DECISION ANALYSIS APPLICATIONS FOR THE SUSTAINABILITY OF GLOBAL URBAN WATER RESOURCES AND DRAINAGE SYSTEMS

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ABSTRACT

Water is one of the most vital elements needed for life. In many countries water supplies, especially for critical drinking water, are either being depleted or polluted. Too often these problems are magnified due to the lack of reliable drainage systems that provide proper stormwater and sanitary sewage collection and treatment of human generated wastewater. These problems cause health concerns and impact the quality of life. Solutions in one country are not necessarily transferable to another, as every community is unique; each community has special needs for water and drainage systems. Too often in the past, countries have tried to implement systems that are not suitable to their local needs and concerns. Consequently, there is a global need to create a systematic decision analysis tool to provide strategies for finding sustainable water resources and drainage systems solutions. A new sustainable decision analysis system is developed to address these problems and concerns. This paper serves as an introduction for future more fully developed examinations of various urban water use and drainage issues worldwide, such as water supplies polluted with arsenic, and water reuse in arid regions.

KEYWORDS
Sustainable, Framework, Water Resources, Drainage Systems, Infrastructure, Metrics, Measures, Facets

INTRODUCTION

Water is one of the most vital elements needed for life, and almost every civilization across the globe is facing serious problems with its water resources and drainage systems (UN-Water, 2005). In many countries water supplies, especially for critical drinking water, are either being depleted or polluted (UN-Water, 2005). Too often these problems are compounded by to the lack of reliable drainage systems that provide proper stormwater and sanitary sewage collection and treatment of human generated wastewater (UN-Water, 2005). Collectively, these problems cause health concerns and impact the quality of life. Therefore, The United Nations has launched the 'Water for Life' decade during 2005 – 2015 to stress the importance of this resource worldwide.

Since the dawn of civilization, tribes and then followed by formal governments, have been attempting to solve urban water resources problems (UN-Water, 2005). Solutions are complex, the task of solving the problems has multiple stages, resources to construct the physical infrastructure are expensive, lessons learned in one project are not uniformly disseminated and too often a solution to a problem in one area causes unintended consequences for someone else.

Solutions in one country are not necessarily transferable to another, as every community is unique; each community has special needs for water and drainage systems. Too often in the past, countries have tried to implement systems that are not suitable to their local needs and concerns (UN-Water, 2005). Vital details that should have been included in the solution may not be considered and, unfortunately, can then result in transforming the original problem with compounding effects on local communities.

Consequently, there is a global need to create a systematic decision analysis tool to provide strategies for finding sustainable water resources and drainage systems solutions. One such tool originating in the nineteen sixties is the Logical Framework Approach (LFA). The United Sates Agency for International Development (USAID) in 1969 developed the LFA (Finlayson, 2004). The LFA is often mandated by international project donors such as the Asian Development Bank and the European Union; the LFA is an analytical tool (characterized by the LF Matrix depicted in Figure 1) that helps planners and managers to:

- *"Analyze the existing situation during project preparation,*
- *Establish a logical hierarchy of means by which objectives will be reached,*
- *Identify potential project risks,*
- *Establish how outputs and outcomes can be monitored and evaluated, and*
- *Present project summary."* (Wageningen International, 2006)

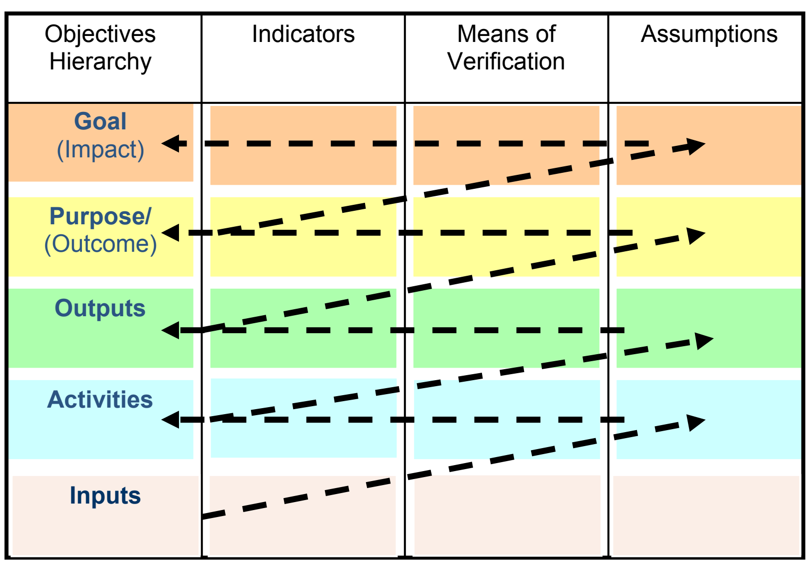

Figure 1 The Logical Framework Matrix (NORAD, 1999)

The LFA continues to evolve as a methodology for improving the systematic planning of development projects. In its current form, it is a process-orientated approach for involving stakeholders in project design and management. Though the LFA is widely used internationally, it has been criticized as:

- *"Focusing too much on problems rather than opportunities and vision,*
- *Being used too rigidly, leading people into a 'blueprint' approach to project design,*
- *Limited attention to problems of uncertainty where a learning or adaptive approach to project design and management is required, and*
- *A tendency for poorly-thought-through sets of activities and objectives to be entered into a Participatory Planning Monitoring (PPM) table, giving the appearance of a logical framework when in fact the key elements of the analytical process have been skipped."* (Bakewell and Garbutt, 2005)

In an attempt to respond to the cited criticisms of the LFA approach listed above, this paper provides an introduction to a complimentary analytic approach to the LFA that is specifically designed for the planning and management of sustainable urban water resources and drainage systems. This new approach can be applied to specific projects and programs throughout the world. To illustrate this new approach, this paper serves as an introduction for future more fully developed examinations of various urban water use and drainage issues worldwide, such as water supplies polluted with arsenic, and water reuse in arid regions.

SUSTAINABLE DECISION ANALYSIS SYSTEM (SDAS)

The sustainable decision analysis system (SDAS) addresses the various needs and concerns of the stakeholders in order to allocate and implement the appropriate sustainable solution(s) for the community. This system has a framework (structure of knowledge) that identifies the required knowledge and organizes it in a working structure.

Referent Framework

To address the criticisms levied against the LFA, a framework that explicitly defines systems constituents such as planners, owners, designers, builders, subcontractors is needed. Likewise, extending the LFA to include objectives into what, where, who, when, why, and how is needed. Thus, from the information technology discipline, the Enterprise Architecture Framework (Zachman, 1987) is proposed as a foundation for the SDAS. Figure 2 shows the Zachman framework. The framework consists of perspectives and abstractions. The perspectives (row) represent the constituents and the knowledge level this constituent represents. Scope is related to planner, enterprise model to owner, system model to designer, technology constrained model to builder, and detailed representations to subcontractor.

Each perspective represents a prototypical view of the domain. Consequently each perspective different type of information to conceptualize, design, build, and operate a system. For example the type of data the owner requires is different from the builder's. The columns represent the different moments of concern about the data. That is, the columns represent abstractions for the "who, why, what, when, where and how" someone needs particular data. These abstractions are both comprehensive and primitive (Zachman, 2003). Each abstraction is different and acts independently from the others.

Abstractions *Perspectives*	**DATA** **What**	**FUNCTION** **How**	**NETWORK** **Where**	**PEOPLE** **Who**	**TIME** **When**	**MOTIVATION** **Why**
SCOPE (contextual) Planner	List of things important to the business Entity = Class of business thing	List of processes the business performs Process = Class of business process	List of locations in which the business operates People = Major Organizational Unit	List of organizations Important to the business People = Major Organizational Unit	List of Events / Cycles Significant to the business Time = Major business event / cycle	List of business goals/strategies Ends/Means = Major Business goal/strategy
BUSINESS MODEL (conceptual) Owner	e.g., Semantic model Entity = Business entity Relationship = Business relationship	e.g., Business process model Process = Business process I/O = Business resources	e.g., Business logistics system Node = Business location Link = Business linkage	e.g., Work flow model People = Organization Unit Work = Work product	e.g., Master schedule Time = Business event Cycle = Business cycle	e.g., Business plan End = Business objective Means = Business strategy
SYSTEM MODEL (logical) Designer	e.g., Logical data model Entity = Data entity Relationship = Data relationship	e.g., Application architecture Process = Application function I/O = Users views	e.g., Distributed system architecture Note = I/S function (Process, storage, etc.) Link = Line characteristics	e.g. Human interface architecture People = Role Work = Deliverable	e.g., Processing structure Time = System event Cycle = Processing cycle	e.g., Business rule model End= Structural assertion Means = Action assertion
TECHNOLOGY MODEL (physical) Builder	e.g., Physical data model Entity = Segment / Table Relationship = Pointer / Key	e.g., System design Process = Computer function I/O = Data elements / Sets	e.g., Technology architecture Node = Hdw/System software Link = Line specifications	e.g., Presentation architecture People = User Work = Screen formats	e.g., Control structure Time = Execute Cycle = Component cycle	e.g., Rule design End = Condition Means = Action
DETAILED PRESENTATIONS (out-of-context) Subcontractor	e.g., Data definition Entity = Field Relationship = Address	e.g., Program Process = Language statement I/O = Control block	e.g., Network architecture Node = Address Link = Protocol	e.g., Security architecture People = Identity Work = Job	e.g., Thing definition Time = Interrupt Cycle = Machine cycle	e.g., Rule specification End = Sub-condition Means = Step
FUNCTIONING ENTERPRISE	e.g.: DATA	e.g.: FUNCTION	e.g.: NETWORK	e.g.: ORGANIZATION	e.g.: SCHEDULE	e.g.: STRATEGY

Figure 2 Zachman Framework (Zachman, 1987)

Framework Extension

Zachman proposes five rules that help us to transform the information systems framework to one postulated for decision analysis applications for sustainability of global urban water resources and drainage systems. These rules are:

- Each column has a simple generic model
- Each cell model specializes its column's generic model
- No meta concept can be classified into more than one cell
- Do not create diagonal relationships between cells
- The logic is generic, recursive

The new framework and its' components are discussed step by step in the following paragraphs. The explanation is from top to bottom i.e. from the biggest to the smallest component in the framework.

Level One

The first level of the framework is the project component. The project can be identified as water, drainage, or water and drainage system issues that are facing a community. This level is implicitly identified in Zachman. Figure 3 shows the project component of the SDAS framework. This figure shows some water and drainage issues around the world.

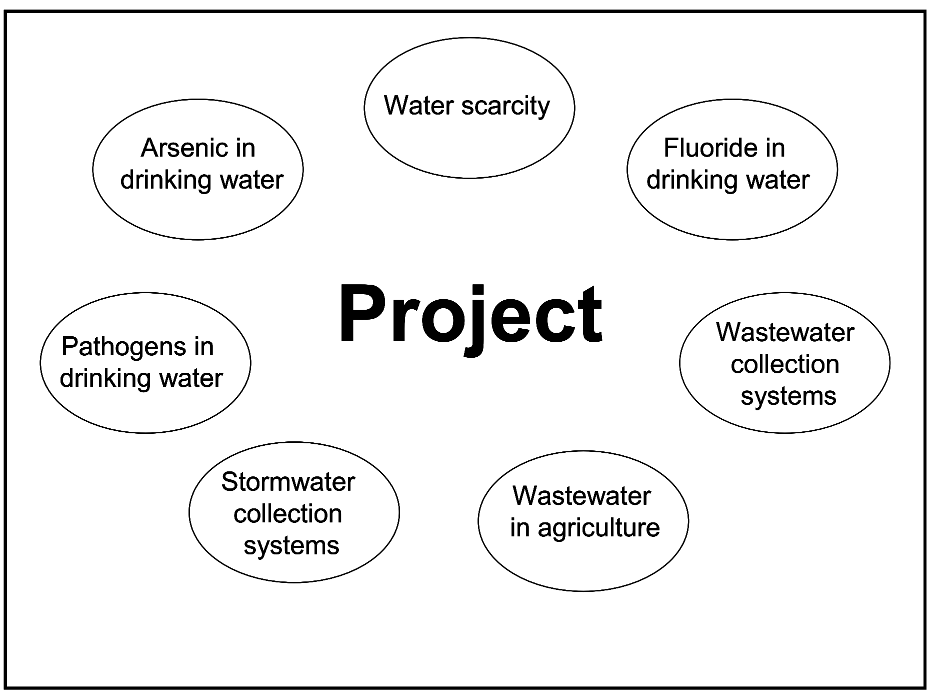

Figure 3 Project component of SDAS framework

Level Two

The second level of the components includes the facets that define the macro-scale of the required knowledge for any project. These facets are the broad headings for certain metrics of interest by the stakeholders to achieve sustainability, collectively working together. Figure 4 shows the facets needed to achieve sustainability. The general facets that are chosen are public health, economical and financial, social and cultural, education and training, infrastructure, environment and ecology, transferability, and resources. This level is not represented in Zachman's framework; however, this level is important to identify the different facets to achieve a sustainable system.

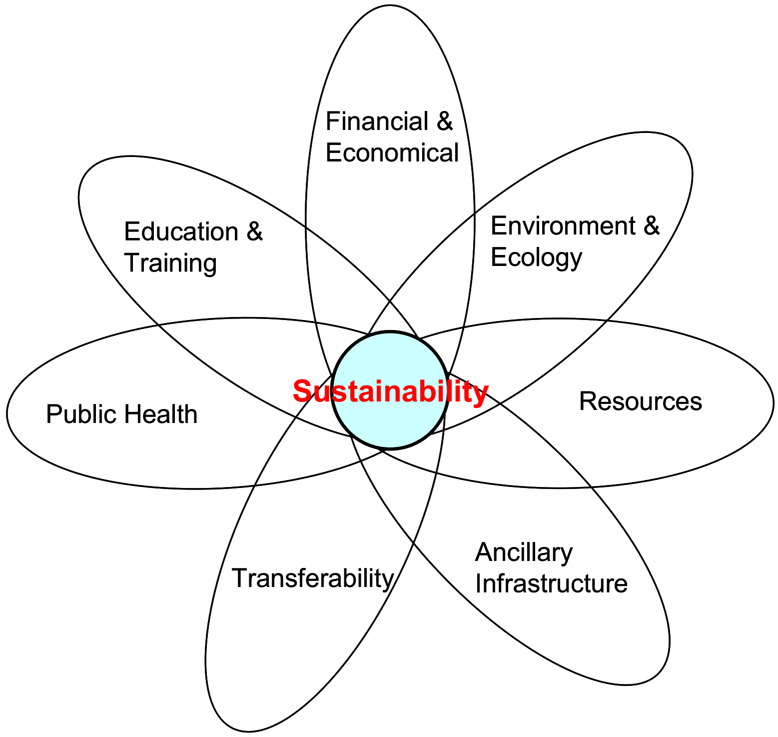

Figure 4 Facets working collectively to achieve sustainability

The facets and the matrix elements that are mentioned below come from in-house discussions with various experts, and have been confirmed by meetings and dialogues with experts from academia and industry (e.g. Dean of Engineering at Western Michigan University and President of Alabama Power) about implementing systems and their components. These facets were further confirmed through readings from various documents issued by funding organizations such as the World Bank, the World Health Organization (WHO), and the United Nations International Children's Emergency Fund (UNICEF). These facets can be expanded according to the needs of every project. Figure 5 shows the facets in the SDAS framework.

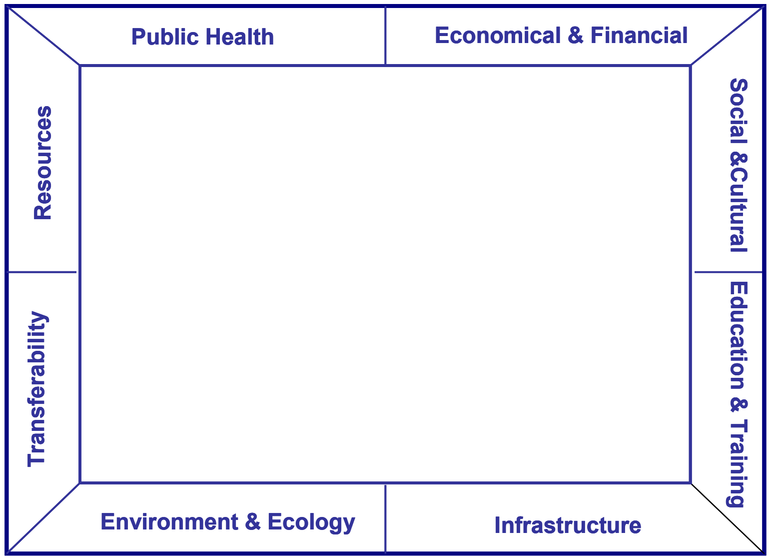

Figure 5 Facets in SDAS framework

Level Three

The third level organizes the micro-scale of information (measures) for the project within the SDAS framework. The stakeholders being considered are the owner, user, designer, and builder. The stakeholders (perspectives) are slightly different than Zachman's. The planner in Zachman's framework is part of the owner in the new framework and the sub contractor is part of the builder. A new stakeholder added to the framework is the user. The users are key players in accepting or rejecting any system (including performing simple maintenance) and the user is a critical component of the decision analysis process.

This level is then expanded into a matrix that has stakeholders on one axis and a set of metrics on the other, and is further explained below. The metrics that are under consideration can be abbreviated in a 7 letter word, DEMONS^2 (AISCE, 2006). The DEMONS^2 are dependability, efficiency, maintainability, occupation, neglect, safety, and security. The metrics are discussed thoroughly in the DEMONS^2 section. Figure 6 shows the stakeholders and the metrics relationship in the framework.

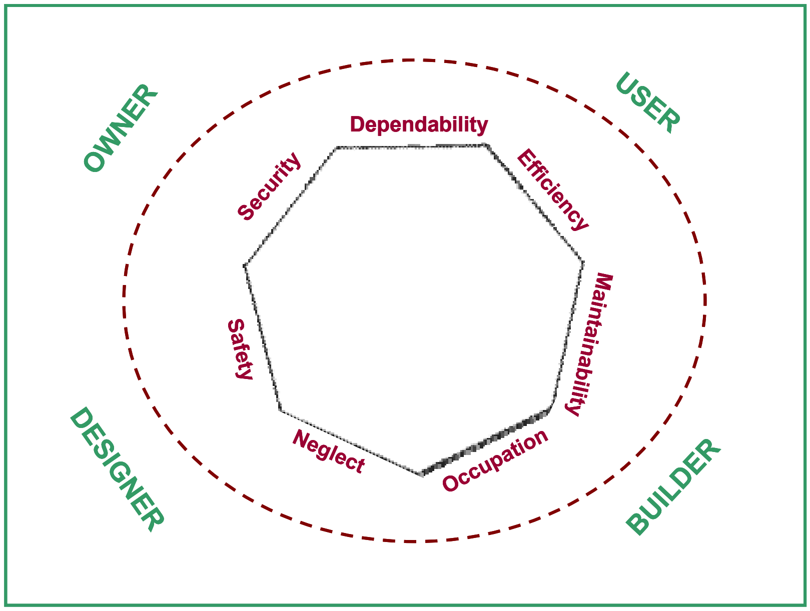

Figure 6 Relationship of stakeholders with indicators / metrics in the SDAS framework

The relationship between the stakeholders goes further than shown on Figure 6. In order to have a successful sustainable output from the decision system, the stakeholders should share different information (knowledge) between them. This knowledge transfer might be through different channels. One example is by having the designer responsible for information and every stakeholder would provide him with the required knowledge. Figure 7 models this relationship. Additionally, the designer and builder are boxed together here, so the builder is not specifically separated out at this time.

Another example for knowledge sharing is by having an external entity such as a facilitator to collect the knowledge from the stakeholders and then distributing them to where needed. This is shown in Figure 8.

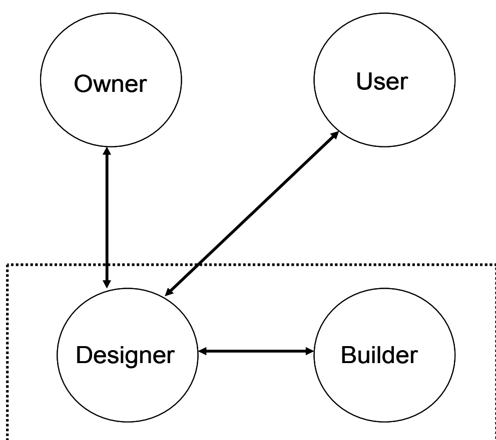

Figure 7 Relationship between the stakeholders in information sharing

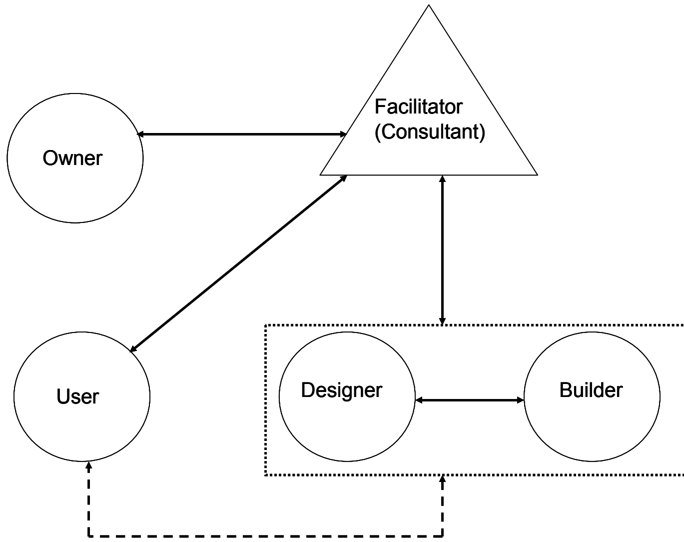

Figure 8 Relationships between stakeholders with the presence of a facilitator

As mentioned previously, the link between the second level (Facets) and third level (Stakeholder vs. DEMONS[2]) of the framework and the knowledge within the third level (Measures) is represented in a matrix, presented in Table 1.

Table 1 Matrix of required knowledge within each SDAS facet (e.g. Public Health, Social & Cultural, Transferability, etc.)

Metric / Stakeholder	Dependability	Efficiency	Maintain-ability	Occupation	Neglect	Safety	Security
Owner	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc
User	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc
Designer	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc
Builder	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc	• Measure 1 • Measure 2 • etc

The final product of these different levels is the framework shown in Figure 9.

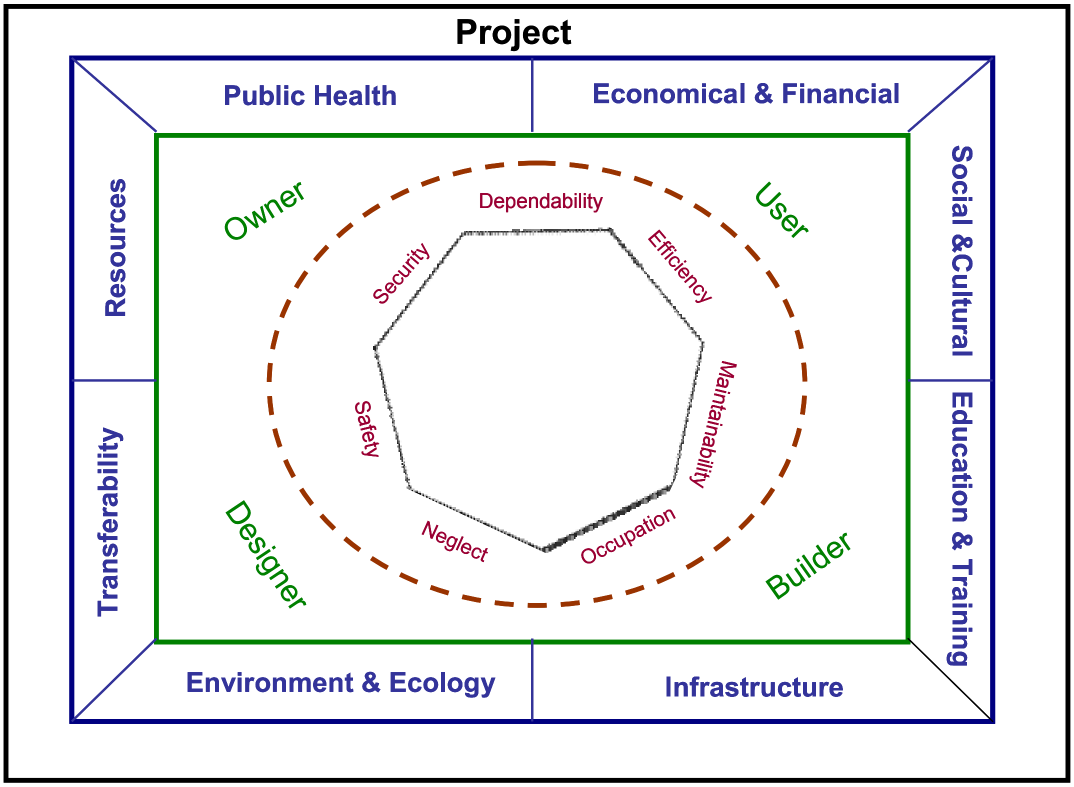

Figure 9 SDAS framework for decision analysis for sustainable water and drainage systems

The SDAS framework can be represented as a flowchart diagram (Work Break-down Structure, or WBS), to show the different working levels in the framework. The first level is the project, the second level is the facets, and the third level is the stakeholders and metrics. The flowchart is shown in Figure 10.

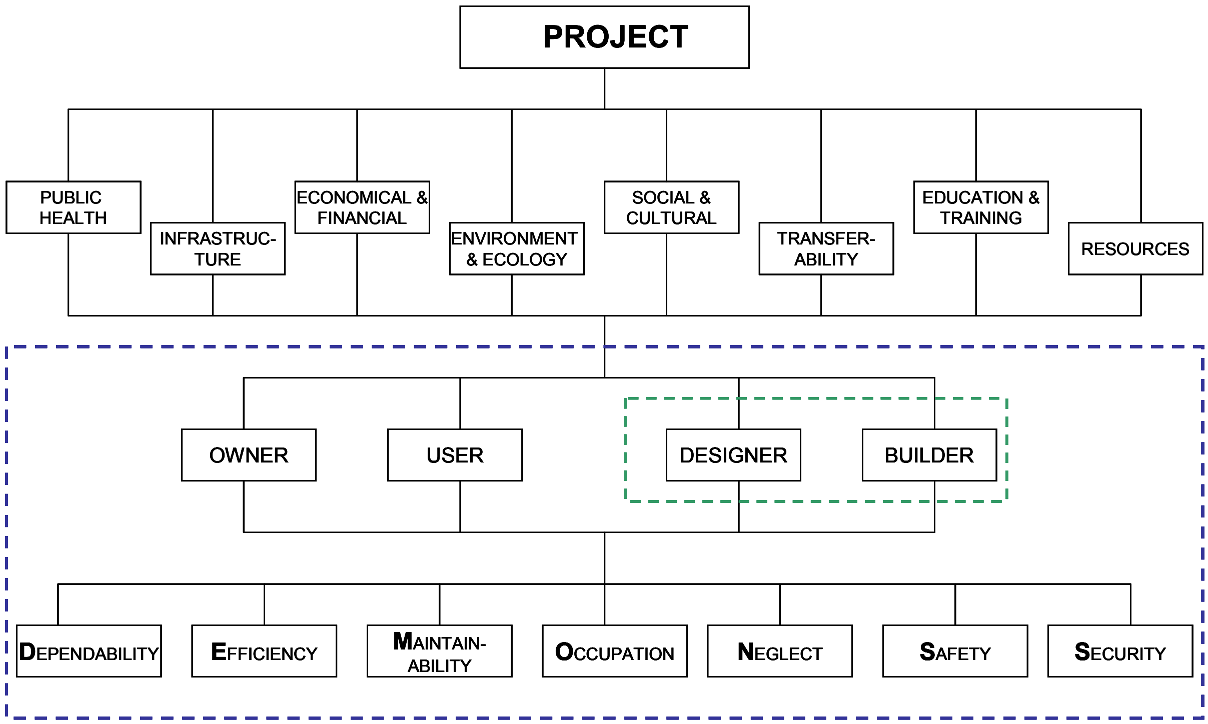

Figure 10 Framework represented as a flowchart diagram

DEMONS^2

The Aging Infrastructure Systems Center of Excellence (AISCE) at The University of Alabama, Tuscaloosa (UA) studied the problems caused by aging infrastructure and found out through research and industry, a set of common metrics affects any asset. The metrics are abbreviated, as mentioned above; as DEMONS^2.

The DEMONS^2 definitions are modified according to this research for sustainable urban water resources and drainage systems, but the general definitions remain the same. These definitions are important because they set the required knowledge behind each metric.

Each one of the metrics has measures to address concerns that the stakeholders are concerned about. These measures are general organizing working titles in order to set the basic ground of available knowledge (information and data) to fill in the matrix (Table 1). Suggested measures for each metric are also identified. These measures are not an exhaustive list and other measures can be added. The measures can be repeated in more than one metric and are not exclusive to a specific metric. Further, these measures will be tested and verified in different projects for their applicability to these metrics.

Dependability

Dependability is a metric of the ability of a sustainable system to operate or function according to its design parameters during its design life span, or its ability to operate when called upon, or its ability to produce reliable results, or the ability to accommodate updates and changes due to technical advancement, all within the expected operational environment conditions.

Dependability is a thoroughly discussed metric in the reviewed literature. It is a heavily implemented measure by industrial and computer systems. There are measures in this metric that some researchers use as individual metrics by themselves. The following measures can be abstracted from the definition of dependability:

- Accessibility
- Accountability
- Accuracy
- Adaptability
- Availability
- Confidence
- Cost
- Durability
- Integration
- Modification
- Reliability
- Resilience
- Robustness

Efficiency

Efficiency is a metric of the usage of the available resources for sustainable systems, such as network, materials, people, equipment, sensors, or any other asset, in order to produce a high ratio/percentage of useful output levels in relation to the systems' input levels.

Efficiency is most often found in industrial applications where it tries to link the input and output as previously mentioned in the definition. The suggested measures for this metric are the following:

- Availability
- Consumption
- Cost
- Input
- Output
- Productivity
- Time

Maintainability

Maintainability is a metric that involves preserving, servicing, fixing, part replacement, refurbishing, or renewing any asset in sustainable systems through various remediation options in order to continuously provide an acceptable level of services, to prevent breakdowns, to extend the useful life, to ensure safety, to maintain efficiency, or to preserve from failure, decay or decline. Maintenance may occur proactively or upon failure. Proactive maintenance may be triggered by impromptu or periodically scheduled inspection or testing, remote sensing, or by failure analysis.

Every system needs to have and consider this metric. Maintainability allows the system to keep on running smoothly and the following measures have significant impact on this metric:

- Accessibility
- Accountability
- Availability
- Cost
- Responsibility
- Time

Occupation

Occupation is a metric that involves creating or preventing the loss of valuable knowledge of sustainable systems. Through the capturing of that knowledge and making it available to those who need it, when they need it, for the right costs. This knowledge may be captured through interviewing, documenting, story telling, mentoring, shadowing, debriefing, after-action-reviews, or communities of practice, and it may be stored in document repositories, databases, or expert systems. When the need arises to transfer the captured knowledge, techniques such as training, expert systems, story telling, mentoring, or accessing a document repository may be used.

Occupation is related to the knowledge that is within the system and many systems are starting to recognize its importance on a larger scale due to the loss of experienced people through retirement or changing jobs. Measures that affect occupation include the following:

- Accessibility
- Availability
- Cost
- Knowledge transfer

Neglect

Neglect is a metric of abandoning or lack of proper care and/or necessities for the sustainable water and drainage systems to perform according to the goals that were set to make the system function properly and effectively.

Neglect is not usually mentioned in system studies. However, this metric is important in the sense of addressing the negative impacts that might occur if the system is not maintained. The following measures are considered for the neglect metric:

- Accessibility
- Accountability
- Availability

- Cost
- Knowledge transfer
- Responsibility

Safety

Safety is a metric for the lack of risk, danger, or potential hazard to humans, equipment, materials, environment or other property, that is imposed on any asset or system of assets in the sustainable systems, as a result of their nature, maintenance status, or design parameters.

Safety is an important metric in order to reduce the risk on the life and health. Additionally, other stakeholders need to decrease their liability in the event of an accident. The following measures are considered for the safety metric:

- Accessibility
- Accountability
- Availability
- Cost
- Impacts
- Responsibility
- Vulnerability

Security

Security is a metric of the level of protection that is provided to the sustainable system assets, including personnel, data, and equipment, keeping them from harm, threat, unauthorized access, misuse, or corruption, that would affect their integrity, confidentiality, or safety.

Security used to be an issue that was dealt with on a micro scale and was system specific. The recent 21st century global issues have made security one of the highest priorities; therefore, it has become a macro scale metric. The following measures are applicable to the security metric:

- Accessibility
- Accountability
- Availability
- Cost
- Responsibility
- Vulnerability

CONCLUSIONS

The described framework that the Sustainable Decision Analysis System (SDAS) is based upon has been modified and fine tuned for environmental problems, specifically for urban water resources and drainage systems. This system is a modification of a successful enterprise framework in industry and information systems and it is a valuable tool from another discipline that will be valuable when applied to environmental problems. The developed system is very flexible and can be modified according to the project. Stakeholders will gain a comprehensive outlook for the water and/or drainage system problems under consideration.

FUTURE WORK

Future work consists of putting the Sustainable Decision Analysis System into action. Several example problems from different communities around the world will be studied and analyzed using the SDAS. The first issue being studied is the arsenic problem in Far East Asia, such as in Bangladesh. This example examines candidate sustainable solutions for such a devastating problem that would suit the community under study.

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