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A decision support system for benchmarking the energy and waste performance of schools in Toronto

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Abstract

Background: The Toronto District School Board (TDSB) oversees the largest school district in Canada and has been spent more than one third of its annual maintenance budget on energy and waste. This has directed attention toward system-wide reductions to both energy consumption patterns and waste generation rates. In this paper, a decision support system (DSS) that can process unit-incompatible measures is used for rating, ranking, and benchmarking the schools within the TDSB.

Results: The DSS permits the ranking of any set of schools by contextually evaluating their relative attractiveness to other identified school groupings. Consequently, the DSS was used to explicitly rank each school's performance within the district and to determine realistic energy improvement targets. Achieving these benchmarks would reduce system-wide energy costs by twenty-five percent.

Conclusions: The TDSB study demonstrates that this DSS provides an extremely useful approach for evaluating, benchmarking and ranking the relative energy and waste performance within the school system, and the potential to extend its much broader applicability into other applications clearly warrants additional exploration.

Keywords: Benchmarking Performance, Data Envelopment Analysis, Decision Support Systems, Energy & Waste

Background

Representing more than 600 schools, the Toronto District School Board (TDSB) oversees the largest education constituency within Canada. In the 2003 fiscal year, the TDSB allocated $48 million of its annual budget to the energy and waste requirements of the school system, but within three years, found that the energy and waste expenditures had escalated to more than $69 million (Christie 2003, 2007; Christie & Coppinger 2006). This rapid forty percent increase in spending during a period of public economic retrenchment necessitated stringent attention toward system-wide reductions to both energy consumption patterns and waste generation rates (Christie 2003, 2007; Christie & Coppinger 2006).

While the need to decrease energy consumption and minimize waste was universally acknowledged, to achieve long-term success in these efforts, the TDSB resolutely believed that any successful systematic reduction efforts would need to adequately address three critical questions: (i) what initiatives would achieve the most effective results; (ii) how could these "most effective reduction initiatives" actually be identified; and, (iii) how effective would these initiatives prove to be once implemented (Christie 2003) Additional "essential components" to effectively implement any proposed reduction schemes necessitated that improvement initiatives had to include: (i) the establishment of realistic benchmarks for each school to strive toward; (ii) the setting of achievable annual performance targets for each school; (iii) a commitment to rational and objective management of the system data; and, (iv) an assurance of transparency and neutrality in policy-setting and decision-making (Christie 2003, 2007; Christie & Coppinger 2006). Unfortunately, it proves to be an extremely difficult process to evaluate system-wide performance and to establish benchmarks when there are multiple incommensurate criteria measurements present (Camp 1995), which was the case within the

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budgetary-constrained and politically-charged environment of the TDSB (Christie 2003, 2007; Christie & Coppinger 2006).

Decision support systems (DSS) are intelligent information systems based on decision models that can be used to extract large quantities of data from databases, to provide interfaces and methods for effectively processing it, and for deriving meaningful decisions of managerial/economic significance from it. DSS have been used to analyze a wide variety of performance information and to provide a readily-accessible medium for distributing any knowledge generated to a wide variety of stakeholders (Lin *et al*. 2008). In this paper, a DSS that can simultaneously combine unit-incompatible energy and waste performance measures is introduced for evaluating the system-wide energy and waste performance of the schools within the TDSB. This DSS incorporates several data envelopment analysis (DEA) modules that had been developed in Yeomans (2004) and threads these modules together using commonly available software (Albright 2010; Seref et al. 2007; Zhu 2003). The underlying DEA methodology has been shown to hold advantages over many other multi-criteria methods by providing an objective decision-making tool that does not require variables to have the same scale or conversion weights applied to them (Cook & Zhu 2008; Zhu 2003), while permitting a simultaneous combination of both quantitative and qualitative measures (Cook *et al*. 1996).

The DSS developed can be used to rate and rank each school according to its energy and waste performance relative to the other schools in the system by recursively partitioning the schools into sub-groups of relatively superior and inferior performers. In addition, the DSS can establish realistically achievable improvement targets for each school by benchmarking their performance against the operations of schools in higher efficiency categories. This relative performance comparison between the schools is important since it ensures that the underlying analysis involves the use of energy and waste values actually occurring at peer institutions within the TDSB and not through "externally-generated", potentially unrepresentative values.

The DSS developed directly addresses the TDSB's three requisite "critical questions" while simultaneously addressing most of the key issues in the "essential components" identified above. Furthermore, the most practical contribution from this approach is that, since DEA can be readily implemented using common spreadsheet software linked together by relatively straightforward VBA programming (Albright 2010; Seref et al. 2007; Zhu 2003), this entire methodology can be implemented on virtually any computer. Consequently, practitioners in any organization could easily modify and extend this methodology to match their own very specific multi-criteria applications and circumstances. An illustrative example of an application of the DSS is provided through an analysis of a subset of the high schools in the TDSB.

Results and Discussion

The primary purpose in the performance evaluations of most organizational systems is to appraise the current operations of individual entities and to benchmark these against peer entities to identify best practices. While individual performance measure, or "gap", analysis has often provided the fundamental basis for performance evaluation and benchmarking (Zhu 2003), it remains a difficult task to satisfactorily combine multiple disparate, unit-incompatible, single-criteria measurements into an overall conclusion (Camp 1995). Since a complex entity's actual performance generally represents multifaceted phenomena, the use of single measures in gap analysis explicitly ignores all interactions, substitutions, and tradeoffs between the various performance measures. Therefore, it is a rare occurrence when a one-measure-at-a-time gap-analysis can suffice for the purposes of an effective performance evaluation of organizational systems (Camp 1995; Zhu 2003).

Clearly it is difficult to evaluate an organization's performance or to establish benchmarks when there are multiple measurements present (Camp 1995). If the specific algebraic functional relationship between performance measures is known, then established multi-criteria techniques can be used to estimate best-practice levels of performance. These algebraic functional forms cannot be specified without *a priori* information on the corresponding tradeoffs and, unfortunately, such information is generally unavailable in most practical situations. However, when the best practices of similar types of operations can be identified empirically at a specific point in time, it becomes possible to empirically estimate the resulting best-practice level of performance, or efficient frontier, using these observations (Zhu 2003).

DEA has proved to be an effective empirical tool for identifying multi-criteria efficient frontiers, for subsequently evaluating relative performance efficiencies, and for implicitly estimating the tradeoffs inherent within the empirically designed frontier. DEA's empirical orientation and absence of *a priori* assumptions establish it as the ideal analytical instrument for application to a wide variety of practical situations, since its underlying theoretical basis is consistent with the practice of rating entities by concurrently examining the relative efficiencies of their multiple performance measures. Furthermore, DEA allows performance comparisons to be made between numerous entities that have been evaluated by multiple, unit-incomparable measures without employing any *a priori* weightings or conversion factors typically required in other methods. Since the process is adaptable and invariant to data type, DEA permits the inclusion and comparison of non-numeric environmental-type variables that might prove incomparable using many other techniques (Zhu 2003). By incorporating DEA into its DSS, the focus of performance evaluation for the TDSB application could shift from a characterization of each school's energy and waste usage in terms of single measures to evaluating performance from a mathematically rational, multidimensional system perspective (Linton *et al.* 2007; Yeomans 2004). Consequently, inherent energy and waste relationships and their role in performance ranking can be explicitly brought into the analysis in a rational, transparent, and neutral fashion.

An overview of the energy and waste DSS for the TDSB

The DSS, itself, contains a series of specific DEA modules (more fully explained in subsequent sections) for conducting the performance evaluation of the TDSB. The first module recursively partitions the selected schools into sub-groups of relatively superior and inferior performers according to their energy and waste performance. The second module then determines realistically achievable energy and waste improvement targets for each school by benchmarking them against the system-wide operations for schools in selected higher performance categories. If desired, the DSS can also execute a third module to establish an explicit rank ordering of each school relative to any desired set of schools within the TDSB.

The set of DEA modules was created using readily available spreadsheet optimization software linked together by a combination of straightforward programming. In order to make the entire analysis process readily accessible to the various system users, the DSS was implemented using Microsoft Access and Microsoft Excel together with VBA (contained in all Microsoft Office products) as the programming language. By using these specific computer packages, the entire set of modules for evaluating the performance of the TDSB was created using software residing on most current personal computers. In the following sections, each of the individual DEA modules used in the DSS is explained in detail and illustrated using data from 65 high schools in the TDSB.

DEA relative performance rating module

The first module in the DSS partitions any selected group of schools into relatively superior and inferior performers based upon their energy and waste performance. In DEA terminology a decision-making unit (DMU) designates the specific entity being studied (Zhu 2003). For the example, the set of DMUs consists of the 65 high schools in the TDSB. Each DMU possesses a set of inputs and outputs that represent its multiple measures of performance and, for the high schools, these inputs and outputs consist of various observed energy and waste measures. While a considerable number of different combinations of energy and waste performance indicators could have been selected from the available data, for illustrative purposes the example in this paper contains only two inputs and four outputs. The inputs considered were (i) school enrolments measured in terms of the number of students and (ii) school sizes measured in square metres (sqm), while the set of outputs consisted of (i) total energy consumption measured in gigajoules (GJ), (ii) total energy costs in dollars ($), (iii) total waste in kilograms (Kg), and (iv) waste diversion percentage (%).

One analytical requirement for DEA is that all inputs have to be measured in units where "less is better", while all outputs have to be expressed in units in which "more is better". Hence, prior to implementing any of the procedures, the DSS transforms all selected inputs and outputs into a format consistent with this analytical requirements. Table 1 provides a complete list of the transformed inputs and outputs for the 65 schools.

The analytical approach of DEA evaluates the data by "enveloping" the entities being studied based upon the values of the performance measures. The underlying concept of DEA requires an evaluation of each DMU through a projection onto an empirically constructed, multi-dimensional efficient frontier. The enveloping process determines the efficiency of DMUs by: (i) creating an $m + s$ dimensional surface, or "efficient frontier", of the efficient DMUs (where m represents the number of inputs and s represents the number of outputs); (ii) assigning an efficiency score of $\theta = 1$ to any DMU on the efficient frontier; (iii) determining the distance from the frontier for all inefficient DMUs; and, (iv) calculating the value of θ for inefficient DMUs as its proportional, multi-dimensional distance from the efficient frontier. The efficiency score of any inefficient DMU is always a value of $\theta < 1$. The enveloping constructs an efficient frontier of the best-practice entities and also shows how any inefficient DMU can be improved by providing the amounts and directions for improvement to its specific measures (Zhu 2003).

In assessing the high schools, the overall goal is to identify the system's best performers by contrasting each school's observed performance metrics relative to those of every other school considered. However, DEA only determines whether a school is efficient ($\theta = 1$) or inefficient ($\theta < 1$). The magnitude of θ cannot be used to establish relative degrees of inefficiency between non-efficient schools. Because the relative performance of any school can be contrasted only to an identified best-practice frontier, actual measures of relative inefficiency would change only when the best-practice frontier is altered (that is, when one or more of the efficient

Table 1 Each high school's energy and waste input/output measurements transformed into appropriate format for DEA usage

FACILITY NAME	Floor Area sqm	Student Enrollment	Transformed Total Energy GJ	Transformed total Energy Cost	Transformed Total Waste Kg	Diversion (%)
Agincourt CI	19,554	1,533	19,826	$254,168	3,488	10.25
Albert Campbell CI	22,964	2,115	3,275	$1	3,546	9.59
Bendale BTI	14,693	855	15,794	$227,171	5,169	15.56
Birchmount Park CI	16,826	1,276	23,304	$287,084	5,150	41.52
Bloor CI	13,656	797	28,974	$314,772	3,924	18.07
Cedarbrae CI	23,668	1,557	14,999	$202,965	4,415	40.02
Central Commerce Collegiate	20,729	1,034	20,843	$298,930	6,114	100
Central Etobicoke HS	11,086	492	21,900	$291,602	5,025	35.99
CW Jefferys CI	16,401	1,057	22,486	$279,963	5,189	12.24
David & Mary Thomson CI	21,576	1,628	14,098	$206,145	5,856	8.95
Downsview SS	21,483	877	9,661	$176,278	5,514	13.05
Dr Norman Bethune CI	14,254	1,130	23,011	$286,933	5,682	56.31
Earl Haig SS	24,849	2,394	21,630	$146,889	1,159	69.46
Eastdale CI	5,501	197	34,717	$407,993	5,834	81.85
Eastern HS of Commerce / Subway Academy I	18,330	1,155	26,755	$342,930	5,520	53.13
Emery CI	22,306	1,570	16,563	$190,444	6,139	100
Etobicoke CI	19,367	1,502	22,215	$232,432	4,776	30.52
Etobicoke School of the Arts	12,537	889	22,467	$319,969	5,270	37.14
Frank Oke SS	4,322	154	34,371	$413,854	5,755	25.6
George Harvey CI	25,025	1,183	13,911	$179,360	4,635	30.21
Georges Vanier SS	23,721	1,045	1	$15,462	5,859	0
Greenwood SS / School of Life Experience	7,847	404	32,836	$379,072	5,982	69.35
Harbord CI	18,437	1,040	22,577	$213,196	4,992	33.39
Heydon Park SS	7,475	220	36,678	$441,925	6,122	0
Humberside CI	17,655	1,150	24,382	$304,460	5,226	63.09
Inglenook Community School	1,607	128	40,091	$488,102	6,317	89.74
Jarvis CI	21,783	1,313	19,217	$265,879	5,066	66.76
Kipling CI	12,276	729	27,813	$362,378	5,504	21.96
Lakeshore CI	16,208	920	22,371	$302,844	5,276	38.44
Lawrence Park CI	15,634	1,026	27,163	$336,863	5,149	49.39
Leaside HS	13,560	1,163	27,529	$339,132	5,369	37.07
Malvern CI	14,331	1,046	28,028	$345,788	4,982	41.88
Maplewood HS	10,728	523	25,715	$312,227	5,914	100
Martingrove CI	14,737	1,041	32,751	$331,622	5,691	48.38
Nelson A Boylen CI	9,708	611	28,556	$325,182	6,033	0
Newtonbrook SS	18,230	1,789	14,985	$170,648	5,443	0
North Albion CI	15,961	1,110	26,433	$332,279	3,934	20.16
North Toronto CI	16,046	1,114	28,736	$355,959	2,802	20.76
Northern SS	29,471	1,998	16,571	$223,581	1	21.05
Northview Heights SS	23,864	1,444	17,419	$220,008	3,644	18.95
Oakwood CI	18,588	983	28,163	$349,240	6,155	38.56
Parkdale CI	14,435	631	28,357	$342,029	5,639	64.45
RH King Academy	17,796	1,469	18,416	$228,731	4,751	36.07

Table 1 Each high school's energy and waste input/output measurements transformed into appropriate format for DEA usage *(Continued)*

Richview CI	11,030	992	27,608	$344,498	5,335	39.36
Riverdale CI	23,418	1,217	21,011	$210,624	3,854	29.29
Rosedale Heights SS	16,271	680	22,744	$289,208	5,503	50.75
Runnymede CI	13,491	806	29,109	$366,070	5,504	43.94
Scarlett Heights Entrepreneurial Academy	11,528	749	28,293	$348,189	369	3.31
School of Experiential Education	2,525	86	37,662	$459,735	3,814	79.81
Silverthorn CI	16,537	1,263	20,870	$242,216	4,868	38
Sir John A Macdonald CI	17,324	1,576	12,097	$105,763	4,444	10.15
Sir Robert L Borden BTI	13,246	722	21,546	$268,610	4,820	23.52
Sir William Osler HS	11,010	359	22,425	$304,830	5,725	39.89
Thistletown CI	15,540	1,103	21,448	$296,117	5,002	24.78
Ursula Franklin Academy	19,001	405	26,430	$320,347	4,395	63.15
Vaughan Road Academy	17,021	839	26,630	$324,903	5,610	67.77
Victoria Park SS	20,525	1,295	16,123	$211,734	5,823	76.02
West Hill CI	20,161	1,338	7,304	$105,948	2,922	15.03
West Toronto CI	19,852	813	18,979	$152,372	4,665	61.43
Western Technical-Commercial School / The Student School	44,367	1,220	6,691	$73,962	4,191	57.35
Weston CI	18,317	1,271	21,145	$206,202	4,546	37.46
Westview Centennial SS	25,323	1,385	11,118	$101,969	3,430	21.95
William Lyon Mackenzie CI	11,619	1,231	25,392	$316,995	6,039	100
Woburn CI	20,126	1,458	22,884	$264,443	3,887	69.23
York Mills CI	16,207	1,373	23,638	$274,777	3,012	73.49

schools is removed). However, a recursive enveloping module can be created that stratifies the schools into numerous levels, or groupings, of relative best-practice frontiers, rather than the single DEA frontier.

The stratifying module of the DSS proceeds by removing all of those schools placed onto the original best-practice frontier and then using the original DEA enveloping methodology to form a new second-level best-practice frontier from the set of remaining schools. That is, once a first efficient frontier is calculated, all of the associated efficient schools are removed from further consideration and a new efficient frontier based only upon the remaining, initially inefficient schools is calculated. The schools on this second-level efficiency frontier are subsequently removed, permitting a third-level frontier to be constructed, then a fourth-level frontier, and so on, until no schools remain. The final result from this stratification is the creation of a series of efficient frontiers. The recursive procedure stratifies the original set of schools into L groupings of school efficiencies, with the specific value for L algorithmically determined, *a posteriori*, by an "empty-set" stopping rule.

When the stratification module was applied to the high school data, the 65 schools were partitioned into $L = 12$ distinct groups with 2, 2, 3, 6, 9, 10, 10, 5, 7, 5, 3, and 3 schools assigned to each respective efficiency stratum (see Table 2). This stratification effectively partitions the high schools into distinct groupings of comparably-performing schools based upon the multi-criteria measurements of their energy and waste performance.

Benchmark module for generating realistic energy and waste performance targets

Benchmarking is widely used for the identification and adoption of best practices and as a means for improving performance and increasing productivity. Benchmarking can be thought of as the process of defining valid measures of performance comparison among peer schools, using these to determine the relative standing of the peer schools, and ultimately in establishing standards of excellence for performance improvement. The TDSB had stated in their "essential component" requirements that, in order to improve their system-wide energy and waste usage, it was crucial for them to be able to determine attainable performance benchmarks and to establish achievable annual performance targets for each school (Christie 2003). Clearly the satisfaction of these components would necessitate the creation of multi-

Table 2 Changes required to each high school's current energy and waste measures to advance into the next higher efficiency group

	Changes required to original outputs to attain efficiency at the next higher level				
DMU No.	**DMU Name**	**Change to Total Energy GJ**	**Change to Total Energy Cost $**	**Change to Total Waste Kg**	**Change to Diversion(%)**
Level 1					
26	Inglenook Community School	0	0	0	0
49	School of Experiential Education	0	0	0	0
Level 2					
14	Eastdale CI	−5,374	−80,109	−483	8
19	Frank Oke SS	−5,720	−74,248	−562	64
Level 3					
22	Greenwood SS / School of Life Experience	−7,256	−109,030	−335	20
24	Heydon Park SS	−3,413	−46,177	−195	90
33	Maplewood HS	−5,334	−77,604	−265	55
Level 4					
35	Nelson A Boylen CI	−6,411	−98,118	−96	8
42	Parkdale CI	−4,340	−36,153	−348	4
44	Richview CI	−5,423	−46,343	−718	5
53	Sir William Osler HS	−11,658	−96,559	−317	2
55	Ursula Franklin Academy	−8,319	−88,192	−1,443	17
63	William Lyon Mackenzie CI	−7,230	−73,073	−584	7
Level 5					
7	Central Commerce Collegiate	−4,022	−47,268	−1,321	5
8	Central Etobicoke HS	−1,757	−23,397	−620	3
12	Dr Norman Bethune CI	−389	−13,090	−30	0
28	Kipling CI	−5,553	−39,705	−603	2
34	Martingrove CI	−1,720	−73,754	−299	3
47	Runnymede CI	−5,031	−34,249	−515	4
48	Scarlett Heights Entrepreneurial Academy	−55	−671	−5,337	14
56	Vaughan Road Academy	−6,589	−60,058	−342	4
65	York Mills CI	−11,079	−133,216	−2,822	8
Level 6					
5	Bloor CI	−1,359	−14,768	−1,924	9
16	Emery CI	−2,444	−33,938	−401	5
18	Etobicoke School of the Arts	−6,006	−23,782	−392	3
25	Humberside CI	−2,360	−21,550	−386	4
30	Lawrence Park CI	−1,642	−19,472	−410	3
31	Leaside HS	−1,369	−15,909	−252	2
32	Malvern CI	−1,400	−17,269	−539	2
46	Rosedale Heights SS	−1,224	−12,518	−238	2
52	Sir Robert L Borden BTI	−1,970	−33,561	−441	17
59	West Toronto CI	−3,580	−127,440	−551	7
Level 7					
3	Bendale BTI	−6,958	−61,342	−350	36
11	Downsview SS	−4,154	−4,813	−151	18
15	Eastern HS of Commerce / Subway Academy I	−1,860	−6,006	−97	1

Table 2 Changes required to each high school's current energy and waste measures to advance into the next higher efficiency group *(Continued)*

29	Lakeshore CI	−2,506	−11,754	−205	10
37	North Albion CI	−1,868	−17,433	−206	14
38	North Toronto CI	−624	−7,736	−2,715	23
41	Oakwood CI	−11,928	−138,862	−162	51
54	Thistletown CI	−1,156	−2,288	−39	9
57	Victoria Park SS	−17,854	−184,878	−70	1
64	Woburn CI	−929	−19,192	−158	3
Level 8					
4	Birchmount Park CI	−1,966	−33,642	−434	13
9	CW Jefferys CI	−189	−17,568	−44	27
21	Georges Vanier SS	−28,555	−309,719	−174	0
23	Harbord CI	−485	−88,334	−107	4
27	Jarvis CI	−3,704	−17,101	−326	4
Level 9					
13	Earl Haig SS	−1,326	−122,171	−2,108	4
20	George Harvey CI	−8,662	−36,385	−364	2
36	Newtonbrook SS	−3,185	−72,412	−333	31
45	Riverdale CI	−1,451	−14,550	−1,151	2
50	Silverthorn CI	−1,998	−52,234	−341	2
60	Western Technical-Commercial School / The Student School	−12,969	−166,149	−624	9
61	Weston CI	−2,175	−81,412	−595	4
Level 10					
1	Agincourt CI	−2,368	−30,352	−1,648	6
6	Cedarbrae CI	−4,810	−39,285	−533	5
10	David & Mary Thomson CI	−12,958	−105,347	−152	0
17	Etobicoke CI	−117	−1,224	−226	0
43	RH King Academy	−2,774	−8,051	−141	1
Level 11					
40	Northview Heights SS	−3,353	−17,186	−285	2
51	Sir John A Macdonald CI	−10,389	−174,200	−746	2
62	Westview Centennial SS	−8,051	−110,998	−1,294	8
Level 12					
2	Albert Campbell CI	−18,940	−232,431	−1,230	21
39	Northern SS	−2,571	−18,254	−4,099	2
58	West Hill CI	−15,242	−130,494	−2,138	11

criteria benchmark targets to improve each school's performance and it would be imperative that the various competing stakeholders within the system felt that these targets had been set fairly, objectively, and transparently (Christie 2003, 2007). As observed in the previous section, the stratification module partitioned the 65 high schools into 12 sets of comparably performing groups in which all schools within a higher grouping were better performers than any school in each of the lower groupings. In this sense, the stratification module could be viewed as a type of benchmarking, since the module creates various different performance groupings of peer-efficient schools to which any underperforming schools could be benchmarked.

However, by using the stratification module's output, it becomes possible to establish performance goals for less efficient schools by benchmarking their current energy and waste usage against the more efficient operations of the schools in any of the higher performing strata. For an inefficient DMU, it is possible to calculate the changes needed to its inputs/outputs for it to become efficient relative to the DMUs on the efficient frontier. These efficiency targets would be the specific values that the inputs and outputs of the inefficient DMU would need to attain in order to move onto the efficiency frontier. For the benchmarking and target setting required in the TDSB case, the set of DMUs in the following procedure would consist of one specific, inefficient DMU under evaluation (i.e. DMU_0) and all of the DMUs in the next higher contextual grouping. Hence, assume that there exists a set of n DMUs, with each DMU_j, $j = 1, \ldots, n$, consisting of m input measures x_{ij}, $i = 1, \ldots, m$, and s output measures y_{rj}, $r = 1, \ldots, s$. Suppose that DMU_0 is being evaluated with x_{i0} and y_{r0} representing its ith input and rth output measures. Let s_i^-, $i = 1, \ldots, m$, and s_r^+, $r = 1, \ldots, s$, represent the i^{th} input and r^{th} output slack variables, respectively, and let ε be some non-Archimedean scalar. Then by solving the optimization model:

$$\min \theta - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)$$

subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i0} \;\; i = 1, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r0} \;\; r = 1, \ldots s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \;\; j = 1, \ldots, n$$

efficiency targets $\hat{x}_{i0} = \theta^* x_{i0} - s_1^-$, $i = 1, \ldots, m$, and $\hat{y}_{ro} = y_{r0} + s_\gamma^{+*}$, $r = 1, \ldots, s$, can be calculated for each of the inputs and outputs of DMU_0. The presence of the non-Archimedean ε in the objective function effectively allows the minimization over θ to pre-empt the optimization involving the slacks, s_i^- and s_r^+. This creates a two-stage optimization process with the maximal reduction of the inputs being achieved in the first stage via the optimal θ^*, followed by the movement onto the efficient frontier achieved in the second stage via the subsequent optimization of the slack variables. This approach to multi-criteria benchmarking proves particularly suitable to practical situations in which no objective or pre-existing engineered standards are available to define efficient or effective performance.

For illustrative purposes, an incremental goal for each school to progress only into the next highest level of efficiency was set. While a longer-term perspective might seek to advance all schools into the very highest level of performers, these intermediate targets establish more attainable improvements that each inefficient school would need to undertake in order to move into the next higher level of efficiency. Hence, the benchmarking module was used to calculate the specific efficiency targets required for each school to proceed into the next higher category of energy and waste performance and Table 2 shows the specific improvements required in each measure in order to reach the calculated targets. The specific changes shown in Table 2 represent: (i) annual reductions in energy use; (ii) annual reductions in energy expenses; (iii) annual reductions in the quantity of solid wastes generated; and, (iv) annual increases in the percentage diversion of solid wastes. While the target-setting module actually produces multi-criteria measures for improvement, if the changes in Table 2 were to be achieved, then one significant subset of these improvements would be the 25 % percent reduction in annual energy costs. This reduction, alone, represents a direct annual cost savings of $3.7 million from the current energy budget of $14.9 million allocated to the TDSB's high school. Furthermore, if the established targets were achieved, the table shows potential reductions of over 300,000 GJ of energy and of 44,000 Kg of waste. It should be noted that an analogous percentage cost, energy and waste improvements would be obtained from the targets set for the entire set of the more than 600 schools of the TDSB.

Rank ordering module

While the stratification module partitions the schools into distinct levels of energy and waste performers, it does not rank order the standings of any of the schools within each grouping. If only a small number of schools were under consideration in an analysis or if a large number of groupings each containing only a very small number of schools had been produced, then the stratification, itself, might be sufficient for actually ranking the specific schools. For the general case, however, the stratification might not prove restrictive enough to permit sufficient degrees of preference discrimination. If this situation proves to be the case, then a contextual attractiveness concept can be incorporated into the DSS to permit an explicit ranking of the schools (Simonson & Tversky 1992; Tversky & Simonson 1993). Obtaining relative attractiveness scores for the schools requires that relative performance be defined with respect to some particular evaluation context and the L partitions from the stratification module can be used to supply these contexts.

Define $H_q^*(d)$ to be the d-degree, $d = 1, \ldots, L - l_0$, contextual attractiveness of $DMU_q = (x_q, y_q)$ from some specific level $\mathbf{E}^{l_0}$, $l_0 \in \{1,\ldots, L-1\}$. $H_q^*(d)$ can be calculated by solving the model:

$$H_q^*(d) = \min H_q(d) \quad d = 1, \ldots, L - l_0$$

subject to:

$$\sum_{j \in F(E^{l_0+d})} \lambda_j x_j \le H_q(d)\, x_q$$

$$\sum_{j \in F(E^{l_0+d})} \lambda_j y_j \ge y_q$$

$$\sum_{j \in F(E^{l_0+d})} \lambda_j = 1$$

$$\lambda_j \ge 0 \quad j \in F\left(\mathbf{E}^{l_0+d}\right)$$

DMU_q is viewed as a more attractive option than another DMU if it possesses a larger value for its contextual attractiveness measure $H_q^*(d)$. Hence, it is possible to rank each school within each stratum using a direct sorting of these contextual attractiveness scores. Since all schools within a contextual grouping are considered better performers than any school in a lower contextual group, when the rankings within each grouping are subsequently concatenated, a complete, rank ordering of the entire set of selected schools will be produced, *de facto*.

Using the next-lower stratification grouping as the appropriate context, the attractiveness scores $H_q^*(d)$, for each high school were calculated. Since any school is considered more efficient than the other schools within its grouping if it possesses a larger contextual attractiveness score, it now becomes possible to rank order the schools within each stratum by sorting these scores. Concatenating these individually sorted groupings produces a comprehensive rank ordering from 1 to 65 based upon the energy and waste usage in all of the schools. The results of this contextual scoring system, the subsequent sorting within each partition, and the overall efficiency ranking of each high school within the TDSB are shown in Table 3.

If a large number of schools existed within any particular level after the stratification stage, then a situation might occur in which two or more of the schools each received exactly the same attractiveness measure. This tied ranking problem can be alleviated by incorporating a lexicographic ranking modification into the procedure described above and could be accomplished in the following manner. In order to reduce the likelihood of tied rankings, the lexicographic procedure would be used to calculate attractiveness measures for each school by using *every* level lower than it as the contextual basis. Hence, each school in the highest level would receive L-1 separate contextual attractiveness scores, each school in the second highest level would receive L-2 separate attractiveness scores, and so on. A lexicographical rank ordering of schools within each specific grouping would then be performed with greater emphasis given to attractiveness scores calculated from closer contextual groupings (i.e. through an alphabetical or dictionary style of sorting). This multi-scoring, lexicographic rank ordering process would produce additional discriminating powers by reducing the likelihood of ties occurring between schools within any specific grouping. However, since no tied-scores occurred in the contextual attractiveness calculations already performed, this lexicographic ranking produces the same rank ordering as Table 3.

Conclusions

In this paper, a DEA-based DSS for analyzing, rating, ranking, and benchmarking the multi-criteria energy and waste system of the schools in the TDSB has been studied. Several benefits of this DSS were demonstrated through an illustrative investigation of 65 Toronto high schools. The DSS stratified the schools into similarly-efficient groupings based upon their energy and waste usage. The DSS then generated realistic energy and waste improvement targets for any relatively inefficient school against another grouping of benchmarked schools. Amongst other findings, it was shown that achieving these target reductions would produce system-wide energy cost savings of twenty-five percent. The DSS also permits the ranking of any set of schools by contextually evaluating their relative attractiveness to other identified school groupings. The findings with respect to the high schools have been extended in an analysis of all 600 schools within the TDSB. Based upon the TDSB study, DEA has shown itself to be an extremely useful approach for evaluating, benchmarking and ranking the relative energy and waste performance within the school system, and the potential for its much broader applicability to other applications clearly warrants additional exploration.

Methods

The mathematical models of each of the DEA modules were created as separate computer models within Microsoft Excel worksheets (Albright 2010; Seref et al. 2007; Zhu 2003). The optimization of the spreadsheets of these DEA models was performed using the standard, built-in Excel Solver function. The data for all 600 schools in the TDSB can be found in Christie (2003) and the data for the 65 schools used in the analysis appears in Table 1. All data was stored in a Microsoft Access database. The programming language used to link together the various components was VBA which is contained in all Microsoft Office products. Hence, the mathematical and computer-based DSS for evaluating

Table 3 Overall rankings of high schools based upon contextual attractiveness scores calculated relative to the next lower partitioning group

DMU No.	DMU Name	Attractiveness Score Hq(d)	Overall Ranking
Level 1			
49	School of Experiential Education	0.406	**1**
26	Inglenook Community School	0.251	**2**
Level 2			
19	Frank Oke SS	0.539	**3**
14	Eastdale CI	0.422	**4**
Level 3			
33	Maplewood HS	0.540	**5**
22	Greenwood SS / School of Life Experience	0.510	**6**
24	Heydon Park SS	0.378	**7**
Level 4			
44	Richview CI	0.862	**8**
42	Parkdale CI	0.798	**9**
35	Nelson A Boylen CI	0.725	**10**
53	Sir William Osler HS	0.640	**11**
63	William Lyon Mackenzie CI	0.541	**12**
55	Ursula Franklin Academy	0.531	**13**
Level 5			
12	Dr Norman Bethune CI	0.889	**14**
34	Martingrove CI	0.870	**15**
65	York Mills CI	0.848	**16**
56	Vaughan Road Academy	0.844	**17**
47	Runnymede CI	0.821	**18**
48	Scarlett Heights Entrepreneurial Academy	0.802	**19**
28	Kipling CI	0.773	**20**
7	Central Commerce Collegiate	0.728	**21**
8	Central Etobicoke HS	0.707	**22**
Level 6			
52	Sir Robert L Borden BTI	0.914	**23**
25	Humberside CI	0.895	**24**
30	Lawrence Park CI	0.861	**25**
16	Emery CI	0.826	**26**
32	Malvern CI	0.795	**27**
31	Leaside HS	0.763	**28**
5	Bloor CI	0.757	**29**
18	Etobicoke School of the Arts	0.745	**30**
59	West Toronto CI	0.712	**31**
46	Rosedale Heights SS	0.642	**32**
Level 7			
54	Thistletown CI	0.896	**33**
64	Woburn CI	0.859	**34**
57	Victoria Park SS	0.825	**35**

Table 3 Overall rankings of high schools based upon contextual attractiveness scores calculated relative to the next lower partitioning group *(Continued)*

3	Bendale BTI	0.823	**36**
37	North Albion CI	0.820	**37**
11	Downsview SS	0.816	**38**
38	North Toronto CI	0.769	**39**
15	Eastern HS of Commerce / Subway Academy I	0.760	**40**
29	Lakeshore CI	0.716	**41**
41	Oakwood CI	0.671	**42**
Level 8			
4	Birchmount Park CI	0.852	**43**
23	Harbord CI	0.769	**44**
9	CW Jefferys CI	0.724	**45**
21	Georges Vanier SS	0.699	**46**
27	Jarvis CI	0.647	**47**
Level 9			
36	Newtonbrook SS	0.905	**48**
45	Riverdale CI	0.851	**49**
20	George Harvey CI	0.840	**50**
61	Weston CI	0.792	**51**
50	Silverthorn CI	0.787	**52**
13	Earl Haig SS	0.725	**53**
60	Western Technical-Commercial School / The Student School	0.547	**54**
Level 10			
10	David & Mary Thomson CI	0.756	**55**
1	Agincourt CI	0.709	**56**
17	Etobicoke CI	0.524	**57**
6	Cedarbrae CI	0.510	**58**
43	RH King Academy	0.418	**59**
Level 11			
62	Westview Centennial SS	0.706	**60**
40	Northview Heights SS	0.541	**61**
51	Sir John A Macdonald CI	0.534	**62**
Level 12			
58	West Hill CI	0.923	**63**
39	Northern SS	0.889	**64**
2	Albert Campbell CI	0.657	**65**

the performance of the TDSB was created using software residing on essentially all personal computers.

Abbreviations
DSS: Decision support system; DEA: Data envelopment analysis; TDSB: Toronto district school board; DMU: Decision making unit; VBA: Visual basic for applications.

Competing interests
The author declares that there are no competing interests.

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Author's contributions
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