Enhancing strategy design and planning in public utilities through "dynamic" balanced scorecards: insights from a project in a city water company

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Abstract

In the last decade there has been an increasing effort to provide public utilities managers with planning and control tools, to take into account not only operational but also strategic issues. Among them are customer satisfaction, internal business process efficiency, business image, and bargaining power against other counterparts (e.g., the municipal administration). Often, however, such an effort has been oriented to generate a large volume of data, focused only on financial indicators and on a static view of the relevant system. This paper shows how the use of "dynamic" balanced scorecards can significantly improve the planning process in a strategic learning perspective. Insights from a project in a municipal water company are analysed and discussed.

Syst. Dyn. Rev. **24**, 175–213, (2008)

Coping with dynamic complexity in public utility management through new planning and control systems

In order to improve efficiency in public utility management, in the past decade governments have been undertaking privatization policies. Higher competition and decentralized decision making were expected to result in greater accountability and performance. However, this transformation of the public utility sector has significantly increased managerial complexity. In fact, since local governments tend to maintain control over company equity, they have to run competitive firms by simultaneously playing the roles of owner, ruler, budget designer and social service provider (Horváth and Gábor, 2001).

In particular, because of the regulations required by the social relevance of public utility services, management is subject to several limitations in the use of policy levers. Dynamic complexity of management tasks has also been dramatically increased by the fast technological evolution and the rising concern about environmental and social issues, which have led to rapid changes in regulations.

Another important complexity factor in such a peculiar environment is related to the wide range of stakeholders who play an active role in the legislative and policy-making process. Regulatory agencies, local government associations, representatives of the professional and business community, and

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Received April 2007; Accepted January 2008

System Dynamics Review Vol. 24, No. 2, (Summer 2008): 175–213
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/sdr.395

expertise in assisting public organizations in designing their own policies and outlining consistent programmes to link strategy and implementation. In particular, strategic planning and control, goal-setting, performance measurement and reporting, as well as system dynamics modelling aimed at supporting strategic planning and control have been used both in research and consulting projects (mainly with the Sicilian Government Administration, and with the Municipality of Palermo). He is the author of several publications.

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consumer protection agencies may take part in the formulation of company policies. This increases the effort management has to make in order to balance the different interests that public utilities have to satisfy.

Therefore, to pursue competitiveness and financial stability and, at the same time, to meet different social needs, public utility managers need appropriate strategy design and planning tools that allow them to take into consideration both stakeholders' expectations and the sustainability of company policies.

To this end, traditional planning and control systems exclusively based on financial indicators are insufficient to communicate to shareholders and other stakeholders the value creation process the management wants to foster through the designed strategy (Neely *et al.*, 2003, p. 129). As a matter of fact, if not accompanied by other indicators, financial measures do not provide an accurate picture of the company's direction and, hence, can lead the management to seek short-term goals rather than long-term growth.

For instance, managers may be reluctant to invest in intangible assets in order to avoid reductions of current financial results (Norreklit, 2000, p. 66). In the long term, however, such a policy may imply lower efficiency and effectiveness, as well as customers' and other stakeholders' dissatisfaction.

Another drawback in the use of only financial indicators is associated with the difficulty in measuring non-monetary goals. This may hinder communication of companies' strategy to managers and employees at different levels of the organization hierarchy, and generate incongruence between strategic decisions and daily operations.

For the above reasons, there has been a growing effort to provide public utilities with tools aimed at supporting decision makers in planning and control, by taking into account not only financial indicators but also intangible variables (e.g., customer satisfaction, business image and bargaining power against other counterparts) and their dynamic interdependencies. Therefore, more relevant, selective and systemic reporting systems are needed.

Although the availability of such information might appear to be an easy task today, in the information age planning and control tools are often characterized by access to a huge volume of analytic data, which actually overloads the decision-making process (Todd and Palmer, 2001, p. 1). A proper planning and control system design implies, on the contrary, a focus on the key indicators of companies' efficiency and effectiveness, and on their dynamic interdependencies.

This article aims to offer empirical evidence of the greater benefits public utility managements can obtain by integrating the balanced scorecard (BSC) approach to performance measurement with system dynamics (SD) methodology in the analysis of cause-and-effect relationships between key variables of the company system. Such analysis will also attempt to show how combining BSC with SD models may offer specific insights into a number of wider fields of current scholarly conversation. Among them, primarily:

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- the resource-based view of the firm (Warren, 2002, pp. 15–29; Morecroft, 2007, pp. 59–85);
- model validation (Forrester and Senge, 1980; Barlas, 1996; Balderstone, 1999);
- technology acceptance (Davis and Venkatesh, 1996; Wang and Liu, 2005; Kanungo, 2003).

With this purpose in mind, a case study based on a research project with a city water company will be analysed and discussed.

Formulating public utilities' strategy through balanced scorecards

Since its introduction in 1992 (Kaplan and Norton, 1992), the use of BSC has spread widely among private and public companies, as a performance measurement system enabling managers to translate strategy into a correlated set of performance indicators from several business perspectives.

Unlike traditional performance measurement systems, the BSC considers both financial and non-financial performance, through a balanced set of lead and lag indicators so that companies can simultaneously evaluate the results achieved and their progress towards the implementation of a strategy in core business areas.

According to Kaplan and Norton, the BSC enables companies to measure financial results while simultaneously monitoring progress in building capabilities and acquiring the intangible assets they need for future growth (Kaplan and Norton, 1996b). Therefore, they explicitly recognize the BSC as a strategic tool for the control of both lag and lead indicators (Norton, 2001, p. 4).

The increasing popularity of the BSC is due to the support it gives to management in avoiding disconnections between strategy and implementation.

The BSC also stresses the idea of cause-and-effect relationships between measures in order to avoid the possibility that performance improvement in one area may be at the expense of performance in other areas. Kaplan and Norton, indeed, explicitly stated the systemic interrelationships within and between four key perspectives (financial, customer, internal processes, learning and growth), incorporating both lead and lag indicators, which impact on organizational performance. The alignment of the strategy throughout the company, in fact, is the result of the causal linkages between the objectives in all four perspectives (Martinsons *et al.*, 1999, p. 83).

More precisely, this approach is aimed at offering a systematic and comprehensive road map for organizations to follow in translating their mission statements into a coherent set of performance measures. These measures are not only intended to control company performances, but also to articulate and communicate the organization's strategy (Mooraj *et al.*, 1999, p. 490) and to help align actions from different levels of management for the achievement of a common goal (Malina and Selto, 2001, p. 54).

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Furthermore, the BSC enhances managers' understanding of strategies and stimulates the creation of a common company vision. The BSC, indeed, forces managers to elicit, compare and discuss their implicit assumptions and beliefs and to articulate them for the formulation of company's strategy (Malmi, 2001, pp. 210–214). Managers, in fact, are requested to contribute to the implementation of the BSC by identifying a set of objectives that are connected by causal relationships that are consistent with the vision and mission of the company.

However, it has been remarked how—in order to encourage openness and frankness of expression (Wisniewski and Dickson, 2001, p. 1065)—the support of an external facilitator leading the BSC construction process is often necessary. This would also allow the elicitation of managers' mental models.

The BSC has been adopted by various public utilities in different sectors, such as electricity provision (Kaplan and Norton, 1996b; Morisawa, 2002; Niven, 1999), telecommunication (Zingales and Hokerts, 2002) and transportation (Olve *et al.*, 2004). Also in the water management sector there are a few applications of BSCs. For example, the City of Eugene's Wastewater Division (a section of the Oregon Public Works Department responsible for the wastewater treatment service) and the Charleston CPW (a municipal corporation that provides both water and wastewater treatment services to the City of Charleston) developed a BSC to include in their performance measurement system other management areas that were not covered by their environmental management system, such as the financial perspective.[1] The BSC approach helped these companies to set objectives and performance measures that, while not important from an environmental point of view, were relevant from the corporate management perspective. As a result, these companies could utilize this holistic approach to balance the costs of new capital investments with the benefits of meeting environmental goals. Another example of application of the BSC to the water management sector is provided by Metrowater (Auckland City's water and wastewater utility), which used the BSC as a platform to measure the company's progress towards company objectives.[2] This approach helped Metrowater to implement a comprehensive benchmarking against other utility companies in order to identify opportunities to become more efficient. Finally, the Water Utility Enterprise (Santa Clara Valley Water District)[3] and the Sydney Water Corporation[4] (a water utility that runs drinking water and wastewater treatment services in the Sydney region) used the BSC approach to design their business plan, including key objectives and targets from different managerial perspectives for all division levels.

In particular, the adoption of such a strategic performance measurement system supports public utilities in (Bracegirdle, 2003, p. 4):

- providing both public accountability to local governments and citizens and internal accountability between the different levels of management;
- improving performance in terms of quality, quantity and costs of the services through better strategic planning;

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- determining expenditure, by allocating budget resources to measurable results that reflect agreed priorities.

The translation of the company strategy into a causal map of financial and non-financial indicators required by the BSC makes this approach particularly valuable for public utilities to align the often conflicting objectives of the relevant number of shareholders and other stakeholders involved in public utilities' policy-making processes. In fact, more than other private companies, public utilities need a high level of consensus from local authorities and citizens before implementing a designed strategy. In this regard, the causal tree including the objectives in all the business perspectives is a powerful communication tool for the management to clarify to different key actors how the company intends to achieve higher performance. A clear statement of company strategy through the BSC map may enhance cohesion among shareholders and other stakeholders and help management to explain to them how some of their goals may conflict with each other and with the company's overall strategy.[5]

Moreover, BSC can help public utilities in simultaneously evaluating the achieved results and their progress towards long-term value creation. For instance, most of the service contracts between local governments and public utilities contain a detailed description of the required service quality and do not allow public utility managers to set tariffs.[6] Consequently, the search for higher financial results usually leads to cost-cutting activity. However, cost reduction may affect long-term investment, such as personnel training, equipment maintenance and information system implementation. Such a policy can improve short-term financial indicators at the expense of long-term performance drivers. Therefore, the balance between lag and lead indicators required by the BSC approach can help public utilities to avoid those cost-cutting activities that hinder future growth.

The BSC is also a valid tool to foster a cultural change in the management of the company at different levels of the organization (Braam *et al.*, 2002, p. 17). Despite the privatization process, most of the public utilities are still experiencing relevant difficulties in shifting their culture from state company to private company. Aligning the reward system to the objectives included in the BSC helps employees to address their efforts towards company success, generating greater commitment and consensus around business strategies.

"Dynamic" balanced scorecards to enhance strategy design and planning

In spite of its widely recognized advantages, the BSC presents some conceptual and structural shortcomings. Linard *et al.* (2002, p. 1) assert that BSC fails in translating companies' strategy into a coherent set of measures and objectives because of the lack of a rigorous methodology for selecting the metrics

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and for establishing the relationship between the metrics and the corporate strategy.

It has been also remarked (Sloper *et al.*, 1999, p. 1) that the BSC is a static approach. The links among the parameters inside the four perspectives do not express their dynamic relationships. As a result, in the analysis of the strategy delays between actions and their effects on the system are ignored.

Moreover, these relationships follow an open-loop logic and, hence, they do not consider feedbacks (Linard and Dvorsky, 2001, pp. 3–4). Although Norton and Kaplan stress the importance of feedback relationships between scorecard variables to describe the trajectory of the strategy, the cause-and-effect chain is always conceived as a *bottom-up* causality, which totally ignores feedbacks, where only the variables in the lower perspectives affect the variables in the upper perspectives.

In addition, the BSC approach does not help policy makers in understanding whether a given performance measure ought to be considered as an outcome (or *lag*) indicator or as a driver (or *lead*) indicator. Furthermore, it does not support organizations in understanding how to affect performance drivers, which in turn will influence the outcome measures.

Kaplan and Norton also warn managers that the BSC, though correctly implemented in terms of balance between lead and lag indicators and causal relationships, does not point out whether (Kaplan and Norton, 1996b):

- the vision is wrong;
- the model is not a valid description of the strategy;
- the performance indicators are incorrect.

In particular, the BSC approach does not support in understanding:

- how strategic asset accumulation and depletion processes triggered by the use of different policy levers affect performance drivers;
- how performance drivers affect outcome indicators;
- how outcomes will affect strategic asset accumulation and depletion processes.

In order to cope with the above-mentioned flaws, "the BSC can be captured in a system dynamics model that provides a comprehensive, quantified model of a business's creation value process" (Kaplan and Norton, 1996a, p. 67). Therefore, "dynamic systems simulation would be the ultimate expression of an organization's strategy and the perfect foundation for a Balanced Scorecard" (Norton, 2000, pp. 14–15).[7]

The SD approach enables the creation of interactive learning environments (ILEs). The use of such simulators supported by a learning facilitator can help managers understand the dynamic relationships between performance variables included in the BSC. In fact, the elicitation of the causal chain between performance drivers and outcomes may enhance managers' learning process

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and, thus, their ability to comprehend how different strategies might affect organization performance over time. In particular, ILEs based on SD models offer managers a virtual world where they can test their hypotheses and evaluate the possible effects of their strategies without bearing the costs and risks of experimenting with them in the real world (Sterman, 2000, p. 35; Richmond, 2001, p. 14; Morecroft and Sterman, 1994).

However, SD models allow validating only factual judgements, i.e., how managers perceive the system operates (Ritchie-Dunham, 2002, pp. 7–10). In order also to validate value judgements, i.e., what managers want the system to achieve, elicitation of mental models in SD group model building is needed (Hammond *et al.*, 1977; Simon, 1997).

We believe that public utilities can successfully apply the SD approach in the formulation of BSCs for:

- assessing company strategy and vision and their coherences in order to detect potential side effects;
- validating the causal map representing company's strategy against reality;
- filtering performance measures in order to select the smallest number of proper indicators of a company's progress towards strategic goals;
- simulating the effect of performance drivers on financial and non-financial outcomes in order to detect the most opportune policy levers;
- implementing what-if analysis to learn about potential future scenarios and threats.

The use of simulation results increases the communication power of the BSC, further supporting public utilities in clarifying the strategy to different counterparts, enhancing social actors' cohesion and balancing conflicting goals coherently with company growth sustainability. Therefore, the combination of BSC and SD models offers public utility managers a proper strategy design and planning tool to pursue both stakeholders' expectations and the sustainability of company policies.

In order to demonstrate the above assumptions, the following sections of this article will show results from an applied research project, which was focused on the creation and use of an SD model supporting a BSC to foster strategic decisions in a public utility company.

Building a "dynamic" BSC in a city water company: a case study

In the previous section benefits related to the adoption of the "dynamic" balanced scorecard (DBSC) were demonstrated. In order to provide empirical evidence of this concept, an analysis of a DBSC application to a municipal water company (Amap) will be developed in the following sections of this article.

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Amap has been running the municipal water provisioning and distribution service for the area of Palermo since 1950. With the intent of fostering public utility efficiency and effectiveness, in the last decade the Italian government implemented a set of reforms. In particular, in 1994 the management of water resources was reorganized in order to avoid waste and to improve the quality of the service provided to citizens–customers.

Government regulations have been merging the sewer and wastewater treatment management with city water provisioning and distribution management, making all the municipal water service companies handle the so-called integrated water cycle. In addition to this business re-engineering process, the regulator introduced competition for the management of the water service that led to a privatization process, which implied the transformation of all the Italian city water companies from public agencies to joint stock companies. In this new scenario, the regulator assigns the water management service for a specific area to the company with the highest effectiveness, in terms of service quality, and with the best efficiency, in terms of service costs.

With the aim of increasing Amap's competitiveness and to foster a deep cultural change, a research project was started by the authors with Amap.[8] An ILE based on an SD model was built in order to support performance measurement and improvement, according to the BSC approach.

By a deep involvement of Amap's key managers in the modelling process, the research team identified the main performance variables and policy levers, and the system structure describing their causal relationships. The project lasted 12 months, four of which were devoted to qualitative modelling; six months were needed to build the SD simulation model embodying a BSC, and the remaining two months were allocated to apply the DBSC to the company's planning and control processes.

In the following sections we will describe the DBSC model-building process carried out at Amap, and the related benefits on the strategic decision-making process.

Using the BSC chart to start a strategic planning process

The changes in the water provision service rules described above made Amap perceive the need to improve its performance in terms of both financial outcomes and quality of the service supplied to customers. However, it was lacking a shared vision of the company's mission as well as a coherent strategy for its accomplishment. Furthermore, communication between the different levels of the organization was almost absent and just a few of the middle managers and line workers were aware of the company's overall performance.

In particular, Amap presented some of the dysfunctional behaviours reported by Linard (1996, pp. 4–5):

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- negative operating incomes were balanced by public contributions, whose volume was dependent upon the political power of the Board of Directors;
- managers focused on specific tasks and most of them were unaware of how their activity was contributing to company's results;
- the management information system was characterized by the production of a number of reports that were mainly responding to bureaucratic routines, instead of strategic information needs;
- evaluation programs were perceived as a "*weapon*", by which managers could be blamed for bad performance, rather than as a tool to enhance managers' efficiency.

In order to create a shared vision of business strategy, to stimulate communication among managers, and to avoid strategy disconnections among the different levels of the organization, the project team proposed to the Board of Directors the implementation of a DBSC. The Board organized a number of meetings with top and middle managers with the purpose of designing an information system that could be used to monitor business unit performance. The final result was a long list of activity indicators, included in a 40-page report. Neither a common strategy was designed nor were causal linkages connecting these activity measures.

With the aim of translating the produced list of indicators into a BSC map, the project team conducted several interviews with Amap's key managers. These interviews fostered the elicitation of their tacit knowledge about business processes and causal relationships between policy levers, performance drivers (lead indicators), financial and qualitative outcomes (lag indicators). This allowed the project team to significantly reduce the long list of indicators included in the initial report. A bounded range of relevant and selective performance measures was framed through a BSC chart, according to the traditional bottom-up approach (Figure 1).

As the reader may notice, unlike Kaplan and Norton's proposed scheme, the "learning and growth" perspective is at the top of Amap's BSC diagram. Indeed, the *company image index* can be considered as an indicator of Amap's capacity to learn how to combine conflicting shareholders, customers and local community's objectives in order to create synergies that are necessary for the company's growth.

More specifically, Figure 1 shows how Amap's proposed strategy mainly consisted in improving the company image by higher efficiency and effectiveness in the provision of water in order to increase its competitiveness for the management of the integrated water service in the area of Palermo. According to managers' mental models, such a goal could have been achieved by increasing the availability of water sources and, hence, the volume of water distributed to households. In this regard, Amap was able to satisfy only 60% of the standard consumption *per capita* stated in the client service charter. Therefore, increasing the volume of water distributed to households was perceived

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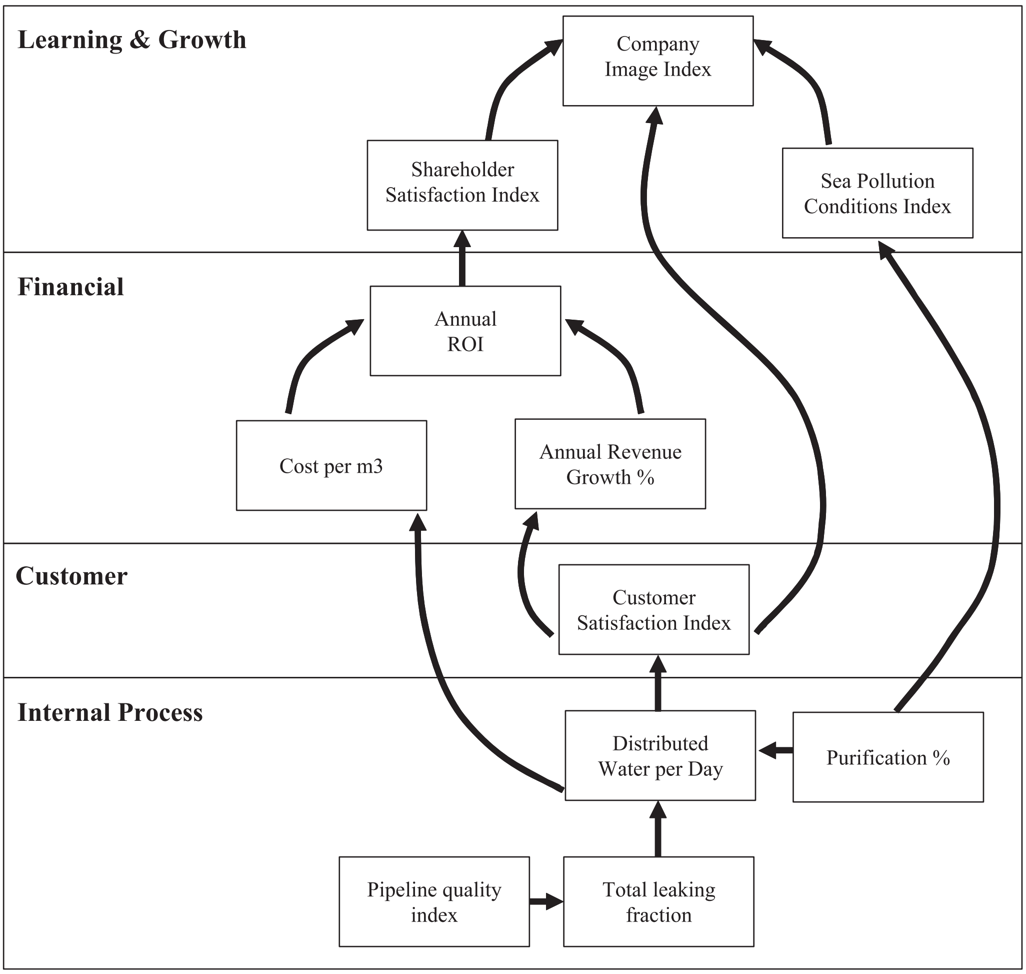

Fig. 1. Amap's traditional performance measures BSC chart

as a high-priority goal. An increase in the volume of distributed water would have improved both customer satisfaction and financial results, through higher revenues and lower unit costs (since the overhead costs would have been spread on a larger volume of supplied water). The improvement in customer satisfaction, by a better service, and of shareholder satisfaction, by higher financial results, would have led to an enhanced company image.

For this reason, a great deal of effort was devoted to the search for new sources and to the acquisition of the right to exploit a larger percentage of the existing sources (all the lakes are shared among Amap and other water management companies or hydroelectric companies). With this purpose in mind, Amap evaluated the opportunity to invest in the construction of a purification

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plant for the treatment of wastewater. Basically, in the purification plant, the sewage collected is subjected to a specific purification process so that it can be used for agricultural purposes. Because of this investment, Amap could have distributed the purified wastewater to farmers, thereby increasing the volume of drinkable water distributed to households.

Furthermore, according to the company's management, purification of the wastewater would have improved sea pollution conditions. The planned investment, therefore, would have given evidence of the company's commitment to the cleanness of the seashore and, hence, to the improvement of the life quality of the community served. This, in turn, would have further enhanced the company's image and, hence, its advantage over other potential competitors in the management of integrated water services in the area of Palermo.

However, a relevant problem Amap also had to face was the high leaking rate of its pipelines. In fact, it was necessary to improve the quality of pipelines by replacing the quite old existing distribution network. The obsolescence of Amap's pipelines caused a high rate of leakage, which significantly reduced the volume of water distributed to households. This phenomenon, on the one hand, contributed to customer dissatisfaction, and on the other hand further worsened the efficiency of the distribution process and, hence, company financial results.

The above framework was very supportive to Amap's managers in order to articulate their own views about strategies to undertake. However, as already discussed, the traditional BSC approach is not sufficient to figure out either the strategic resources to build, or the processes through which they will interact to affect company performance.

In Amap, for example, it was clear that the purification policy would have led to a greater volume of distributed water and to lower sea pollution and, hence, to higher customer and community satisfaction and, eventually, company image. Nevertheless, the management was still evaluating the adoption of this policy because of the high investment and production costs, which would have had a negative impact on company financial results, reducing shareholders' satisfaction and, consequently, the image of the company as an efficient administrator of the municipal water service.

Therefore, the BSC chart portrayed in Figure 1 only suggested what policy levers the management should use, and not how and when the company should act on these policy levers to balance the conflicting objectives of both shareholders and customers and community.[9]

Turning the BSC chart into a causal loop diagram

Since the bottom-up causality depicted in Figure 1 does not take into consideration feedback loops between and within the four perspectives, the project

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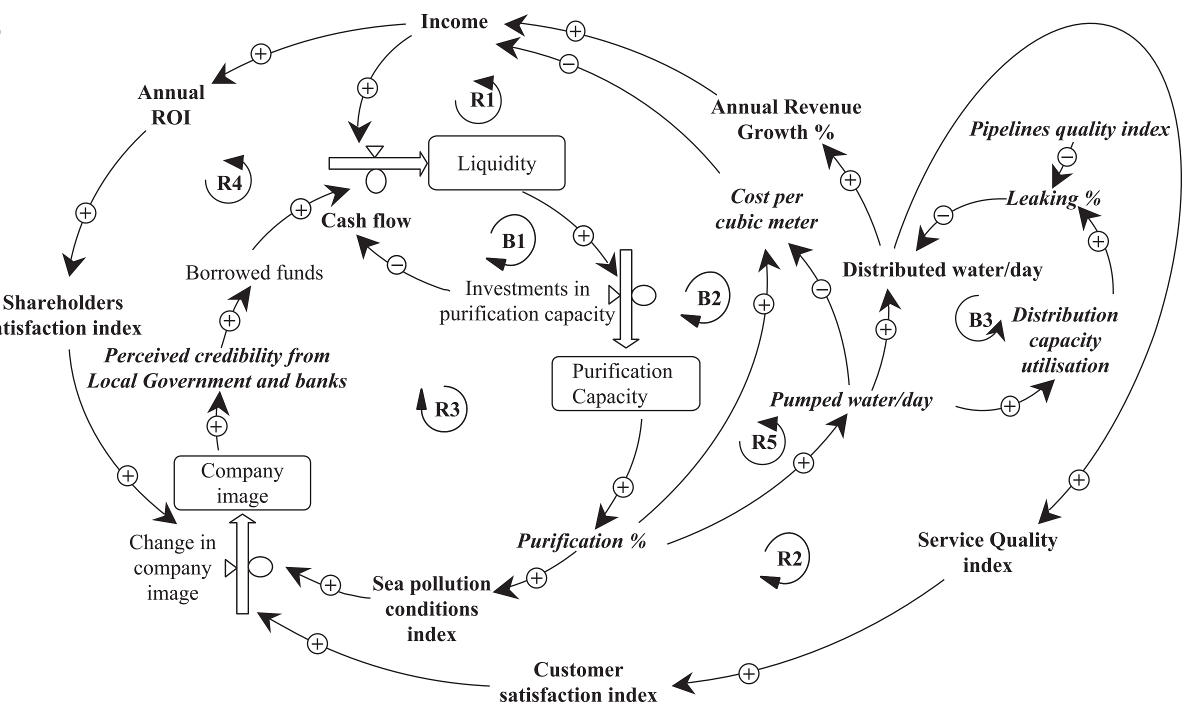
(a)



team moved to a more detailed causal loop analysis, which evolved to the diagrams depicted in Figure 2. The causal loop diagrams in Figure 2 describe the main cause-and-effect relationships between the key variables of the business system. They show a number of reinforcing and balancing loops, whose dominance over time, according to different scenarios, is likely to produce different effects in both company lead and lag indicators.

Such feedback loops depict the effects of policies affecting the dynamics of strategic resources, such as purification capacity, corporate image, liquidity, accounts receivable and workers. According to the dynamic resource-based view of the firm (Morecroft, 2007, pp. 59–85; Warren, 2002, pp. 15–29), strategic assets are modelled as stocks (or levels) of available tangible or intangible factors in a given time. Their dynamics depend on the value of corresponding inflows and outflows. Such flows are modelled as 'valves' on which decision makers can act through their policies, in order to influence the dynamics of each strategic asset, and therefore—through them—business performance drivers and outcome indicators.

In particular, Figure 2(a) shows a number of feedback loops associated with purification capacity policies, while Figure 2(b) depicts feedback loops related to distribution capacity and accounts receivable collection policies.

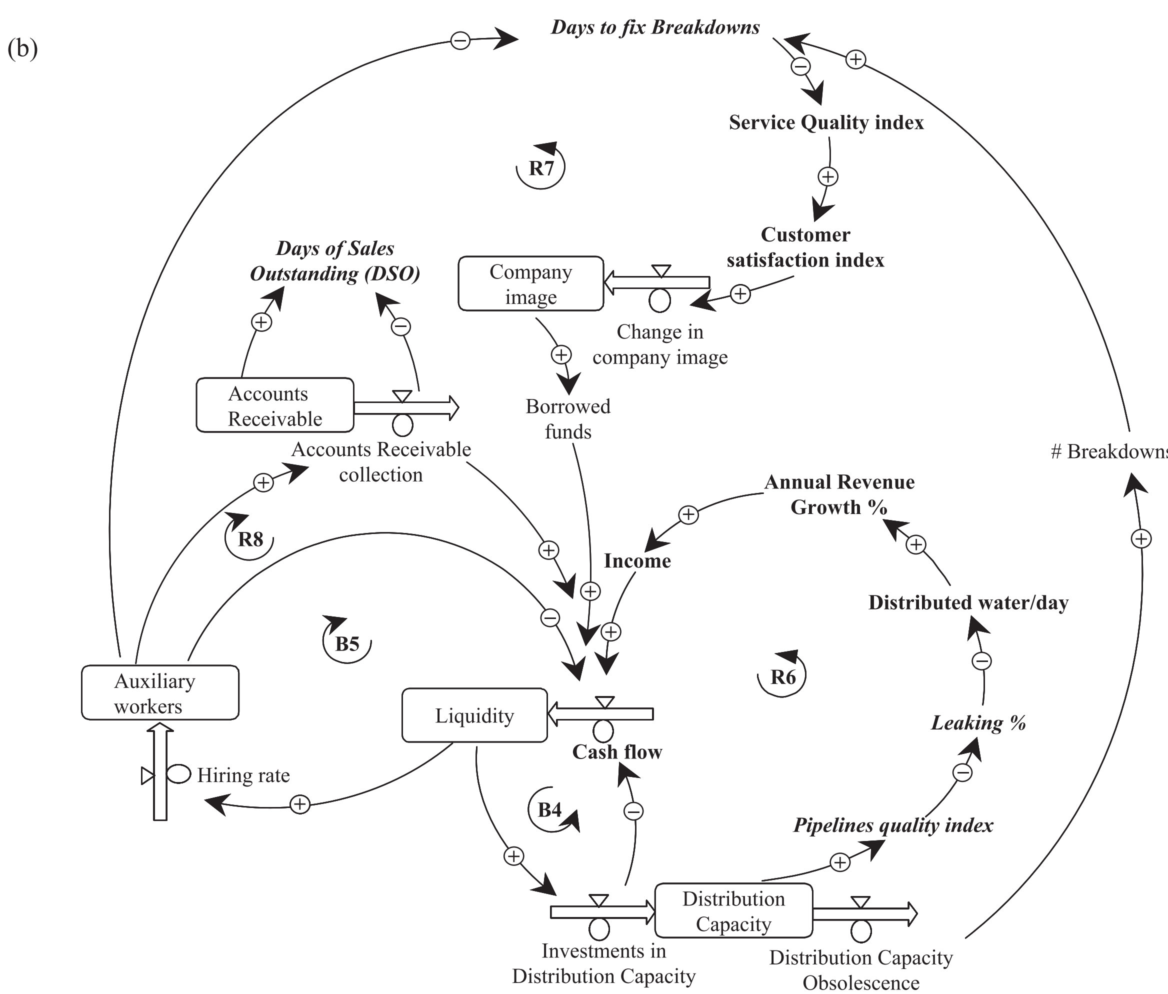


Fig. 2. (a) Purification capacity policies. (b) Distribution capacity and accounts receivable collection policy

According to loop R1 in Figure 2(a), investments in purification capacity would enable the company to pump (performance driver) and distribute more water to households (outcome indicator). This would result in higher revenues (outcome indicator). An increase in the revenue growth percentage would lead to a higher income and—other conditions being equal—cash flows (outcome indicators). A higher cash flow will lead to a rise in available financial resources to reinvest in the acquisition of more purification capacity.

Furthermore, the more water distributed to households, the higher the service quality and customer satisfaction[10] (outcome indicators) will be. This will improve company image,[11] which in turn will increase the perceived credibility of the firm in the financial market and towards the local government (performance driver). A higher company credibility will allow business decision makers to better negotiate funds to borrow from different stakeholders, and therefore to increase cash flows to reinvest in purification capacity (loop R2). Another effect of a higher purification percentage (performance driver) associated to a purification investment policy is an improvement in the sea pollution conditions index,[12] leading to higher company image, a better credibility towards funders and higher cash flows available for more investment in purification capacity, implying a further increase in the water purification percentage (loop R3).

A higher volume of water distributed to households also implies—other things being equal—an increase in income and in the annual ROI, resulting in an improvement in shareholder satisfaction.[13] A higher shareholder satisfaction would increase company image and, again, the funds the firm can attain to finance its purification policy (loop R4).

According to the loop R5, the larger the volume of distributed water, the bigger the basis upon which to spread overhead costs and, all other things being equal, the lower the water unit cost will be. A reduction in the cost per cubic metre of distributed water should increase the company's income and liquidity to reinvest for the purification policy.

Figure 2(a) also shows a number of balancing loops, whose dominance could undermine business growth and, if not promptly detected and properly counteracted, evolve into crisis.

Loop B1 shows how higher investment in purification capacity implies a reduction in total company cash flows. This provides a possible limit to growth in the investment policy, if its returns from higher income and borrowed funds are not able to provide higher cash flows.

Loop B2 describes how the increase in the wastewater purification percentage would determine a rise in the cost per cubic metre of water (because of the additional variable costs of the purification process). A boost in water unit costs would negatively affect income. This could cause a reduction in the financial resources and, hence, would prevent the company from acquiring new purification capacity.

Furthermore, as shown in loop B3, if the volume of pumped water grows faster than the distribution capacity, an increase in distribution capacity utilization would occur and, consequently, the leaking rate would be higher, negatively impacting on the quantity of water distributed to customers. In fact, the more water Amap pumps through the pipelines, the higher is the pressure, and hence the greater is the volume of leakage through the holes, joins, etc. As a consequence, the cost per cubic metre of water would be higher, reducing the financial results that could be invested in purification capacity acquisition.

As referred to in the last section of the paper, the high leakage rate was a major problem experienced by the firm. Figure 3 shows how leakages had been

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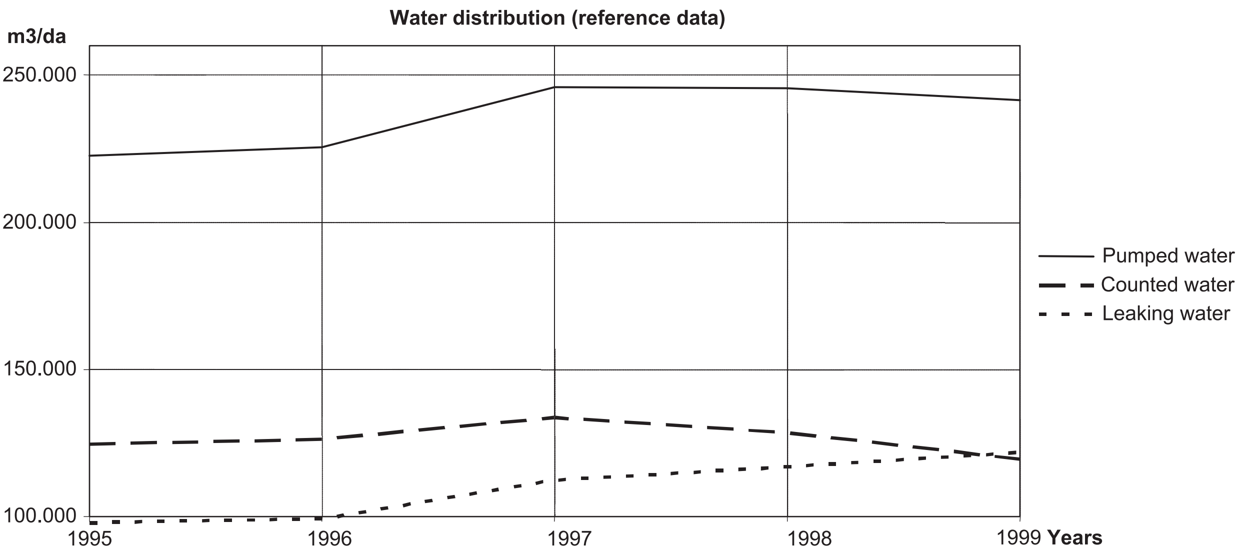

Fig. 3. Amap's water distribution reference behaviour

increasing from 1998 to 1999, though in this period the measured volume of water had been decreasing. The main reason for such an unintended phenomenon was identified, through the modelling sessions, as the bad pipeline quality, due to the high average age of the Amap's water conduits: the older a pipeline, the greater the leakage will be.

While discussing the above problem in group model-building sessions (Vennix, 1996), during which the causal maps reported in Figure 2 were sketched and agreed with participants in order to create shared mental models (Mathieu *et al.*, 2000), the company's management remarked that, in order to reduce the leaking rate and increase the volume of distributed water, Amap had been undertaking a policy aimed at offsetting distribution capacity obsolescence outflows (see Figure 2(b)). Such a policy would have increased the pipeline quality,[14] which would have implied a lower leakage rate. This would have led to higher distributed water, increased revenues, income and—other things being equal—cash flows and liquidity to sustain further investment in distribution capacity (loop R6 in Figure 2(b)).

Another reinforcing loop (R7) associated to distribution capacity investment policy is related to the allocation of more auxiliary workers to the repair of breakdowns in the distribution capacity system, caused by its obsolescence rate. As shown in Figure 2(b), the higher the number of auxiliary workers allocated to repairing tasks, the shorter the time to fix breakdowns will be. This will increase service and customer satisfaction, leading to higher company image and capability to negotiate funds to boost cash flows. Higher liquidity

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resulting from increased cash flows could be reinvested in hiring more auxiliary workers. A larger auxiliary worker staff will allow the firm to further reduce the time to fix breakdowns.

However, a trade-off problem may concern the allocation of auxiliary workers here. In fact, they could also alternatively be employed to suspend the service to those clients who delay the payment of their bills. As the company had already experienced, after the suspension of the water provision a large percentage of tardy customers are more inclined to be punctual in paying their debts, which on one side decreases the average days of sales outstanding (performance driver), and—on another side—has a positive influence on cash flows and liquidity available for further investment (loop R8).

Similarly, in relation to investment in purification capacity, higher distribution capacity investments and auxiliary worker hiring rate imply a reduction in total company cash flow. This provides a possible limit to growth in the above investment policies, if their returns from higher income and borrowed funds are not able to provide higher cash flows.

The analysis of the above feedback loops with company managers in a group model-building context allowed the project team to obtain more insights compared to the traditional bottom-up approach of the BSC. Other lead and lag indicators were identified and then monitored—see the final BSC chart in Figure 4. Such a BSC chart was linked to the SD model that was built, based on the causal loop analysis illustrated above. Simulation results from the SD model were also depicted through the above chart.

The robustness of the proposed policies summarized here was then evaluated through an SD simulation model, based on a BSC, which was developed as a second step of the project, focused on the feedback loop analysis previously depicted in Figure 2.

Outlining the "dynamic" BSC

As remarked, the adoption of a dynamic resource-based view of the firm allowed us to identify as stocks the main strategic resources for the achievement of the company objectives over time, referred to as the four different BSC perspectives (Figure 4). The dynamics of the system provided by such resources impacts on the net of lead indicators, which in turn affects the outcome measures that were originally depicted in Figure 1.

As previously underlined, among relevant strategic resources were identified:

- *capacity*, in terms of both volume of water and wastewater that can be processed, and of pipeline network quality;
- *auxiliary workers*, who may be involved in maintenance and service suspension tasks;
- *financial resources*, in terms of company liquidity, local government funds and bank debts Amap can invest to implement the designed strategies.

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Perspectives	Objectives	Measures	Targets	Current Situation	Initiatives
Learning & Growth	Improve Company Image through a higher satisfaction of shareholders and local government, and through a better life quality of the served community.	Company Image Index	NAN	NAN	– Keep a satisfying flow of dividends to shareholders. – Invest in wastewater refinement plants.
		Shareholder Satisfaction Index	NAN	NAN	
		Service Quality Index	NAN	NAN	
		Sea Pollution Conditions Index	NAN	NAN	
Financial	Improve profitability through cost reduction and revenue growth.	DSO	NAN	NAN	– Intensify controls on tardy customers. – Intensify exploitation of internal financial opportunities (dividends and credits collection).
		Tardy Customers %	NAN	NAN	
		Annual ROI	NAN	NAN	
		Total Cost per m3	NAN	NAN	
		Annual Revenue Growth %	NAN	NAN	
Customer	– Increase customer punctuality. – Increase customer satisfaction through a better service.	Customer Satisfaction Index	NAN	NAN	– Intensify controls on service quality features.
		Demand Fulfilment %	NAN	NAN	
		Service Reduction %	NAN	NAN	
		Days to Fix Breakdowns	NAN	NAN	
Internal Process	– Improve suspension process efficacy. – Increase water provision through refinement. – Reduce leakage. – Reduction of pipeline breakdowns through better auxiliary workers allocation and wear conditions	Days to Suspend Service	NAN	NAN	– Shorten pipeline replacement period. – Invest in wastewater refinement plants. – Allocate effectively auxiliary human resources.
		Leaking %	NAN	NAN	
		Pumped Water per Day	NAN	NAN	
		Purification %	NAN	NAN	
		Pipeline Repair %	NAN	NAN	
		Pipeline Quality Index	NAN	NAN	

Fig. 4. DBSC charts to input objectives (targets) and simulated results (current situation)

Corresponding inflows and outflows were then identified in more detail than in the qualitative analysis, to detect and simulate the process through which such resources are subject to change over time, either according to adopted policies or due to external factors (e.g., obsolescence, human resource attrition).

With this purpose in mind, material delays (i.e., the time to replace pipelines, fix breakdowns, etc.) and information delays (i.e., the time to detect tardy customers and to start the credit collection process) affecting inflows and outflows were calculated based on past data, where it existed, or on managers' estimation, when formal data were not available.

As shown in Figure 5, the stock-and-flow model was developed around four sectors:[15]

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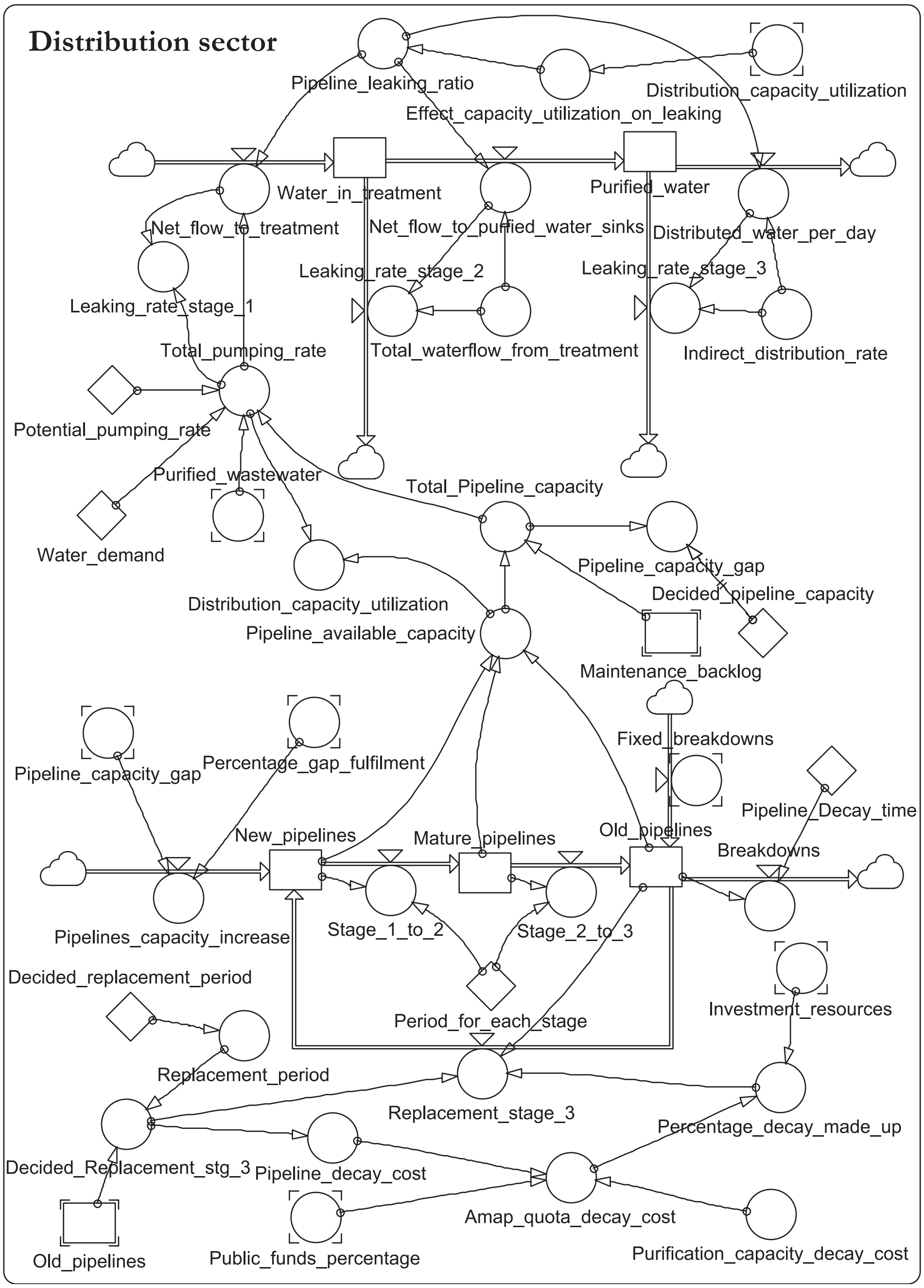
Fig. 5. The four sectors of Amap's simulation model



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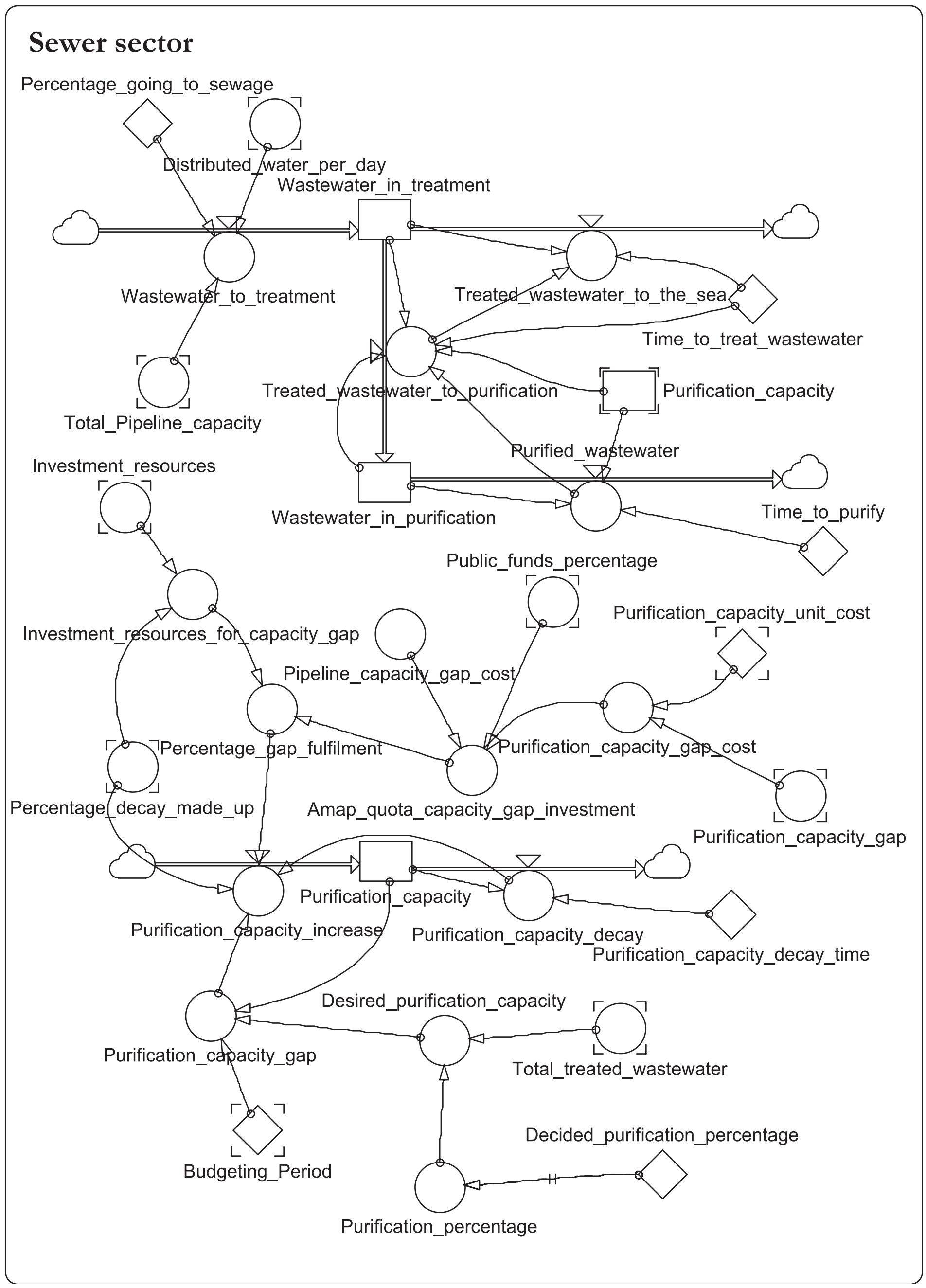

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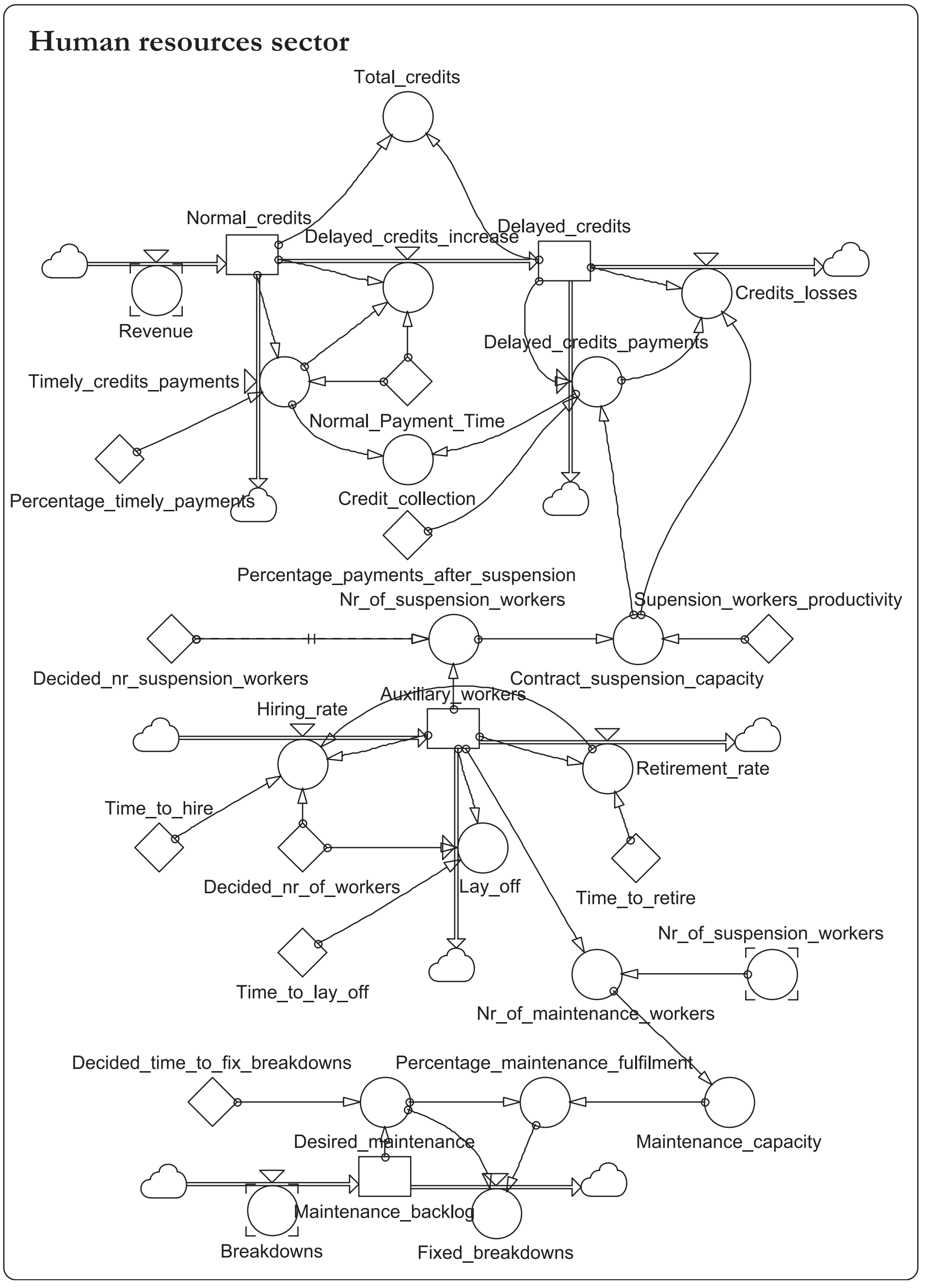

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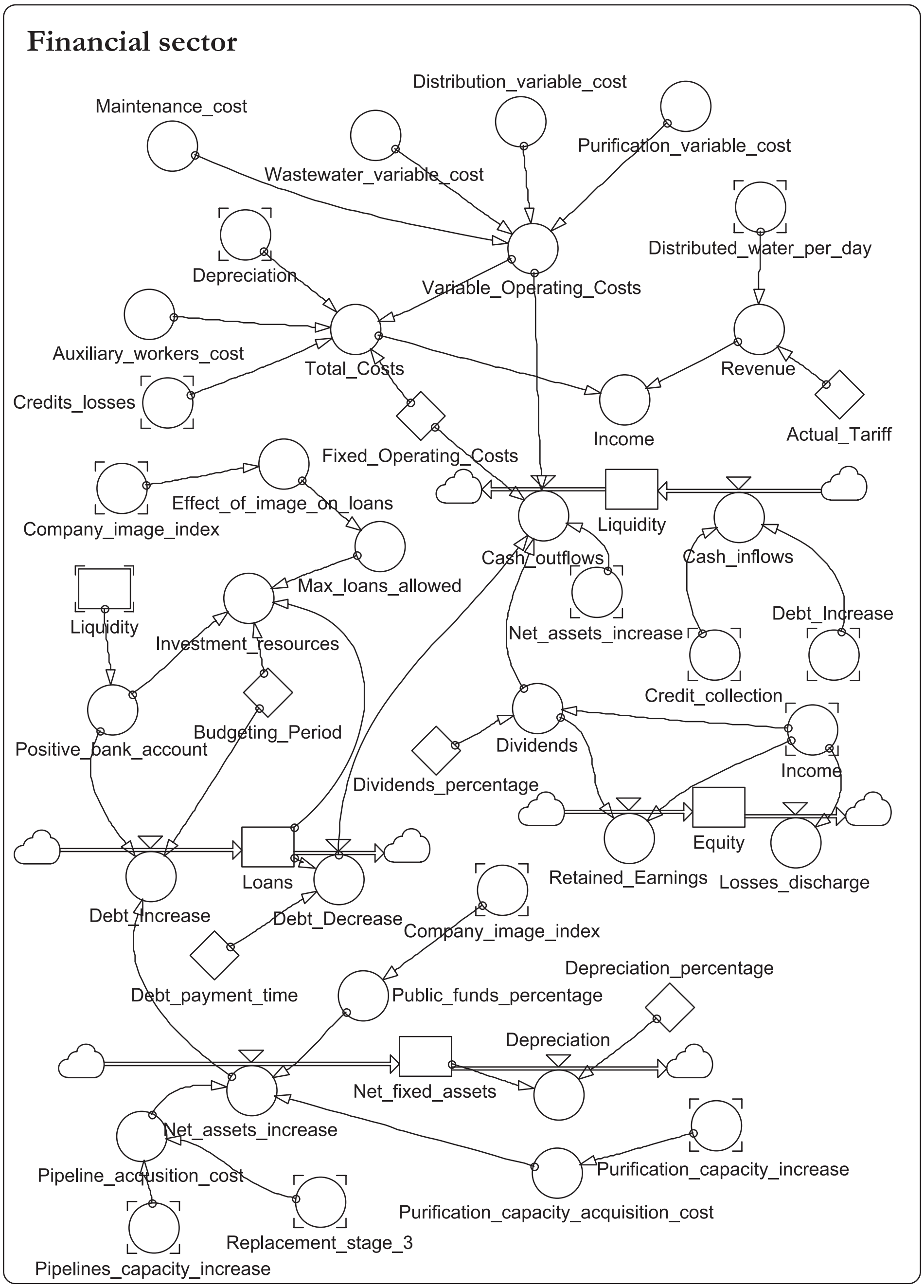

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(a) the *distribution sector*, which analyses the adduction and distribution process of the water and the aging process of pipelines;
(b) the *sewer sector*, which refers to the collection and purification of wastewater;
(c) the *human resources sector*, which describes the allocation of the auxiliary workers between the maintenance activity and the activity of service suspension to tardy clients;
(d) the *financial sector*, where the dynamics of the net income, cash flows and financial resources are analysed.

Different causal linkages exist between the four sectors. In the financial sector, resources available for investments in distribution and sewer capacity are calculated, based on liquidity and the possibility of borrowing funds. Firstly the model proportionally allocates such resources to replace old distribution pipelines and decayed purification capacity (see the "Percentage_decay_made_up" variable). Then, the residual resources are proportionally allocated to increase both pipeline and purification capacities (see the "Percentage_gap_fulfilment" variable).

In turn, the renewal of pipelines and increase in purification capacity produce costs and debts, which affect the company income, loans and liquidity. Moreover, the "breakdowns" flow in the distribution sector determines the maintenance backlog that the auxiliary workers have to reduce. The maintenance activity generates an increase in the fixed pipeline capacity, which enhances the distribution capacity, and costs, which reduce the company income.

An ILE, embodying both the SD and the accounting models portraying balance sheets, was built on the basis of the above-mentioned sectors, in order to facilitate use of the simulator. Through the ILE the management can easily:

- input the initial model parameters according to company data;
- insert the company objectives in the different perspectives through a BSC chart;
- experiment with different policies under various scenarios through a control panel including the modelled policy levers and a scenario-setting board;
- evaluate company strategy through several tables and graphs, reporting the simulated impact of the interrelated set of policies according to the selected performance indicators.

Figure 6 shows the ILE control panel through which managers can make decisions and have access to other sections of the simulator to appreciate the effects of their policies over a four-year period.

In order to foster perception of the usefulness and ease of use of the DBSC—and therefore to stimulate technology acceptance (Davis and Venkatesh, 1996)—key managers were involved in several workshops to test the SD model.

In particular, Amap's water distribution reference behaviour with regard to the period from 1994 to 1999 was replicated. Furthermore, a second set of

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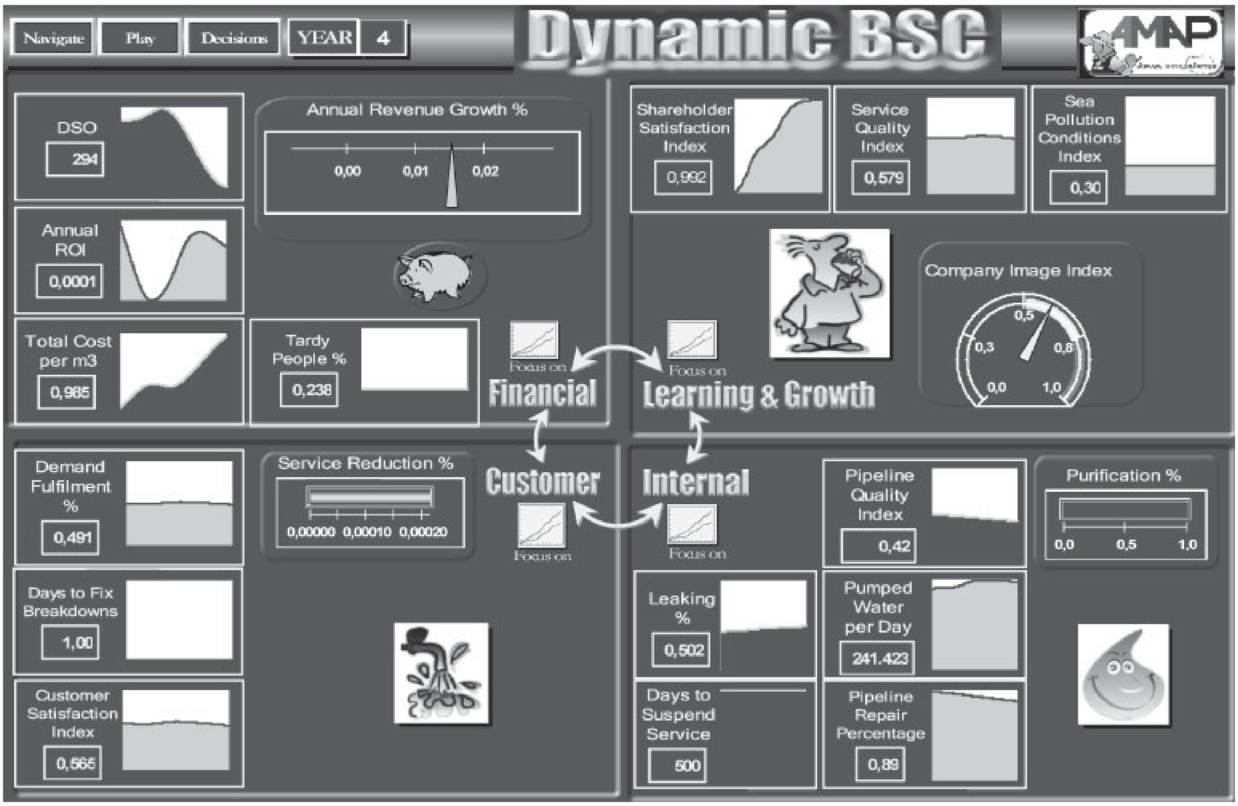

Fig. 6. DBSC control panel for testing strategy

interviews was conducted to test whether the model structure and policy implications were adequately representing real management processes (Barlas, 1996; Forrester and Senge, 1980).

Management participation also led to the design of a computer interface that could support decision makers in dealing with the complexity of the company system (Howie *et al.*, 2000).

Scenario analysis

Once enough confidence was built in the SD model, the ILE was used for what-if analysis and strategy testing under different potential scenarios. The differences between expected and actual results of simulations stimulated a deep learning process. An example of simulated scenarios is described in Table 1 and shown in Figure 7. Two alternative scenarios are depicted:

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Table 1. Decision parameters setting for scenario analysis

Scenarios	Decision parameters (simulation time = 0)				
	Dividends percentage	Decided replacement period	Decided no. of suspension workers	Decided no. of workers	Decided purification percentage
Refinement policy	90%	90 years	10	130	100%
Combined purification and replacement policy	90%	35 years	10	130	100%

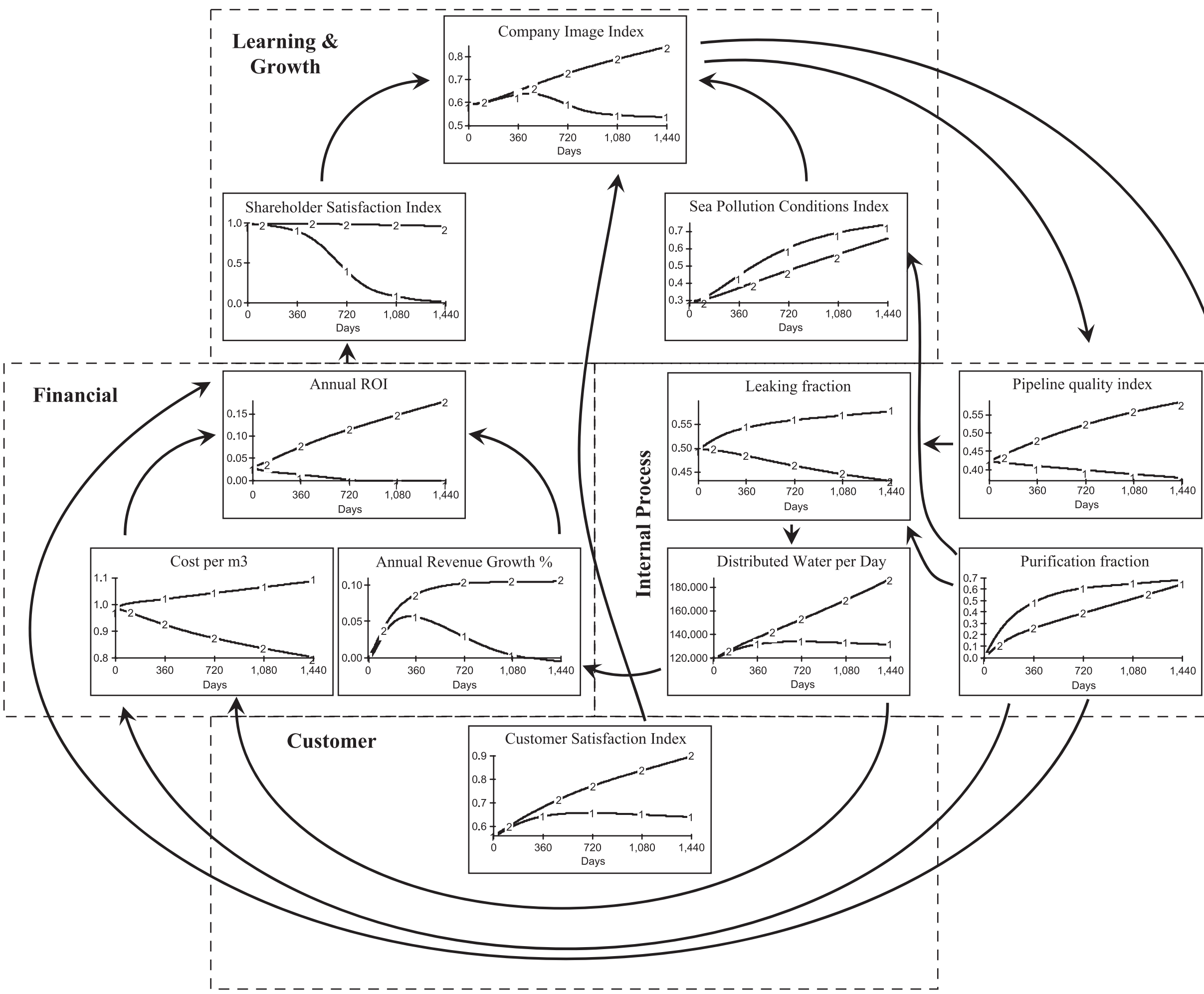

Fig. 7. Amap's strategy simulation results included in the DBSC causal loop diagram

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(a) purification policy (line 1);
(b) combined purification and replacement policy (line 2), which implies a shorter pipeline replacement time.

Table 1 shows the main decision parameters and corresponding values for policy analysis. As the reader may notice, while the first scenario implies an investment in purification capacity to recycle 100 percent of collected wastewater (see both the "Decided_purification_percentage" input and the "Wastewater_to_treatment" flow variables in the sewer sector of Figure 5), the second scenario supports such investment in purification capacity with a reduction in the pipeline replacement period from 90 to 35 years (see the "Decided_replacement_period" input variable in the distribution sector of Figure 5), aimed at increasing the pipeline quality index (see feedback loop "B3" in Figure 2(a) and "R6" in Figure 2(b)).

Figure 7 allows decision makers to understand the circular relationships between performance indicators pertaining to the four traditional BSC perspectives. In fact, it matches the static BSC view, previously reported in Figure 1, with the feedback perspective of the system structure underlying experienced results, which was analysed in Figure 2.

In particular, if we refer to the first scenario, from the behaviour reported in Figure 7 we can detect short- and long-term effects on company image related to a strong purification policy. Short-term effects can be referred to loop R3 previously shown in Figure 2 (purification fraction → sea pollution conditions index → company image index → local government's funds → purification fraction).

In the long run, however, the effects produced by the above reinforcing loop are counterbalanced by loop B2, which is followed by loop R6, previously shown in Figure 2. In fact, provided that scenario 1 only implies an investment of available funds in the improvement of purification infrastructures, although a higher purification fraction could increase the volume of pumped water per day, a lack of investment in pipeline renewal gradually reduces its quality index, which drops the volume of distributed water. This determines a reduction in the customer satisfaction index, which also decreases revenues, ROI and liquidity. A lower liquidity makes further investments in the purification infrastructure more difficult, which weakens loop R1 and makes loop B2 dominant.

Furthermore, a lower ROI undermines shareholders' satisfaction in the long run, and reduces company image. A lower company image is also likely to make it more difficult to raise funds for investment in the replacement of pipelines, which further reduces its quality index and increases the leakage fraction. This reinforces the death spiral synthesized in loop R6.

The above simulation results are quite counterintuitive. Although the purification policy gives a better outcome in terms of sea pollution conditions, it is less profitable if compared to the combined policy. In fact, even if a combined purification and replacement policy is likely to generate lower results in terms

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of improvements in sea pollution conditions, it can give rise to a higher company image. This is because company image depends on both environmental and financial performance.

Pursuing a sustainable strategy in the long run, in terms of strong company image, is a major prerequisite for Amap to gain stakeholders' confidence and be competitive in water service management.

Including in the DBSC the company image as a synthetic performance indicator has significantly supported Amap's management in designing strategies that could take into account different stakeholders' expectations. In fact, company image is an index combining a number of factors ranging from financial results to sea pollution conditions and quality of service.

Conclusions

This article has tried to demonstrate the usefulness of an approach aimed at matching the SD methodology with the BSC framework. The development of ILEs portraying DBSCs can successfully enable managers to better understand cause-and-effect relationships between variables pertaining to the four traditional BSC perspectives.

In particular, the article has advocated the opportunity to adopt such an approach to strategy design and planning in public utilities, where a deep cultural change and major performance improvement are strongly required.

The case study here described has demonstrated some benefits obtained by an Italian city water company in using a DBSC to enhance strategy design and planning. In the Amap case, strategic mapping and simulation through the SD methodology has proved to successfully enhance managers learning and capability to identify causal relationships between policy levers and company performance, and better communicate strategy with stakeholders.

The model here discussed also provides further research insights into policies aimed at handling the demand profile and the "seasonality" factor, on both the supply and demand sides. In an environment where rainfall is low and suffering a long-term diminution, the issue of demand management suggests another significant problem to focus on, particularly concerning household use (including sewerage) and agriculture.[16]

Notes

1. Continual improvement in utility management: a framework for integration. http://www.charlestonwater.com/documents/continual_improvement_in_untility_management.pdf.
2. Metrowater's Water Asset Management Plan 2004. Document available from the authors on request.

3. Water Utility Enterprise's Annual Business Plan Fiscal Year 2005. http://www.valleywater.org/media/pdf/FY05%20WUE%20ABP%20Final.pdf.
4. Continual improvement in utility management: a framework for integration. http://www.charlestonwater.com/documents/continual_improvement_in_untility_management.pdf.
5. In order to pursue such cohesion a strategic planning process, framed according to a BSC map, must be based on the elicitation of key actors' mental models (Doyle and Ford, 1998; Mathieu *et al.*, 2000). This is not an easy task, since different stakeholders may not take an active part in the planning process. Therefore, embodying their own perceptions and expectations into a strategic planning model requires a higher effort by managers to perceive their own views. This could be done through workshops and group model-building sessions (Vennix, 1996) led by a learning facilitator.
6. For example, in Italy the public water service is ruled by Act n. 36/1994, which prescribes a mathematical formula to calculate the tariffs based on several parameters, such as volume of distributed water and average service cost.
7. The advantages related to the use of SD modelling to implement the BSC approach have been also emphasized by other authors (Akkermans and van Oorschot, 2005; Ritchie-Dunham, 2001).
8. The project was a further development of the research conducted by the second author of this paper as part of his Masters Program in System Dynamics at the University of Bergen. The authors wish to thank Prof. Pål I. Davidsen for his valuable contribution to the project start-up.
9. This issue provides an interesting example of how a BSC applied to a public utility company may support managers in designing appropriate strategies to combine both stakeholders' expectations and sustainable company policies. In the following sections it will be shown how this issue can be even better explored through the combination of BSC and SD models into a DBSC.
10. Customer satisfaction was modelled as an index, i.e., as a function of the different aspects of the service provided to clients, such as the volume of distributed water to customers, the average percentage of water service reduction, and the average response time to fix pipeline breakdowns.
11. Company image was modelled as an index, i.e., as a function of the different aspects that express the overall performance of the company, such as shareholder satisfaction, water pollution conditions, and customer satisfaction concerning the quality of the service provided.
12. The sea pollution conditions were modelled as an index, i.e., as a function of a ratio between treated and purified wastewater (numerator) and total collected wastewater (denominator). Such an index represents another important outcome indicator portrayed in the model.
13. Shareholders' satisfaction was modelled as an index, i.e., as a function of a ratio between the difference between the actual and desired dividends

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(numerator) and the desired dividends (denominator). Such an index represents another important outcome indicator portrayed in the model.

14. Pipeline quality was modelled as an index, i.e. as the complement to one of the weighted wear levels related to differently aged pipelines. Each wear level could have a range value between zero and 1. Such an index represents another important outcome indicator portrayed in the model.
15. Figure 5 shows an excerpt of the stock-and-flow structure underlying the SD model developed by the project team. Since the original SD model contains 42 stocks and 922 array elements and scalars, a simplified version of the model has been built by the authors in order to produce a shorter model equation list, which is provided in the Appendix of this article. The full model equations list is available on request from the authors.
16. The authors are grateful to an anonymous referee for suggesting such insightful thought, which implies further challenges for improving the mental models of AMAP's managers.

Appendix: equations of the simplified version of AMAP'S DBSC

Distribution sector

Stocks and flows

- Mature_pipelines(t) = Mature_pipelines(t-dt) + (Stage_1_to_2 - Stage_2_to_3)*dt INIT = 97388.6 (m^3/day)

Inflows:
Stage_1_to_2 = New_pipelines/Period_for_each_stage
Outflows:
Stage_2_to_3 = Mature_pipelines/Period_for_each_stage

- New_pipelines(t) = New_pipelines(t-dt) + (Replacement_stage_3 + Pipelines_capacity_increase - Stage_1_to_2)*dt INIT = 78592.17 (m^3/day)

Inflows:
Replacement_stage_3 = Decided_Replacement_stg_3*Percentage_decay_made_up
Pipelines_capacity_increase = Pipeline_capacity_gap*Percentage_gap_fulfilment
Outflows:
Stage_1_to_2 = New_pipelines/Period_for_each_stage

- Old_pipelines(t) = Old_pipelines(t-dt) + (Fixed_breakdowns + Stage_2_to_3 - Replacement_stage_3- Breakdowns)*dt INIT = 123973.31 (m^3/day)

Inflows:
Fixed_breakdowns = Desired_maintenance*Percentage_maintenance_fulfilment
Stage_2_to_3 = Mature_pipelines/Period_for_each_stage

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Outflows:
Replacement_stage_3 = Decided_Replacement_stg_3*Percentage_decay_made_up
Breakdowns = Old_pipelines/Pipeline_Decay_time

- Purified_water(t) = Purified_water(t-dt) + (Net_flow_to_purfied_water_sinks - Leaking_rate_stage_3- Distributed_water_per_day)*dt INIT = 187084.63 (m^3)

Inflows:
Net_flow_to_purified_water_sinks = Total_waterflow_from_treatment*(1-Pipeline_leaking_ratio)
Outflows:
Leaking_rate_stage_3 = Indirect_distribution_rate-Distributed_water_per_day
Distributed_water_per_day = Indirect_distribution_rate*(1-Pipeline_leaking_ratio)

- Water_in_treatment(t) = Water_in_treatment(t-dt) + (Net_flow_to_treatment - Net_flow_to_purfied_water_sinks - Leaking_rate_stage_2)*dt INIT = 205972.63 (m^3)

Inflows:
Net_flow_to_treatment = Total_pumping_rate*(1-Pipeline_leaking_ratio)
Outflows:
Net_flow_to_purified_water_sinks = Total_waterflow_from_treatment*(1-Pipeline_leaking_ratio)
Leaking_rate_stage_2 = Total_waterflow_from_treatment-Net_flow_to_purfied_water_sinks

Auxiliaries and parameters

- Amap_quota_decay_cost = (Pipeline_decay_cost+Purification_capacity_decay_cost) * (1 - Public_funds_percentage)
- Decided_Replacement_stg_3 = IF (Replacement_period<31 * 360, Old_pipelines/360, Old_pipelines/(Replacement_period-30*360))
- Distribution_capacity_utilization = Total_pumping_rate/Pipeline_available_capacity

- Effect_capacity_utilization_on_leaking = GRAPHCURVE (Distribution_capacity_utilization, 0,0.1,[0,0.31,0.52,0.68,0.81,0.89,0.95,0.98,0.99,0.995,1"Min:0;Max:2;Zoom"])
- Indirect_distribution_rate = MIN (Purified_water / Time_in_purified_water_sinks, Total_Pipeline_capacity)
- Leaking_rate_stage_1 = Total_pumping_rate-Net_flow_to_treatment
- Percentage_decay_made_up = IF (Investment_resources > Amap_quota_decay_cost, 1, Investment_resources DIVZ1 Amap_quota_decay_cost)
- Pipeline_available_capacity = New_pipelines+Mature_pipelines+Old_pipelines

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- Pipeline_capacity_gap = MAX (0, DELAYMTR (Decided_pipeline_capacity, 90, 3, Decided_pipeline_capacity)-Total_Pipeline_capacity)/Budgeting_Period
- Pipeline_decay_cost = Decided_Replacement_stg_3*Pipeline_unit_cost
- Pipeline_leaking_ratio = Reference_pipeline_leaking_ratio_per_stage * Effect_capacity_utilization_on_leaking
- Purification_capacity_decay_cost = Purification_capacity_decay * Purification_capacity_unit_cost
- Replacement_period = MAX(Decided_replacement_period*360, 31*360)
- Total_Pipeline_capacity = Pipeline_available_capacity+Maintenance_backlog
- Total_pumping_rate = MIN (Total_Pipeline_capacity, Potential_pumping_rate + Purified_wastewater,Water_demand/(1-Reference_pipeline_leaking_ratio_per_stage*3))
- Total_waterflow_from_treatment = MIN (Total_Pipeline_capacity, Water_in_treatment/Time_of_treatment)
- Decided_pipeline_capacity = 300000 (m^3/day)
- Decided_replacement_period = 90 (years)
- Period_for_each_stage = 360*15 (days)
- Pipeline_Decay_time = (50-45)*360 (days)
- Potential_pumping_rate = 241423.33 (m^3/day)
- Reference_pipeline_leaking_ratio_per_stage = 0.15 (dimensionless)
- Time_in_purified_water_sinks = 1 (days)
- Time_of_treatment = 1 (days)
- Water_demand = 245000 (m^3/day)

Sewer sector

Stocks and flows

- Purification_capacity(t) = Purification_capacity(t-dt) + (Purification_capacity_increase - Purification_capacity_decay)*dt INIT = 0 (m^3/day)

Inflows:
Purification_capacity_increase = Purification_capacity_decay * Percentage_decay_made_up + Purification_capacity_gap*Percentage_gap_fulfilment
O*utflows*:
Purification_capacity_decay = Purification_capacity/Purification_capacity_decay_time

- Wastewater_in_purification(t) = Wastewater_in_purification(t-dt) + (Treated_wastewater_to_purification - Purified_wastewater)*dt INIT = 0 (m^3)

Inflows:
Treated_wastewater_to_purification = MIN ((Purification_capacity -Wastewater_in_purification) / Time_to_treat_wastewater+Purified_wastewater, Wastewater_in_treatment/Time_to_treat_wastewater)

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Outflows:
Purified_wastewater = MIN (Purification_capacity, Wastewater_in_purification)/ Time_to_purify

- Wastewater_in_treatment(t) = Wastewater_in_treatment(t-dt) + (Wastewater_to_treatment-Treated_wastewater_to_the_sea - Treated_wastewater_to_purification)*dt INIT = 108320.53 (m^3)

Inflows:
Wastewater_to_treatment = MIN (Total_Pipeline_capacity, Distributed_water_per_day * Percentage_going_to_sewage)
Outflows:
Treated_wastewater_to_the_sea = Wastewater_in_treatment/Time_to_treat_wastewater - Treated_wastewater_to_purification
Treated_wastewater_to_purification = MIN ((Purification_capacity -Wastewater_in_purification) / Time_to_treat_wastewater+Purified_wastewater, Wastewater_in_treatment/Time_to_treat_wastewater)

Auxiliaries and parameters

- Amap_quota_capacity_gap_investment = (Purification_capacity_gap_cost + Pipeline_capacity_gap_cost)*(1-Public_funds_percentage)
- Desired_purification_capacity = Total_treated_wastewater*Purification_percentage
- Investment_resources_for_capacity_gap = IF (Percentage_decay_made_up<1, 0, MAX (0, Investment_resources-Amap_quota_decay_cost))
- Percentage_gap_fulfilment = MIN (Investment_resources_for_capacity_gap DIVZ1 Amap_quota_capacity_gap_investment,1)
- Pipeline_capacity_gap_cost = Pipeline_capacity_gap*Pipeline_unit_cost
- Purification_capacity_gap = MAX (0, Desired_purification_capacity - Purification_capacity)/ Budgeting_Period
- Purification_capacity_gap_cost = Purification_capacity_gap*Purification_capacity_unit_cost
- Purification_percentage = DELAYMTR (Decided_purification_percentage, 90, 3, Decided_purification_percentage)
- Total_treated_wastewater = (Treated_wastewater_to_the_sea + Treated_wastewater_to_purification)
- Decided_purification_percentage = 0 (dimensionless)
- Percentage_going_to_sewage = 0.85 (dimensionless)
- Purification_capacity_decay_time = 360*45 (days)
- Time_to_purify = 1 (days)
- Time_to_treat_wastewater = 1 (days)

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Human resources sector

Stocks and flows

- Auxiliary_workers(t) = Auxiliary_workers(t-dt) + (Hiring_rate -Lay_off - Retirement_rate)*dt INIT = 130 (person)

Inflows:
Hiring_rate = (MAX ((Decided_nr_of_workers - Auxiliary_workers)/Time_to_hire, 0) + Retirement_rate)
Outflows:
Lay_off = ABS(MIN((Decided_nr_of_workers-Auxiliary_workers)/Time_to_lay_off, 0))
Retirement_rate = Auxiliary_workers/Time_to_retire

- Delayed_credits(t) = Delayed_credits(t-dt) + (Delayed_credits_increase - Credits_losses-Delayed_credits_payments)*dt INIT = 8718332 (€)

Inflows:
Delayed_credits_increase = (Normal_credits/Normal_Payment_Time)-Timely_credits_payments
Outflows:
Credits_losses = MIN (avrg_unit_credit_per_contract * Contract_suspension_capacity, Delayed_credits/Min_time_to_suspend_contracts)-Delayed_credits_payments
Delayed_credits_payments = MIN(avrg_unit_credit_per_contract*Contract_suspension_capacity, Delayed_creditsMin_time_to_suspend_contracts)*Percentage_payments_after_suspension

- Maintenance_backlog(t) = Maintenance_backlog(t-dt) + (Breakdowns - Fixed_breakdowns)*dt INIT = 114.79 (m^3/day)

Inflows:
Breakdowns = Old_pipelines/Pipeline_Decay_time
Outflows:
Fixed_breakdowns = Desired_maintenance*Percentage_maintenance_fulfilment

- Normal_credits(t) = Normal_credits(t-dt) + (Revenue - Delayed_credits_increase - Timely_credits_payments)*dt INIT = 27959546 (€)

Inflows:
Revenue = Distributed_water_per_day*Actual_Tariff
Outflows:
Delayed_credits_increase = (Normal_credits/Normal_Payment_Time)-Timely_credits_payments

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Timely_credits_payments = (Normal_credits / Normal_Payment_Time) * Percentage_timely_payments

Auxiliaries and parameters

- Average_unit_credit_per_contract = Total_credits/tot_nr_of_service_contracts
- Contract_suspension_capacity = Nr_of_suspension_workers*Suspension_workers_productivity
- Credit_collection = Timely_credits_payments+Delayed_credits_payments
- Desired_maintenance = Maintenance_backlog/Decided_time_to_fix_breakdowns
- Maintenance_capacity = Nr_of_maintenance_workers*Productivity_of_maintenance_workers
- Nr_of_maintenance_workers = IF ((Auxiliary_workers-Nr_of_suspension_workers)<0, 0, (Auxiliary_workers-Nr_of_suspension_workers))
- Nr_of_suspension_workers = MIN (Auxiliary_workers, DELAYINF (Decided_nr_suspension_workers, 90,1,Decided_nr_suspension_workers))
- Percentage_maintenance_fulfilment = MIN(Maintenance_capacity/Desired_maintenance,1)
- Total_credits = Normal_credits+Delayed_credits
- Decided_nr_of_workers = 130 (person)
- Decided_nr_suspension_workers = 10 (person)
- Decided_time_to_fix_breakdowns = 1 (days)
- Min_time_to_suspend_contracts = 60 (days)
- Normal_Payment_Time = 45 (days)
- Percentage_payments_after_suspension = 0.5 (dimensionless)
- Percentage_timely_payments = 0.7 (dimensionless)
- Productivity_of_maintenance_workers = 1.42 (m^3/day/person)
- Supension_workers_productivity = 10 (contract/person/day)
- Time_to_hire = 180 (days)
- Time_to_lay_off = 90 (days)
- Time_to_retire = 30*360 (days)
- Total_nr_of_service_contracts = 175000 (contract)

Financial sector

Stocks and flows

- Equity(t) = Equity(t-dt) + (Retained_Earnings - Losses_discharge)*dt INIT = 4255309 (€)

Inflows:
Retained_Earnings = IF(Income<0,0,Income-Dividends)
Outflows:
Losses_discharge = IF(Income<0,ABS(Income),0)

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- Liquidity(t) = Liquidity(t-dt) + (Cash_inflows - Cash_outflows)*dt INIT = 469066 (€)

Inflows:
Cash_inflows = Credit_collection+Debt_Increase
Outflows:
Cash_outflows = Debt_Decrease+Dividends+Auxiliary_workers_cost+Variable_Operating_Costs+Fixed_Operating_Costs+Net_assets_increase

- Loans(t) = Loans(t-dt) + (Debt_Increase - Debt_Decrease)*dt INIT = 0 (€)

Inflows:
Debt_Increase = MAX(0,Net_assets_increase-Positive_bank_account/Budgeting_Period)
Outflows:
Debt_Decrease = Loans/Debt_payment_time

- Net_assets(t) = Net_assets(t-dt) + (Net_assets_increase - Depreciation)*dt INIT = 7603486 (€)

Inflows:
Net_assets_increase = (Pipeline_acqusition_cost + Purification_capacity_acquisition_cost) * (1-Public_funds_percentage)
Outflows:
Depreciation = Net_assets*Depreciation_percentage

Auxiliaries and parameters

- Auxiliary_workers_cost = Auxiliary_workers*Daily_salary
- Balance_check = Tot_Assets-Tot_Liabilities_Equity
- Distribution_variable_cost = Total_pumping_rate*Distribution_unit_cost
- Dividends = IF(Income<0,0,Income*Dividends_percentage)
- Effect_of_image_on_loans = GRAPHCURVE(Company_image_index,0,0.1,[0,0.09,0.24,0.47, 0.78,0.97,1.06,1.12,1.16,1.19,1.2"Min:0;Max:1.2;Zoom"])
- Income = Revenue-Total_Costs
- Investment_resources = (MAX(0,(Max_loans_allowed-Loans))+Positive_bank_account)/ Budgeting_Period
- Long_term_liabilities = Loans+Other_LT_liabilities
- Maintenance_cost = Fixed_breakdowns*Breakdown_unit_cost
- Max_loans_allowed = Reference_loans_allowed*Effect_of_image_on_loans
- Neg_bank = IF(Liquidity<0,-Liquidity,0)
- Pipeline_acqusition_cost = Pipeline_unit_cost*(Pipelines_capacity_increase+Replacement_stage_3)
- Positive_bank_account = IF(Liquidity>=0,Liquidity,0)

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- Public_funds_percentage = GRAPHCURVE(Company_image_index,0,0.1,[0.6, 0.6,0.677,0.738, 0.772,0.795,0.813,0.83,0.841,0.849,0.85"Min:0.6;Max:0.85"])
- Purification_capacity_acquisition_cost = Purification_capacity_increase* Purification_capacity_unit_cost
- Purification_variable_cost = Purified_wastewater*Purification_unit_cost
- Revenue = Distributed_water_per_day*Actual_Tariff
- Short_term_liabilities = Other_ST_liabilities+Neg_bank
- Tot_Assets = IF(Positive_bank_account>0,Positive_bank_account,0)+Net_ fixed_assets+ Total_credits+Other_current_assets
- Tot_Liabilities = Short_term_liabilities+Long_term_liabilities
- Tot_Liabilities_Equity = Tot_Liabilities+Equity
- Total_Costs = Depreciation+Fixed_Operating_Costs+Variable_Operating_ Costs+ Auxiliary_workers_cost+Credits_losses
- Variable_Operating_Costs = (Distribution_variable_cost+Wastewater_variable_ cost+Purification_variable_cost+Maintenance_cost)
- Wastewater_variable_cost = Wastewater_to_treatment*Wastewater_treatment_ unit_cost
- Actual_Tariff = 1.0342 (E/m^3)
- Breakdown_unit_cost = 3 (E*day/m^3)
- Budgeting_Period = 360 (days)
- Daily_salary = 80 (E/day/person)
- Debt_payment_time = 360*5 (days)
- Depreciation_percentage = 0.06/360 (1/days)
- Distribution_unit_cost = 0.11442 (E/m^3)
- Dividends_percentage = 1 (dimensionless)
- Fixed_Operating_Costs = 74410.22 (E/days)
- Other_current_assets = 20211455+3907945+2419510 (€)
- Other_LT_liabilities = 2220764+11287854+ 42716526 (€)
- Other_ST_liabilities = 10808887 (€)
- Pipeline_unit_cost = 390 (E*day/m^3)
- Reference_loans_allowed = 5000000 (€)
- Purification_capacity_unit_cost = 300 (E*day/m^3)
- Purification_unit_cost = 0.12 (E/m^3)
- Wastewater_treatment_unit_cost = 0.02 (E/m^3)

BSC variables

Auxiliaries and parameters

- Annual_revenue_growth_percentage = DELAYINF(Daily_revenue_growth_ ratio, 360, 1,Daily_revenue_growth_ratio)*360
- Annual_ROI = Daily_Amap_ROI*360
- Average_pipelines_wear = (New_pipelines * Wear_weight_stage_1 + Mature_ pipelines* Wear_weight_stage_2+Old_pipelines*Wear_weight_stage_3)/Pipeline_ available_capacity

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- Average_service_reduction_percentage = Maintenance_backlog/Total_Pipeline_capacity
- Company_image_index = (Sea_pollution_conditions_index * Pollution_weight + service_quality_perception*Service_weight+Shareholder_satisfaction_index *Shareholder_satisfaction_weight)
- Cost_per_m3 = Total_Costs/Distributed_water_per_day
- Customer_satisfaction_index = (Effect_of_distribution_on_image *Distribution_weight+Effect_of_response_time_on_image* Response_time_weight+Effect_of_service_reduction_on_image*Service_reduction_weight)
- Daily_Amap_ROI = IF(Income<=0, 0, Income/Tot_Assets)
- Daily_revenue_growth_ratio = (Revenue-Previous_revenue)/Previous_revenue
- Days_to_fix_breakdowns = Maintenance_backlog/Fixed_breakdowns
- Dividend_yield_gap = (Yearly_dividend_yield - Decided_dividend_yield) / Decided_dividend_yield)
- Effect_of_distribution_on_image = MAX (0, GRAPHCURVE (Water_distribution_gap, 0,0.1,[1,0.96,0.89,0.78,0.63,0.4,0.21,0.11,0.05,0.02,0"Min:0;Max:1;Zoom"]))
- Effect_of_response_time_on_image = MAX (0, GRAPHCURVE (Response_time_gap_ratio, 0,1,[1,0.99,0.98,0.95,0.89,0.8,0.66,0.39,0.16,0.03,0"Min:0;Max:1;Zoom"]))
- Effect_of_service_reduction_on_image = MAX (0, GRAPHCURVE (Service_reduction_gap_ratio,0,1,[1,0.99,0.98,0.95,0.89,0.8,0.66,0.39,0.16,0.03,0"Min:0;Max:1;Zoom"]))
- Leaking_fraction = Total_leaking_rate/Total_pumping_rate
- Pipeline_quality_index = 1-Average_pipelines_wear
- Previous_revenue = DELAYPPL(Revenue, 1 ,Revenue)
- Purification_fraction = (Purified_wastewater/Wastewater_to_treatment)
- Response_time_gap_ratio = (Days_to_fix_breakdowns-Decided_time_to_fix_breakdowns)/ Decided_time_to_fix_breakdowns
- Sea_pollution_conditions_index = DELAYMTR(Sea_pollution_improvement_effort, 360, 1,Sea_pollution_improvement_effort)
- Sea_pollution_improvement_effort = Purification_fraction*Recycling_effect_on_sea_pollution+ Wastewater_treatment_service_level*Wastewater_treatment_effect_on_sea_pollution
- service_quality_perception = DELAYINF (Customer_satisfaction_index, 180, 1,Customer_satisfaction_index)
- Service_reduction_gap_ratio = MAX (0, (Average_service_reduction_percentage - Decided_service_reduction_percentage)/Decided_service_reduction_percentage)
- Shareholder_satisfaction_index = GRAPHCURVE (Dividend_yield_gap, -1,0.25,[0,0.03,0.09,0.21,0.5,0.79,0.92,0.97,0.99,1,1"Min:0;Max:1;Zoom"])
- Total_leaking_rate = Leaking_rate_stage_3+Leaking_rate_stage_2+Leaking_rate_stage_1
- Wastewater_treatment_service_level = Treated_wastewater_to_the_sea / Wastewater_to_treatment

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- Water_distribution_gap = (Water_demand-Distributed_water_per_day)/ Water_demand
- Yearly_dividend_yield = Dividends/Equity*360
- Decided_dividend_yield = 0.35 (1/year)
- Decided_service_reduction_percentage = 0.001 (dimensionless)
- Distribution_weight = 0.7 (dimensionless)
- Pollution_weight = 0.2 (dimensionless)
- Recycling_effect_on_sea_pollution = 1 (dimensionless)
- Response_time_weight = 0.15 (dimensionless)
- Service_reduction_weight = 0.15 (dimensionless)
- Service_weight = 0.6 (dimensionless)
- Shareholder_satisfaction_weight = 0.2 (dimensionless)
- Wastewater_treatment_effect_on_sea_pollution = 0.3 (dimensionless)
- Wear_weight_stage_1 = 0 (dimensionless)
- Wear_weight_stage_2 = 0.5 (dimensionless)
- Wear_weight_stage_3 = 1 (dimensionless)

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Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/sdr