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System-based decision trees for the selection of sanitation technologies

A. Ramôa, J. Matos & C. Lüthi (Portugal)

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Decision trees, also called algorithms, provide a systematic and transparent representation of the decision process. Existing algorithms applied to the sanitation sector are either too simple, failing to consider the entire sanitation chain, or excessively complex, leading to counterproductive results. This work presents simplified decision trees to support the selection of sanitation technologies compatible with the local context while, at the same time, it helps to guarantee the required technical compatibility along the sanitation supply-chain, i.e., from the interface to the final destination of products.

Introduction

Informed decision-making is increasingly important if the intended purpose of sanitation interventions is to be achieved. Available information is vast but sometimes insufficiently coherent to effectively support decisions, which is hampered by the common lack of expertise of decision-makers (Mara et al., 2007) and the diversity of interrelated sanitation processes and waste streams (Maurer et al., 2012).

Different decision support tools have been developed, such as frameworks, checklists, models, toolkits and software programmes (Tornqvist et al., 2008). One of the ways of modelling decisions is through the use of decision trees, also called algorithms, which represent an organized list of guided questions leading the user to a logical solution to a problem (McGuire et al., 2005). Among other advantages, decision trees provide a systematic and transparent visual representation of the decision process.

The first algorithms for technology selection in sanitation were developed by Kalbermatten et al. (1982), Winblad and Kilama (1985), Franceys (1991) and Mara (1996). More recently, Fenner et al. (2007) has applied a decision tree for disaster-relief situations, Mara et al. (2007) have incorporated more recent sanitation technologies, and Thye et al. (2011) have focused on emptying technologies. Nevertheless, these tools do not completely reflect the real complexity of taking sanitation decisions. In particular, they offer guidance for the selection of a single element (e.g. septic tank or pit latrine, or just an emptying technology), rather than considering the sanitation system as a whole (Castellano et al., 2011). This is believed to be insufficient because benefits from sanitation are undoubtedly more effective when the interface, conveyance, treatment and disposal/reuse of generated products are collectively taken into account (Maurer et al., 2012). Buuren (2010) appears to be the only reference considering the entire sanitation-chain when developing a decision tree. However, it turns to be too complex and therefore possibly counterproductive.

This work presents simplified system-based decision trees to support a preliminary selection of appropriate sanitation technologies taking into account the whole sanitation system. Therefore, it is expected to help guarantee the technical compatibility along the sanitation supply-chain and the accomplishment of higher sanitation benefits, namely regarding health and environmental aspects.

Definition of sanitation systems

The use of the system concept is a suitable way of considering the entire sanitation-chain. A sanitation system comprises a set of technologies dealing with human excreta and wastewater, along different functional groups: user interface, collection, conveyance, treatment and disposal/reuse (Tilley et al., 2014).

The number of all possible combinations of technologies from different functional groups is considerably high, and a lot of them cannot even coexist in the same system. For this reason, Maurer et al. (2012) applied a compatibility-based procedure to eliminate dysfunctional sanitation systems. Tilley et al. (2014) have defined "System Templates", which represent commonly-found compatible combinations of technologies. Finally, Buuren (2010) has defined 12 systems divided into 58 options, differing, e.g., in the need for sewage pumping or the application of enhanced storage capacity of sewers. This last system disaggregation is believed to be too complex for undertaking preliminary technical decisions. Therefore, the systems defined in this paper (Table 1) expand and/or disaggregate the templates from Tilley et al. (2014), thus guaranteeing the following advantages: a) the compatibility between technologies is more easily ensured; b) the number of systems is reasonable; c) considered technical solutions are adequate to developing countries.

Table 1. Main characteristics of defined sanitation systems

System Code	Type of Interface & Collection	Technologies along the supply-chain		Template (Tilley et al., 2014)
		Interface & Collection	Transport, Treatment & Disposal/Reuse	
I_{on}	Single and simplified (dry)	Dry toilet + single pit / single ventilated improved pit latrine (VIP)	When the pit is full, it is filled with soil and a tree can be planted above. No need for transport or treatment.	1
I_{off}			Sludge needs to be removed and transported using a human- or motorized-power technology for further treatment. Use/disposal is needed for treated sludge and for treated effluent.	
II_DVIP_{on}	Double or composting chamber (dry)	Dry toilet + double VIP	Generated pit humus/compost has undergone some level of treatment in the collection step, so it is to be manually removed directly for use/disposal. If the system is off-site ("off"), there will be also the need to transport the products from the collection step to the final site of disposal or reuse.	2
II_DVIP_{off}				
II_FA_{on}		Dry toilet + Fossa alterna		
II_FA_{off}				
II_CC_{on}		Dry toilet + composting chamber		
II_CC_{off}				
III_{on}	Diverted (dry)	Urine diverting dry toilet + vaults and tank	Resulting dried faeces and urine have already undergone some level of treatment. Dried faeces are to be manually removed (and transported, in case of off-site" systems) to further application or disposal. For the urine, if the system is on-site ("on"), it is to be locally applied; if off-site ("off"), urine can be applied after being emptied and transported to final location.	4
III_{off}				
IV	Single and simplified (wet)	Pour flush toilet + single pit / single VIP	Same as I_{off}.	1
V_{on}	Double (wet)	Pour flush toilet + twin pits	Same as II.	3
V_{off}				
VI_{on}	Single with further treatment (wet)	Pour flush toilet /cistern toilet + Septic tank / anaerobic baffled reactor / anaerobic filter	Effluent is locally discharged. Latrine/toilet needs to be emptied and sludge transported off-site for further treatment before disposal/reuse.	6
VI_{off}			Same as VI_{on}, except that the effluent is conveyed to an off-site location to be treated.	7
VII	None (wet)	Pour flush toilet / cistern toilet	Blackwater is conveyed and treated before final disposal/reuse.	8
VIII	Diverted (wet)	Urine diverting flush toilet	Brownwater follows the same path that blackwater in VII. Urine tank is emptied before final application.	9
IX	Biogas reactor(wet)	Pour flush + biogas reactor	Sludge is preferably used on-site due to high volume and weight. Produced biogas can also be used.	5

Two main factors differentiate defined systems: i) the water dependency (dry systems include systems I, II and III, while water-based systems range from IV to IX); and ii) the type of technology at the interface & collection. In particular, as System II greatly varies in terms of the technical requirements of possible technologies at the interface & collection, this System was further divided as follows: double ventilated

improved pit latrine (II_DVIP), Fossa Alterna (II_FA) and composting chamber (II_CC). A final distinction applies to systems I, II, III, V and VI, which relates to the localised or decentralised use/disposal of the generated products, and results in the division between "on-" and "off-site" systems.

The distinct characteristics of systems, namely the potential for resource recovery, the required soil permeability, the inputs required for the functioning of the systems, the access needed for desludging, among others, were used as a basis for formulating the questions posed in the algorithm presented below in order to support the identification of systems and related technologies appropriate for a certain context.

A system-based decision algorithm for technology selection

The methodology developed here intends to allow a preliminary assessment of sanitation systems. It is to be used as part of a planning process, e.g., Sanitation 21 (Parkinson et al., 2014), being relevant when sanitation technologies are to be selected. Although representing a simplified approach, detailed knowledge of the local situation is crucial for the application of the methodology. It comprises three main steps:

1. Systems that are potentially compatible with the existing situation are identified (this decision is to be based on the selection algorithm presented below);
2. Identified systems need to be further detailed by iteratively selecting technologies from each required functional group, i.e., from the collection to the final disposal/re-use of generated products;
3. For each identified system, post-selection questions are to be answered so that selected alternative systems are narrowed down, and most preferable ones are ranked.

This work is mainly focused on step 1, which is supported by the algorithm presented below. Decisions to be taken in step 2 may be guided by the brief explanation of systems found in the column "Technologies along the supply-chain" in Table 1, and complementary, by consulting the existing literature on sanitation technologies. Finally, this work also provides some guidance for undertaking step 3.

1. The decision algorithm

This algorithm aims at identifying appropriate systems for the situation under analysis. It is to be used as a check for certain aspects in order to better guarantee that selected systems are technically adequate. It starts by investigating the water consumption level and the greywater disposal method (Figure 1). This allows determining whether appropriate systems are waterless or water-based. The second key consideration is an issue increasingly reflected in literature: the need to design sanitation solutions with resource recovery in mind to maximize the use of resources (e.g. nutrients, water, energy), as well as to ensure that technologies are not over- or under-designed to achieve the appropriate level of treatment (Strande et al., 2014). Therefore, the algorithm provides suggestions on which type of systems to look for according to enduses of final products. However, it is important to note that if the user is not interested in the recovery of a particular product, it does not mean that the system is inappropriate. For instance, Systems II, which results in the production of pit humus which can be used as soil conditioner, may be a feasible option even if there is no interest in the use of this product for agriculture, as humus might end up being just disposed of in the field.

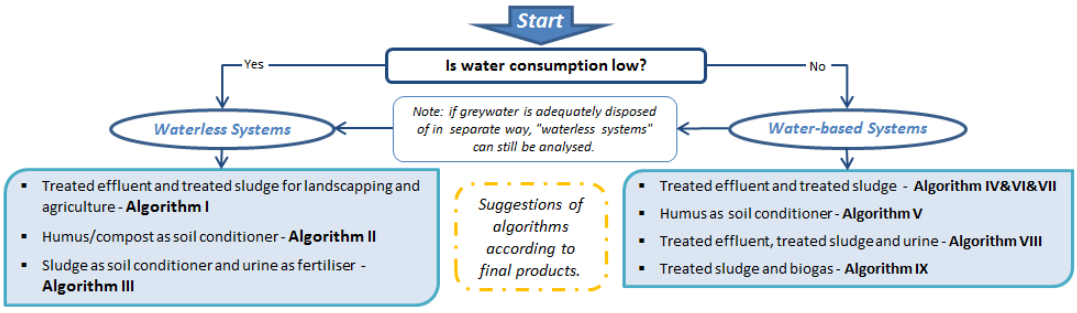

Figure 1. Starting point of the decision algorithm

For simplicity reasons, and according to the suggestions obtained from Figure 1, the decision algorithm is further divided into parts to which the user is directed to (Figure 2). The names of these parts relate to the numbering of systems from Table 1. Each part contains a series of boxes with questions, whose answers ("yes"/"no") enable the user to identify feasible options. When there is more than one question in a box (each represented by a bullet), an affirmative answer to all of the questions is needed to continue with the option "yes". Also, thresholds are not defined because this is a preliminary assessment which does not intend to go into much detail on the technical aspects of the different solutions. Finally, when a "re-think" point is reached, the user is advised to re-think about solutions, e.g., finding ways of transporting sludge which are, at the present, not available. If solutions are not identified, the user should be directed back to the starting point (Figure 1) to consider other systems for selection. For example, in a neighbourhood with low water consumption, appropriate systems are waterless (I, II or III). If using digested sludge as soil conditioner is culturally acceptable, one can start analysing Algorithm II, for instance. The first question is whether sludge can be manually collected in an adequate way. If that is not presently the case because people performing this activity do not have good working conditions, the algorithm reaches the option "Re-think". This means that it may still be possible to identify ways to improve those working conditions. If for some reason that is not possible, the planner should try another Algorithm. Imagining the soil is appropriate for digging pits and for absorbing the leachate, groundwater level is low and that space is enough for digging new pits, System I_{on} can be considered an appropriate alternative. Then, Algorithm III should also be tried. After checking all possibly adequate systems, the next steps correspond to selecting the technologies for each required functional group (from interface to disposal/re-use) and then answering the post-selection questions in order to further define the appropriateness of identified alternatives.

2. Post-selection questions

It is also proposed in this methodology, in the third step, that a set of questions are asked as final checks of the preliminary assessment in order to further eliminate inappropriate alternatives. These post-selection questions are required when assessing every single system, the reason why they are presented in this step, rather than being included in the decision trees above. The questions are the following:

- is the system environmentally compliant, e.g. regarding existing regulations?
- is it technically appropriate, e.g. concerning existing knowledge and capacities?
- is it financially viable in the long-term?
- is it socially acceptable?
- is it institutionally appropriate and/or is the private sector able to provide services along the supply-chain?
- does the existing infrastructure belong to one of the possible alternatives? (this might be an important point because it makes use of investments that have already been taken)
- are there synergies or special concerns related to stormwater and sanitation systems?
- are dry cleansing materials and/or anal cleansing water adequately disposed of in the systems (in some cases they may shorten the life of the pits, make them difficult to empty or hinder treatment processes)

Answering these questions will also eventually help to rank alternative systems in order of preference.

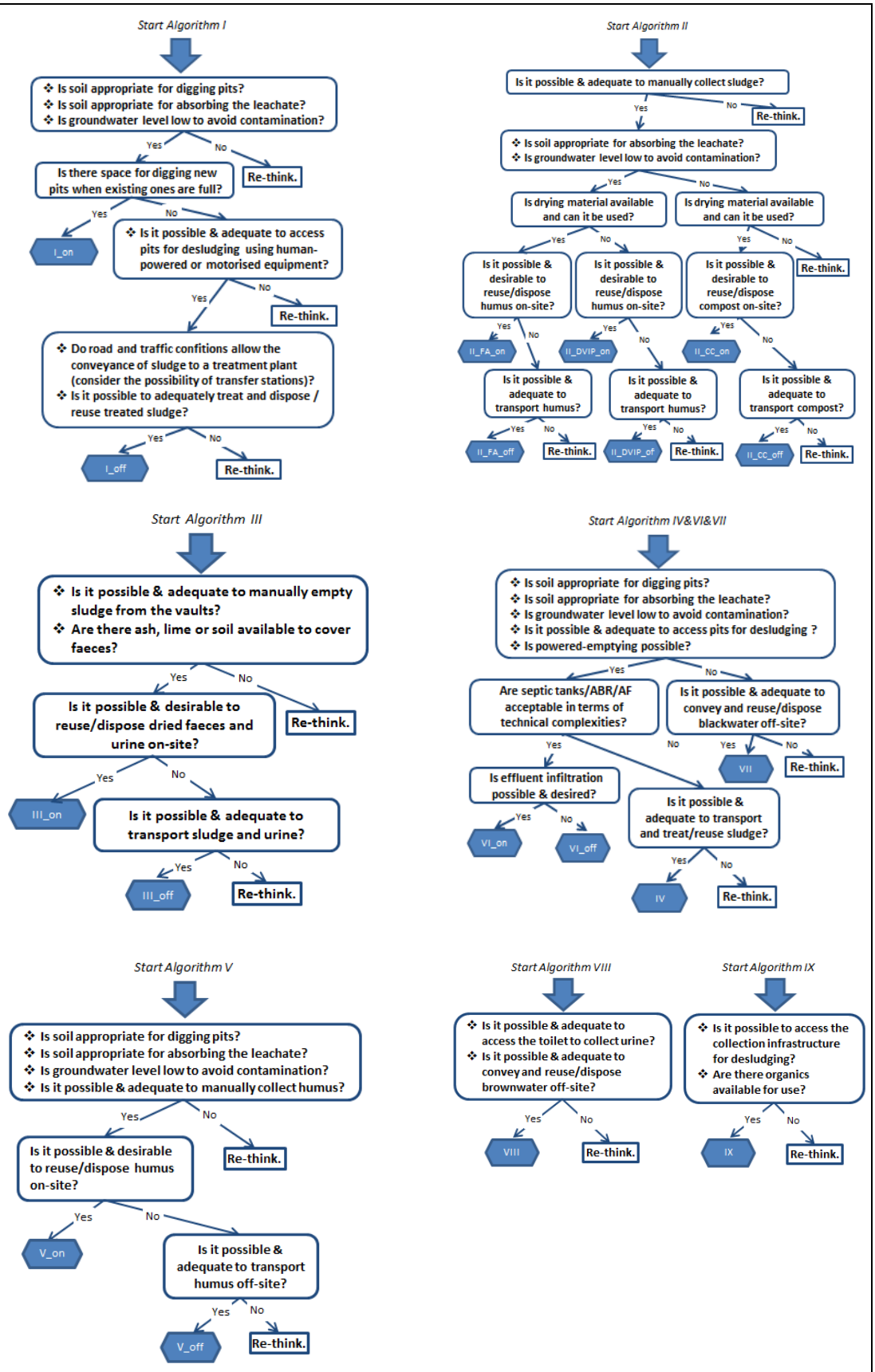

Figure 2. Algorithms pertaining to the system-based methodology

Final considerations

This paper has presented a system-based decision-making methodology for the selection of sanitation technologies in order to support planning processes. As other previously-developed decision trees, it does not intend to replace engineering judgments but rather facilitate transparent decisions.

In particular, this methodology is believed to present distinct advantages over previous works. Firstly, the application of the system concept into decision algorithms provides a simplified and more comparable approach to consider the whole system chain, from the interface to the final destination of sanitation products, while excluding combinations of technical solutions which are unfeasible. Secondly, the methodology intends to ensure that every sanitation solution complies with site-specific conditions, while prompting the planner to consider the end-products and their corresponding final uses. Finally, decision trees are sometimes criticised because they deal with absolute answers that may not correspond to the complex reality. Conversely, questions here do not intend to simply exclude solutions but rather to help understanding what is needed for a system to be compatible with the current situation, which may imply, for example, modifications in financial frameworks, management procedures or awareness raising. Therefore, the methodology may be used not only to identify potential systems, but also to determine what is needed to complement existing ones and thus provide better sanitation services.

Summing up, this methodology intends to represent a simplified way of exploring comprehensive sanitation technological solutions which are adequate to local specificities. Based on the local knowledge of each situation, it is then expected that the application of this tool will help planners to know what questions to ask to eliminate unfeasible technology combinations and to select the potential alternatives systems for further discussion from the point of view of the entire sanitation supply-chain.

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Contact details

Ana Rita Ramôa, José Saldanha Matos
Instituto Superior Técnico, University of Lisbon
Av. Rovisco Pais, 1, 1049-001 Lisbon,
Portugal
ana.ramoa@tecnico.ulisboa.pt;
jose.saldanha.matos@tecnico.ulisboa.pt

Christoph Lüthi
Department for Water and Sanitation in Developing Countries (SANDEC), Eawag
Eawag, P.O. Box 611, 8600 Dübendorf,
Switzerland
christoph.luethi@eawag.ch