Decision Support for Selection of Food Waste Technologies at Military Installations

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Abstract

The selection of an appropriate technology for waste management in a way that enhances sustainability is a complex problem requiring information from multiple disciplines. This decision is made more complex for large, diverse organizations for which individual sites or components have different requirements and capacities for waste management. For U.S. Army installations, sustainable waste management is a major obstacle for resource constrained and overburdened installation personnel. The Army has prioritized landfill diversion at installations; there is a significant push for each installation to develop and implement waste management plans that follow high-level goals set by U.S. Army Installation Management Command (IMCOM). The main objective of this study is to demonstrate an excel-based dashboard tool incorporating Multi-Criteria Decision Analysis (MCDA) for site-specific waste management technology selection. The dashboard uses the preferences of an installation and a series of weighted metrics to evaluate technologies. With this information the dashboard can rank the technologies to identify those that simultaneously meet IMCOM's objectives and are appropriate for specific sites' capabilities and resources. Fourteen different technology makes and models were compared in this version of the decision model including dehydrators, pulpers, garbage disposals, containerized in-vessel composting, windrow composting, forced-air static composting, and containerized anaerobic digestion. MCDA provides for transparent comparison of technologies for all sites, and the dashboard visualizes the level of appropriateness of each technology for each site. The approach developed here adds value in that it utilizes the priorities of the organization and identifies the best performing waste management technology given the specific capacity and capabilities of an individual site.

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43 Keywords: Multi-Criteria Decision Analysis, Food waste, Sustainability, U.S. Army,

44 Technology selection

1. Introduction

Selection of a waste management technology is a complex issue because of two major aspects. Firstly, it requires consideration of information and analysis from several different disciplines, namely economics, supply management, engineering, physics, and chemistry. Secondly, selection requires communication and understanding of different perspectives from within an organization from suppliers to handlers, and safety officers to management. A recent review of MCDA in the development of industrial waste management approaches internationally (Khalili and Duecker 2013) shows how the objectives of these systems have become increasingly complex over recent decades. Babalola (2015) conducted a study to evaluate different treatment options for large volumes of food and organic waste and their suitability for Japan using MCDA. Similarly Mir et al. (2016) used MCDA to compare and rank 11 Municipal Solid Waste treatment method scenarios for Malaysia environmentally and economically. Decision analysis, therefore, has been widely advocated and implemented as a means to provide a transparent analysis and a way to consider and reconcile different perspectives in the selection of waste management (Morrissey and Browne 2004). Stakeholder engagement utilizing multi-criteria decision analysis (MCDA) to support municipal solid waste management has been reported to facilitate communication, evaluate conflicts and support the ranking of different strategies (Soltani et al. 2015). The approach presented here furthers the application of decision analysis to waste management in that it allows an institutional perspective to be implemented across different sites with different capacities and capabilities.

Consider the added complexity of selecting a waste management technology for a large diverse institution. The institution itself may have priorities that it would like to implement across the organization. However, components of that institution are likely to have different constraining factors and capacities to select a technology. One site may be limited in financial resources, another in the availability of land and a third in the capacity of personnel to dedicate to sorting or processing food waste. For large, diverse organizations, therefore, the selection of a waste management technology must include additional considerations. A selected technology must meet specific institutional goals; however, the same technology is not likely to be appropriate at every site across the entire organization. As sites vary in their access to resources such as water, electricity, space, or personnel, the selection of a technology must comply with the site's capacities. As an example, some United States (U.S.) Army installations consist of a few buildings for a small National Guard unit while others support populations of over 100,000 (Hemmerlybrown, 2011; Harmon, Goran & Harmon, 2014).

In the U.S., large governmental organizations struggle with the management of food waste. U.S. EPA studies show that food waste alone constitutes 14.5 percent of non-hazardous U.S. municipal solid waste (MSW), and when all compostable waste materials are considered, that number increases considerably (2013). The U.S. Army is an organization responsible for feeding a large and highly variable population. Although the locations of its installations vary in size, resources, and climate, the overall waste reduction and reuse goals are uniform for the entire organization. Moreover, waste management technology selection is a critical issue for the U.S. Army due to progressive sustainability goals such as its Net Zero Initiative announced in 2011.

89 These goals have happened to co-occur with foreseen reductions in financial and labor resources
90 within the military (Foster, 2011; IMCOM, 2011). U.S. Army Installation Management
91 Command (IMCOM) handles the day-to-day operations of U.S. Army installations domestically
92 and abroad. Installations are required to adequately feed their soldiers and thus must provide
93 food in excess (Medina et al., 2014). Training activities can create weekly variations in
94 population, further exacerbating the oversupplying of food and the resulting food waste
95 (Holsinger, 2011). Although installation-specific rates of organic and food waste generation are
96 variable, Fort Polk's dining facility was reported to generate 40 percent of the installation's
97 MSW in 2000 (Holcomb et al. 2008). A 2007 analysis of data from the Army's Solid Waste
98 Annual Report System [SWARS] Database, shows that collectively 18.9 percent of all solid
99 waste from installations is organic waste (Holcomb et al 2008).

100
101 Currently food waste management technology selection at Army installations is performed by
102 installation personnel without much guidance or a clear set of evaluation parameters; developing
103 a more effective and transparent method for technology selection is an important goal for
104 IMCOM decision makers (Foster, 2011; IMCOM, 2011). To address this issue, a dashboard tool
105 was developed where proposed technologies can be evaluated using MCDA to compare the
106 relative utility of different alternatives along multiple criteria by specifying the utility function
107 and the tradeoffs between criteria (Belton and Stewart, 2002). The value MCDA provides for
108 transparent, integrated evaluation of alternatives and quantitative trade-offs between objectives
109 (Howard, 1988; Keeney and Raiffa, 1976) has led to its wide application in many fields (Linkov
110 and Moberg, 2011; Ferreira, Santos, & Rodrigues, 2010; Tony et al., 2011). MCDA is often used

in technology selection including waste management processes (Soltani et al. 2015; (Khalili and Duecker 2013)).The dashboard tool provides a means to consider and visualize both the broader organizational priorities and the capabilities of an individual site in order to gauge a technology's suitability.

This paper presents the design, function, and initial implementation of the dashboard decision support tool to aid U.S. Army Installations in the selection of food waste management technologies. The goal of the dashboard was to display both the relative utility of each technology according to management objectives, as well as the proportion of criteria that fall outside the range that can be accommodated at a specific site. As an initial sensitivity analysis, three scenarios representing installations with different constraints were processed through the dashboard. The U.S. Army installation of Fort Hood, TX,was used as a case study because results from a previous food waste management feasibility study were available for comparison.This application, therefore focuses on the US. Army; however the approach for determining the feasibility of different technologies at a specific site according a larger organization perspective would support many hierarchical organizations outside the government.

2. Methods

This approach was developed to enable the consideration of both the priorities of the sites' overarching organization as well as the capabilities and limitations of a specific site. In the con-

text of the U.S. Army, a hierarchy of objectives, criteria, and metrics were identified to capture what IMCOM and installation Waste Managers hope to achieve through use of a food waste management technology (U.S. Department of the Army, 2011). This hierarchy consisted of five objectives, 35 criteria, and 55 metrics (Fig.Figure1). The objectives' hierarchy formedthe basis for the quantitative evaluation of different technologies. Criteria decompose each objective into its constituent parts, and wereevaluated only within the context of their parent objective. Metrics under each criterion are measurable properties that characterize part of the system and wereused to quantify and compare the performance of the technologies.

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Figure 1. Hierarchy of objectives, criteria, and metrics used to capture the organizational perspective for the use of food waste management technologies. Criteria are listed below each objective, and metrics below each criterion. The structure of the decision model is based off this hierarchy.

A range of alternative technologies were compared by the dashboard via their evaluation over each of the 55 metrics by subject matter experts. For the purpose of this study, IMCOM selected 14 technologies for comparison of their ability to reduce food waste weight and volume and to repurpose waste. The technologies selected included several models of dehydrators, two models of pulpers, an in-vessel composter, an anaerobic digestion system, and windrow and forced air composting systems. In addition, two business-as-usual food waste disposal scenarios were considered, an industrial garbage disposal and landfill disposal; neither of these options diverts any percentage of food waste from landfills. Field experience, manufacturer information, as well as knowledge of technology implementation and operation at U.S. military installations were used to score each alternative for every metric in the hierarchy.

For the dashboard, metrics were also connected to the capacity of a specific installation to accommodate a technology. To ascertain installations capabilities and limitations, installation personnel were asked to fill out a pre-interview document and contacted for an in-person interview. The pre-interview document consisted of 30 “yes” or “no” questions that align to each metric, and were designed to identify areas of constraint for the installation. Pre-Interview questions which received a “no” answer were followed-up on at the in-person interview. Upon completion of the interview, a site’s capabilities and limitations were reflected in the

development of a green, yellow, and red range for each metric (Figure 2). The “green” range for a metric question reflected that the site would be comfortable in committing that level of resource or accommodating that consequence of implementing a new technology. The “yellow” range reflected that the site would be able to commit that level of resource or accommodate that consequence of implementing that technology, if necessary. The “red” range reflects that the site would not be able to commit that level of resource or accommodate that consequence of implementing the technology.

Criteria: Processing/Retention	Processing/retention notes how long it takes to process waste			
Metric: Time	Time refers to whether food waste will be processed the day it is generated, over an extended period of time, or not at all			
3	Food waste is not processed	Red		
2	Food waste is processed over an extended period of time	Yellow	2	2
1	Food waste is processed the same day it is generated	Green		

Figure 2. Example of capabilities and limitations of an installation for metric reflected by “green,” “yellow,” and “red” ranges. Note that the installation cannot accommodate a technology that does not actually process food waste (i.e. the landfill). The installation can accommodate a technology that processes waste over an extended period of time (i.e. windrow composting), if necessary. However, a technology that can process waste the same day it is generated would be preferred (i.e. dehydrator).

Each of the objectives, criteria, and metrics were weighted to reflect the high-level priorities of the organization for which the dashboard was used. The weights were set using a modified "SMARTER" (Simple Multi-Attribute Rating Technique Exploiting Ranks) approach (Edwards and Barron, 1994). SMARTER is a modified swing-weighting technique allowing the decision maker to identify the objective that is the most important to them and weigh the other objective

relative to that one (Belton and Stuart 2002; Riabacke et al. 2012). In this approach, an organization respondent assigned an importance score of 100 to the top ranked objective and determined the importance of the other objectives relative to that objective. This process was repeated for the criteria under each objective, and the metrics under each criterion. Equal weighting among objectives, criteria, and metrics was allowed, as were weights of zero. Normalized weights summing to 100% were calculated preserving the ratios of importance between objectives, criteria or metrics. Initial weights were selected for IMCOM to reflect the Army's Net Zero goals. Although various MCDA methodologies have been utilized for different applications, the top performing alternatives are likely to be conserved across methodologies (Huang et al. 2011).

Once the technologies performance was evaluated, the relative weights set, and the installations capabilities and limitations gauged, data was entered into the dashboard and utilized by the tool's MCDA algorithm. The utilized approach was Multi Attribute Utility Theory (MAUT; Keeney and Raiffa 1976; Wallenius et al. 2008). Although different MCDA approaches have been utilized to identify waste management solutions (Achillas et al, 2013), MAUT is an appropriate technique to determine the overall utility of each alternative (Linkov and Moberg 2012). For simplicity, the value of each metric was assumed to increase linearly with the performance score (i.e. value functions were linear-additive) for each objective, criterion, and metric. The algorithm calculated each technology's utility as a product of that technology's relative performance, and the weights applied to each metric. The total utility, $y(i)$, for a technology, i , was calculated as Equation(1) (Neumann & Morgenstern, 1944):

$$y(i) = \sum_{m=1}^M w_m z_i \quad (1)$$

where M was the number of possible metrics on which technology i can be evaluated, w_m was the relative importance weight specified for each metric and m is an index of metrics such that $1 \leq m \leq M$, and z_i was the performance score of technology i on metric m . The performance of each metric was considered over a local scale based on the minimum and maximum performance of the technologies evaluated on each specific metric.

The dashboard allowed for the visualization of the MCDA results with a series of tables evaluating the technologies performance over each objective, criterion, and metric. The main table was a summary table (Figure 3), where column one listed the technologies evaluated. Columns two and three show two color displays, the first shows the color (red, yellow, or green) that corresponds to the color range where the highest proportion of metrics fell (MAX). The second display used color mixing to show the color associated with the average across the three color ranges (AVG). Columns four, five, and six gave the proportion of the metrics that fell into each color range (R = red, G = green, Y = yellow) for the installation. The seventh column gave the overall MCDA score for the technology generated over all the objectives, criteria, and metrics. By sorting this table first by lowest proportion of metrics in the red range, and then by the overall MCDA score, a ranking of technologies that were most appropriate and implementable for a specific site was developed, which simultaneously considers how each technology meets the high-level priorities set by the organization (the overall MCDA score). For

example, in Figure 3, Technology 8 had 50% percent of its score in the red range, 25 percent of its score in the yellow range, and 25% of its score in the green range; the MAX color for the technology was red and the AVG color was orange. Although the outcomes are designed to inform installation waste management personnel, the tool was not designed to be distributed; the interface was, therefore, not evaluated and refined following user feedback.

Alternative Name	Max.	Avg.	R	Y	G	Score
Technology 1			0.000	0.000	1.000	1.00000
Technology 2			0.000	0.250	0.750	1.00000
Technology 3			0.500	0.000	0.500	0.27083
Technology 4			0.000	0.500	0.500	0.93750
Technology 5			0.000	1.000	0.000	0.33333
Technology 6			0.250	0.750	0.000	0.33333
Technology 7			0.500	0.500	0.000	0.00000
Technology 8			0.750	0.250	0.000	0.00000
Technology 9			0.750	0.000	0.250	0.33333
Technology 10			1.000	0.000	0.000	0.00000

Figure 3. Screenshot of an example dashboard results summary table showing how the MAX and AVG colors are a mix of the proportion of the metrics that fall into each color range (R, Y, G).

3. Results and Discussion

The results of the dashboard ranked each technology according to its level of suitability for the needs of a specific site while also considering management level priorities and goals. As a sensitivity analysis of the selected weights, three scenario installations were developed each designed to be constrained in the application of resources for waste management in a different way. The scenarios were labeled Fort No-Land, Fort No-Money, and Fort No-Water to reflect

limited availability of space, financial resources and water, respectively, for implementation of food waste diversion. Some of the key differences in the installations capabilities under each of these scenarios are listed in Table 1. The same objective, criteria and metric weights were used all three scenarios, and are reported in TablesTable 2-6.

Table 1: Major constraint differences for three scenario installations.

Metric	Fort No-Land	Fort No-Water	Fort No-Money
Land Available	¼ acre	10 acres	10 acres
Volume of Water Acceptable to Process Waste	High	Low	High
Water Sources Permissible for Use	Potable or Non-Potable	Non-Potable	Potable or Non-Potable
Cost of Electricity Affordable Annually	\$3,000-\$7,000	\$3,000-\$7,000	\$2,000-\$5,000
Highest Capital Cost Affordable	\$1,000,000	\$1,000,000	\$150,000

Table 2:Weights for the Human Capital Objective, and underlying Criteria, and Metrics as percent of total score. Note that criteria and metrics with weights of 0.00% were unweighted in the model.

Objective	Objective Weight	Criteria	Criteria Weight	Metric	Metric Weight
Human Capital	8.48%	Personnel Requirement	0.57%	Full-Time Equivalent (FTE)	0.57%
				Personnel Quantity	0.00%
		Technical Expertise	0.56%	Training Hours	0.28%
				Required Certification	0.28%
		Knowledge Management	0.56%	Annual Training	0.28%
				Update Training	0.28%
				Institutional Retainment	0.00%*
		Occupational Health & Safety	5.65%	Necessary Considerations	5.65%
				Protective Measures	0.0%
		Effective Collaboration	0.57%	Chain of Command	0.0%
				On-Site Contractors and Local Community	0.57%

		Permitting Estimation	0.57%	Likelihood of Requiring a Permit	0.57%
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Table 3: Weights for the Natural Capital Objective, and underlying Criteria, and Metrics as percent of total score. Note that criteria and metrics with weights of 0.00% were unweighted in the model.

Objective	Objective Weight	Criteria	Criteria Weight	Metric	Metric Weight
Natural Capital	33.91%	Operational Space	6.52%	Land Resources	6.52%
				Mission Training Areas	0.00%
		Natural Resources	0.65%	Impact on Site (Land Clearing)	0.65%
				Impact on Natural Resource Quality	0.00%*
		Water Requirement	3.92%	Volume Water/Weight of Waste Processed	1.96%
				Type of Water Required	1.96%
		Air Quality	4.56%	Relative Risk	4.56%
				Potential for Air Emissions	0.00%
		Effluent Quality	4.56%	Relative Risk	4.56%
				Stormwater Impacts	0.00%
		Pest/Vector Management	0.65%	Risks	0.65%
				Required Counter Measures	0.00%
		Residual Material Generation	5.88%	Solid	1.96%
				Liquid	1.96%
				Hazardous	1.96%
		Climate/Weather Issues	0.65%	Sensitivity of Technology to Weather Conditions	0.65%
				Potential Risk due to Extreme Weather Events	0.00%
		Utilization of Created Energy	6.52%	Potential for Recoverable Energy	6.52%

Table 4: Weights for the Built Capital Objective, and underlying Criteria, and Metrics as percent of total score.

Objective	Objective Weight	Criteria	Criteria Weight	Metric	Metric Weight
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Built Capital	10.14%	Mobile Infrastructure	1.60%	Equipment	0.70%
				Generator Needs	0.36%
				NTV Use	0.54%
		Fixed Infrastructure	0.54%	Building Construction	0.27%
				Road Construction	0.0%
				Rail or Distribution Network	0.0%
				Sanitary Sewer	0.27%
		Re-Purposed Infrastructure	0.53%	Utilities	0.53%
		Computerized Capability	0.53%	Capacity	0.53%
		Electricity Required	5.35%	kWh/Volume	5.35%
		Fuel Required	0.53%	Gallons of Diesel Fuel/Ton Processed	0.53%
		Fuel Storage Needs	0.53%	Narrative	0.53%
		Maintenance Needs	0.53%	Effort Required	0.53%

Table 5: Weights for the Financial Capital Objective, and underlying Criteria, and Metrics as percent of total score. Note that criteria and metrics with weights of 0.00% were unweighted in the model.

Objective	Objective Weight	Criteria	Criteria Weight	Metric	Metric Weight
Financial Capital	22.05%	Capital Costs	6.89%	Cost/Volume	6.89%
		Equipment Installation Costs	0.69%	Cost/Volume	0.69%
		O&M Costs	0.69%	Average Cost/Volume	0.69%
		Utility of Products	6.89%	Utility/Volume	6.89%
		Opportunity Costs	0.00%*	Capacity Limiting	0.00%
		Miscellaneous Costs	6.89%	Upgrades/Features for Operation	6.89%

Table 6: Weights for the Performance Objective, and underlying Criteria, and Metrics as percent of total score.

Objective	Objective Weight	Criteria	Criteria Weight	Metric	Metric Weight
Performance	25.42%	Throughput	3.86%	Weight/Time	3.86%

		Processing/Retention	2.25%	Time	2.25%
		Pre-Processing	3.22%	Description	3.22%
		Post-Processing	4.18%	Description	4.18%
		Waste Reduction	6.44%	Percent Waste Remaining	6.44%
		Use of Product	5.47%	Type of Product and Uses	5.47%

TablesTable 7-9 list the top ranked technologies and their respective strengths and weaknesses revealed by the analysis for each scenario installation.

Table 7: Top three recommended technologies for Fort No-Land and accompanying metrics advocating for (Technology Strengths) or against (Technology Weaknesses) the technology's selection.

#1 Technology		#2 Technology		#3 Technology	
Containerized Composting System		Dehydrators		Forced-Air Static Composting	
Technology Strengths:	Technology Weaknesses:	Technology Strengths:	Technology Weaknesses:	Technology Strengths:	Technology Weaknesses:
<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • No necessary safety considerations for operation 	<ul style="list-style-type: none"> • High O&M needs and costs • Low throughput (lbs/day) per unit • High capital cost for number of units required • Footprint within 0.25 acres, but additional space for operations required 	<ul style="list-style-type: none"> • Low O&M needs and costs • Low risk to air and effluent quality • Minimal space requirement per unit • 90% food waste volume reduction • Residual material can be used as feed for composting or anaerobic digestion 	<ul style="list-style-type: none"> • Low throughput (lbs/day) per unit 	<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • High annual throughput (lbs/year) 	<ul style="list-style-type: none"> • Requires more than 0.25 acres • Requires multiple pieces of equipment • Requires multiple FTEs • Requires one or two non-tactical vehicles (NTVs) • Requires building construction for associated composting activities

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279 **Table 8: Top three recommended technologies for Fort No-Money and accompanying metrics**
 280 **advocating for (Technology Strengths) or against (Technology Weaknesses) the technology's**
 281 **selection.**

#1 Technology		#2 Technology		#3 Technology	
Industrial Garbage Disposal		Dehydrators		Windrow Composting	
Technology Strengths:	Technology Weaknesses:	Technology Strengths:	Technology Strengths:	Technology Weaknesses:	Technology Strengths:
<ul style="list-style-type: none"> • Low capital cost • Low electricity requirement • Low risk to air quality • Minimal space requirement per unit 	<ul style="list-style-type: none"> • Does not truly divert waste but rather sends it to a waste water treatment plant • High O&M needs and costs 	<ul style="list-style-type: none"> • Low O&M needs and costs • Low risk to air and effluent quality • Minimal space requirement per unit • 90% food waste volume reduction • Residual material can be used as feed for composting or anaerobic digestion 	<ul style="list-style-type: none"> • Low capital cost • Low electricity requirement • Low risk to air quality • Minimal space requirement per unit 	<ul style="list-style-type: none"> • Does not truly divert waste but rather sends it to a waste water treatment plant • High O&M needs and costs 	<ul style="list-style-type: none"> • Low O&M needs and costs • Low risk to air and effluent quality • Minimal space requirement per unit • 90% food waste volume reduction • Residual material can be used as feed for composting or anaerobic digestion

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284 **Table 9: Top three recommended technologies for Fort No-Water and accompanying metrics**
 285 **advocating for (Technology Strengths) or against (Technology Weaknesses) the technology's**
 286 **selection.**

#1 Technology		#2 Technology		#3 Technology	
Forced-Air Static Composting		Windrow Composting		Containerized Composting System	
Technology Strengths:	Technology Weaknesses:	Technology Strengths:	Technology Strengths:	Technology Weaknesses:	Technology Strengths:
<ul style="list-style-type: none"> • 100% waste conversion to 	<ul style="list-style-type: none"> • Requires multiple 	<ul style="list-style-type: none"> • 100% waste conversion 	<ul style="list-style-type: none"> • 100% waste conversion 	<ul style="list-style-type: none"> • Requires multiple 	<ul style="list-style-type: none"> • 100% waste conversion to

high value compost • Low electricity requirement • High annual throughput (lbs/year)	FTEs	to high value compost • Low electricity requirement • High annual throughput (lbs/year)	to high value compost • Low electricity requirement • High annual throughput (lbs/year)	FTEs	high value compost • Low electricity requirement • High annual throughput (lbs/year)
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289 For a land constrained installation such as Fort No-Land, the containerized composting
290 system and forced-air static composting technologies ranked higher than one would expect
291 because they require a significant commitment of land (Figure 4). However, the Land Resources
292 metric is only one of 55 metrics and accounts for only 6.5% of the total score. While forced-air
293 static composting did perform very highly, its land requirement exceeds the land availability of
294 Fort No-Land and thus it is not a feasible technology for an installation such as Fort No-
295 Land. Windrow composting performed much worse than forced-air static composting, because
296 the latter can process almost six times as much food waste per acre of land available.

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Alternative Name	Max.	Avg.	R	Y	G	Score
Containerized Composting System			0.046	0.166	0.788	0.69852
Dehydrator Company 2 (~800lb Capacity Model)			0.080	0.189	0.731	0.66884
Dehydrator Company 2 (~525lb Capacity Model)			0.080	0.189	0.731	0.66592
Dehydrator Company 2 (~300lb Capacity Model)			0.080	0.242	0.677	0.65611
Dehydrator Company 1 (~250lb Capacity Model)			0.080	0.242	0.677	0.65023
Dehydrator Company 1 (~650lb Capacity Model)			0.080	0.242	0.677	0.64199
Force-Air Static Composting			0.081	0.328	0.592	0.54342
Industrial Garbage Disposals			0.084	0.291	0.625	0.55271
Pulper (1250lb/hr Model)			0.126	0.245	0.629	0.56419
Pulper (1000lb/hr Model)			0.126	0.299	0.575	0.54554
Dehydrator Company 2 (~125lb Capacity Model)			0.134	0.189	0.677	0.62446
Windrow Composting			0.193	0.259	0.548	0.54142
Landfill/BAU			0.256	0.134	0.610	0.57573
Containerized Anaerobic Digestion System			0.301	0.074	0.625	0.46928

Figure 4. The overall ranking of technology alternatives is shown for Fort No-Land in a screenshot from the dashboard. Results are sorted from lowest “R” (percent of scores in the red-range) to highest “R.”

For a financially constrained installation like Fort No-Money, garbage disposals perform very well in terms of capital cost and electricity costs (Figure 5). If an installation is more concerned with finances than diverting food waste the selection of a garbage disposal may be appropriate. In comparison, windrow composting has a very high capital cost but confers financial strengths. Windrow composting requires low or near zero annual electricity costs. It generates a high value product that can be sold or used by the installation. It also reduces

landfill tipping fees and transportation costs incurred in sending food waste to a landfill. When a site produces a large volume of food waste, windrow composting has an economy of scale advantage over technologies such as dehydrators or pulpers.

Alternative Name	Max.	Avg.	R	Y	G	Score
Industrial Garbage Disposals			0.082	0.297	0.621	0.52268
Dehydrator Company 2 (~800lb Capacity Model)			0.155	0.179	0.666	0.66757
Dehydrator Company 2 (~525lb Capacity Model)			0.155	0.179	0.666	0.66496
Dehydrator Company 2 (~300lb Capacity Model)			0.155	0.179	0.666	0.65551
Windrow Composting			0.180	0.174	0.645	0.55687
Force-Air Static Composting			0.193	0.173	0.635	0.57375
Dehydrator Company 2 (~125lb Capacity Model)			0.208	0.126	0.666	0.62402
Containerized Composting System			0.219	0.013	0.769	0.69795
Landfill/BAU			0.242	0.140	0.618	0.57573
Pulper (1250lb/hr Model)			0.262	0.242	0.496	0.53007
Pulper (1000lb/hr Model)			0.262	0.242	0.496	0.51824
Dehydrator Company 1 (~250lb Capacity Model)			0.277	0.132	0.590	0.64977
Dehydrator Company 1 (~650lb Capacity Model)			0.277	0.132	0.590	0.64114
Containerized Anaerobic Digestion System			0.346	0.051	0.603	0.43812

Figure 5. The overall ranking of technology alternatives is shown for Fort No-Money in a screenshot from the dashboard. Results are sorted from lowest “R” (percent of scores in the red-range) to highest “R.”

As an installation with constraint on its water resources, the dashboard's output for Fort No-Water reflects the technologies that require the least amount of water as the most appropriate, specifically forced-air static composting, windrow composting, and containerized composting system. These technologies had the lowest number of metrics in the red range (Figure 6).

Alternative Name	Max.	Avg.	R	Y	G	Score
Force-Air Static Composting			0.006	0.262	0.732	0.57375
Windrow Composting			0.006	0.262	0.732	0.55687
Containerized Composting System			0.039	0.094	0.867	0.69795
Dehydrator Company 2 (~800lb Capacity Model)			0.039	0.127	0.835	0.66757
Dehydrator Company 2 (~525lb Capacity Model)			0.039	0.127	0.835	0.66496
Dehydrator Company 2 (~300lb Capacity Model)			0.039	0.180	0.781	0.65551
Dehydrator Company 1 (~250lb Capacity Model)			0.039	0.180	0.781	0.64977
Dehydrator Company 1 (~650lb Capacity Model)			0.039	0.180	0.781	0.64114
Dehydrator Company 2 (~125lb Capacity Model)			0.092	0.127	0.781	0.62402
Pulper (1250lb/hr Model)			0.143	0.164	0.694	0.53007
Industrial Garbage Disposals			0.143	0.291	0.567	0.52268
Pulper (1000lb/hr Model)			0.143	0.217	0.640	0.51824
Containerized Anaerobic Digestion System			0.210	0.182	0.608	0.43812
Landfill/BAU			0.275	0.141	0.584	0.57573

Figure 6. Overall Ranking of Technology Alternatives for Fort No-Water is shown in a screenshot from the dashboard. Results are sorted from lowest “R” (percent of scores in the red-range) to highest “R.”

327 The utility of the dashboard is dependent on eliciting a set of weights that reflect the
328 perspective of management over a wide range of conditions. For this papers application
329 theweights reflect IMCOM’s focus on achieving the goal of Net-Zero waste, while conserving
330 resources and ensuring health and safety. With the Natural Capital Objective weighted at just
331 over one third of the dashboard’s total score, the weights emphasize the reduction of
332 environmental impacts from waste processing. Other highly weighted criteria include those that
333 deal with the affordability of waste management and the safety of waste management technology
334 operators. Therefore, the weights of the dashboard are considered to be robust from the
335 perspective of IMCOM’s current needs. The focus on increasing installation sustainability under
336 constrained circumstances may increase the importance of economic and environmental
337 objectives under new policies. Following any future U.S. Army policy changes, the MCDA
338 algorithm allows weights to be changed to reflect the new policy or perspective. The robustness
339 of these derived and calibrated weights could be further determined through the development of
340 more hybrid scenario installations, and review of the outcomes.

341
342 To assess the performance of the calibrated dashboarda case study application was
343 undertaken at Fort Hood, TX. Fort Hood has substantial resources at its disposal for achieving
344 Net Zero Waste and has been focused on food waste diversion. Fort Hood was selected for the
345 case study because the results of a previously performed a feasibility study compared the
346 applicability of several different food waste diversion technology alternatives for this site. The
347 earlier feasibility study considered a subset of the metrics included in the dashboard, including
348 the annual volume of waste generated at Fort Hood, the capital, equipment installation, and

operation and maintenance costs of the technology alternatives, the land available at Fort Hood, the existing infrastructure at the site, and the potential for the generation of a useful product from the food waste management technologies. Fort Hood's Net Zero Waste and Sustainability Program Manager was interviewed regarding the capabilities of Fort Hood to accommodate food waste diversion technologies. All the information necessary to run the dashboard for Fort Hood was gained from the initial consultation. After the sensitivity analysis, the dashboard was run using the capabilities and limitations reported in the interview. Table 10 lists the top ranked technologies and their respective strength and weaknesses. The results from the dashboard were compared to those of the earlier feasibility study.

Table 10: Top three recommended technologies for Fort Hood and accompanying metrics advocating for (Technology Strengths) or against (Technology Weaknesses) the technology's selection.

#1 Technology		#2 Technology		#3 Technology	
Windrow Composting		Forced-Air Static Composting		Dehydrators	
Technology Strengths:	Technology Weaknesses:	Technology Strengths:	Technology Strengths:	Technology Weaknesses:	Technology Strengths:
<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • High annual throughput (lbs/year) 	<ul style="list-style-type: none"> • Moderate O&M costs 	<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • High annual throughput (lbs/year) 	<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • High annual throughput (lbs/year) 	<ul style="list-style-type: none"> • Moderate O&M costs 	<ul style="list-style-type: none"> • 100% waste conversion to high value compost • Low electricity requirement • High annual throughput (lbs/year)

Alternative Name	Max.	Avg.	R	Y	G	Score
Windrow Composting			0.007	0.259	0.734	0.55687
Force-Air Static Composting			0.012	0.310	0.677	0.57931
Dehydrator Company 2 (~525lb Capacity Model)			0.092	0.137	0.771	0.66218
Dehydrator Company 2 (~800lb Capacity Model)			0.092	0.137	0.771	0.66162
Dehydrator Company 2 (~300lb Capacity Model)			0.092	0.137	0.771	0.64806
Dehydrator Company 2 (~125lb Capacity Model)			0.092	0.137	0.771	0.61985
Dehydrator Company 1 (~250lb Capacity Model)			0.099	0.137	0.764	0.64523
Containerized Composting System			0.120	0.062	0.818	0.67934
Industrial Garbage Disposals			0.135	0.291	0.574	0.52204
Containerized Anaerobic Digestion System			0.146	0.198	0.656	0.43939
Dehydrator Company 1 (~650lb Capacity Model)			0.168	0.068	0.764	0.62995
Pulper (1250lb/hr Model)			0.169	0.137	0.694	0.52481
Pulper (1000lb/hr Model)			0.238	0.068	0.694	0.50853
Landfill/BAU			0.262	0.141	0.597	0.57573

Figure 7. The overall ranking of technology alternatives for Fort Hood is shown in a screenshot from the dashboard. Results are sorted from lowest “R” (percent of scores in the red-range) to highest “R.”

The dashboard results corroborate the results of the earlier feasibility study performed for Fort Hood which recommended windrow composting over dehydrators. Windrow and forced-air static composting are the top performing technologies according to the dashboard (Figure 7). The metrics that support the accommodation of these technologies include the volume of waste generated each year at the site, required electricity, the rate of waste conversion to a usable product, and the value of the generated product. The dehydrators (except for one model) ranked

third because of their scores for capital cost, risks to air and effluent quality, space requirements, their reduction of food waste volume(~90 %), and the production of viable feedstock for composting or anaerobic digestion. The containerized composting system was not ranked in the top three technologies because its higher capital cost and operations and maintenance (O&M) costs, as well as its limited throughput per unit. According to the dashboard, the reason that windrow and force-air static composting have a lower percentage of metrics in the red range than dehydrators is due to the difference between these technologies throughput and electricity consumption.

4. Conclusion

Overall the results show that this approach for technology selection has potential for large, multi-layered organizations to produce recommendations for waste management approaches that are both organizationally consistent and site-specific. All the outcomes reflect the trade-offs between objectives at the management level. The percentage of metrics in the “red” is the sum of the weights of those metrics that a specific site was unable to accommodate. Therefore, those technology alternatives with a lower percentage of metrics in the red are the management-preferred options which the site is most able to implement.

The U.S. Army's need for efficient selection of sustainability technologies and the resource constraints it is likely to face in the coming decades necessitates a tool such as the IMCOM dashboard. The dashboard approach builds upon previous MCDA applications but differs in that it classifies acceptability ranges for each evaluated metric for every use of the tool. An alternative approach would have been to change or limit the value scale for each case in which the tool was applied. However, this would limit the comparison of the tool's outputs across sites, because the MCDA model itself would be different. By preserving the model and adding the dashboard visualization, we allow the technology performance to be consistent across applications and identify the different capacities of individual application sites.

Decision analysis has a recent history of facilitating the selection of waste management and sustainable technologies (Morissey and Browne 2004; Khalili and Duecker 2013; Soltani et al. 2015). Life-cycle assessment and cost benefit analyses have also been shown to provide insight into these processes (Hutchins and Sutherland 2008; Othman et al. 2013; Fakoya et al. 2013). However, MCDA provides the additional strengths of consideration of the perspectives of multiple stakeholders (Soltani et al. 2015) and transparent consideration of conflicting criteria (Kou et al. 2011). In this paper, we demonstrate that MCDA evaluation of different alternatives by a larger organization can be used to inform the selection of a specific entity with known constraints and capabilities. The potential of the model to capture the needs of a specific organizational component and aid in the selection of a suitable technology were deemed practical and feasible as a result of the scenario installation tests and a case study for Fort Hood. While the dashboard was used in the context of waste management and the Army, it can be applied where

technologies need to be compared across a large organization comprised of multiple units. The approach is valuable because it provides a visualization of how different technologies fulfill the priorities of an organization and reflects the practical limitations of implementation at a specific site. This advancement adds value in that an organizational perspective can be consistently applied over a range of conditions to identify the highest utility alternatives.

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