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An information system for monitoring the Chilean salmon industry sustainability

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ABSTRACT

Today and years to come, one of the most challenging problems of the global economy is to keep maintaining and developing the correct balance of the environment from which resources are extracted. For this, we believe that Information Systems and formal methodologies for sustainability measures definition are related to decision making and management control. In this work, a methodology as a means to determining and implementing reliable, understandable, relevant and accessible sustainability indicators for the interaction between the environment, the economy and the society will be examined. Sustainability measures were implemented in a Decision Support System using a multidimensional modeling based architecture. The proposed methodology for indicators definition and the Information System were successfully applied to the Chilean salmon industry. The usage of the indicators and the stakeholders' opinions over the resulting Information System, proved that the proposed Decision Support System is of great importance to the sustainable development of the Chilean salmon industry.

1. Introduction

Information Systems (IS) have been extensively used as a necessary technological tool through which a company or any institution must have to differentiate themselves in any market or field. Firstly, in the late 60s and early 70s, studies about computer systems to support decision making was first observed as a field in organizational decision making and interactive computer systems by Keen and Morton (1978). Then, in the mid-70s, companies started to visualize strategic information among data and several ISs were implemented as a differentiating element between competitors. Based on this promising technology, companies were able to gather the business operational data, and extract a whole new level of information to support the decision making. Based on this, new computing technologies and the development of the database theory, invented by Codd (1983) in the early 70s, was taken into account in the early 1980s. In the mid 80s a new era of Decision Support Systems (DSS) was developed, and Executive Information Systems (EIS), Group Decision Support Systems (GDSS) were created as an improvement on old fashioned DSSs created a decade ago. The truth potential of these systems was determined from the early 90s to the present day. Hardware technology, database systems, telecommunications, Internet and software development evolved into an unimaginable power, now considered as one of the most significant elements of today's society and global economy.

Sustainability has been considered a key solution to economical, environmental and social related problems. However it has not been fully understood and employed (Mulvihill and Milan, 2007). This term has been widely used since the World Commission on Environment and Development in 1987, where it was defined as "development that meets the needs of the present world without compromising the ability of future generations to meet their own needs" (Nations, 1987). Often, the concept of environmental, social and economical equilibrium is associated with sustainability as a means of gathering stakeholders' attention to social, economical and environmental problems. Today's economy and development demands an environmental resource extraction that needs to be regulated. Therefore, stakeholders must be aware of critical indicators of social sustainability, economical sustainability and environmental sustainability, and the way in which they relate to one another. ISs has been argued as first, an effective way of sharing information between stakeholders, second, of building environmental awareness in both organizations and the community, and third, of facilitating the enforcement of environmental regulations as discussed by Mankoff et al. (2007a), Chen et al. (2008), Petrini and Pozzebon (2009), and Arceo and Granados-Barba (2010).

Today, the continuous awareness of environmental related industries as discussed by Bansal and Roth (2000) and Arrow et al. (1995), such as the salmon industry, has targeted the assistance of

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firms, communities, the government, authorities, and amongst others stakeholders. In this sense, there is an important need to measure the sustainable development of an industry in the mid and long-term. Sustainable development is essentially driven to satisfy today's needs, often in relation to productivity, but maintaining a balance between all components presented in the environment, such as natural resources, stakeholders profits, jobs, education, health, poverty, and crimes.

Furthermore, changing technological factors such as innovation projects, the development of information systems, amongst other, are equally important than previously mentioned factors for sustainability awareness in the fishery industry. The political will of the country is another external factor which decides the fate of any natural resource in the region. In the following, some of these technological factors, as well as political considerations, will be included in economical, social, and environmental indicators.

Over the last years, the salmon industry in Chile was considered the second largest industry of its kind behind Norway, with 38% of global production (SalmonChile, 2006). In mid-2007 the Chilean salmon industry was a seriously affected by the presence of the Infectious Salmon Anemia (ISA) virus in the south of Chile. As discussed by Furci and Pinto (2008) and Pinto (2007), before the ISA virus, the salmon industry was a fertile ground of business development, but with a serious lack of sustainable development. No indicator systems were used, and the relationship between the environment, the economy and the society was not considered by any governmental or private institution. As stated by the Chilean Corporation of Fundings for Production (CORFO), with an adequate IS for sustainability, an effective control of the ISA virus could have been deployed. Without an adequate Information System of indicators, there is no sustainability awareness, and there is no control and management of the environment, economy and society.

In this work, the perception of relevant factors regarding the salmon industry was gathered and analyzed following a proposed methodology. Then, several discussions were carried out with community groups on the salmon industry, that aimed to standardize and clarify a definition of sustainability from amongst the diverse groups that were offering conflicting definition of sustainability. This process has contributed to what today defines sustainability indicators and stakeholders requirements. A list of economic, social and environmental indicators was defined, from which both the availability and quality of the data sources was analyzed case by case. Several filters were considered, where current existence, access, quality and digitalization capability of the data were taken as the principal factors. Finally, in order to satisfy all IS requirements, a Data Warehousing (DW) architecture was proposed as a DSS for the sustainability of the salmon industry.

This paper is structured as follows: Section 2 introduces previous and related work on multidimensional modeling in DSS where a DW architecture is presented, as well as IS for environmental and salmon sustainability and related work on sustainability indicators for the salmon industry. The proposed sustainability indicator identification methodology is presented in Section 3, as well as the applied case in the Chilean salmon industry. In Section 4 the multidimensional modeling and proposed DSS is presented and described, followed by the deployment step of the system. Finally, in Section 5 conclusions of the above content is provided.

2. Related work

In this section, related work on sustainability and indicators modeling is presented, as well as Information Systems for Ecological Sustainability and Data Warehousing with Multidimensional Design for Decision Support Systems.

2.1. Sustainability and indicators modeling

Today, there is an active global debate about sustainable development and the social responsibility of the enterprise, which are important topics to be considered in sustainable indicators or measures development (Gall, 2008). The United Nations (UN), the European Union (EU), the Organization for Economic Cooperation and Development (OECD), Environment Canada (EC), the World Bank (WB), the International Institute for Sustainable Development (IISD), and a great many other institutions who themselves must develop their global indicators towards sustainability. One of the main milestones in this topic is the Agenda 21 (Commission on Sustainable Development, 1992), under the supervision of the UN, in which the general guidelines stipulate the development of sustainability. Specifically, one of the main topics was the development of indicators for ecological sustainability.

A general concept of sustainability was proposed in the 1972 Stockholm Conference in Environment of the UN, then formalized by the Brundtland report (Nations, 1987). Here, it was stated that a sustainable development must satisfy the needs of the present without affecting future generations' capacity of satisfying their own needs. Furthermore, Pearce et al., according to Reading (2004), proposed that sustainability is the development of a system whose previous goals have been obtained. Later, in 1993 Pearce et al. argued that sustainability is the awareness of not transferring the development costs to future generations, or at least compensating these costs. Finally in 1994, according to Viederman (Recife, Brazil, 1994) sustainability is a participative process that creates a community vision that both respects and prudently employs all resources (natural, human, human created, social, cultural, scientific, etc.). All previously stated definitions share the global vision that both economical and social change for the long-term must be aware of natural resources and the ecological systems from which resources are extracted.

Indicators are a powerful tool that provides information on the current state of a given matter. For this, indicators aim to achieve three main functions: simplify, quantify and communicate. They are an important tool to gather and present relevant information regarding a complex reality. The development of sustainability indicators have defined themselves as local, sectorial and ecological indicators (European Commission, 2003; Pastille, 2002; Segnestam, 2002).

Environmental indicators and sustainable development are new compared to social and economical indicators. In the Rio Earth Summit 1992 on environment and development, the issues around global needs for information on environmental conditions was addressed and recognized, as well as their tendencies and impact. To achieve this, not only has it been necessary to collate new data from different sources, but also one needs to redefine the sustainability indicator frameworks, as well as defining the methodologies behind new indicators.

It is of common knowledge that sustainability indicators must be able to reflect the current state of a given environment, to identify the goals of a community and to determine the progress achieved towards these goals. Indicators with these characteristics are relevant, and shareholders must be identified from a given environment to ensure ownership and the commitment to maintain and update these indicators. Given all this, sustainability indicators must be reliable, understandable, relevant and accessible, reflecting the interaction between the environment, the economy and society.

A lot of work has been carried out in this area (Society, 2009; Pacific Northwest Salmon Habitat Indicators, 1998; Zenetos et al., 2003), where one of the main problems lies in defining the most accurate IS architecture to manage and maintain sustainability indicators (Chen et al., 2008), and furthermore to communicate them openly to all the stakeholders without information asymmetry. Finally, as discussed in Mankoff et al. (2007b), the human interaction with an environmental information system, as well as the influence on the society is of crucial relevance to the usage of the IS. An application on coastal fisheries being considered as complex ecological and social systems is presented in Morales-Nin et al. (2010). Here, the policies considered for the development of management tolls to conserve biodiversity and its social structure are presented,

Previous work on defining Stakeholder preferences has been proposed in Philcox et al. (2010), where different qualitative and quantitative methods were used in order to analyse the preferences of local stakeholders for alternative management options. A review on principles, contexts, experiences, and opportunities when dealing with stakeholders (Grimble and Wellard, 1997) was developed with the objective of building a framework for natural resource management with stakeholders' information.

2.2. Information systems for ecological sustainability

Information Systems to maintain environmental responsibilities were previously produced in order to keep stakeholders well informed and updated on the social, economical and environmental development of a given ecological related industry. In Chen et al. (2008), a conceptual model to integrate information systems into stakeholders' adoption of effective practices for ecological sustainability was introduced. Here, IS are suggested to be the mean to computerize, communicate and transform data related events relevant to the ecological sustainability.

Furthermore, Chen et al. (2008) proposed that by the usage automated procedures to manage relevant information, authors proposed that the *Eco-Efficiency* concept must be obtained. This concept is extended by *Eco-Equity*, acquired by the informative role of IS, which finally provides the complete idea around *Eco-Effectiveness*, a main outcome from the sustainability of an ecological environment. By previously focusing on the *Eco-Efficiency* and the *Eco-Equity* concepts, the stakeholders can effectively share relevant information regarding the social, economical and environmental problems. Then, given the shared interest among stakeholders, the adoption of *Eco-Efficient* and *Eco-Equitable* practices are determined by the mimetic, coercive or normative pressure defined by the society. Finally, the adoption of *Eco-Effective* measures is where the ecological sustainability is improved.

However, to the best of our knowledge, IS architectures have not been considered a main interest for researchers, but it has been a priority for ecological-business oriented industries and governments, such as that of the salmon industry. In this domain, many IS around the world have been developed, with a wide range of systems' architecture to provide information on sustainability measures. Amongst the main IS for sustainability information, the following list of web-sites is presented (last access 12/14/2010):

- An Ecosystem Approach to Sustainable Aquaculture (ECASA)[1]
- European Environment Agency (EEA)[2]
- European Environment Information and Observation Net (EIONET)[3]
- European Aquaculture Technology & Innovation Platform (EATIP)[4]
- Canadian Sustainability Indicators Networks (CSIN)[5]
- International Sustainability Indicators Network (ISIN)[6]

Each one of the previous web-sites presents different levels of development and indicators related to sustainability. An interesting development is the ECASA project carried out by the European Marine Aquaculture. Here, as presented on their web-site (European Marine Aquaculture, 2004), the ecosystem sustainability awareness is gathered taking into consideration the following project stages:

1. To identify indicators that affects aquaculture on ecosystems through expert groups, workshops and meetings.
2. To identify indicators of the main drivers for ecosystem changes through expert groups, workshops and meetings.
3. Identify data sources to determine previously defined indicators.
4. Develop tools to present the indicators, as well as models to encapsulate best process understanding.
5. Test models and indicators in a wide variety of communities, and gather as many as possible comments about the testing phase.
6. Select the final group of tools and indicators.

The most relevant step stems from a sense of owning the project. As pointed out by the project developers, interaction between stakeholders is of great importance by which the practical relevance and success of the project will be determined by this sense of ownership.

It is important to notice that none of the previous mentioned web-sites provided the possibility of accessing the data online and carrying out calculations. All previously presented web-sites are static, and in this light the only interaction with the end-user occurs through downloading static reports. Analytical processing for a better understanding of sustainability measures is not permitted. Following this analysis, to the best of our knowledge, no strategic decision support IS architecture has been provided.

2.3. Data Warehousing and multidimensional design for decision support systems

It is common knowledge that Transactional Systems (TS) were not designed for decision support or knowledge extraction from data (Malinowski and Zimnyi, 2008; Rebolledo and Velásquez, 2009). On the one hand, every time TS is used for this tasks, complex processes must be executed directly over transactional repositories, causing an overhead in the business performance and systems' users activity (Kimball and Ross, 2002). Alternatively, Information Systems (IS) for decision support or knowledge extraction are not flexible enough to carry out changes in information requirements in a simple and fast way (Winter and Strauch, 2004; Giorgini et al., 2005). In most companies, if the IT department manages to handle end-user requirements for TS, it is likely that end-user will alter its requirements over time. To manage this, IT departments have identified two main issues that a strategic DSS must have: The first is associated with the Independence between Transactional Systems and Information Repositories. The second is related to the flexibility of handling new end-users' requirements. Together, these two requirements have been managed using Data Warehousing and OLAP[7] technologies (Gardner, 1998).

[1] ECASA: http://www.ecasa.org.uk/index.htm (Online; accessed 05.10.10).
[2] EEA: http://themes.eea.europa.eu/indicators/ (Online; accessed 05.10.10).
[3] EIONET: http://www.eionet.europa.eu/ (Online; accessed 05.10.10).
[4] EATIP: http://www.eatip.eu/ (Online; accessed 05.10.10).
[5] CSIN: http://www.csin-rcid.ca/ (Online; accessed 05.10.10).
[6] ISIN: http://www.sustainabilityindicators.org/ (Online; accessed 05.10.10).
[7] OLAP: Acronym from Online Analytical Processing.

According to Inmon (2005), a DW is a collection of business oriented, integrated, non-volatile, time variables which organizes information for decision making. This is because it handles the data generated to businesses; it gathers data from different data sources, into an analysis oriented structure, supports only insertion of new records, never deleting or changing them and every record is associated to a period of time. Given these properties, as TS provides data regarding throughout the day's transactions, a DW has been used as an information aggregation. The main differences between these Information Systems are presented in Table 1.

An important aspect of DW architecture is that the data must be previously cleaned and consolidated so as to be used. At the time the data was extracted from the TS, several advantages can be detected. Another advantage is that the time to obtain the information has reduced, as the information system architecture is specifically designed to data analysis, and it does not function as a transactional system. It is fundamental that, regarding any Data Warehousing project, the quality of the data presented by the end-users' must be flawless. Such data is designed and presented for decision support (Shankaranarayanan and Cai, 2006). Given this, the success of any Data Warehousing project is directly related to how stakeholders assess and evaluate the quality of the data (Giannoccaro et al., 1999; Velásquez and Palade, 2007b). For further details, a general background on the meaning of data quality for decision support is presented in Wang and Strong (1996).

Much of Data Warehousing architecture advantages lie in Multidimensional Modeling. Even though economic investments in both project development and management are considerably more important than Transactional Information Systems, as well as the complexity and project failure probability, multidimensional modeling is a key component of DW architectures as it enables the Online Analytical Processing operations (OLAP) (Chaudhuri and Dayal, 1997; Jarke et al., 1999). However, research on multidimensional modeling and some components have changed over time as new applications, technologies and methodologies have been introduced on the DW field (Rizzi et al., 2006). Nevertheless, the main idea of a cube that stores business domain data mapped into dimensions has been maintained over time (Franconi and Kamble, 2004).

3. Methodology to identify performance indicators for sustainability: an applied case in Chilean industry

Regarding the development of any IS it is necessary to gather all relevant information requirements from the end-users. On the following, the methodology used for the stakeholders identification and their respective information requirements for sustainability are discussed.

3.1. Stakeholders identification and sustainability indicators definition

Before defining the sustainability indicators, the first step to consider is the definition of stakeholders which were defined initially over communities and municipalities where the salmon farming is considered as both direct and indirect activity.

To define the communities and municipalities where stakeholders will be identified, the methodology first analyzes the population census to determine communities in which the work can be carried out. Despite some communities having relations with the salmon farming industry, the communities selected were those in which a significant percentage of the Active Economic Population (AEP) was related to the fishing activity. This indicates that the population is highly related to the production as well as the entire logistic chain activity of fishing within these geographic areas. Then, together with the AEP, it was necessary to determine the percentage of the population whose principal economical activity is fishing, aquaculture and other fishing related activities. With regards to this, an initial hierarchy of communes was determined.

This analysis permits us to determine relevant communes in which stakeholders were defined. However, not all sectors of these communes were linked to the fishing industry, and therefore, a second stage of analysis was required. The same AEP analysis applied to communes was repeated towards concerning districts, which consisted of a lower level of aggregation on the geographic scale of analysis. This allowed one to define the sectors within communes where the fishing industry has a greater level of influence.

An important step for the development of this research is the economical characterization of the different communes in Chile. As the economical behavior of Chilean communes is strongly related with the salmon industry, the agriculture and forestry, different criteria must be defined in order to categorize and select the right stakeholders universe. Communes can belong to more than one category, if they satisfy the selected criteria. For this, economical and physical characteristics were defined for each commune and analyzed.

Previous methodology applied to the Chilean communes over the whole country generated in the following areas: Puerto Montt, Cabulco, and Chiloé (fundamentally the Chilean communes Quemchi, Castro, Chonchi, Quellón). Geographic representation of the Region where Salmon industry is being developed in Chile is presented in Fig. 1

In these communes and geographic sectors, the main actors and parties who had expressed interest are identified in the following:

Table 1
This table presents the main differences between transactional information systems and the Data Warehousing architecture (Velasquez and Palade, 2008).

Information systems	Data Warehousing architecture
Information extraction directly over transactional databases	Information extraction over consolidated copies of transactional databases
Can affect the performance of transactional systems	Well designed, and does not affect transactional systems performance
End-user must wait for the system to adapt for new requirements	More flexible, the end-user can extract information directly from the DW repositories
End-user depends on others obtaining the information needed	End-user is autonomous, and can directly retrieve the information required
Given complex requirements, the Information System adapts slowly	Given complex requirements, there are three possible scenarios: • The Data Warehouse adapts dynamically given prior requirements and design features • A new data source must be added to in response to the requirement, without modifying previous data sources • The requirement must be implemented and additional data sources must be considered

Fig. 1. 10th Region of Chile, "Región de los Lagos", where the Salmon Industry is developed [www.chileeduca.cl, Online; accessed 13-December-2010].

- Government institutions with national and regional representation.
- Municipal institutions.
- Representative members from firms in the salmon industry (both cultive and processing business activity).
- Representative members from firms related to the salmon industry.
- Representative members from the aquaculture industry firms.
- Representative members from the union of workers in salmon's industry firms, and artisan fishers union.
- Representative members from native communities.
- Representative members from neighbors.
- Representative members from non-governmental organizations (NGO) (mainly environmental NGOs)
- Representative members from technical studies centers and consultancy (e.g. Universities, environmental consultants, etc.)

Afterwards, the participative step was applied which consists of open interviews with stakeholders in order to acknowledge their opinions on the fishing industry. Then, participative workshops were held with these actors which strived to validate information gathered from the interviews. This work aims to permit stakeholders to share the realities of each other's experiences, generating a dynamic interaction and reflection about their beliefs attitudes and real life experiences. The list of indicators was compiled during the stakeholders final interviews and workshop sessions, as not to encourage partiality in their own opinions regarding the sustainability of the salmon industry.

A team of experts composed of anthropologists, biologists, economists and industrial engineers, analyzed state of the art projects for the sustainable development of fishing and aquaculture industries (more details in Section 2.2). Experts introduced a list of 150 indicators for sustainability. Then, the previous list was reduced to a short list of 60 indicators after analyzing the most representative indicators using stakeholders opinions together with a list of indicators, following a methodology described by Rice and Rochet (2005). Therefore, the list of indicators was reduced taking into consideration several factors, such as the concreteness, the theoretical basis, the public awareness, the cost measurement, the historical data available, the sensitivity, the specificity and the responsiveness of each one of the indicators. These factors where measured for each indicator using four different values: High, Fair, Moderate and Low. For each Stakeholder, the values were gathered, and ordered in a two dimensional matrix. Afterwards, the indicators were listed and ordered using the weighted average of each factor, given the relevance of each Stakeholder considered, and then within the most important indicators, those with availability of data were selected to compile the short list of indicators.

At this stage, all this information presented a local vision of sustainability from different Stakeholders separated by communes. To determine a global vision of sustainability, previous information was analyzed and common elements as well as conflicting ones were compared with international experience on sustainability indicators measurement. All this stated a preliminary global perception of sustainability and a preliminary list of sustainability indicators. Finally, a second interview with Stakeholders was performed in order to validate the perception of sustainability from the indicators' list, and a final workshop was carried to highlight the results and all Stakeholders perceptions and opinions on sustainability. In this final workshop international experts in the field were invited in order to provide their experience in similar projects. As a result of this, a global vision of sustainability was determined, as well as a preliminary list of indicators for environmental, social and economical aspects of the salmon industry.

To conclude the Stakeholders interviews and workshops, the salmon industry is a sustainable industry taking into consideration whether the following attributes are obtained:

- The salmon production must be compatible with native fauna preservation.
- Zones in which the industry operates must be a natural equilibrium and must consist of a rational use of resources and a reasonable disposal of wastes.
- Production must be determined from the capacity of the discharge of biological bodies in the water employed.
- Production must be considered together with scientific development to ensure a compatible relationship with the environment.
- The industry must provide not only a high number of employees, but also a just remuneration to employees.
- The industry must be able to generate a national providers network with a great degree of influence, thus considering natural resources as well as human resources.
- The industry must contribute indirectly to health, education and basic services conditions to the communities.
- The industry must coordinate procedures that prevent the occurrence of natural disasters or unexpected situations that could create negative outcomes
- The industry must generate both trusting relationships and respect to local communities, encouraging an open dialogue and incorporating representatives from communities to influence decision making.

The final list of indicators, extracted directly from the short list defined with stakeholders, and filtered again under data availability constraints, is presented as follows:

1. Environmental Indicators:
   - Number of fishing farms where anaerobic conditions have occurred.
   - Density of fishing production.
   - Number of fishes escaped from fishing farms.
   - Tons of salmon produced in lake fishing farms.
   - Percentage of fishing farms with high risk diseases.
   - Percentage of non-compliance identified during visits Governmental institutions.
   - Number of scientific publications every 100,000 Tons of salmon production in the same period of time.
2. Economical indicators:
   - Number of occupational accidents.
   - Sectorized contribution to the Gross domestic product (GDP).
   - Number of employees with permanent employment.
   - Number of employees generated by fisheries.
   - Number of female employees generated by fisheries.
   - Number of employees by educational levels in the fisheries sector.
   - Number of days taken by employees under medical permission.
   - Per capita income of the principal occupation in the fishing sector.
   - Per capita income of the principal occupancy level of education in the fishing sector.
   - Per capita income of the household who declared their main income in the fisheries sector.
   - Percentage of female employees on fisheries within the total employment in the industry.
   - Relationship between fishing sector wages and salaries in national average.

- Professional training rate.
- Patents paid per capita.

3. Social indicators:
   - Construction quality of houses.
   - Percentage of crimes reported by the total number of habitants.
   - Authorized surface construction (by the municipality).
   - Seasonal employment by economic sector.
   - Continuous employment by economic sector.
   - Average number of students in schools.
   - Number of households with incomes below the minimum wage.
   - Total enrollment of students in a given level of education.
   - Net effect of immigration and emigration on the population of a commune.
   - Percentage of population growth.
   - Percentage of high school graduation.
   - Number seized by type of crime.
   - Proportion of people who rent homes.
   - Area planted by fishing farm types.
   - Poverty rate.

3.2. Stakeholders' information requirements for sustainability

As stated in Chen et al. (2008), to contribute to a better understanding Stakeholders' perception of the indicators, an Information System must be defined. It is important to identify their information systems requirements. These requirements were defined after Stakeholders' opinion on how sustainability indicators were needed to be presented. Specifically, information requirements are listed as follows:

- The information about indicators must be presented in a website that any member of the communities or outsiders can gain access.
- The information must present historical analysis capabilities within a flexible system.
- Indicators must be analyzed in aggregated levels of information.
- The system must be updated periodically, thus maintaining previous information in order to make strategic analysis of indicators.
- The quality of the information must be taken into consideration.
- Over time, government regulations and the state of the art in related topics can improve the way sustainability must be measured. For this to succeed, the system must be flexible enough to manage future changes in the formulation of the indicators.
- The Decision Support System must be capable to deploy efficiently new indicators, from the repositories to the end-user interfaces.

Based on previous requirements, a Decision Support System (DSS) to gather all sustainability indicators. To model the DSS, a multidimensional information structure was proposed, where a Data Mart architecture and an Online Analytical Processing tool were sufficient and appropriate enough to satisfy Stakeholders' requirements.

4. Building the information system for salmon industry

The Sustainability Indicators Systems for the Salmon Industry (ISIS[8]) was developed as a DSS to gather the sustainability indicators where any user could have access. To model the DSS, a multidimensional information structure was proposed, where a Data Mart architecture was an appropriate solution to this problem. The indicators defined must present a high variability rate over time on every aggregated level, in spite of a progressive increase of data volume.

Previously stated requirements can be achieved combining web-based technology and Data Warehouse architecture. Hypothetically, we state that through the usage of these technologies, the low cost time of accessing the information, together with public access to the information requirements can in fact improve the availability and usage of the information throughout the whole spectrum of stakeholders.

The Data Warehousing architecture is flexible and robust for the storage of historical indicators, thus being able to incorporate the evolution of data (sustainability indicators) through time. Is important to note that these information systems are assumed to be deployed using the right hardware and software implementation.

The web technology, mainly using the three-layer architecture, firstly enables an easy way to store the data, secondly manages the process and business rules, and thirdly manages the graphical user's interface. One of the main advantages here is that it minimizes the changes on any layer of data sources. The business processing or else the graphical user interfaces can be independently modified, as all layers are networked with very specific information flowing between sources.

This paper proposes to maintain the sustainability indicators by storing them in a database-like repository, and the business rules as an independent program that consults the data sources. Fig. 2 shows the method used for acquiring, maintaining and managing knowledge about sustainability indicators. On the left, there are three repositories: Economical indicators data sources (EIDS), Social indicators data sources (SIDS) and Environmental indicators data sources (ENIDS). Previously stated data sources are gathered in a Data Mart repository, where a pre-processing stage is implemented in a Data Staging Area.

4.1. Data Warehouse development and management

Data Warehousing development is an iterative process that begins with basic information requirements from users. The initial modeling, the prototype presentation and validation adjusts and the information requirements update until systems' users are satisfied with the IS. As the purpose is geared to provide information to end-users, its development must be considered. The identified information needs and the iterative process is driven by the end-users and their IS perception, which is most likely to be updated during the development of the IS.

Data Marts are known for their simplicity and low cost development of short term presentable results from the IS. For this project we defined this kind of technological architecture. The implementation was to acquire a Proof Concept Data Mart, where the complexity, the low risk on development, and immediate results were divulged to Stakeholders and end-users were better defined which indicated improvements on the IS requirements.

Firstly, the technological architecture definition requires the correct implementation of the Data Mart. Hardware, software, networking components and security elements were defined in this stage. Then, after implementing the Data Mart, the conceptual design of the IS was carried out taking into consideration the following:

- The quality of data was verified, the data cleaned together with the Extraction, Transformation and Loading (ETL) of algorithms are defined. This stage is fundamental to the system, as several

[8] ISIS: Spanish term for Sustainability Indicators for the Salmon Industry.

data sources were considered to have built the sustainability indicators.
- Data repositories for the Data Staging area and the Data Mart were then modeled from the initial extraction procedure to the data staging, and also for the final representation of the indicators respectively.
- Metadata is populated and the data was initially loaded into the Data Staging area.
- Cleaning and processing algorithms are applied to update the data stored in the Data Mart repository.
- Once the Data Mart repository is built and populated, the data update process design is determined to prepare for future ETL process automatization including the backing up of policies and the restoring of procedures.

Open Source technologies were used in the *proof-concept* Data Mart and the end-user tools to analyse sustainability indicators. The Online Analytical Processing (OLAP) tool was implemented using the JasperServer open source project (JasperServer, 2010), together with a MySQL database (MySQL, 2010).

Finally, after the system was developed and validated by Stakeholders, a final technological transfer was considered. An authority organism for the aquaculture and the fishing industry was selected to host the sustainability indicators information system.

4.2. Data warehousing technological architecture

The IS architecture proposed for the development, fully encapsulates the DW architecture, enabling the mixture management of the project to develop the web-site and build a Data Warehousing project with traditional milestones for the project management.

As illustrated in Fig. 2, the proposed IS is determined by the three tier architecture which are defined by the data, application and presentation tier. Here, the data tier represents the Data Warehousing repositories for sustainability indicators and the website user information management repositories. The application tier is defined by all the business rules implemented in OLAP engines and the web-site's user management procedures (Rizzi et al., 2006). Finally the presentation tier is determined by the end-user OLAP tools and the complete project web-site, consisting of relevant information about the sustainability indicators definition. It is important to notice that the business rules for the Extraction, Transformation and Loading of data from transactional data sources is presented in the data tier. This multi-tier architecture has been previously proposed by Velásquez and Palade (2007a) and successfully implemented in web-based information systems for knowledge extraction.

4.3. Sustainability indicators repository

The Sustainability Indicators Repository stores the information gathered and processed by the extraction and transformation algorithms. Fig. 3 shows a generic model of sustainability indicators repository, which is based on the Data Mart architecture. This repository is implemented using the Data mart architecture in a Constellation model (Kimball and Ross, 2002). For each sustainability concept, whether it is environmental, social or economical, there is a list of indicators. These indicators are separated in fact tables that shares common dimensions and sustainability concepts.

Repository presented in Fig. 3 is the general presentation of the Constellation model. In the current model used for the IS, there are 14 fact tables and shared 10 dimensions. Among all dimensions, the only one that is shared by all fact tables is the "Time" dimension. This model has proven to be able to manage all previously stated IS requirements.

4.4. User interface and stakeholders requirements

As an information system can be considered successful when users physically use the system, the user interface developed for the proposed DSS was of great importance. Among the information system requirement defined by Stakeholders, the OLAP operations were one of the most critical. The information about indicators was gathered in Plone (2010) a Content Management System where relevant information about indicators and the OLAP system was deployed in JasperServer (2010).

The usage of the information system was validated with two usability surveys, where end-users evaluated the system within a series of usage questions. The usability results shows that in the first version of the system, several improvements were to be made in order to achieve the end-users standards. For this reason, the navigation side-bar for indicators was introduced, as well as dynamic charts and a general explanation of what any indicator stands for. The final survey results shown that the end-users were

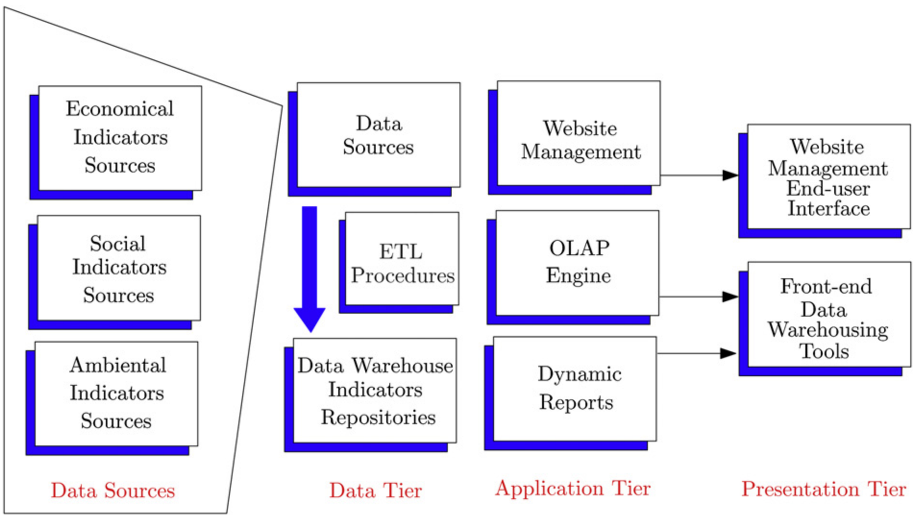

Fig. 2. Three tier architecture representing the Data Warehousing and Web-site environments.

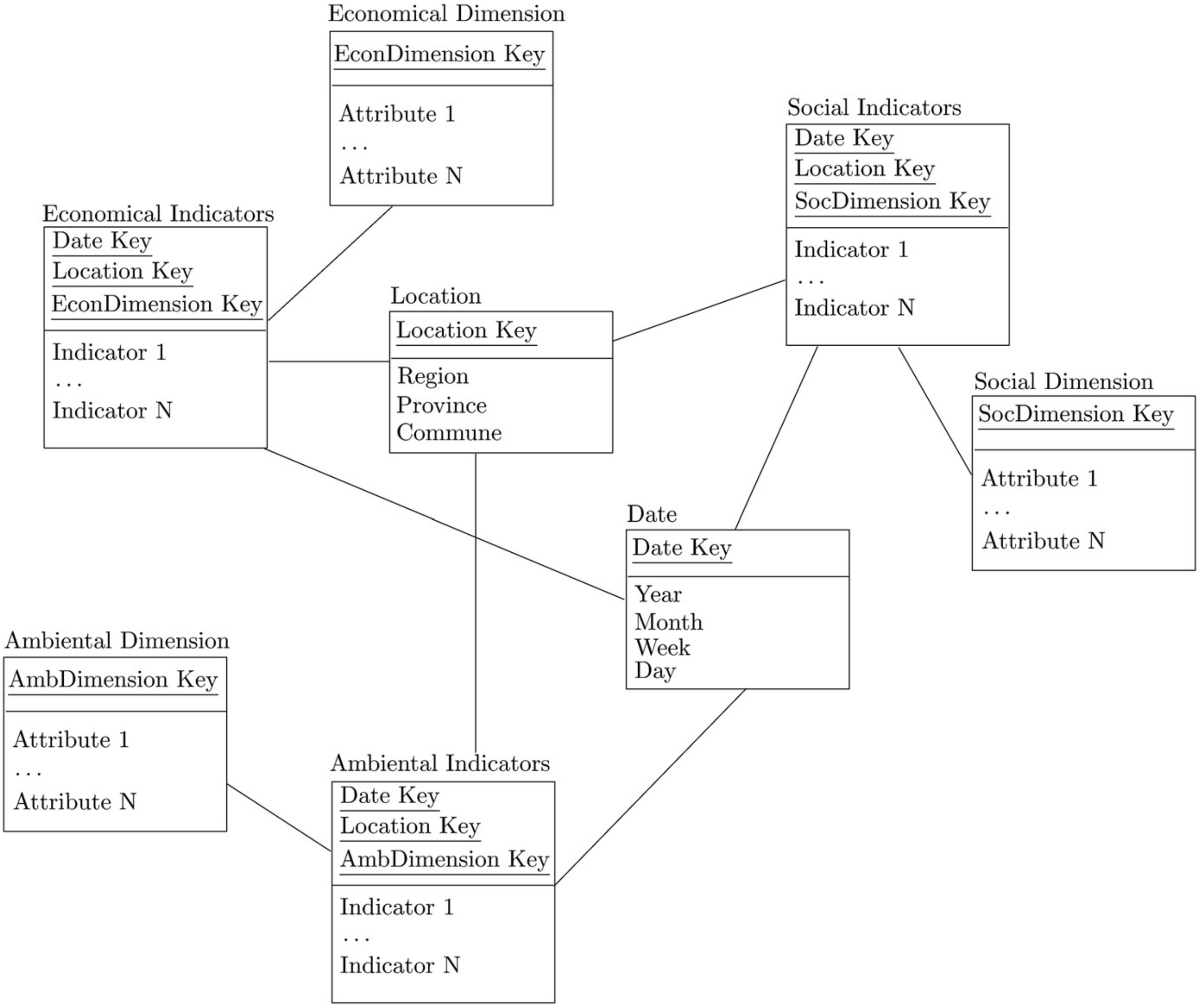

Fig. 3. Constellation diagram model used for the indicators repository.

generally satisfied with the final version of the system, and no further changes were considered.

5. Conclusion

A general methodology to obtain sustainability indicators is presented and successfully applied to the Chilean salmon industry, where a flexible Decision Support System was developed using multidimensional modeling. A Data Warehousing architecture, particularly a Data Mart, a simplified, reduced, and specialized version of a Data Warehouse was proposed. Sustainability indicators were obtained through an iterative process using Stakeholders' perception of sustainability, experts' opinions, and previous work on sustainability information systems.

The Data Mart introduced several properties that are to be considered as the required technological architecture for the Decision Support System. One important factor to take into consideration is that the fast results and quick validation of Stakeholders or end-users was a key component for the success of the project. The project management for a Data Mart was compatible with the iterative process of sustainability indicators defined by Stakeholders. This is due to the fact that the system were developed, new indicators could be added or eliminated without additional development costs.

The multidimensional modeling of the Data Mart showed that it was capable of supporting new indicators that were successfully defined due to the special properties of fact tables that share several dimensions in a constellation design. Here, some of the new indicators were mapped onto a fact table depending on whether there were a set of shared dimensions and whether it was a social, economical or environmental indicator. This suited the features of sustainability indicators, and furthermore was a key component to promoting the DSS development, as it is highly probable that some of the sustainability indicators might slowly alter their multidimensional nature through time. End-user requirements for the sustainability indicators system were satisfied using traditional multidimensional OLAP operators.

In terms of analytical tools, the proposed DSS deals with all requirements stated by stakeholders and end-users in general. As the success of the information system is directly related to the usage of the system, end-users' analytical requirements were considered as a priority in the development and deployment of the DSS.

The perception of relevant actors from the salmon industry, or Stakeholders, was analyzed. Then, several discussions were carried out with community groups related to the salmon industry that aimed to standardize the groups notions of sustainability. It was crucial that this process lent itself to the correct definition of sustainability indicators. Stakeholders and a group of local and international experts was gathered to share experience and opinions that determined a preliminary list of indicators. Finally, the preliminary list of economic, social and environmental indicators was revised, from which the availability of sources and data was analyzed case by case. To obtain the final list of indicators, some filters were taken into consideration. The main filters considered pointed to the existence of the data source, and drew ones awareness to issues around the access to data, the quality and the digitalization capability of the data.

The final information system presented could have been of great importance for the effective control of the ISA virus, that critically affected the Chilean Salmon industry during the development of this research. The information gathered within the Stakeholders pointed out that with the usage of the right sustainability information system, many issues regarding the ISA virus could have been minimized.

To conclude, there is a DSS architecture and a methodology to determine Stakeholders and sustainability indicators that can be recommended for the contribution of sustainability, but not only for the salmon industry. By using the presented methodology, the awareness of sustainability in any industry can incorporate a better understanding of how the society, the economy and the environment are related, and how they evolve in proximity with one other through the usage of sustainability indicators. A strategic Decision Support System consisting of these indicators needs to be presented to Stakeholders in order to obtain a long-term Eco-efficiency to improve our usage of resources, so the subsequent generations could learn about the evolution of the sustainability indicators in order to improve their own usage of natural resources.

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