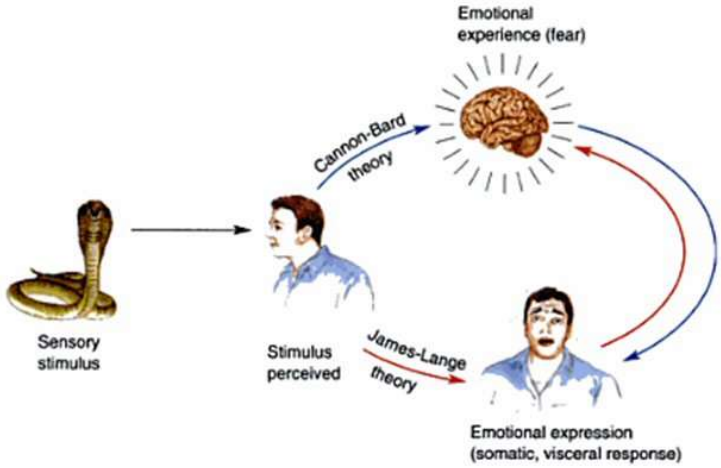


**Figure A.3. Comparison of the James-Lange and Cannon-Bard theories of emotion.** According to James-Lange theory (red arrows), the man perceives the frightening animal and reacts with physical manifestations. As a consequence of such unpleasant physical reaction, he develops fear. In the Cannon-Bard theory (blue arrows), the frightening stimulus leads, first, to the feeling of fear which, then, brings about the physical response (Bear et al., 2007).

**Two-factor Theory or Schachter-Singer Theory.** Stanley Schachter and Jerome Singer (1962) proposed another theory which suggests that for an emotion to occur there must be a physiological arousal, and second there must be an explanation for the arousal. So there must be some kind of attention-getter and the reason why it got that specific person's attention.

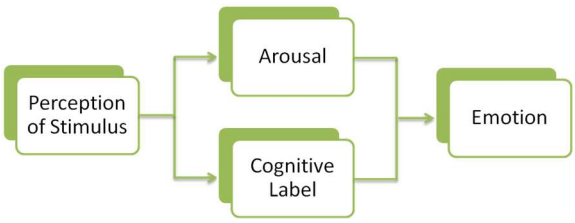


**Figure A.4. Schachter-Singer theory of emotion.**

Therefore, to really understand what emotions people are having at a particular time, they use the cues in environment at the same time to help them determine the current emotion. This labeling process depends on two factors: *(i)* some element in the situation must trigger a general, nonspecific arousal marked by increased heart rate,

tightening of the stomach, and rapid breathing; *(ii)* people search the situation/environment for cues that tell them what has caused the emotion.

> **EXAMPLE:** *You are walking down a dark alley late at night. You hear footsteps behind you and you begin to tremble, your heart beats faster, and you breathing deepen. Upon noticing this arousal you realize that this comes from the fact that you are walking down a dark alley yourself. This behavior is dangerous and therefore you feel the emotion of fear.*

**Cognitive Appraisal Theory or simply Appraisal Theory.** The Cognitive Appraisal Theory builds on the Schachter-Singer Theory, taking it to another level. It proposes that when an event occurs, a cognitive appraisal is made (either consciously or subconsciously), and based on the result of that appraisal, an emotion and physiological response follow.

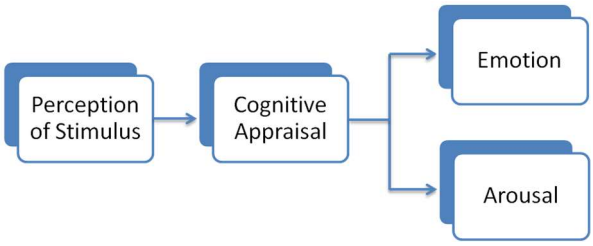


**Figure A.5. Cognitive appraisal theory.**

Different versions of this assumption can be found in various cognitive appraisal theories of emotion (Arnold, 1960; Ortony & Turner, 1990; Lazarus, 1991a; Scherer et al., 2001).

According to Lazarus (1991a) there are three aspects of appraisal: *(i)* primary (relevance); *(ii)* secondary (options); and *(iii)* reappraisal (anything changed).

> ***EXAMPLE:*** *You are walking down a dark alley late at night. You hear footsteps behind you and you think it may be a mugger so you begin to tremble, your heart beats faster, and your breathing deepens and at the same time you experience fear.*

# Annex B Social Functions of Emotion

According to Keltner & Haidt (1999), emotions can be socially functional at four levels of analysis: *(i)* the individual (or intrapersonal); *(ii)* dyadic (or interpersonal – between two individuals); *(iii)* group (set of individuals that directly interact and has some temporal continuity); and *(iv)* cultural level (within a large group that shares beliefs, norms and cultural models).

At the individual level, emotional responses within the individual serve two broad social functions (Oatley & Jenkins, 1996). First, emotions *inform the individual* about social events and conditions that require attention or action (Campus et al., 1989) and, second, emotion-related physiological (Levenson, 1992) and cognitive processes (N. Schwarz, 1991; Clore, 1994) *prepare the individual* to respond to those social interactions, even in the absence of any awareness of an eliciting event (Oatley & Jenkins, 1996).

At the dyadic level, the focus is on how emotions organize the interactions of individuals in meaningful relationships: *(i)* Emotional expression *helps individuals know other emotions, beliefs, and intentions* (Fridlund, 1992), thus rapidly coordinating social interactions, as when children rely on parents' facial emotion to assess whether ambiguous situations, stimuli, and people are safe or dangerous (Klinnert et al., 1983); *(ii)* Emotional communication *evokes complementary and reciprocal emotions in others* that help individuals respond to significant social events, as when an embarrassed individual evokes amusement in others (Keltner et al., 1997); and *(iii)* Emotions *serve as incentives or deterrents for other individual's social behavior* (Klinnert et al., 1983).

At the group level of analysis, emotions help collections of interacting individuals who share common identities and goals meet their shared goals, or the super-ordinate

goals of the group. Groups, such as families, work groups, or social clubs, are the systems with respect to which the functions of emotion are interpreted. Emotions *help individuals to define group boundaries and identify group members* (Durkheim, 1965), as is apparent when supporters cheer for their favorite team (Keltner & Haidt, 1999). In addition, within groups, the differential experience and display of emotion may *help individuals define and negotiate group-related roles and statuses* (e.g. (Clark, 1990; Collins, 1990)), for instance, higher status is typically attributed to angry than to sad man (Tiedens, 2001; Brescoll & Uhlmann, 2008). Furthermore, emotions may resolve certain group challenges, such as resource allocation, for example by solidifying the group bonds and thereby preventing discord or conflicts.

At the cultural level, finally, emotions allow people to shape their cultural identity, to teach cultural norms and values to their children and to preserve their cultural inheritance. Some of the social functions attributed to this level overlap with those at the group level of analysis.

# Annex C Solar Energy Industry Network Assessment Questionnaire

This annex includes the excerpt of the questionnaire related to the emotion support system that was filed by the solar energy partners during the event in Chennai, India in February 2015.

# Collaborative Networks Overview

| | | |
|---|---|---|
| **1.** Name of Company: | | |
| **2.** Street Address: | | **3.** Telephone: |
| P.O. Box: | City: | **4.** Fax: |
| Zip Code: | Country: | **5.** E-Mail: |
| **6.** Contact Person: | | Title: |
| **7.** Legal Status (e.g. Partnership, Private Limited Company, Government Institution) | | |
| **8.** Year Established: | | **9.** Number of Employees: |
| **10.** Gross Annual Turnover : | | **11.** Annual Export Turnover |
| **12.** Type of Business/Products: | Manufacturer ☐ Sole Agent ☐ | Supplier ☐ |
| **13.** Type of Business/Services/Work: | Engineering ☐ Civil Work ☐ | Governmental Institution ☐ |
| **14.** References (main customers, country, year and technical field of products, services or work): | | |
| **15.** Overview on Collaborative network | | |
| **16.** List of Products/Services/Work or combined Product Service Systems offered within the Collaborative network | | |
| **17.** Desired Functionalities for Collaborative Network Support | | |

| 18. Further interest in GloNet results (Please mark your interest with a X) | Further GloNet SW evaluation | GloNet User meetings | Your wish |
|---|---|---|---|

## 5. Additional Functionalities

### 5.1 Emotional Support System

The main purpose of the Emotional Support System is to provide mechanisms, through non-intrusive means, to estimate the emotion that the collaborative network is "feeling". For that functionalities were developed concerning the estimation of a particular emotion of a Member and the collective emotion of the network. Recommendations are also proposed to the Administrator in order to enhance the emotional state of the network.

| | Disagree 1 | 2 | 3 | 4 | Agree 5 |
|---|---|---|---|---|---|
| Globally the Emotional support system fits its purpose | | 20.00 % | 20.00 % | 50.00 % | 10.00 % |
| The implemented functionalities support the emotional monitoring of the network and its members. | | 8.33 % | 25.00 % | 66.67 % | |
| The non-intrusive evidences used to estimate the collective and member emotional state are adequate in the context of collaborative networks | | 8.33 % | 33.33 % | 58.33 % | |
| The use of Member expectancy and satisfaction surveys as evidence, to estimate the Member emotion, are adequate | | 16.67 % | 8.33 % | 33.33 % | 41.67 % |
| Which other improvements would you suggest regarding the Emotional Support System? | It is good that expectations are considered; not sure if applicable in India (would require longer assessment) | | | | |

# Annex D Solar Energy Industry Lead User Assessment Questionnaires

This annex includes the excerpt of the assessment questionnaire related to the emotion support system that was filled in by a lead user in the solar energy during the event in Chennai, India in February 2015.

## GloNet – lead user evaluation – Chennai 25 Feb 2015

### 1.1 Profile of lead-users

**description of service-enhanced complex products*
**description of stakeholders characteristics*
**description of collaborative network structure*

| Abstract elements | | use case 1: |
|---|---|---|
| Product | Complex (physical) product | Panel and equipment manufacture |
| | Long life-cycle | 20 Years |
| | Business services | warranty for 2 years & Extended for O&M |
| | Mass customization | Yes |
| Stakeholders | Product/project designers | No |
| | Product manufacturers | Yes |
| | Service providers | Yes |
| | Support entities | Yes |
| | Customers and users | NO |
| Organizational structures | Strategic alliance /Manufacturers VBE | Yes |
| | Customer related community | NO |
| | Product development VE | Yes |
| | Product servicing VE | Yes |

### 1.2 Lead-user Prozesse

| PLC phase | Total | Main business process | Lead user 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pre 0 | | 0.1 Call for tender | ✓ | | | | | | | | | |
| | | 0.2 Concept development | | | | | ✓ | | | | | |
| 1st | | 1.1 Product design | | | | | | | | | | ✓ |
| | | 1.2 Process design | ✓ | | | | | | | | | ✓ |
| 2nd | | 2.1 Production | | | | | | | | | | ✓ |
| | | 2.2 deployment | | | | | | | | | | |
| 3rd | | 3.1 Support | | | | | ✓ | | | | | |
| | | 3.2 upgrade | | | | | ✓ | | | | | |

Table 1: main business processes per lead user

## *1.2 VO formation and operation support*

### 1.2.1 Overview

| Network Emotional Support System |
|---|
| The main purpose of the Emotional Support System is to provide mechanisms, through non-intrusive means, to estimate the emotion that the collaborative network is "feeling". For that functionalities were developed concerning the estimation of a particular emotion of a Member and the collective emotion of the network. Recommendations are also proposed to the Administrator in order to enhance the emotional state of the network. |
| **Main Functionalities** |

| | |
|---|---|
| Estimate Member emotional state | View actual Collective emotional state |
| View actual Member emotional state | View past Collective emotional state |
| View past Member emotional states | Manage Collective emotional evidences |
| Manage Member emotional evidences | View recommendations |
| Estimate Collective emotional state | |

### 1.2.2 KPIs

➢ **Fit for purpose**

| Assessment of the Emotional Support System | Disagree 1 | 2 | 3 | 4 | Agree 5 |
|---|---|---|---|---|---|
| In general, the implemented functionalities correspond to relevant requirements needed to assess emotions in a collaborative network | | | ✓ | | |
| The implemented functionalities support the emotional monitoring of the network and its members. | | | | ✓ | |
| The non-intrusive evidences used to estimate the collective and member emotional state are adequate in the context of collaborative networks | | | ✓ | | |
| The use of Member expectancy and satisfaction surveys (input from Administrator) as evidence, to estimate the Member emotion, are adequate | | | ✓ | | |
| Globally the system fits its purpose | | | ✓ | | |
| Proposed improvements | | | | | |

➢ **Presentation of the information**

| Assessment of the Emotional Support System | Disagree 1 | 2 | 3 | 4 | Agree 5 |
|---|---|---|---|---|---|
| The user interface allows a smooth and simple visualization and navigation through the implemented functionalities | | | | ✓ | |
| The usability of the system is adequate | | | | | ✓ |
| Proposed improvements | | | | | |

| Assessment of the Emotional Support System | Disagree 1 | 2 | 3 | 4 | Agree 5 |
|---|---|---|---|---|---|
| The user interface allows a smooth and simple visualization and navigation through the implemented functionalities | | | ✓ | | |
| The usability of the system is adequate | | | ✓ | | |
| Proposed improvements | | | | | |