Applying Tropos4AS to Water Security Domain: Recycled Water System Case Study

Safa Al Sadi, Layla Saleh
Engineering Systems and Management
Masdar Institute of Science and Technology
Abu Dhabi, UAE
Email: {salsadi,lsaleh}@masdar.ac.ae

Davor Svetinovic
Electrical Engineering and Computer Science
Masdar Institute of Science and Technology
Abu Dhabi, UAE
Email: dsvetinovic@masdar.ac.ae

***Abstract*—In this study, we elicit and specify a goal model for the recycled water system of Abu Dhabi Emirate, along with the constraints and strategies defined within the system boundary. The preliminary results are evaluated using Systems Dynamics approach by modeling and simulating the goals and requirements defined using Tropos for Adaptive Systems (Tropos4AS) method. System Dynamics methodology allows investigation of the interactions between goals and the evaluation of the results. This paper demonstrates preliminary evaluation of the System Dynamics ability in validating requirements engineering models. Moreover, the linking of System Dynamics and Troposa4As is found promising since it seems it can improve the collaboration between goals of different stakeholders for better planning, by considering the prioritized goals resulting from the hybrid analysis.**

***Index Terms*—goal-oriented requirements engineering, Tropos4AS, system dynamics, water security**

I. Introduction

Significant research has been devoted to the water scarcity issue due to its importance and the impact that it could create in hindering the sustainable development [1], [2]. Sustainability of water resources is considered as critical to sustainable development in energy, food, health, education, etc., especially with the population growth, climate change and other uncertainties.

In fact, managing water resources efficiently is a necessity, and the potential of recycled water resource to improve the water system could be tremendous. In this context, many methods could be used to develop this complex system such as optimization, system dynamics, system modeling language, etc. However, these methods should start by precisely specifying the goals and requirements as a critical step towards taking correct decisions where any mistake could lead to huge losses. In order to develop an efficient system, we need to have a clear understanding of its main goal and its operation. Basically, this involves a complex process of identifying, recognizing and deciding on the system's goals, requirements and functionality.

Requirement Engineering (RE) consists of analyzing and outlining the set of activities that are essential for structuring and constructing a system where the functionality and the outcome meet the stakeholders requirements [3]. Tropos for Adaptive Systems (Tropos4AS), an extension to Tropos, is one of the Goal-Oriented RE (GORE) approaches that helps the software engineer capturing, detailing and analyzing at the design stage the precise knowledge and decision measures that will guide self-adaptation at run-time. Its technique brings the high level requirements, in the form of goal-models, to operation time, allowing the system to reach their satisfaction, to reflect upon them and to guide its behavior according to them [4].

Having a rigorous model helps generating accurate forecasts thus facilitating the effective planning and decisions making. Therefore, this study aims to use a Tropos4AS to specify goal models, with the assistance of System Dynamics approach, that characterizes the recycled water system of Abu Dhabi Emirate. The paper presents related work, research method, models development, results and evaluation.

II. Background and Related Work

A. Requirements Engineering

GORE methods from RE provide a systematic approach for extracting, evaluating, analyzing, modeling and determining software requirements. These approaches are built based on certain fundamental concepts and principles, they focus on the needs of the stakeholders and express their requests in a natural way, concentrating on their requirements and objectives, rather than how to meet them [5], [6]. The main idea of goal models consists of developing a graph presenting all goals with their connections: how higher-level goals are refined into lower-level ones and, contrariwise, how lower-level goals contribute to higher-level one, where the goal is defined as a statement of intent that the system should realize and accomplish through the collaboration of its different components [7]. Thus, a goal model helps the engineers to distinguish the best solution from a set of alternatives by studying how those different solutions satisfy and improve the quality of the requirements.

Numerous GORE languages and approaches are available in literature (e.g., Keep All Objectives Satisfied (KAOS), i*, Security Quality RE (SQUARE), Tropos, etc.) KAOS is a GORE approach initially applied by systems analysts to satisfy the requirements through the achievement of the goals [8]. This method is initially considered for application in "knowledge acquisition in automated specification," it enables to build a whole comprehensive model using a goal tree structure with parent goals and sub-goals under the responsibility of agents, such as, companies, government, and nongovernmental organizations [9]. In addition, it discusses the fundamental activities of the RE process, which are at the first stage elicitation, analysis, validation, negotiation, and at the second stage documentation and management [10]. On the other hand, KAOS has some drawbacks too; this approach does not support informally or imprecisely defined soft goals [9] and it lacks the description of system's scenarios which is an essential task for engineers to understand the sequences of the system and the constraints that are present in the system.

The Tropos approach, is considered as an agent-oriented software engineering (AOSE) approach that covers the entire software or system development process. This methodology is based on two main ideas: firstly, the concept of agent and all the related notions, such as goals and plans that are used in all stages of the system development, from the early investigations and analysis down to the actual application. Secondly, Tropos concept covers the very early stages of requirements analysis, consequently allowing for a profound understanding of the environment where the software will operate [11]. Tropos methodology spans into four phases: early requirements, late requirements, architectural design and detailed design. Notions of agent, goal and task dependency are used to model and examine requirements, architectural and detailed design, as well as the implementation of the final system [4].

In his study, Morandini developed a framework for engineering adaptive systems called Tropos4AS. Its framework provides analysts with modeling features to enhance the requirements analysis on the precise knowledge and decision criteria that an adaptive system needs to autonomously adjust to dynamic changes. It also contains a planning to software agents for prototyping and performing requirements simulation. Accordingly, it helps analysts in their requirements validation and refinement phase. Tropos4AS framework is based on three key modeling features aiming simultaneously to capture the specific requirements knowledge from, and to decrease the gap between requirements-time abstractions and a run-time representation of requirements for adaptation as well. These three key modeling aspects are [4]: 1) A goal model that includes information on the goal types and the associated satisfaction conditions. 2) An environment model that represents the elements surrounding the system in various conditions, as well as their effects on the system goals achievements and satisfactions. 3) A failure model aiming to support engineers to specify the unwanted states of affair and to allow them to design recovery techniques, to anticipate predictable failures or to recover from the unpredictable ones.

B. System Dynamics

System Dynamics approach was developed by Jay Forrester at Massachusetts Institute of Technology in 1950 [12], [13]. This methodology is mainly used to characterize, examine and analyze complex systems with nonlinear dynamics over time using stocks, flows, internal feedback loops, and time delays. It is considered a more reliable analysis tool in terms of short and midterm forecasts than other statistical tools. It is distinguished by the fact that it has the potential to predict a closer demand forecasts to reality since it is based on a historical calibrated data [12]. The applications of System Dynamics in the water field are abundant. Example of applications [13]: integrated water resources management to address complex issues in water planning and management, forecasting demand, and studying the effect of different government subsidy policies on water use. The simulation software used for the development of System Dynamics models is called Vensim PLE. This software allows for data calibration, optimization, sensitivity analysis including Monte Carlo Simulation, as well as discrete decision analysis.

C. Recycled Water Sector in the Emirate of Abu Dhabi

Basically, the water supply sources in the Emirate of Abu Dhabi have not witnessed a noticeable change since 2009 [14], and they are divided into 3 groups, groundwater with 63%, desalinated water with 28% and recycled water with 9%, of the total water supply in the emirate [15]. Abu Dhabi Water and Electricity Company (ADWEC) handles the desalinated water production, transmission and distribution through various Power and Water Purchase Agreements with private operators, Abu Dhabi Transmission & Dispatch Company, and Abu Dhabi Distribution Company with Al Ain Distribution Company, respectively [16].

Recycled water is managed by Abu Dhabi Sewerage Services Company (ADSSC) starting from wastewater collection to treatment down to the disposal of bio-solids and excess recycled water. Unfortunately, only 26% of water used by domestics returns to sewer due to poor demand side management of the public, such as irresponsible outdoor water usage including but not limited to car washing, irrigation, pools filling, etc. Moreover, about 25% of the desalinated water is lost from the system due to inefficient transmission and distribution or illegal consumption. However, some efforts are placed to face such losses and decrease them down to an average of 17.5% by 2030 as announced by the Regulation and Supervision Bureau in Abu Dhabi [17].

On the other hand, only 52% of recycled water is used while the rest 48% is discharged into the sea or in the open desert because of insufficient transmission and distribution capacity [18]. Currently, the recycled water is treated up to the Tertiary level quality and is used in amenity, while in future it is targeting district cooling, food crops agriculture and aquifer's recharge [17]. Although the Environment Agency - Abu Dhabi (EAD) and Abu Dhabi Food Control Authority (ADFCA) [19] have approved the safe use of Tertiary level recycled water in irrigating eggplant, sweet corn, dates, many fruit trees and vegetables which are considered as low risk food agriculture, the public is still not accepting this option due to the lack of awareness and absence of policy enforcement tools. However, Regulation and Supervision Bureau (RSB) highlighted the need for an enhanced or extra polishing step for Tertiary level recycled water before using it in potential future options [17].

Currently, the Enhanced level (beyond Tertiary) treatment is considered only in a pilot project at Al Nahda farms for the purpose of irrigation relieving the use of groundwater [20]. While the fourth level treatment technology is one of the future options, as announced by EAD and ADFCA [9, 29]. This technology will be able to treat industrial wastewater for the same sector usage [21]. Accordingly, with the adoption of such advanced technologies and plants capacity expansion efforts that are taking place in the emirate, recycled water will be enhanced which will help in: first decreasing the pressure on desalinated water and groundwater usage in the areas where high water quality is not required, second reducing energy consumption, third cutting down CO_2 emissions and finally saving money.

III. Research Method

In this section, an overview of the analytical assessment approach followed in this study is explained. The investigation of the characteristics of any system qualitatively is considered fundamental. It allows for understanding of the complexity of the system and its behavior. Thus, we first investigate the status of the recycled water supply system in the Emirate of Abu Dhabi to understand its state and dynamic behavior, along with the demand side. The objective of this step is to get an insight about the system actors who have an influence on system complexity due to requirements and goals prioritization. More specifically, we model the recycled water current status and strategies placed (or aimed to be in place) towards achieving the government goal of maximizing the recycled water usage and enhancing the system accordingly [14].

By focusing on Abu Dhabi Emirate case study, we aim to evaluate the capability of Tropos4AS approach in characterizing complex systems. With the assistance of System Dynamics approach, we aim to evaluate the goal models developed by Tropos4AS. Such step will enable assessing and updating developed goal models if change in requirements are needed towards making the system more rigorous, through testing their potential empirically in System Dynamics. The research method followed in this study is as follows:

1) Data collection: the data used in this study is collected from literature, including governmental reports, brainstorming, observation, and discussion with an expert from the field of water resources management (EAD). Few assumptions are made:
    - Public Acceptance Rate is considered to be 42.8% [1] [22], and assumed fixed throughout the analysis, where it only affects the demand for enhanced recycled water in agriculture.
    - Wastewater treatment plants capacity is implicitly considered while modeling, and assumed capable to receive and treat all RTS amount since some of the current treatment plants are overly used while rest are of sufficient capacity [23]. However, capacity of transmitted recycled water amount will vary as part of strategies discussed in this paper.
    - Potential demand areas to be covered in this study are as per Table I.
    - The recycled water generated from the tertiary treatment plant will be ultimately used for Amenity as a first priority then Forestry sectors.
    - Recycled water supply to Agricultural sector to be of enhanced quality.

2) Tropos4As goal modeling: In this section, we will develop the Tropos4AS goal model for the recycled water supply system of Abu Dhabi Emirate showing the extended parts of Tropos goal models in terms of adoption to environmental changes and identification of possible failures, by understanding the problem, identifying actors and their goals in terms of strategies related to recycled water enhancement (e.g., technologies, infrastructure, demand side management, etc.), and detecting the interactions between the model elements. The next step is describing the system's functional and non-functional requirements within its operational environment in the form of one actor related to other actors through number of dependencies. Finally, detailed goal model is specified.
3) System Dynamics modeling: A System Dynamics model is built in Vensim PLE application simulating Tropos4AS models in order to asses defined goals and prioritize them. The System Dynamics model is validated through built-in error-informing variables and units checking, as well as conformance to the literature and logical expectations. System Dynamics approach is based on mathematical modeling technique that can represent and analyze complex systems. It enables us to understand the dynamic behavior of the recycled water system and monitor the goal satisfaction towards improving the decision making in our system at run-time. The approach begins with defining the problem, parameters and goals, and proceeds through the mapping and modeling stages. We can then study and analyze how the system should behave and the corresponding run-time satisfaction criteria. However, we will rely on Tropos4AS RE approach in early stages modeling of System Dynamics model. Furthermore, System Dynamic will allow us highlighting the key parameters in the context of our system that affect goal satisfaction, and modifying different parameters or exogenous variables. These simulations clarify how our system behaves when an expected or an unexpected change happens in its environment at the run-time phase. In our recycled water system case, the parameters affecting conditions of our environmental model are mainly the RTS, the transmission capacity and the public awareness.

[1] A survey conducted in 2009 to test people awareness on the water scarcity issue in Abu Dhabi Emirate, and it was found that only 42.8% of respondents are aware of the issue importance.

TABLE I: Assumptions of Demand for Recycled Water

Sector	Status	Assumption
Amenity	Demand for Tertiary level recycled water = 90.1 MIGD Demand for desalinated water = 133.63 MIGD	Continue the supply of recycled water and substitute the use of desalinated water by available Tertiary level recycled water.
Forestry	Demand for groundwater = 209.8 MIGD	Substitute the use of groundwater by available Tertiary level recycled water.
Agriculture	Demand for groundwater = 1033.5 MIGD	Substitute 30% of current demand for groundwater (310.1 MIGD) by available Enhanced level recycled water.

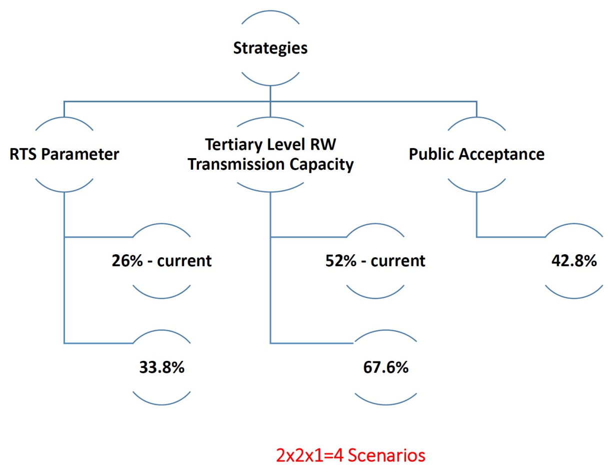

Fig. 1: Sensitivity analysis

4) Results Evaluation[2]: A sensitivity analysis is performed on the following built-in strategies in the form of exogenous parameters which are: RTS Rate Parameter, Tertiary Level Recycled Water Transmission Capacity Parameter as well as a fixed Public Acceptance Rate, resulting into four scenarios as per Figure 1.

IV. RESULTS

The Tropos4AS modeling methodology has been defined considering the key properties that need to be engineered into an adaptive system. This methodology helps the system to adapt autonomously, by using a combination of current capabilities and conditions at run-time. The assumed stakeholder in our case is Abu Dhabi Government and the actor is ADSSC, they are both the decision makers of our project. Once the stakeholders and actors have been assigned, the second step is to define the goals. Our main goal is to enhance the recycled water system in Abu Dhabi Emirate. This can be achieved by ensuring the satisfaction of two goals: increasing the recycled water usage from one side and improving the efficiency of the system from the other side.

It is essential to include in our system the main goals to reach as well as the sub-goals, to specify what effects the environment has on the system at run-time in addition to the potential errors that lead to the failure of our system, and the possibility and plans to monitor these errors to get back our system to the right track towards achieving the main goal. As aforementioned, the Tropos4AS modeling methodology concepts are extracted from i* methodology, and its development procedure is based on the agent-oriented software engineering methodology Tropos which focuses mainly on the actors representing the system-to-be. Consequently, Tropos4AS allows modeling requirements taking into consideration the behavior of the system to satisfy all its goals. The model includes three main components:

- An extended goal model with the corresponding run-time satisfaction conditions.
- An environment model indicating the critical key elements in the operational phase of our system that affect the goal satisfaction.
- A failure model pointing out any potential errors that may lead to the failure of our system consequently preventing the system from achieving its goals and the inclusion of the necessary recovery plans.

Extended Goal Model: Tropos4AS methodology includes information about the dynamics of goal satisfaction in goal models, which is a characteristic of this approach to allow monitoring the goal satisfaction as well as the decision-making in an adaptive system at run-time. The extended model includes the main goals as well as the sub-goals in addition to the plans required and necessary to apply for the satisfaction of these goals. Figure 2 shows the extended goal model of our case study.

In order to fulfill the main goal, which is to enhance the recycled water system in Abu Dhabi Emirate, we need to ensure the satisfaction of the two major components in the model which are the increase of the recycled water usage and the enhancement of the system efficiency. The sub-goals related to the satisfaction of these goals are included in the model. First, increasing the collection, by improving the collection of the recycled water we can increase the recycled water usage and consequently achieve our main goal. The plan necessary for the satisfaction of this goal is to enhance the return to sewer rate as well as the improvement of the transmission system. Second, increasing the transmission capacity, where this sub-goal is one of the essential ones to increase the recycled water usage as well. The necessary plans are to develop projects to improve the plants' capacities and to enhance efficiency of the

[2]Variable names between brackets are as used in System Dynamics Model in Vensim PLE

transmission in the system. Third, the public acceptance which is another important aspect affecting the usage of the recycled water. To achieve that goal, we need to treat the recycled water to the enhanced level, after the tertiary one, by using advanced technologies. Using such an advanced treatment should lead to the population having more trust in the purity and safety of this water.

Finally, it is necessary to develop more enhanced technologies used for the recycled water process. By doing so, we are ensuring the satisfaction of both main goals, increasing the recycled water usage and the improvement of the system efficiency. The essential plans needed are first to enhance the wastewater treatment process and then the privatization of the recycled water related project that is considered as a long-term plan.

Environment Model: Adaptivity's main concept is how the behavior of a system is modified whenever any kind of changes happen in its environment in order to keep its functionality as required. The environment model points out the dependencies among the agents and stakeholder goals and its intentional and non-intentional environment at the run-time stage. Tropos4AS methodology adds the concept of conditions and context in order to outline the run-time goal satisfaction procedure in response to any environmental changes. In this regard, precise conditions are connected to goals, showing the constraint or the context necessary in the environment for the achievement of this specific goal at run-time.

In our case study, and as represented in Figure 3, the first condition is related to the collection control. We need to maintain a collection of not less than a 26% of the wastewater, which is the current amount in Abu Dhabi Emirate. Failing to do so will affect the amount of resulting recycled water produced, reducing the amount of recycled water used, affecting therefore the goal to increase the recycled water usage. The second condition to apply is associated to the usage control. The amount of the treated wastewater discharged into the sea should not exceed 48%, the current amount in Abu Dhabi. In case this volume is surpassed, the usage control will be affected and accordingly the efficiency of our system will decrease affecting directly the main goal and preventing the enhancement of the recycled water system. The third condition to apply is to sustain the current transmission capacity, and not going below 52%, which is the current amount transmitted in Abu Dhabi Emirate. Going below this limit may have negative consequences on both the recycled water usage and the efficiency of our system thus preventing the satisfaction of our main goal to enhance the recycled water system in Abu Dhabi Emirate. Finally, it is important to include the public awareness and acceptability of the recycled water. Approximately 42% of Abu Dhabi inhabitants are assumed aware of the importance of the recycled water, consequently they accept and encourage the usage. Agitating the treated wastewater system negatively affects the trust of people in the system and in the purity of the recycled water, thus decreasing its usage and preventing the satisfaction of the main goal in our model.

Failure Model: Another important feature of the Tropos4AS modeling methodology is that it introduces a failure model. Its main objective is to provide means for capturing exceptional circumstances and probable undesirable activities at the run-time stage. These activities are reflected in the model as errors leading to failures of the system. They are mainly a result of any uncompleted requirement, or a consequence of circumstances that were not taken into consideration at the requirements analysis stage or the design-time stage. The failure model helps anticipate any error of failure at the run-time phase by adding the recovery activities known as plans.

Through the following Figure 4, we explain the failure model of our case study that includes potential errors and the failures resulting from these errors, and the necessary recovery activities or required plans. First, cutting the transmission and a plant shutdown are both potential errors that can happen to our system at run-time and lead to a failure in the operation, thus leading to a disruption in the supply of the recycled water affecting directly the recycled water usage which will decrease subsequently. In order to deal with this failure, many recovery activities could be taken, such as transmitting recycled water via tankers. This action can be considered as a short-term plan action guaranteed immediately. Another short-term plan is to follow the safe disposal strategies of wastewater into the sea or desert. Additional recovery activity is the maintenance of the damages and the repair of the disruption, both of which may be considered either long-term or short-term depending on the size of the damages and the time needed for the restoration. Another set of errors presented in our model is whenever a leakage in the transmission happens or if the plants are overloaded, these errors cause a drop in the efficiency in our system and highly affect our main goal to enhance the recycled water system in Abu Dhabi Emirate. As restoration plans, we first propose to control the leakages and to provide the necessary maintenance and reparation. Furthermore, recovery activities are to propose projects to enhance the transmission infrastructure and to increase the recycled water treatment plants capacity.

Linking between the extended goal model, environmental model as well as failure model built using Tropos4AS generates a comprehensive full model for the recycled water system in Abu Dhabi.

While this is the work in progress, and we are currently integrating the results of Tropos4AS with the System Dynamics model, we have already produced some results that show the gaps in recycled water supply resulting from running the System Dynamics model over the agreed scenarios, as presented in Figure 5. So far, the scenario 2 seems to be the best having the minimum shortfall amount, indicating that the RTS rise has a great impact on reducing the supply gap. Maximizing both strategies results in the second minimum supply gap where the system could satisfy almost 33% of its demand for Tertiary recycled water and 43% of its demand for Enhanced recycled water. The BAU scenario is found better than further enhancing Tertiary recycled water transmission capacity, thus saving cost.

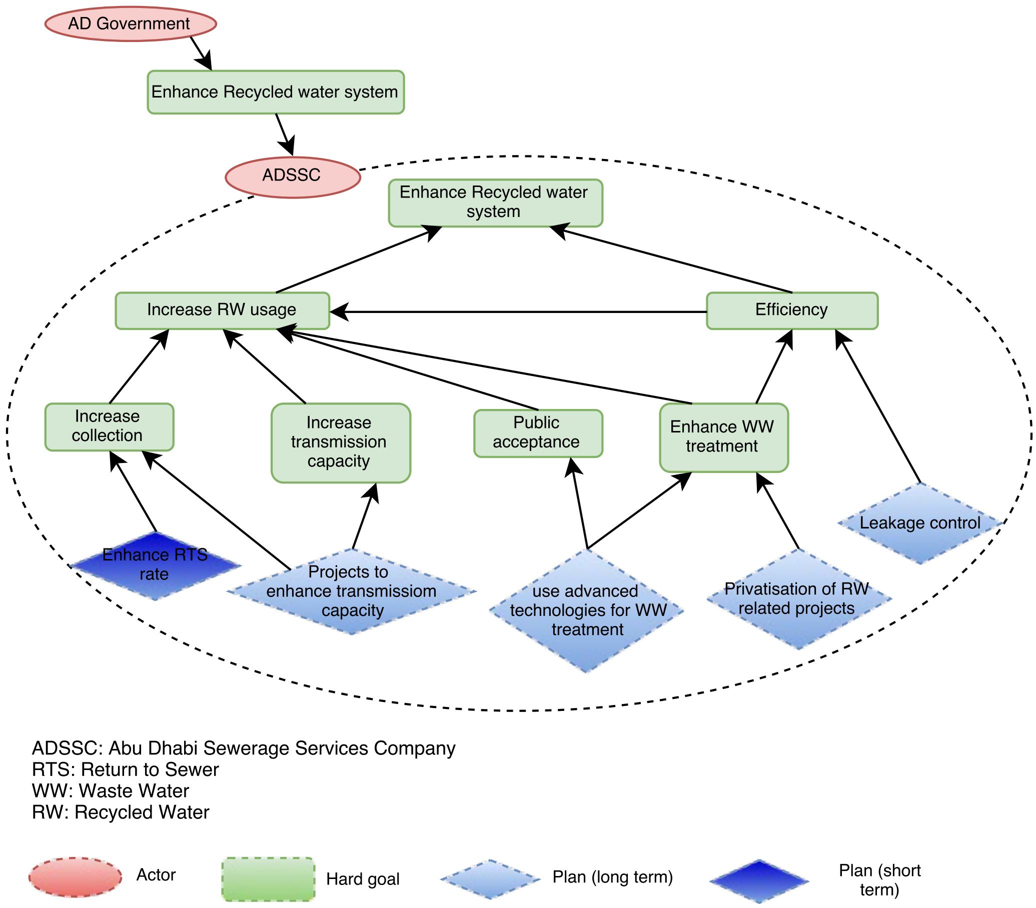

Fig. 2: Extended Goal Model

V. Discussion

In this paper, we have shown the preliminary results of system modeling using Tropos4AS and System Dynamics through a case study of Abu Dhabi Emirate recycled water system. We are currently simulating the goal models and short-term plans defined in Tropos4AS using Vensim PLE, and running four different scenarios including BAU. The full results of this study will be based on the identified system boundary, modeling setup and assumptions.

A. Outcomes

In the previous sections, we have presented the applicability of Tropos4AS at the recycled water system in Abu Dhabi Emirate. Linking between System Dynamics and Tropos4AS seems promising so far. The System Dynamics method is helping us evaluate the goals built in Tropos4AS, where maximizing the wastewater collection has more impact on system improvement than maximizing transmission capacity under the given modeling setup. Thus, so far it seems that investing in maximizing the return to sewer amounts has a higher potential and could further enhance the recycled water system in Abu Dhabi Emirate. Adopting enhanced treatment technologies to treat the amount that used to be discharged has a potential too in covering a good portion of the agricultural demand, and substituting the use of depleting groundwater resources. Public awareness is indeed important for system enhancement although no effect has been noticed in our analysis so far. We believe this is due to a lower amount of supply available than impacted demand.

B. Research Contribution

By investigating the literature, we could not find any application on water systems in general and in recycled water system in particular using either goal-based or agent-based modeling methods. This is most likely due to the engineering discipline distance. In our study, we applied Tropos4AS procedure to the recycled water system in Abu Dhabi Emirate, using real data and hopefully providing tangible results by the time the study is fully completed. Furthermore, this study contributes to the knowledge of stakeholders impact on recycled water system, and highlights the potential and possible risk of the current plans or decisions, thus accordingly helping in improving the system towards making it more resilient and vulnerable.

Combining Tropos4AS and System Dynamics methods have a potential to be a valuable addition to the RE research. Linking between both approaches and using the resulted unified validated model will support robust scenarios testing,

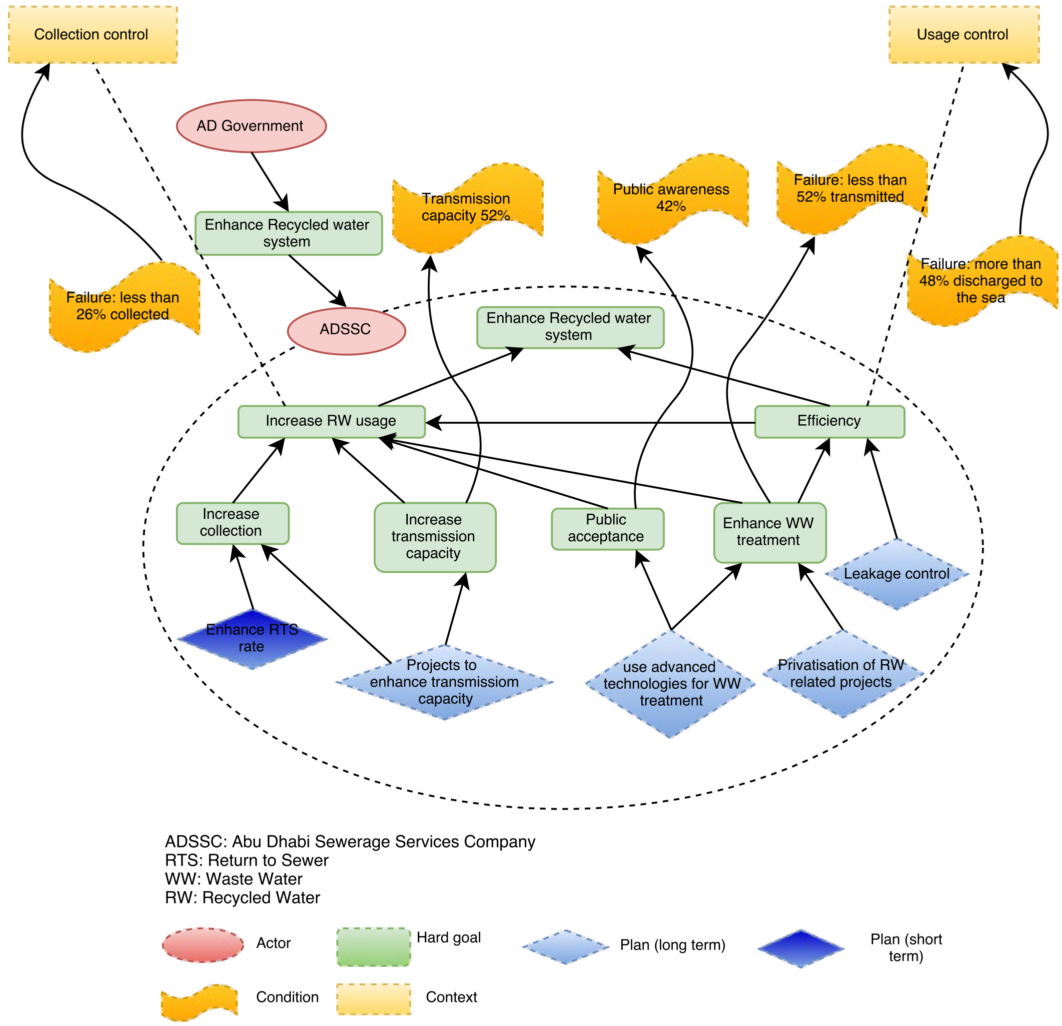

Fig. 3: Environment Model

thus investigating the power of potential strategies in future as well as improving the decision making. This study is the first of its kind since RE helps defining requirements for System Dynamics models but the opposite relation has never been investigated. So far, we can see both methods complementing each other effectively.

C. Limitations

An important limitation we faced in our study is meeting the stakeholders and actors, which are in our case representatives from Abu Dhabi Government and ADSSC, to perform a deeper investigation of the interaction between system actors and goals. This restriction is preventing us from having their comments, plans, and other feedback on different conditions, errors and failures that our system may face at run-time. Having data about system design and operation could have better impact on system improvement if available. Furthermore, the study has not so far considered seasonality in demand and production capacity planning due to the limited scope in addition to the time constraint.

VI. Conclusion and Future Work

This paper has reported the positive preliminary results in our work on integrating Tropos4AS and System Dynamics method in order to produce comprehensive goal models that can be quantified, simulated, and used in decision making in water security domain. Given our current progress, we should be able to present full results during the workshop.

Besides the potential of enlarging the scope of this study and making it more detailed, the boundary could also be improved by integrating the other water resources in Abu Dhabi Emirate and use the resulting model as an integrated water resources management tool. Other potential strategies that could be further analyzed are: water treatment plants capacity improvement, controlling leakage from water system, analyzing the effect of water price on return to sewer rate, etc. Furthermore, the future work should also monitor and analyze the correctness of the model during the system operation. This should be done through the implementation and collection of data from the implemented system and comparison with the model. Evaluating the results could be better visualized using

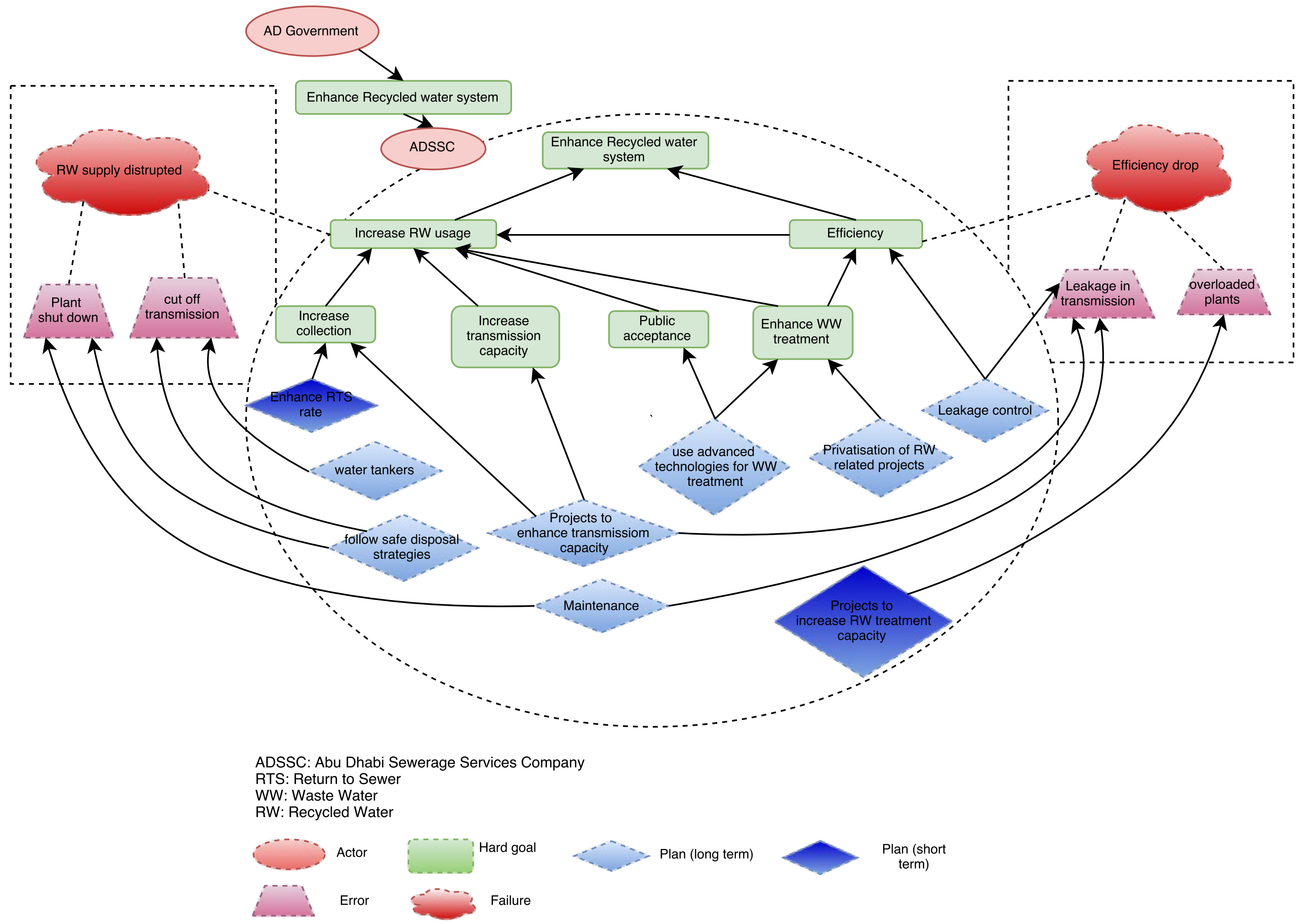

Fig. 4: Failure Model

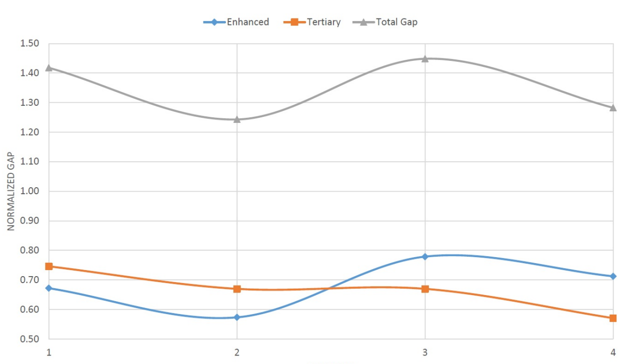

Fig. 5: Normalized Recycled Water Gap

multi-criteria decision analysis from economic, social and environmental perspective. Finally, introducing the uncertainties such as seasonality and demand growth rate will make the analysis more representative.

REFERENCES

[1] R. Koudstaal, F. R. Rijsberman, and H. Savenije, "Water and sustainable development," in *Natural Resources Forum*, vol. 16. Wiley Online Library, Conference Proceedings, pp. 277–290.

[2] A. K. Biswas, "Water for sustainable development in the 21st century: a global perspective," *International Journal of Water Resources Development*, vol. 7, no. 4, pp. 219–224, 1991.

[3] I. Sommerville, "Integrated requirements engineering: A tutorial," *IEEE software*, vol. 22, no. 1, pp. 16–23, 2005.

[4] M. Morandini, L. Penserini, A. Perini, and A. Marchetto, "Engineering requirements for adaptive systems," *Requirements Engineering*, pp. 1–27, 2015.

[5] L. F. C. Rojas, S. M. Lince, and E. E. Peña, "Goal oriented requirements engineering supported by the semat kernel," in *Software Engineering Research and Innovation (CONISOFT), 2016 4th International Conference in*. IEEE, 2016, pp. 65–70.

[6] D. M. Fernandez and B. Penzenstadler, "Artefact-based requirements engineering: the amdire approach," *Requirements Engineering*, vol. 20, no. 4, pp. 405–434, 2015.

[7] D. F. Mendonça, G. N. Rodrigues, R. Ali, V. Alves, and L. Baresi, "Goda: A goal-oriented requirements engineering framework for runtime dependability analysis," *Information and Software Technology*, vol. 80, pp. 245–264, 2016.

[8] E. Yu, "Modelling strategic relationships for process reengineering," *Social Modeling for Requirements Engineering*, vol. 11, 2011.

[9] J. Horkoff and E. Yu, "Interactive goal model analysis for early requirements engineering," *Requirements Engineering*, vol. 21, no. 1, pp. 29–61, 2016.

[10] A. Alva and L. Young, "L-square: Preliminary extension of the square methodology to address legal compliance," in *Evolving Security and Privacy Requirements Engineering (ESPRE), 2014 IEEE 1st Workshop on*. IEEE, 2014, pp. 25–30.

[11] M. Morandini, L. Penserini, and A. Perini, "Automated mapping from goal models to self-adaptive systems," in *Proceedings of the 2008 23rd IEEE/ACM International Conference on Automated Software Engineering*. IEEE Computer Society, 2008, pp. 485–486.

[12] E. Suryani, S.-Y. Chou, R. Hartono, and C.-H. Chen, "Demand scenario analysis and planned capacity expansion: A system dynamics framework," *Simulation Modelling Practice and Theory*, vol. 18, no. 6, pp. 732–751, 2010.

[13] I. Winz, G. Brierley, and S. Trowsdale, "The use of system dynamics simulation in water resources management," *Water resources management*, vol. 23, no. 7, pp. 1301–1323, 2009.

[14] "Water then and now," Environment Agency-Abu Dhabi (EAD), Online Database, 2011. [Online]. Available: https://www.environmentalatlas.ae/resourceOfLife/waterThenAndNow

[15] "Annual policy brief of advancing sustainable groundwater management in abu dhabi," Environment Agency-Abu Dhabi (EAD) & Abu Dhabi Food Control Authority (ADFCA), Report, , 2012. [Online]. Available: http://www.ead.ae/wp-content/uploads/2014/03/Groundwater-PB-Eng.pdf

[16] P. Paul, A. K. Al Tenaiji, and N. Braimah, "A review of the water and energy sectors and the use of a nexus approach in abu dhabi," *International journal of environmental research and public health*, vol. 13, no. 4, p. 364, 2016.

[17] "Supporting the abu dhabi economic vision 2030," Regulation and Supervision Bureau (RSB), Report, 2013. [Online]. Available: https://goo.gl/cu7i79

[18] M. Griffiths, "Abu dhabi regulatory frameworks and policies to ensure sustainable water supply," in *MENA Water Forum*. Regulation & Supervision Bureau (RSB), 2014, Conference Proceedings.

[19] "Maximizing recycled water use in the emirate of abu dhabi," Environment Agency - Abu Dhabi (EAD) & Abu Dhabi Food Control Authority (ADFCA), Report, 2013. [Online]. Available: https://goo.gl/HSmC2s

[20] M. Dawoud, O. Sallam, and M. Abdelfattah, "Treated wastewater management and reuse in arid regions: Abu dhabi case study," Environment Agency Abu Dhabi (EAD), Report, 2012.

[21] "Reusing water for industrial processes and irrigation in saudi arabia." [Online]. Available: http://www.kemira.com/en/newsroom/whats-new/Pages/reusing-water-in-saudi-arabia.aspx

[22] M. Al-Omar, "The role of desalinated water in integrated water resource management in abu dhabi emirate-uae," *The Online Journal of Science and Technology*, vol. 2, no. 4, pp. 90–96, 2012.

[23] "Adssc annual report 2010," Abu Dhabi Sewerage Services Company (ADSSC), Report. [Online]. Available: http://en.adssc.ae/Media_Centre/Annual%20Reports/ADSSC_ANNUAL_REPORT_ENGLISH.pdf