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Chapter 5

Mechanisms for assessing trust level of an organization

In order to "rationally" assess the level of trust in an organization, a series of fact-based criteria about organizations shall be considered. Mechanisms applied for assessing the level of trust in organizations can apply some or all of these criteria to reflect the purpose for which the trust is to be established. Proper mechanisms should exist to support dynamic selection of specific subsets of these criteria. As such to measure the level of trust in organizations, customizable mechanisms need to be developed. This chapter presents a mathematical approach for assessing the level of trust in organizations and introduces formal mechanisms for customization of the input criteria to the mathematical model of trust assessment.

This chapter constitutes mainly material that has been previously published in the International Journal of Production research [Msanjila & Afsarmanesh, 2007a].

5.1 Introduction

Designing and developing *rational (fact-based) mechanisms* for assessing the level of trust in organizations is of particular importance to large and very large VBEs, in which all member organizations are not usually familiar with one another. This chapter presents a conceptual model in terms of mathematical equations. The model is applied to develop rational (fact-based) mechanisms for supporting an objective trust analysis in VBEs. That is to say, developed mechanisms are used to assess the level of trust in organizations. The model, and thus its related mechanisms for assessing the level of trust in an organization comprise measurable trust elements, namely trust criteria, known factors and intermediate factors.

The remaining part of this chapter is organized as follows: related work on the assessment of the actors' level of trust in different kinds of collaboration is presented in Section 5.2; basic concepts relating to level of trust in an organization are presented in Section 5.3 with particular focus on the concept of the comparativeness of trustworthiness; and in Section 5.4 the mathematical model for developing mechanisms to assess the level of trust in organizations is explained.

5.2 Traditional approaches addressing assessment of trust in organizations

In the past, and in most current modus operandi, assessment of the level of trust in individuals and organizations has been subjective, since it has used data such as opinions on the reputation of trustees. However, attempts have been made by different researchers addressing the assessment of the level of trust in individuals and organizations to use objective approaches. In such cases some sort of measurable data were applied to estimate the level of trust in each actor. The fundamental weakness of these suggested approaches is however that the sources of used data and the categorization of the parameters that are used as trust criteria are not properly characterized and difficult to rationally measure. These approaches can be categorized into two groups as addressed below, namely that which provides "probability values" as the final calculated results, and that which provides "expectation values" as the final calculated results.

As discussed in Section 1.3, trust is mostly regarded in both research and practice as the *probability* perceived by a trustor that a trustee will do something [Gambetta, 1988]. Applying mathematical definition, the probability of the occurrence of x is calculated as:

$$P(x) = \frac{No(x)}{No(\cup)}$$

Where P(x) refers to probability that x will occur, No(x) refers to the number of times x can occur and No(U) refers to the number of all possible occurrences.

Some other researchers have described the assessment of the level of trust in actors as expectation of occurrence [Rousseau et al., 1998; Mayer et al., 1995]. Applying mathematical definition for the expectation that x will occur, it can thus be calculated as:

$$E[x] = \sum_{\forall i} P_i * x_i$$

Where P_i refers to the probability that x_i will occur, E[x] refers to the expectation of x.

For expectation, also a key concept in the formula is once again the probability. It is however difficult to compare values of probability related to two or more actors (such as organizations) which may represent their different levels of trust. It is also difficult to reason on the suitability of assessment results for a specific objective, such as selecting potential partners for configuring a VO. The VO might need specific capabilities, such as the financial or technological capabilities and experience, and so on; and these do not lend themselves to reasoning through the use of general probability values.

However, a probability-based assessment works well when trust is regarded as a subjective aspect. It is easier to count opinions that supported the positive reputation of trustees and thus use these to calculate their trustworthiness as probability values. In such practices, the need to formally reason about results assessment is not important. Today, formal mechanisms for assessing the level of trust in organizations are needed to support making formal reasoning on results.

As addressed in Section 2.2.3, the notion of trust itself has been differently interpreted and perceived in the various disciplines that apply this concept in daily practice. Based on their interpretation and perception, trustors in these disciplines prefer to use different kinds of trust elements when assessing the level of trust in trustees. Similarly, the approaches and mechanisms that are employed to manipulate the collected data also differ. In order to exemplify these approaches and mechanisms, we have surveyed several traditional approaches that have been used to assessing the level of trust in: individuals, actors within an online business, as well as individual members within online social communities, as addressed below.

- ***Measuring individuals' level of trust:*** Traditionally, assessing the level of trust in one individual has been carried out on the basis of the opinions of other individuals and, in particular, on information concerning the reputation of the trustee himself/herself. There are different purposes for which individuals may decide to assess the level of trust in their respective trustee a priori to interacting with them. In order to illustrate this, we have studied the assessment of individuals' trust level for the following purposes: admission in higher learning education, the selection of suitable job applicants, the creation of a personal friendship network, and so forth. It was observed that in all of these processes the reputation data of trustees is used as a key source of information in assessing the level of trust. The aspects related to the assessment of the level of trust in individuals are in details addressed in Sections 2.2.2 and 2.2.3.

o ***Measuring the individual's level of trust in an online business:*** It is currently becoming common practice for business processes – such as the selling and buying of products and services – to take place online e.g. the e-commerce. In such a business environment, sellers and buyers interact with each other to complete all necessary transactions virtually, without ever meeting face-to-face. It is thus a challenge for both sellers and buyers to trust each other and subsequently commit to either deliver products and services, or pay for the required products and services. There are traditional approaches that use subjective data which support the creation of trust between these actors. For example, sellers may use their reputation data as recommended by previous customers to convince new buyers. This information is usually made available online at the seller's website. The aspects of trust in e-commerce are addressed in Sections 4.2.

o ***Measuring the individual's level of trust in online social networks:*** Establishing and expanding a personal social network has traditionally been used as a key way to keep up-to-date on different events that take place in one's society [Dasgupta, 1988]. It has also been used as a fundamental approach to quickly gain the trust in a new social network member based on that person's popularity (and thus possesses a large social network of his/her own). These networks are established for different purposes, including sharing knowledge and accessing online entertainments. Nowadays, such networks are established and managed online. Trust between individual members has demonstrated to be a fundamental aspect in facilitating network survival and existence [Preece, 2004]. Therefore, reputation data has proven to be the key source of information when assessing the individuals' level of trust and applying results to the creation of inter-personal trust.

The three approaches presented above highlight the current practice related to trust, which in fact reflects difficulty that exists in carrying out a quantitative assessment of the level of trust in actors, so instead of using reputation data (opinions). Therefore, no quantitative trust criteria data exists. In addition to this, research has realized that it is also difficult to formulate formal measurement mechanisms, such as mathematical equations, to manipulate such data in order to formally assess the level of trust in actors such as organizations. These practiced approaches do not satisfy the need for trust establishment in business-based collaborations, such as needed for VOs, which need to effectively provide a quantitative assessment of the level of trust in organizations within the VBE.

In our research, trust in VBEs is characterized as a multi-objective, multi-perspective and multi-criteria subject. The main source of trust related data is the quantitative measured performance of organizations, expressed in terms of trust criteria. Formal mechanisms, namely mathematical equations, are formulated in order to support the measurement of the level of trust in organizations and reasoning on results. In the remaining part of this chapter, we present an approach for the formulation of the formal mechanisms used for the assessment of the level of trust in an organization.

5.3 Concepts related to assessment of trust

The aim of measuring the level of trust in VBE's member organizations is to support two general purposes, namely, (1) the controlling and monitoring of the balance of the **base level of trust** in member organizations, and (2) evaluating the **specific trustworthiness** of an organization for a specific trust objective. For the rational assessment of the *base level of trust* in organizations, a minimum set of trust criteria, the so-called *base trust criteria* can be defined to be applied. The VBE administrator decides on this set of base trust criteria during the time when the VBE is being established, from a pre-defined general larger set of trust criteria, i.e. the VBE's **pool of trust criteria**, covering all aspects of the five different organizational perspective of trust. This pool of criteria is presented in Section 3.3.1 and Figure 3.6. All organizations in the VBE must provide their trust related "data" for the set of **base trust criteria**. The base trust level represents the minimum acceptable level of trust in each organization in the VBE and to control the balance of trust among member organizations. Furthermore, for each specific objective and purpose, evaluation of the *specific trustworthiness* of organizations becomes necessary. Here, a set of **specific trust criteria** shall be applied, which can be dynamically selected from the pool of VBE trust criteria by the trustor organization, to meet different specific trust objectives he/she may have at the time. Mechanisms are needed to support both the dynamic selection of specific trust criteria, as well as the application of selected criteria to rational evaluation of specific trustworthiness of organizations. Development of these mechanisms is discussed in Chapter 6.

5.4 Measuring and assessing organization's trust level

This section addresses the measurement and rational assessment of the level of trust in an organization in the VBE. We first present the need for assessing this trust level and then describe the base concepts regarding the comparative/relative nature of the assessed trust level. Second, we present the mathematical approach applied to formulate generic mechanisms for assessing trust level of an organization. Finally, we introduce an example VBE, to analyze some complex aspects that can emerge while formulating the mechanisms for assessing trust level of an organization and how they can be handled. This section also presents some corrective measures for mechanisms used for the assessment of the trust level of organizations, so as to record the variations in the preferences of trustors related to their specific set of trust criteria.

5.4.1 Need for trust measurement in VBEs

Requirement analysis and empirical studies identify that establishing trust between organizations is amenable for a smooth management of VBE networks and an antecedent for VBE's effective operational continuity. To ensure that every organization in the VBE meets the minimum established trust threshold, indicators need to be developed and applied to establish a grading and ranking scheme for trustworthiness of an organization. The proposed indicators in this thesis, as described in earlier chapters, comprise what we suggest as an organization's *"trust level or trustworthiness"*. Among others, following represent the main needs for assessing the trust level of organizations in the VBEs:

- ***As a strategy to enhance cohesion among member organizations within the VBE:*** The assessment of the base trust level of an organization in the VBE and particularly, when applying for VBE membership can be perceived as an examination which every organization must qualify in order to enter and remain within the VBE. This may positively influence the cohesion among member organizations and their perceptions that they together belong to a group of trustworthy organizations. As a result, VBE member organizations will perceive as operating in a controlled risk environment.

- ***As a measure for management of the VBE:*** A key activity for a VBE administrator is to ensure that member organizations meet all VBE membership requirements necessary to assure successful VBE continuity. Among others, such requirements include: possessing required competency, achieving good performance, maintaining proper ICT infrastructure for collaboration, and abiding to the VBE working and sharing principles. These aspects are considered and covered by the base set of trust criteria as presented in Section 3.3. Thus assessing trust level of each member organization in the VBE will enable the VBE administrator to have a general but complete picture about how the VBE requirements are met by each organization. Assessing the base trust level of member organizations in the VBE can thus be applied as one of the management measurement by the VBE administrator. Thus assessing the base trust level of organizations within the VBE indicates how the VBE is prepared to compete in the market and in acquiring business opportunities, which are key aspects for its effective future continuity.
- ***As an indicator for establishing objective-specific collaboration:*** When a few organizations in the VBE need to be selected for participation in a specific collaboration, such as in a VO, their evaluated trustworthiness for the specific objective of the VO needs to be measured. The selection of the most fit partner for each task considers the measurement of its trust level. These measurements indicate how trustworthy each member is when compared to other organizations.

As seen from the above examples about the need for assessing trust level of an organization in the VBE, a wide range of trust criteria may be considered while evaluating organization's trustworthiness. Trust in VBEs is characterized by considering a wide variety of aspects that together comprehensively support the rational measurement of trustworthiness of organizations. As such, trust is not a single concept that can be applied to all cases for trust-based decision-making and its measurements depend on both the purpose of establishing a trust relationship and its specific involved actors. Trust level of an organization can be measured rationally in terms of quantitative values of related trust criteria e.g. based on an organization's past performance. The level of trust in an organization is complex and can neither be measured with single value of a single parameter, nor interpreted with a single metric. Nonetheless, an organization's level of trust can be specified on the basis of the values for a set of related trust criteria.

Understanding and interpreting the level of trust in an organization, described and formulated in terms of values of a set of trust criteria, will be complex and difficult to grasp for most decision-makers in organizations, such as managers and directors, if they are not trust experts and do not have sufficient knowledge in both mathematics and computer applications. Thus, the trust level of organizations must be presented in a format that is as understandable as possible to the expected users while not loosing its semantics.

This thesis proposes that the level of trust in organizations should be represented and expressed in terms of a set of qualitative values, and these values can only represent comparative levels of trust in different organizations in a VBE for a specific given trust purpose, and not as absolute levels. A set of "qualitative values" are designed for the level of trust in an organization to be presented to the decision makers that include: *Strongly more trustworthy, More trustworthy, Average trustworthy, Less trustworthy, and Strongly less trustworthy*. As an example, the comparative qualitative values of the trust level of four organizations (ORG-1 to ORG-4) in a VBE are graphically represented in Figure 5.1. This representation is referred to as the "***Trust-Meter***". As shown in this figure, considering selected criteria, ORG-3 is "more trustworthy" that others.

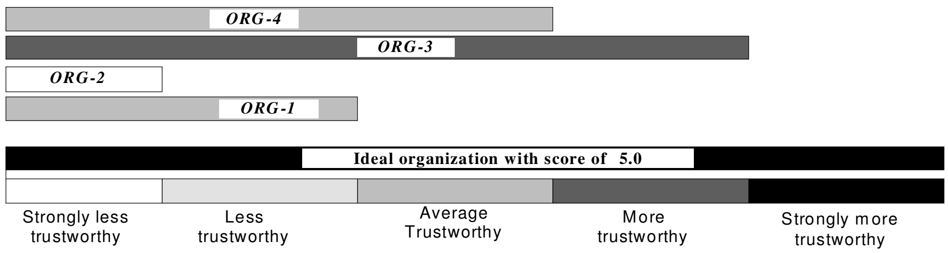

Figure 5.1: A trust-meter for presenting comparative level of trust in organizations

As further addressed below, this figure shows how the level of trust can be compared relatively for a number of involved organizations.

As such, in our approach the trust level of an organization is not an absolute value rather it is computed as a relative value depending on the following aspects:

- ***Involved organizations:*** While assessing the trust level of an organization, its relative score for each trust perspective is computed by comparing the organization's value for each applied trust criterion against the optimal value of that specific criterion, among the all involved organizations. The general equation below exemplifies how the relative score for the economical perspective (S_{ECO}) is computed from the values for its different criteria and the maximum value for those criteria in the VBE.

$$S_{ECO} = f\left(\frac{capital}{\max capital};\frac{financial\_stability}{\max financial\_stability};\frac{VO\_stability\_stability}{\max VO\_based\_stability};\frac{financial\_compliance}{\max financial\_compliance}\right)$$

Thus if some organizations join or leave the collaboration then there is a possibility that optimal values of some trust criteria may change. As a result the value for trust scores may change nevertheless, the relative scores of different organizations remain a good indicator for comparing the trust level of organizations. This illustrate that the trustworthiness of an organization is relative on the basis of involved organizations at the time of the computation.

- ***Applied set of trust criteria:*** In our approach the trust level of organizations is measured in terms of those trust criteria which are preferred and selected by respective trustors, depending on their: trust objectives, trust preferences and trust perceptions. Thus the relative nature of trust level of an organization also depends on these three aspects. As examples, the pool of trust criteria that were preferred and selected by different VBE administrators for experimenting the TrustMan system at their industrial VBEs, are presented in Table 6.3 of Section 6.6.2.

- ***Grading and interpreting scores for the trust level:*** In our approach, the score for the trust level of an organization is given in a range of zero "0" (representing the lowest score) and five "5" (representing the highest score). The intermediate ranges (namely, between 0 and 5) and their specific interpretation and meaning depend on the rating/grading of these scores as preferred by the trustor organization. Table 5.1 shows an example of two possible differences in setting the meaning to the range of scores assigned to different measurements of trust levels by different trustors. Thus the relative nature of trust is also dependent on the interpretation of computed scores by the specific trustor organization.

Table 5.1: Illustration of differences in grading the trust level of an organization

Trust level	**Preferred range for 1st trustor**	**Preferred range for 2nd trustor**
Strongly less trustworthy	$0 < score \leq 1$	$0 < score \leq 1.5$
Less trustworthy	$1 < score \leq 2$	$1.5 < score \leq 2.5$
Average trustworthy	$2 < score \leq 3.5$	$2.5 < score \leq 3.5$
More trustworthy	$3.5 < score \leq 4.3$	$3.5 < score \leq 4.5$
Strongly more trustworthy	$4.3 < score \leq 5$	$4.5 < score \leq 5$

Please note that for the classification of different comparative levels of trust in organizations when specific ranges are not specified as exemplified in Table 5.1, the *lowest resulted value* will be assigned to the category of "*Strongly less trustworthy*" and similarly the *highest resulted value* to the category of "*Strongly more trustworthy*" and the other categories represent a uniform distribution of these two values.

5.4.2 Proposed trust assessment mechanisms

The score for the trust level of an organization is computed as a weighted generalization (e.g. averaging) of scores attained by the organization on the basis of specifically designated trust perspectives. With the base assumption, as addressed earlier in Chapter 3, about the independence of the five trust perspectives, the generic formula is given below.

$$S_{TL} = Average([w_{TEP} * s_{TEP}],[w_{STP} * s_{STP}],[w_{SOP} * s_{SOP}],[w_{ECP} * s_{ECP}],[w_{MGP} * s_{MGP}])$$

Here, "S_{TL}" refers to the relative score for the trust level of an organization. The TEP represents technological perspective, STP represents structural perspective, SOP represents social perspective, ECP represents Economical perspective, and MGP represents managerial perspective of trust in organizations.

Furthermore, "*S*" (also defined further below) refers to the score that an organization acquires from the manipulation of its related values in each trust perspective and for the selected set of trust criteria for that perspective. Also, "W" refers to the weight specified for each trust perspective by each respective trustor organization. When weights are not specified, the Trust Management (TrustMan) system (see Chapter 6) will assume uniform ones for all perspectives designated by the trustor organizations. The sum of these weights must always be equal to one and each weight must range between zero and one.

Similarly, the score for each individual trust perspective, such as STP, will be calculated as a weighted average of scores reached by an organization for each of the trust requirements in that trust perspective. For example, for the structural perspective will be calculated as follows,

$$S_{STP} = Average([w_{STS} * s_{STS}],[w_{BSS} * s_{BSS}])$$

Here, "*STS*" refers to structural strength and "*BSS*" refers to business strength, which together constitute the trust requirements of the structural perspective (Figure 3.6).

The *weighted average of the intermediate factors related to each requirement* also applies to the calculation of the score for that requirement. While a number of generic intermediate factors that will be applied to all VBEs are identified a-priori to a VBE's establishment, and their respective formulas are predefined, in some case more specific intermediate factors might need to be identified and defined during the customization of the generic TrustMan system for one specific VBE domain and/or application, as further exemplified in Section 5.4.5.

The TrustMan system developed for the management of trust in VBEs, provides services for supporting the assessment and measurement of the level of trust in an organization (addressed in detail in Chapter 6), calculating these scores using a pre-defined set of mathematical formulas. These formulas are derived from the causal analyses, such as those diagrammatically represented in the causal diagrams of Figure 3.4, Figure 5.2 and Figure 5.5. Causal diagrams define and depict the inter-relations between **trust criteria, intermediate factors** and **known factors**. While the trustee organizations (VBE member organizations) will provide values for trust criteria, and the values of known factors are already known from the VBE environments, *mathematical formulas must be derived for calculating the values of the intermediate factors.* Based on the calculated values of intermediate factors, the respective trust *scores* can be determined for each organization, in relation to each designated trust perspective of the trustor. Furthermore, the final *comparative trust level* of an organization will be calculated based on the combination of these perspective-based trust scores.

In Section 5.4.3 we present the approach applied to derive formulas for intermediate factors, which greatly influence the calculation of organization's perspective-based trust level. In Section 5.4.5 we apply this proposed approach to derive mathematical equations for a specific example VBE.

5.4.3 Developing mechanisms for assessing trust level of organizations

The proposed mechanism for assessing the trust level of an organization uses mathematical relations. The equations are formulated using the results from the analysis of causal relations between trust criteria, known factors and intermediate factors. To present our approach for formulating the required equations we use the causal diagram shown in Figure 3.4 in Section 3.2.3, that figure is repeated below as Figure 5.2 for reader's convenience.

For the formulation of mathematical equations, based on the results of a causal analysis, the plus sign (+) on an arrow in the diagram translates either to an arithmetic addition or to a multiplication. The minus sign (-) translates either to an arithmetic subtraction or to a division. The selection of appropriate arithmetic operator for the equation is done depending on the semantics of each trust criterion as well as the metric that scales it [Kirkwood, 1998; Ge et al., 2004]. Also, the selection of the correct arithmetic operator considers the *balance of the dimensions*, and when complex relations are involved, *dimensional analysis* can be applied (as for example addressed in mathematics, physics, chemistry, and engineering to check the plausibility of derived equations and computations) [Barenblatt, 1987]. When several criteria (C1 to Cn) influence an intermediate factor (Ft), the *value-metric* of Ft is used to determine how the *value metrics of the C1 to Cn* must be inter-related with each other to produce the Ft.

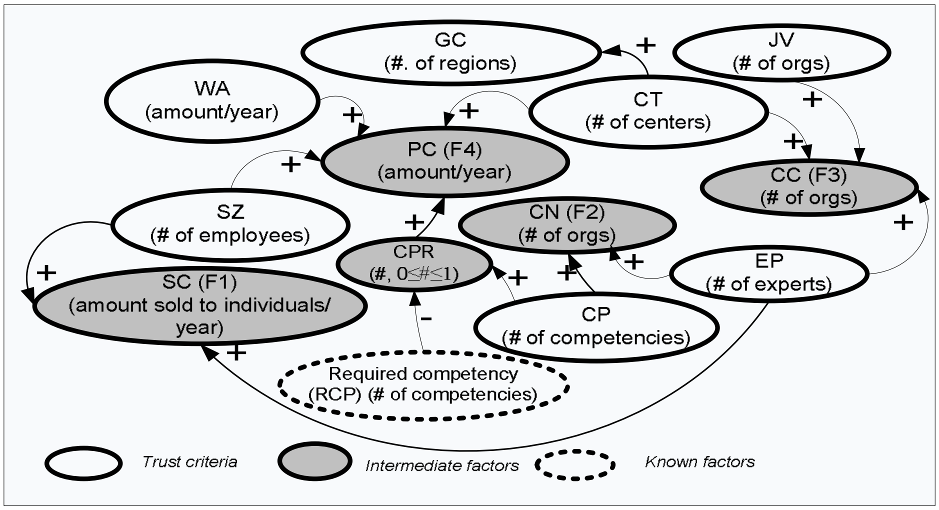

Figure 5.2: Causal influences between trust criteria for structural perspective

This figure is repeated from Figure 3.4 *in Chapter 3, where CPR represents competency ratio and RCP represents required competency in the VBE and all other parameters are defined earlier in Section 3.2.2, and also represented in Table 3.1 and Figure 3.3. This figure shows a qualitative analysis of causal influences between measurable parameters for the structural perspective, namely, the associated trust criteria (size, workload allocation, competencies, experts, centers, joint ventures, and geographical coverage), known factors (required competencies) and intermediate factors (social capital, competency ratio, connections, common context, and production capacity). As an example, please note in Figure 3.4 that the intermediate factor CPR (competency ratio) is positively influenced by one trust criteria CP (competency) and negatively influenced by one known factor RCP (required competency).*

Further, in developing equations for each intermediate factor, all arrows directed towards the respective intermediate factor are considered towards developing its equations [Byne, 2006; Pearl, 1998]. Therefore, the formula for each intermediate factor will be developed in terms of both the criteria and the known factors influencing it, and thus pointing towards it. Clearly, it is feasible that intermediate factors also influence each other but there will be no cycle, in which case the formula of one intermediate factor may be considered as a known factor within the other formula.

Below we present the formulation of generic equations for one trust perspective, namely the structural perspective. Specifically, to present our approach we develop mathematical equations for one intermediate factor – Production Capacity (PC) – as shown in Figure 5.2 for which we use the results of related analysis of causal relations. The derivation of mathematical formulas for the other four trust perspectives, namely: the technological, social, economical and managerial perspectives are presented in Section 5.5.

Example 1: Developing an equation for Production capacity (PC)

We refer here to PC as the amount/number of products/services that an organization can produce and/or provide during a specific period of time. As shown in Figure 5.2 three trust criteria directly influence the behavior of PC, namely: size of the organization (**SZ**)**,** which refers to the number of employees per organization's centre; the workload allocation (**WA**) of employees**,** which refers to the standard amount/number of products/services that a fully qualified employee is able to process in a specified period of time; and organization's centres (**CT),** which refers to the number of branches/offices at different places supporting the production/provision of products/services. PC is also influenced by another intermediate factor, namely the competency ratio (**CPR),** which refers to the ratio of the number of competencies that an organization can offer to the total number of required competencies in the VBE. The arithmetic equation, which relates these four factors to the processing capacity (PC), is represented in the equation below.

$$PC = SZ * WA * CPR * CT$$

Furthermore, each organization has a certain number of competencies that it offers to the VBE. Also the number of competencies required in each VBE is known. Therefore, CPR refers to the competency ratio of the organization and considering the metrics of those factors that influence it as shown in the causal diagram (Figure 5.2), it can be mathematically represented as follows:

$$CPR = \frac{CP}{RCP}$$

Where CP refers to the number of competencies of an organization offered to the VBE, RCP refers to the total number of required competencies in the VBE. Substituting the equation of CPR in the equation of PC generates:

$$PC = SZ * WA * \frac{CP}{RCP} * CT \quad \text{.......................................}\mathbf{(5.1)}$$

By definition, in calculus, the derivative of a parameter "y" with respect to another parameter "x" measures the rate of change of y with respect to x. Therefore, in order to capture the rate of change of every intermediate factor (such as the PC) for the analysis of variation of the trust level of an organization in time durations, we simply apply the above rule. *Assuming all the parameters in the arithmetic equation are continuous in respect to time*, the derivative of equation (5.1) with respect to the time parameter "t" represents the rate of change for each of the trust criterion (or for the known factor) with respect to time, in relation to the rate of change of PC, also with respect to time, as shown in equation (5.2). The derivative equation is used for the analysis of evolution of the level of trust in an organization (such as determining whether the level of trust is increasing, decreasing or uniform) at a certain point in time.

$$\frac{d}{dt}PC=\left(WA*\frac{CP}{RCP}*CT\right)\frac{d}{dt}SZ+\left(SZ*\frac{CP}{RCP}*CT\right)\frac{d}{dt}WA+(SZ*WA*CT)\frac{d}{dt}\left(\frac{CP}{RCP}\right)+\left(SZ*WA*\frac{CP}{RCP}\right)\frac{d}{dt}CT\ldots\mathbf{(5.2)}$$

Moreover, in order to capture the accumulation of values of all parameters over time for intermediate factors, such as the PC, we have applied integral calculus. To apply the integral calculus we have *assumed that all parameters in the arithmetic equation are continuous with respect to time*. Capturing accumulation of values of intermediate factors will support the analysis and computation of average scores for trust level of an organization over a certain interval of time, such as computing its average trust level during the period of its involvement in a VO. In calculus, the integral of a function is an extension of the concept of summation, which in fact provides the accumulation of the first parameter with respect to the second parameter. The process of finding integrals is called integration. The process is usually used to find a measure of totality such as area, volume, mass, and so forth, when its distribution or rate of change with respect to some other quantity, such as *position* or *time,* is specified.

Therefore, the integral of equation (5.2) in this respect provides the accumulation for PC, which also represents the total amount of products that can be produced by the organization during a given period of time such as from t_1 to t_2, as shown in equation (5.3).

$$\int_{t1}^{t2} PC = \int_{t1}^{t2}\left(WA * \frac{CP}{RCP} * CT * SZ\right) + \int_{t1}^{t2}\left(SZ * \frac{CP}{RCP} * CT * WA\right) + \int_{t1}^{t2}\left(SZ * WA * CT * \frac{CP}{RCP}\right) + \int_{t1}^{t2}\left(SZ * WA * \frac{CP}{RCP} * CT\right) \ldots\textbf{(5.3)}$$

The integral equations are used in our study to analyze the averaged accumulation of score for the trust level of an organization in a specific time interval. This enables to get a picture on how the trustworthiness of an organization has been changing accumulatively and thus on the basis of this picture we can predict the future trend of trust level of the organizations.

5.4.4 Corrective measures for assessing trust level

In the TrustMan system as presented in Chapter 6, a list of formulas that formally define inter-relations between trust criteria, intermediate factors, and known factors, are applied for the implementation of mechanisms for assessing the level of trust in each organization. When a trustor designates/selects a number of trust criteria within a trust perspective, the related predefined formulas that constitute these criteria will be invoked. However, in some cases the predefined formulas might also include some other trust criteria that are not selected by the trustor. In such situations, mechanisms are implemented in the TrustMan system to automatically eliminate (nullify) the effects of refused (not selected) trust criteria within predefined formulas, thus ensuring that accurate comparative arithmetic results are obtained for all involved organizations. For example, if a refused (not selected) trust criterion in the equation is related to one selected trust criterion or a known factor with an addition (+) sign or a subtraction (-), then a value of 0 will be assigned to it. Moreover, if the refused trust criterion in the equation is related to one selected trust criterion or a known factor with a multiplication (*) or a division (/), then a value of 1 will be assigned. With this approach the influences of the refused (not selected) trust criteria will be avoided on the final comparative results.

However, values for all selected trust criteria must be a-priori available from all organizations in the VBE and whose trustworthiness is being assessed. Namely, the trustworthiness of any organization for which its values for all selected trust criteria are not available will not be calculated that may in turn result the loss of opportunity for organizations. The TrustMan system identifies such missing values and notifies the trustor as well as the VBE management about the faulty organizations and incomplete values for their trust criteria.

Furthermore, the use of the different kinds of equations presented in Section 5.4.4 may differ. These equations can be used for assessing the level of trust in an organization at a specific point in time, such as the current time. However, it becomes more complex when the level of trust in an organization needs to be assessed on the basis of a large amount of data gathered during a relatively long-period of time in the past. The complexity of an assessment also increases when level of trust in an organization needs to be forecasted for a relatively long-period of time in the future. Simulation can be applied in such special cases, which involves the use of differential equations (such as equations 5.2, 5.3) in order to build the simulation models.

5.4.5 Setting up and customization of organizations trust assessment system for VBEs

Every VBE belongs to a general VBE domain (such as the manufacturing, health, tourism, etc.), and it further represents a specific application area(s) within that domain (e.g. production of clothing, or elderly support services). In order to further present our approach for assessing the level of trust in an organization and go to the low level of addressing trust criteria, we use the example of a VBE that specializes in perishable products. In particular, we address a VBE that specializes in the processing, production, and preservation of perishable food, and further on the specific application area of processed fish products (see example 5.1). In this sub-section, we apply the concepts of HICI approach that was presented in Section 3.2, in order to develop a tailored trust management system for a specific VBE.

Following is a replicable approach with a set of activities that shall be performed to achieve this purpose for each VBE:

- Selecting a set of trust criteria from the generic set of potential trust criteria, to be included within the specific VBE's pool of trust criteria (see "a" below)
- Analyzing the impact of the selected trust criteria and the VBE-generic intermediate factors, on the trust level of organizations in this VBE (see "b" below)
- Analyzing causal influences between the selected trust criteria in the pool, the intermediate factors (both the VBE specific and the generic ones) and the known factors specific to this VBE (see "c" below)
- Formulating equations using the results of the causal analysis, and apply these equations to the development of mechanisms for assessing trust level of organizations in this VBE (see "c" below).

a) Selection of trust criteria from VBE-generic set of trust criteria to form the "VBE's pool of trust criteria"

In VBEs, trustor organizations assess the level of trust in trustee organizations on the basis of specific trust objectives and their preferred perspectives for trust establishment. In Section 3.3 we identified three generic categories of trust objectives for VBEs. The first category of trust objectives, namely "creating trust between organizations", is used in VBEs for any of the following reasons:

- Acceptance of a new organization's membership application in the VBE
- Invitation of potential VBE members to participate in a VO
- Periodic control of the level of trust in VBE member organizations.

To meet the assessment of trust level of organizations such trust objectives, may apply different sets of trust criteria, which will be subsets of the VBE's pool of criteria. Consider the example 5.1 which represents a VBE case used in this chapter to exemplify our approach.

Example 5.1:

Consider an example case of a VBE that specializes in the production and preservation of perishable food, and especially in processed fish products. This specific example is supposed to be focused on fish processing and work in two geographic zones. The first zone *(local center)* is where the fishing is carried out, and where the organizations which do the pre-processing are located. The second zone *(international center)* is a neighboring country in which the international export of smoked, canned, and frozen fish products is carried out, and where the organizations that carry out the final processing steps and marketing are located. The processing activities at the local center include: cleaning fish, cutting off heads, clearing fins, removing entrails, intermediate packaging, etc. The activities at the international center include: removing bones, cutting fish into pieces, smoking, canning, freezing, and packaging according to specific customer demands, preservation treatments, marketing, etc.

Here, the VBE administrator needs to select some trust criteria from the **generic set of trust criteria** as presented in Section 3.3 to include within this **VBE's pool of trust criteria**. The VBE administrator will go through all trust perspectives, in the general set of trust criteria, selecting the preferable trust criteria for the VBE. Each VBE's pool of trust criteria constitutes all trust criteria that are applicable in the VBE for assessing the base trust level as well as for evaluating specific trustworthiness of organizations by different trustors in the VBE. To give examples, in this section, we focus on *structural perspective*. The VBE administrator shall subsequently select specific trust requirements for further realization of the structural perspective. For example, in this case, the *structural strength* and *business strength* requirements would be chosen (see Figure 5.3). Following this selection of trust requirements, the VBE administrator will select preferred trust criteria for each trust requirement. For instance, for the structural strength requirements, trust criteria such as *size*, *competency*, and *number of experts*; and for the business strength requirements, trust criteria such as *centers* and *workload allocation* will be selected. Lastly, the VBE administrator will decide on the *value structure* for each trust criterion.

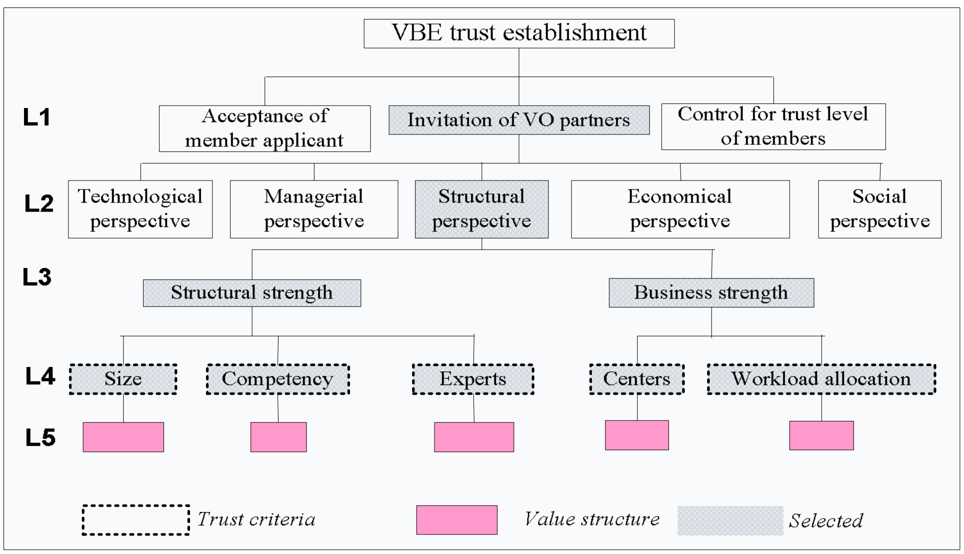

Figure 5.3: A systematic selection of trust criteria

As a part of a customization of the TrustMan system, this figure shows that for the specific trust objective of "invitation of VO partners" (at L1) the VBE administrator has selected the structural perspective (at L2) and in turn both structural strength and business strength (at L3), as well as five trust criteria (at L4) together with their value structure (at L5). Please see the complete set of trust criteria, requirements and perspectives in Figure 3.6.

Using the HICI approach presented in Section 0, Figure 5.3 illustrates this systematic selection of preferred trust criteria. The selection of trust criteria follows the hierarchical analysis that represents the first stage of the HICI approach as presented in Chapter 3.

b) VBE-generic analysis of impact of trust criteria and intermediate factors on trust level of organizations

Impact analysis represents the second stage of the HICI approach as addressed in Chapter 3. Using the impact analysis approach we have defined four intermediate factors – F1 to F4, namely, processing *capacity, connections, common context and social capital* – that are influenced by the five trust criteria that are selected as shown in Figure 5.3, i.e. *size, competency, experts, centers, and workload allocation*. Figure 5.4 shows the impact analysis for the selected trust criteria and their respective intermediate factors.

Please note that many more intermediate factors (i.e. F5 to F16) are further identified with the help of experts during the analysis of causal influences between trust criteria and intermediate factors, as shown in Figure 5.5. The interpretation and explanation of the components addressed in Figure 5.4 are presented in Section 3.2.2.

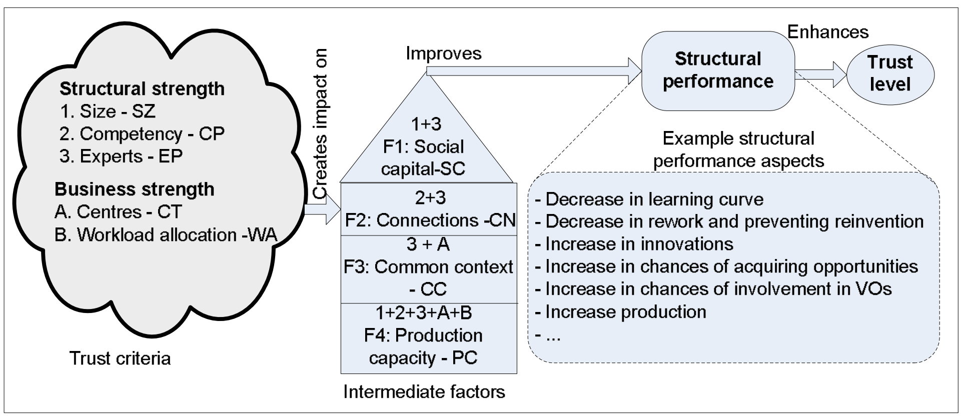

Figure 5.4: VBE-generic impact analysis of the selected trust criteria for the structural perspective

This figure represents a customization of the generic impact analysis for the structural perspective as shown in Figure 3.3. The analysis is done by defining intermediate factors to link selected trust criteria and certain performance aspects. The links indicate how changes of values of trust criteria can create impact on the trust level of organizations. Note the two examples (3.1 and 3.2) in Section 3.2.2 describing this figure.

c) Analysis of causal relations between trust criteria, known factors and intermediate factors in a specific VBE

To effectively assess the level of trust in organizations, inter-relations between trust criteria, known factors and intermediate factors in the VBE environment must be analyzed and well understood. This means that a priori to formulating mathematical equations, which will be used for developing mechanisms for assessing organization's trust level, the scope of the TrustMan system must be analyzed and specified. Specifying the scope of a system is a main concern in the process of systems development due to the continuous changing of system requirements related to users and operational environments. The challenge here is "how do define the scope of the trust management system?" Response to this challenge is not straightforward, because the trust management system is a part of the VBE management system, namely a part of a set of systems that together manage the VBE environment [Maciaszek, 2007]. These systems interoperate by exchanging information and invoking services from each other.

In order to specify the scope of the TrustMan system we therefore need to know the context in which it operates, such as in our case each specific VBE environment. We need to specify the elements that can be considered inside that environment (internal factors) and thus need to be modeled and implemented. We also need to specify elements that can be considered as outside the system (external factors) that require to be analyzed to provide some understanding about any needed interaction between the TrustMan system and the external environment.

Specification of the scope of the TrustMan system is done through classifying its known factors and intermediate factors as shown in the causal diagram illustrated in Figure 5.5, into the internal factors – those that must be included in the equations – and the external factors – those that are considered outside the system and do not need to be included in the equations. For this purpose, both known factors and intermediate factors are analyzed to examine the intensity of their influence on each other, so that they may be divided into those that should be inside the system, and those that should be regarded as external factors. External factors (both known and intermediate) are those factors that while still influencing the system, have an influence which is assumed to be uncontrollable both by the system and its users.

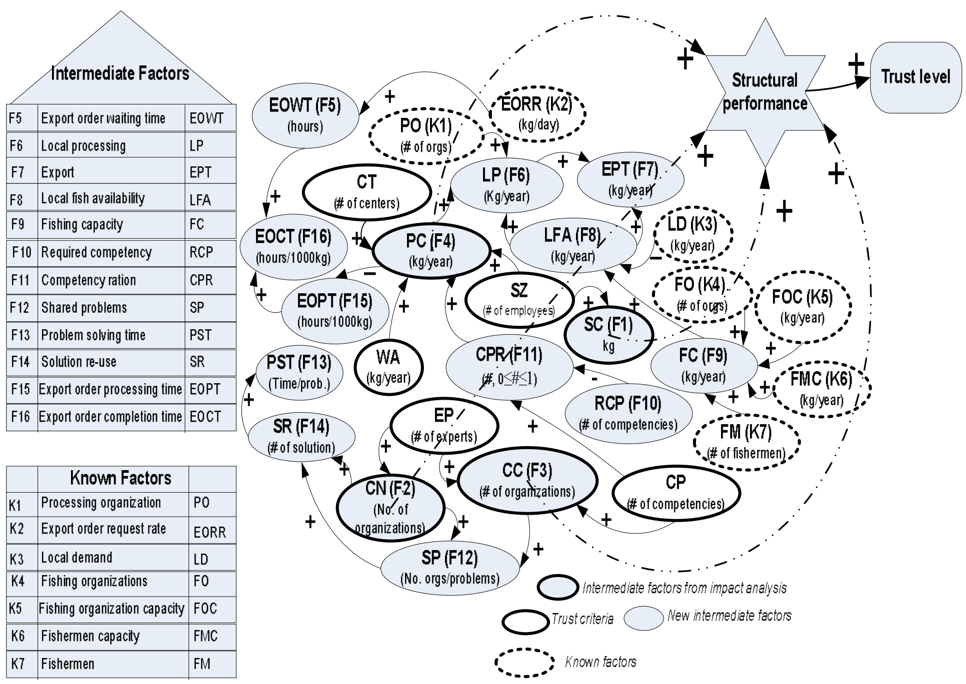

Figure 5.5: Customized causal relations between trust criteria, intermediate factors, and known factors

The analysis considers the selected trust criteria, VBE generic intermediate factors, VBE specific intermediate factors and the known factors. This figure shows an extended and customized causal diagram for the measurable parameters associated with the structural perspective as addressed in this section. Some examples describing this follow below.

Following the division of such external factors and internal factors, the derivation of formulas subsequently focuses *only on intermediate factors that are classified to be inside the system.* Therefore, specifying the system's scope enables a reduction in the number of formulas that have to be derived for intermediate factors, while preserving the expected functionalities and the effectiveness of those parts of the system that can be controlled.

With the help of experts in the field and survey of past research, some inter-relations between pre-defined "general" trust criteria (see Figure 5.2) can be developed a-priori to the establishment of any VBE as exemplified in Section 3.3. However, with the help of trust experts, this generic model of inter-relations may be later customized to different specific VBE domain/application (e.g. as shown in Figure 5.5), and/or it may be required to dynamically define additional new intermediate factors for these inter-relations. In this section, all the intermediate factors and known factors specified in Figure 5.4 are considered to be inside the system.

While customizing and formulating the VBE pool of trust criteria, the inter-relations between trust criteria, known factors, and intermediate factors, as well as the causal influences these have on each other, must be carefully analyzed and modeled. Please note that during customization, further to the identification of new intermediate factors, a number of known factors may be also identified. Known factors represent elements for which their values are known within the VBE environment; for example, the number of required competencies per organization in the VBE (RCP) which can be a generic known factor for any VBE, or the number of fishing organizations (FO) which is a specific known factor for the fish processing VBE.The list of known factors (K1 to K7) is represented in Figure 5.5 for the fish processing VBE. Figure 5.5 illustrates a causal diagram that represents both a set of additional intermediate factors (F5-F16) and a set of known factors (K1 to K7) that are involved in the influence relations between the trust criteria, intermediate factors and known factors. Please note that the metrics for values are represented inside parenthesis in each oval, which are needed and are used in the definition of formulas.

As described in Section 3.2.3, in the causal diagram a plus sign (+) on an arrow indicates that the increase or decrease of the source (first) factor respectively causes an increase or decrease in the destination (second) factor. On the contrary, the minus sign (-) indicates that the increase or decrease in the first factor respectively leads to a decrease or increase in the second factor. As shown in Figure 5.5, for example, "competency ratio" – CPR (intermediate factor) is positively influenced by "competency" –CP (trust criteria) and negatively influenced by "required competency" – RCP (known factor). The CPR positively influences the "production capacity" – PC (intermediate factor). PC is also positively influenced by: "workload allocation" – WA, "size" of the organization– SZ, and "production centers" – CT, which are all trust criteria. The PC itself is known factor that positively influences the structural performance of the organization. Lastly, the structural performance positively influences the trust level of the organization.

For the sake of illustration, we will derive mathematical equations for four intermediate factors. We will derive equations for processing capacity –PC (F4), export order completion time –EOCT (F16), export order processing time –EOPT (F15) and export order waiting time –EOWT (F5) to exemplify *different level of sophistication* needed for the developed formulas. Namely, with the *dimensional analysis* applied to PC (see example 1 in Section 5.4.3), it needs the multiplication and division for equation (5.1). For EOCT (example 3), it needs only addition. However, the examples 4 and 5 require more complex analysis of the interrelationships among the trust criteria, known factors, and the intermediate factors for which the use of queuing theory is needed to derive the required formulas.

Example 2: Developing an equation for processing capacity (PC)
We refer here to PC as the amount of fish (expressed in kilogram, or kg) that an organization can process during a specified period of time. Three trust criteria directly influence the behavior of PC, namely: *size of the organization (**SZ**), which refers to the number of employees; the workload allocation (**WA**), which refers to the standard amount of fish that a fully qualified employee is able to process in a specified period of time; and processing centers (**CT**), which refers to the number of processing centers at different places. PC is also influenced by* one other intermediate factor, namely *the competency ratio (**CPR**), which refers to the ratio of the number of competencies that an organization can offer to the total number of competencies required in the VBE.*

The equations for the example 1 have been formulated as shown in equations (5.1, (5.2) and (5.3) in Section 5.4.3. Considering that the same parameters are also applied here in the example 2, having the same causal relations, the equations for PC in this case are the same as those formulated in example 1. The equations for all other intermediate factors except the "*export order processing time"* – EOPT, and "*export order waiting time*" – EOWT as shown in Figure 5.5 can be formulated following the same approach that is presented in Section 5.4.3. In some cases, the influencing relations of known factors and trust criteria to an intermediate factor are too complex to represent mathematically using direct arithmetic operands and operators, due to the fact that their dimensions cannot be directly balanced. The dimensions of the involved factors in some relations (e.g. influences directed to EOWT and EOPT) cannot directly balance in the equation, due to some specific complex behavior, e.g. statistical behavior, exponential behavior, etc. Furthermore, there are also a number of other aspects (such as waiting time, service rate, etc.) that need to be addressed applying specifically defined mathematical theories, such queuing theories, exponential distribution, Poisson distribution, etc. For the examples 4 and 5 presented below, we use queuing theory to derive equations for the two intermediate factors, namely, EOPT and EOWT. But, below we first present example 3 whose results are later used in examples 4 and 5.

Example 3: Developing equations for export order completion time (EOCT)
Similar to example 1, the respective three equations namely, arithmetic equations, derivative equations, and integral equations for EOCT are generated as follows:

$$EOCT = EOWT + EOPT \quad \textbf{(5.4)}$$

$$\frac{d}{dt}EOCT = \frac{d}{dt}EOWT + \frac{d}{dt}EOPT \quad \textbf{(5.5)}$$

$$\int_{t1}^{t2}(EOCT) = \int_{t1}^{t2}(EOWT) + \int_{t1}^{t2}(EOPT) \quad \textbf{(5.6)}$$

Where the **EOWT** (export order waiting time) is the time that an order is queued and waiting (delay) before the processing of fish can start, the **EOPT** (export order processing time) is the time required to process a specified amount of fish for a given order. These two intermediate factors are addressed below in examples 4 and 5.

Examples 4 & 5: Developing equations for export order waiting time (EOWT) and export order processing time (EOPT)

For these two intermediate factors, we need to apply the ***Queuing theory*** to formulate their respective equations. The Queuing theory [Adan & Resing, 2001] can be simply stated as the mathematical study of waiting in lines (or queues). This theory enables the mathematical analysis of several related processes, including arriving at the (end of the) queue, waiting in the queue, and being served by the server(s) at the front of the queue. This theory guides the derivation and calculation of several performance measures, including the average waiting time in the queue or system, the expected number of entities that are waiting or receiving services, and the probability of encountering the system in certain states, such as empty, full, having an available server, or having to wait for a certain time before being served. Queuing theory is generally considered as a branch of operations research, as a result it is often used when making business decisions about resources needed to provide services. In order to illustrate the underlying principle of the Queuing theory a priori to addressing our example, we examine the M/M/1 queuing system (also known as Markovian Systems) [Adan & Resing, 2001]. Such a system is defined as a system that supports a *multiple number of arrivals* (λ) that are measured as an average number of arrivals based on specified probability distribution, a *multiple number of elements in the queue*, and a *single server* with a service rate (μ) that is measured as the average time needed to serve a single element based on the specified probability distribution. According to the Queuing theory definitions and, in particular, the Markov model, the arrival rate follows *Poisson distribution* with mean λ , and the service rate follows the *exponential distribution* with mean μ . Three main performance parameters are identified in the Queuing theory, namely *response time* (RT), *queuing time* (QT) and *service time* (ST). These parameters are mathematically defined as follows:

$$ST = \frac{1}{\mu}, \qquad QT = \frac{\lambda}{(\mu - \lambda) * \mu}, \qquad \text{and} \qquad RT = \frac{1}{\mu - \lambda}$$

Relating our example to the Queuing theory, we assume that there will be no limitation on the number of export orders received by an organization and that as many orders as possible may wait for processing. We refer to EOPT as the time that an organization will need in order to process a specified amount of ordered fish. We refer to the EOWT as the average time that an export order will wait in queue (delayed) from the time when it was received to the time that the processing of fish begins. Applying Queuing theory we can conclude that the three intermediate factors – EOPT, EOWT, and PC – are statistically related. Comparing with performance indicators applied in the Queuing theory, EOPT is similar to the *service time*, EOWT is similar to the *queuing time*, and PC is similar to the *service rate*. The export requests received by a certain organization to be processed are distinct. Thus both the export order request rate (EORR) and the PC follow the *Poisson distribution*. The EOPT follows the *exponential distribution* since it measures the time required to process a certain amount of fish for a single order. Based on the Queuing theory definitions, the equations for EOPT and EOWT are shown in equations (5.7a) and (5.8a). For this case, EORR is similar to the arrival rate in the Queuing theory. The differential equations for EOPT and EOWT are shown in equations (5.7b & 5.7c) and (5.8b & 5.8c) respectively.

Equations for EOPT:

$$EOPT = \frac{1}{PC} \text{........(5.7a);} \qquad \frac{d}{dt} EOPT = \frac{d}{dt}\left(\frac{1}{PC}\right) \text{......(5.7b);} \quad \int_{t1}^{t2} (EOPT) = \int_{t1}^{t2} \left(\frac{1}{PC}\right) \text{......(5.7c)}$$

Equations for EOWT:

$$EOWT = \frac{EORR}{(PC - EORR)PC} \text{ ....(5.8a);} \quad \frac{d}{dt}EOWT = \frac{d}{dt}\left(\frac{EORR}{(PC - EORR)PC}\right) \text{ ....(5.8b)}$$

$$\int_{t1}^{t2}(EOWT) = \int_{t1}^{t2}\left(\frac{EORR}{(PC - EORR)PC}\right) \text{ ....(5.8c)}$$

Analysis of the causal relations between these intermediate factors in the causal diagram (Figure 5.5) shows that PC is negatively related to EOPT, which proves the fact that a minus sign can be represented as a division in the mathematical equation as shown in equation (5.7a). EORR is positively related to EOWT, but in the equation (5.8a) its representation is a very special case. Although it is in the quotient part of the equation (5.8a), the EORR is negated in the quotient, which indicates that it is in fact positively related to the EOWT.

Export order completion time (**EOCT**), as addressed in example 3, is in principle the sum of EOPT and EOWT, which match the relations as indicated in the causal diagram in Figure 5.5, and also as described in the Queuing theory. Therefore, equation (5.9a) shows the EOCT represented in an alternative equation for equation (5.4), with different parameters. Its respective differential equations are shown in equations (5.9b) and (5.9c).

$$EOCT = \frac{1}{PC - EORR} \text{ ...(5.9a);} \quad \frac{d}{dt}EOCT = \frac{d}{dt}\left(\frac{1}{PC - EORR}\right) \text{...(5.9b)} \quad \int_{t1}^{t2}(EOCT) = \int_{t1}^{t2}\left(\frac{1}{PC - EORR}\right) \text{...(5.9c)}$$

5.5 Analysis of causal influences among trust criteria

In this section, we analyze the causal influences among the trust criteria, the known factors and the intermediate factors for each trust perspective. The results of the causal analysis are then applied to formulate mathematical equations to support the development of mechanisms for assessing level of trust in organizations. In this section, three kinds of mathematical equations are formulated for each intermediate factor. Each equation supports the analysis of different aspects of the inter-organizational trust as follows:

- ***Arithmetic equations***: These equations support the evaluation of trust level of an organization at a certain point in time. For example, they are used to compute trust level of organizations at the day that a selection of partners to join a VO is made.
- ***Derivative equations***: These equations support the analysis of evolution of the trust level of an organization at certain in point in time. For example, they are used to support examining whether the trust level of each selected VO partner is increasing, decreasing or uniform at the time selection of partners is made. The derivative equations are formulated by differentiating the arithmetic equations and for this purpose all parameters in each arithmetic equation, as addressed in Sections 5.5.1, 5.5.2, 5.5.3 and 5.5.4, are assumed to be continuous in respect to time.
- ***Integral equations***: These equations support the analysis of the average of the trust level scores of an organization for a certain interval of time by providing the possibility to capture the accumulations of trustworthiness scores in that period. For example, they are used to support the analysis of the average trust level of an organization for an entire period of its involvement in the VO. The integral equations are formulated by integrating the arithmetic equations and for this purpose all parameters in each arithmetic equation, as addressed in Sections 5.5.1, 5.5.2, 5.5.3 and 5.5.4, are assumed to be continuous in respect to time. Thus the integration of arithmetic equations is performed with respect to time.

5.5.1 Social perspective

As described in Section 3.2, the analysis of causal relations among trust criteria involves identifying both the intermediate factors and the known factors. Trust criteria related to social perspective are presented in Section 3.3.1 and in detail described in Table 3.2. For the this trust perspective, one intermediate factor was identified – *social acceptance (SAC)* – and three known factors, namely (1) *Societal activities (SA),* (2) *Services needed (SN),* and (3) *Societal standards (SS).* Figure 5.6 represents the causal influences between the trust criteria, known factors and intermediate factors.

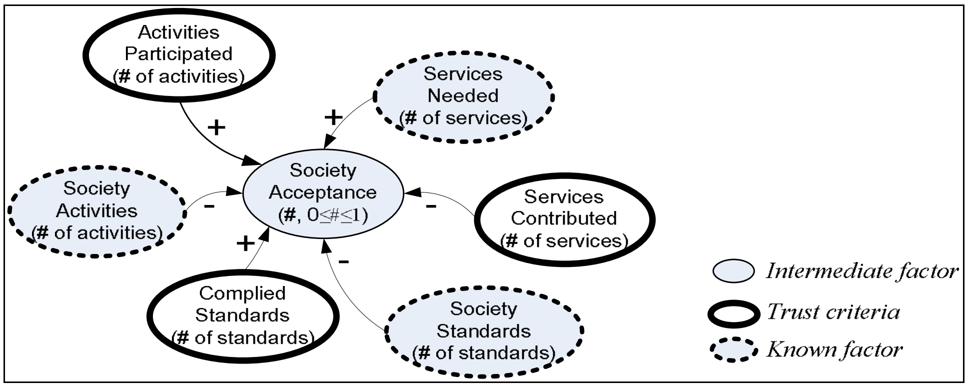

Figure 5.6: Causal influences between trust criteria for social perspective

This figure shows a qualitative analysis of causal influences between measurable parameters for the social perspective, namely, its associated trust criteria, known factors and intermediate factors.

As addressed in Section 5.4.3, results of the causal analysis are applied to the formulation of mathematical equations. The equations are derived by relating an intermediate factor, as the subject of equation, to the trust criteria and known factors. Using the acronyms of trust criteria presented in Table 3.2, below are the arithmetic, differential and integral equations for social acceptance (measured in: # *in a range of* $0 \leq \# \leq 1$):

$$SAC=\frac{1}{3}\left(\frac{AP}{SA}+\frac{SC}{SN}+\frac{CS}{SS}\right); \quad \frac{d}{dt}SAC=\frac{d}{dt}\left[\frac{1}{3}\left(\frac{AP}{SA}+\frac{SC}{SN}+\frac{CS}{SS}\right)\right]; \quad \int_{t1}^{t2} SAC = \int_{t1}^{t2}\frac{1}{3}\left(\frac{AP}{SA}+\frac{SC}{SN}+\frac{CS}{SS}\right)$$

5.5.2 Economical perspective

A number of trust criteria related to the economical perspective are presented in Section 3.3.1 and in detail described in Table 3.3. Figure 5.7 visualizes the causal influences (in a causal diagram) between trust criteria, known factors, and intermediate factors related to economical perspective. Using the acronyms of trust criteria which are presented in Table 3.3, below we present the mathematical equations derived for intermediate factors of the economical perspective as shown in Figure 5.7.

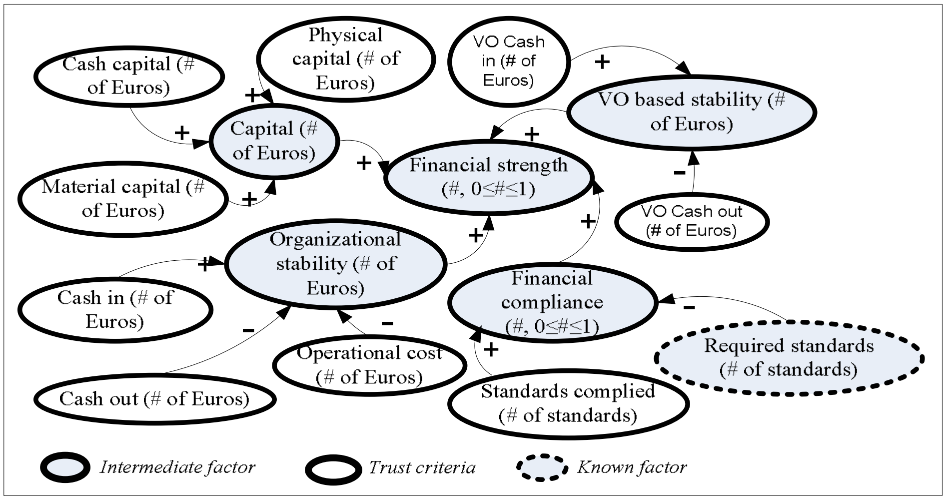

Figure 5.7: Causal influences between trust criteria for economical perspective

This figure shows a qualitative analysis of causal influences between measurable parameters for the economical perspective, namely, its associated trust criteria, known factors and intermediate factors.

***(1) Equations for capital (CA,** measured in: Euros)*

$$CA = CC + PL + MC$$

$$\frac{d}{dt}CA = \frac{d}{dt}CC + \frac{d}{dt}PL + \frac{d}{dt}MC$$

$$\int_{t1}^{t2}(CA) = \int_{t1}^{t2}(CC) + \int_{t1}^{t2}(PL) + \int_{t1}^{t2}(MC)$$

***(2) Equations for VO based stability (VS,** measured in: Euros)*

$$VS = VCI - VCO$$

$$\frac{d}{dt}VS = \frac{d}{dt}VCI - \frac{d}{dt}VCO$$

$$\int_{t1}^{t2}(VS) = \int_{t1}^{t2}(VCI) - \int_{t1}^{t2}(VCO)$$

***(3) Equations for organization stability (OS,** measured in: Euros)*

$$OS = CI - CO - OC$$

$$\frac{d}{dt}OS = \frac{d}{dt}CI - \frac{d}{dt}CO - \frac{d}{dt}OC$$

$$\int_{t1}^{t2}(OS) = \int_{t1}^{t2}(CI) - \int_{t1}^{t2}(CO) - \int_{t1}^{t2}(OC)$$

***(4) Equations for financial compliance (FA,** measured in: # in range of $0 \le \# \le 1$)* where RS (*measured in: # of standards*) refers to required standards

$$FA = \frac{AS}{RS}\ ;\ \frac{d}{dt}FA = \frac{d}{dt}\left(\frac{AS}{RS}\right)$$

$$\int_{t1}^{t2}(FA) = \int_{t1}^{t2}\left(\frac{AS}{RS}\right)$$

***(5) Equations for financial strength (FS,** measured in: # in range of $0 \le \# \le 1$)*

As explained in Section 3.2, when the intermediate factor (source factor) influences another intermediate factor (destination factor), the source factor is assumed as a known factor and its equation can be applied to the equation of the destination factor. For example, as shown in

Figure 5.7 the intermediate factors: capital, organizational stability, financial acceptance are perceived as known factors when formulating equations for the financial strength. Therefore, the arithmetic, differential and integral equations for financial strength (FS) can be formulated as shown below.

$$FS = \frac{1}{2}\left[\left(\frac{OS+VS}{CA}\right)+FA\right]; \quad \frac{d}{dt}FS = \frac{d}{dt}\left(\frac{1}{2}\left[\left(\frac{OS+VS}{CA}\right)+FA\right]\right); \quad \int_{t1}^{t2}(FS) = \int_{t1}^{t2}\left(\frac{1}{2}\left[\left(\frac{OS+VS}{CA}\right)+FA\right]\right)$$

For the implementation of the equation for financial strength (FS) some necessary restrictions/assumptions need to be defined to ensure the correctness of the results that shall be computed using the equation. The following assumptions need to be implemented using some decision mechanisms such as using logical operations or selection mechanisms:

- If $FS \geq 1$ then the value of FS becomes 1 and it will be automatically assigned a score of 5 for the financial trustworthiness. In this case it indicates that the respective organization whose trustworthiness is being computed is making a healthier profit than its capital.
- If $FS < 0$ then the value of FS becomes zero and it will be automatically assigned a score of zero for the financial trustworthiness. In this case it indicates that the respective organization whose trustworthiness is being computed is making a financial loss in its businesses.

5.5.3 Technological perspective

A number of trust criteria related to technological perspective are presented in Section 3.3.1 and in detail described in Table 3.4. The results of the analysis of the causal influences between trust criteria, known factors and intermediate factors related to the technological perspective are shown in Figure 5.8. The following are the acronyms for known factors of the technological perspective.

Required interoperability	RIB	Required software standards	RSS
Required network speed	RNS	Required protocol standards	RPS
Required availability	RAV	Required experience	REP
Required security standards	RSC	Required operating systems	ROS
Required hardware standards	RHS	Required programming languages	RPL

Using the acronyms of trust criteria which are presented in Table 3.4, below we present mathematical equations formulated for six intermediate factors related to technological perspective.

***(1) Equations for experience gained (EG,** measured in: # of projects)*

$$EG = (VP + EP) * YH$$

$$\frac{d}{dt}EG = \frac{d}{dt}[(VP + EP) * YH]$$

$$\int_{t1}^{t2}\left(\frac{d}{dt}EG\right) = \int_{t1}^{t2}([(VP + EP) * YH])$$

***(2) Equations for ICT acceptance (IA,** measured in: # with range of $0 \leq \# \leq 1$)[1]*

$$IA = \left(\frac{AV}{RAV}+\frac{NS}{RNS}+\frac{IB}{RIB}\right)*\frac{1}{3}$$

$$\frac{d}{dt}IA = \frac{d}{dt}\left(\frac{AV}{RAV}+\frac{NS}{RNS}+\frac{IB}{RIB}\right)*\frac{1}{3}$$

$$\int_{t1}^{t2}[IA] = \int_{t1}^{t2}\left[\left(\frac{AV}{RAV}+\frac{NS}{RNS}+\frac{IB}{RIB}\right)*\frac{1}{3}\right]$$

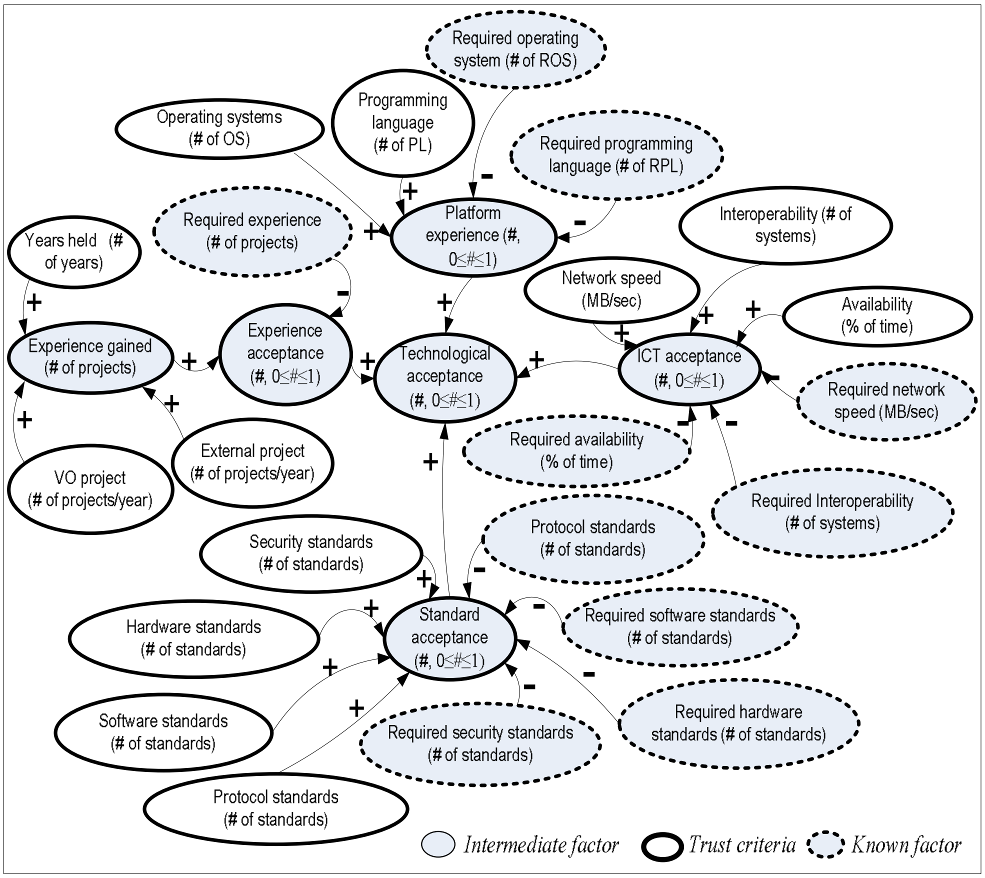

Figure 5.8: Causal influences between trust criteria for technological perspective

This figure shows a qualitative analysis of causal influences between measurable parameters for the technological perspective, namely, its associated trust criteria, known factors and intermediate factors.

***(3) Equations for experience acceptance (EA,** measured in: # with range of* $0 \leq \# \leq 1)$[1]

$$EA = \frac{EG}{REP}$$

$$\frac{d}{dt}EA = \frac{d}{dt}\left(\frac{EG}{REP}\right)$$

$$\int_{t1}^{t2}(EA) = \int_{t1}^{t2}\left(\frac{EG}{REP}\right)$$

***(4) Equations for standard acceptance (SA,** measured in: # with range of* $0 \leq \# \leq 1)$[1]

$$SA = \left(\frac{SC}{RSC} + \frac{HS}{RHS} + \frac{SS}{RSS} + \frac{PS}{RPS}\right) * \frac{1}{4}$$

$$\frac{d}{dt}SA = \frac{d}{dt}\left(\frac{SC}{RSC} + \frac{HS}{RHS} + \frac{SS}{RSS} + \frac{PS}{RPS}\right) * \frac{1}{4}$$

$$\int_{t1}^{t2}\left(\frac{d}{dt}SA\right) = \int_{t1}^{t2}\left(\left(\frac{SC}{RSC} + \frac{HS}{RHS} + \frac{SS}{RSS} + \frac{PS}{RPS}\right) * \frac{1}{4}\right)$$

[1] For the implementation of these equations some necessary assumptions need to be made in order to ensure that the final value of the intermediate factor is always between 0 and 1 inclusive. Thus if the computed value is greater than 1 then the intermediate factor is automatically assigned a value of 1. This indicates that the organization has performed better than the threshold which is set in the VBE.

***(5) Equations for platform experience (PE,** measured in: # with range of* $0 \le \# \le 1$*)*[1]

$$PE = \left(\frac{OS}{ROS} + \frac{PL}{RPL}\right) * \frac{1}{2}$$

$$\frac{d}{dt} PE = \frac{d}{dt}\left(\frac{OS}{ROS} + \frac{PL}{RPL}\right) * \frac{1}{2}$$

$$\int_{t1}^{t2} (PE) = \int_{t1}^{t2}\left(\left(\frac{OS}{ROS} + \frac{PL}{RPL}\right) * \frac{1}{2}\right)$$

***(6) Equations for technological acceptance (TA**, measured in: # with range of* $0 \le \# \le 1$*)*

$$TA = \frac{SA + IA + PE + EA + EG}{5}$$

$$\frac{d}{dt} TA = \frac{d}{dt}\left(\frac{SA + IA + PE + EA + EG}{5}\right)$$

$$\int_{t1}^{t2} \frac{d}{dt}(TA) = \int_{t1}^{t2}\left(\left[\frac{SA + IA + PE + EA + EG}{5}\right]\right)$$

5.5.4 Managerial perspective

A number of trust criteria related to managerial perspective are presented in Section 3.3.1 and in detail described in Table 3.5. The results of the analysis of causal influences between trust criteria, known factors, and intermediate factors related to the managerial perspective are shown in Figure 5.9.

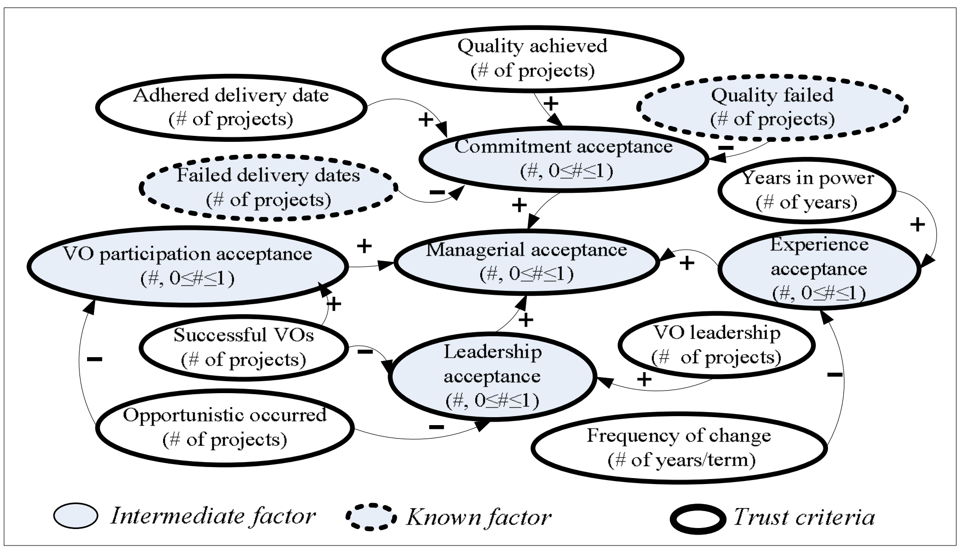

Figure 5.9: Causal influences between trust criteria for managerial perspective

This figure shows a qualitative analysis of causal influences between measurable parameters for the managerial perspective, namely, its associated trust criteria, known factors and intermediate factors.

We have applied the results of the causal analysis to formulate mathematical equations for the intermediate factors as shown in Figure 5.9. For the managerial perspective, we have identified two known factors, namely, the failed delivery dates (FD, *measured in: # of projects*) and the quality failed (QF, *measured in: # of projects*). Using the acronyms of trust criteria presented in Table 3.5, below we present the equations for the intermediate factors related to managerial perspective.

(1) VO participation acceptance (VA) where the sum of OO and SV represents the total number of VOs.

$$VA = \frac{SV}{OO + SV}$$

$$\frac{d}{dt}VA = \frac{d}{dt}\left(\frac{SV}{OO + SV}\right)$$

$$\int_{t1}^{t2}[VA] = \int_{t1}^{t2}\left[\left(\frac{SV}{OO + SV}\right)\right]$$

(2) Leadership acceptance (LA) where the sum of OO and SV represents the total number of VOs.

$$LA = \frac{VL}{OO + SV}\ ;\ \frac{d}{dt}LA = \frac{d}{dt}\left(\frac{VL}{OO + SV}\right)$$

$$\int_{t2}^{t1}[LA] = \int_{t1}^{t2}\left[\left(\frac{VL}{OO + SV}\right)\right]$$

(3) Commitment acceptance (CP) where the sum of AD and FD as well as QA and QF represents the total number of projects that the organizations provided services (participated).

$$CP = \left(\frac{AD}{AD + FD} + \frac{QA}{QA + QF}\right) * \frac{1}{2}$$

$$\frac{d}{dt}CP = \frac{d}{dt}\left[\left(\frac{AD}{AD + FD} + \frac{QA}{QA + QF}\right) * \frac{1}{2}\right]$$

$$\int_{t2}^{t1}(CP) = \int_{t2}^{t1}\left(\left[\left(\frac{AD}{AD + FD} + \frac{QA}{QA + QF}\right) * \frac{1}{2}\right]\right)$$

(4) Experience acceptance (EA)[1]

$$EA = \frac{YP}{FP}\ ;\ \frac{d}{dt}EA = \frac{d}{dt}\left(\frac{YP}{FP}\right);\ \int_{t1}^{t2}[EA] = \int_{t1}^{t2}\left(\frac{YP}{FP}\right)$$

(5) Managerial acceptance (MA)

$$MA = \frac{CA + VA + LA + EA}{4};\ \frac{d}{dt}MA = \frac{d}{dt}\left(\frac{CA + VA + LA + EA}{4}\right);\ \int_{t1}^{t2}[MA] = \int_{t1}^{t2}\left[\left(\frac{CA + VA + LA + EA}{4}\right)\right]$$

Implementation of mathematical equations in TrustMan system

The mechanisms introduced for assessing the trust level of organizations are implemented in the TrustMan system using the mathematical equations presented in this chapter. As addressed in Chapter 6, the TrustMan system provides two integrated services particularly designed to support the measurement of the trust level of organizations, namely, services for the *assessment of the base trust level of VBE member organizations (Service 1)* and for the *evaluation of specific trustworthiness of VO partners (Service 2)*. As such, these services support the analysis of trust in organizations only at specific points in time. For these two services, all related mechanisms for assessing the level of trust in organizations are implemented applying the arithmetic equations. The current implementation of TrustMan system addresses and meets the VBE requirements identified in Chapter 1. Our further research on advanced support systems for VBEs aims at the development of decision support systems based on the analysis of evolution of trust level of organizations. This in turn will require the implementation of the differential equations as addressed in this chapter.

5.6 Chapter discussion and conclusion

As presented in this chapter about the need for assessing trust level of an organization in the VBE, a wide range of trust criteria may be considered while evaluating organization's trustworthiness. Trust in VBEs is characterized as a multi-objective, multi-perspective and multi-criteria subject. Trust is not a single concept that can be applied to all cases for trust-based decision-making [Msanjila & Afsarmanesh, 2006a], and its measurements depend on both the purpose of establishing a trust relationship and its specific involved actors. Trust level of an organization can be measured rationally in terms of quantitative values of related trust criteria e.g. based on an organization's past performance. The level of trust in an organization is complex and can neither be measured with single value of a single parameter, nor interpreted with a single metric. Nonetheless, an organization's level of trust can be specified on the basis of the values for a set of related trust criteria.

Understanding and interpreting the level of trust in an organization, described and formulated in terms of values of a set of trust criteria, will be complex and difficult to grasp for most decision-makers in organizations, such as managers and directors, if they are not trust experts and do not have sufficient knowledge in both mathematics and computer applications. Therefore, the trust level of organizations must be presented in a format that is as understandable as possible to the expected users while not loosing its semantics. This thesis proposes that the level of trust in organizations should be represented and expressed in terms of a set of qualitative values, and these values can only represent comparative levels of trust in different organizations in a VBE for a specific given trust purpose, and not as absolute levels.

Therefore, this chapter has addressed the main research question (MRQ3) and its related sub-questions (SRQ3.1, SRQ3.2, SQR3.3 and SQR3.4). We have presented how the level of trust in an organization can be measured. The chapter has also addressed MQ1 by presenting an approach for developing mechanisms to assess trust level of an organization. In Chapter 7 an integrated view on how all the questions in this dissertation are addressed is presented.

In conclusion, this chapter introduces a mathematical model for organizations' trust assessment, and a replicable approach for customization of the general trust management system for each specific VBE. It has also addressed the formulation of mechanisms for assessing the level of trust in an organization. These mechanisms are formulated by applying mathematical equations which are derived from the results of analysis of causal influences between trust criteria, known factors and intermediate factors. Therefore, the chapter has presented a mathematical approach to generate formal mechanisms for assessing an organization's level of trust. The assessment of the level of trust in an organization might differ in terms of the possible comprehensiveness depending on the time the results will be applied (e.g. forecasting trust level) and the amount of data that need to be applied (e.g. large volume of data from many past years). To address these different levels of complexities three kinds of equations – *arithmetic, derivative, and integral* – are proposed and exemplified.

The mechanisms for assessing trust level of organizations as presented in this chapter, the models of trust relationships as presented in Chapter 4 and set of trust elements as presented in Chapter 3 constitute a key input concepts to the development of the organizational trust management system (TrustMan system) as presented in the next chapter (Chapter 6).