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Environmental Load Reduction by Introduction of Super Water-Saving Toilets at Highway Service Areas in Japan

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Abstract

Japanese highway service areas that have basic facilities such as car parking lots, toilets, and restaurants are required to be comfortable, clean, and safe. The Japanese highway management and maintenance company (NEXCO LTD) owns about 300 service areas where on average 80 toilets are installed in each service area. In these service areas, the scale of these facilities has been increased with around-the-clock operation for users' comfort; therefore, water consumption, energy consumption, and accompanying costs have increased. The toilet facilities especially use large amounts of water and energy to treat the toilet's drainage at each service area. Thus, toilets with low water consumption, low energy consumption, and comfort are indispensable at highway service areas in Japan. In this study, the environmental load reduction by the replacement of conventional toilets with newly developed super water-saving toilets, such as water-recycling urine-diverting toilets and water-recycling urinals, at highway service areas in Japan was examined.Three different types of service areas were selected for the case study. The results obtained show that the environmental load from the service areas (i.e., water consumption and energy consumption) would be reduced greatly by introducing the newly developed super water-saving toilets.

1. INTRODUCTION

Japanese highway service areas that have basic facilities such as car parking lots, toilets, and restaurants are required to be comfortable, clean, and safe. The Japanese highway management and maintenance company (NEXCO LTD) owns about 300 service areas where on average 80 toilets are installed in each service area. In these service areas, the users' comfort is of utmost importance, and these facilities are maintained with consideration of the users' evaluations. For users' comfort, the scale of these facilities has been increased with around-the-clock operation; therefore, water consumption, energy consumption and accompanying costs have increased. In the services area, the toilet facilities especially use large amounts of water and energy to treat the toilet's drainage. Thus, toilets that are comfortable with low consumption of water and energy are indispensable at the highway service areas. Therefore, we have been developing a low-emission-type wastewater treatment system consisting of a urine-diverting toilet and urinal to reduce environmental load (Nakagawa *et* al., 2012).

In this study, quantitative assessment of the environmental load reduction, i.e., water consumption and pollution loads was performed by modelling the replacement of conventional toilets with a newly developed super water-saving toilet system, consisting of water-recycling urinals and water-recycling urine-diverting toilets, at highway service areas in Japan. Other lower environmental impact toilets,

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such as the waterless urinals and the 6 L type flushing toilets were also included in the assessment for comparison. The burden of the energy and the cost was assessed quantitatively to include not only the operation but also the introduction of this system by using the Life Cycle Assessment method.

2. MATERIAL AND METHODS

2.1. Features of the target service areas

In this study, three different service areas (P1, P2, and P3) located in the Tokyo metropolitan area were selected for the case study based on data obtained from NEXCO LTD for the April 2008–March 2009 period (Table 1). In Table 1, P1 (the Minori service area) is one of the middle-scale service areas, and wastewater from this service area is treated by the JOHKASOU which is capable of efficiently treating excrement and urine, and grey water. P2 (the Moriya service area) is one of the large-scale service areas, and the wastewater from this service area is sent to the outside and treated by the public sewage treatment plant which is an industrial structure designed to remove biological or chemical waste products from water. P3 (the Umihotaru service area) is also one of the large-scale service areas and located at the middle of Tokyo Bay. The wastewater from this service area is treated inside the area by the JOHKASOU. From Table 1, the water usage for the toilets accounted for about half of the total water used at P1 and P2. At P2 especially the water used by the toilets was a large amount, being 70,794 m^3/year, and the annual cost was more than $170,000. On the other hand, the amount of water used in toilets at P3 is very small compared to P1 and P2 because the water for the toilets at P3 is reclaimed water and the amount of water shown in Table 1 is for only handwashing. The water supply and wastewater treatment at P1 accounted for a very large percentage (about 40%) of the total energy consumed. On the other hand, the cost of water treatment for the entire P2 facility is very small because the wastewater is sent to the public wastewater treatment plant located outside of the service areas and the cost for wastewater treatment is not included in the cost of water treatment for the entire P2 facility. These service areas with large and small amounts of water and energy consumption were selected as the target service areas.

2.2. Scenarios for the assessment

Table 2 shows the flush volume of the sitting toilets and the urinals at P1,P2, and P3.

For the assessment, two kinds of sitting toilets, i.e., the newly developed water-recycling urine-diverting toilet (RT) and the 6 L type flushing toilet (6T), as well as two kinds of urinals, the newly developed water-recycling urinals (RU), and waterless urinals (WU) were considered. Three scenarios with the sitting toilets and urinals mentioned above were considered. In each scenario, it was assumed that all existing toilets shown in Table 1 were replaced with the abovementioned sitting toilets and urinals.

The scenarios were performed with the following assumptions:

Scenario 1: All existing toilets are replaced with the newly developed RTs and WUs. Waterless urinals need no water, and urine is trapped in the cartridge installed under the toilet bowl. Urine is removed from both the RT and the WU.

Scenario 2: All existing toilets are replaced with 6Ts and WUs. In this case study, 6Ts are recently used in the highway service areas in Japan, and only the amount of urine trapped in the WUs is considered.

Scenario 3: All existing toilets are replaced with RTs and RUs. Urine is removed from both the RTs and RUs.

In scenario 1, it seems the least amount of water is used because the urinals are waterless. However, their operation will require significant cost and maintenance. In scenario 2, current toilets are replaced with the 6 L type water-saving toilets and in scenario 3 the low-emission system consisting of the newly developed RT and RU is used. Table 3 shows the flush volume of the toilets in scenarios 1–3.

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Table 1 Feature of each service area for the case study

		P1	P2	P3
Size of service area		Medium	Large	Large
Wastewater treatment		JOHKASOU	Sewage	JOHKASOU
Number of Users (/ Year)		565,750	8,080,000	2,140,000
	Men (/ Year)	351,000	4,202,000	1,110,000
	Women (/ Year)	214,000	3,878,000	1,030,000
Number of Toilets	For Men	U 30/ S 10[a]	U 64/ S 28[a]	U 48/ S 24[a]
	For Women	For kids 0/ S 32	For kids 5/ S 80	For kids 5/ S 68
	For Handicapped	2	2	2
Amount of Water Use	Total Amount (m^3/Year)	16,138	132,670	28,552 (Reused water:41,539)
	Total Cost (Dollar/Year)	37,200	320,200	139,000
	For toilets (m^3/Year)	8,316	70,794	2,378 (Reused water:35,944)
	Cost for toilets (Dollar/Year)	16,281	170,862	11,800
	Ratio of toilet water use for entire facility (%)	43.8	53.4	54.7
Amount of Effluent (m^3/Year)		16,548	134,249	70,478
Cost for sewage system (Dollar/Year)		--	219,800	--
Electricity	Total (kWh/Year)	233,681	3,250,368	8,202,572
	Total Cost (Dollar/Year)	35,200	426,900	966,800
	For water treatment (kWh/Year)	93,641	39,192	156,950
	Cost for water treatment (Dollar/Year)	14,100	5,200	81,000
	Ratio of water treatment for entire facility (%)	40.1	1.2	10.3

[a] U 30 / S 10 : The number of urinals is 30 and the number of sitting toilets is 10.

Table 2 Flush volume of the toilets in the existed service areas

	Existing system		
	P1	**P2**	**P3**
Sitting Toilet(L/flush)	10	8	10
Urinal (L/flush)	6	4	4

Table 3 Flush volume of the toilets in the scenarios1-3

	Sitting Toilet		**Urinal**	
Toilets	**RT**	**6T**	**RU**	**WU**
Flush volume (L/flush)	0.6	6	0.25	0

2.3. Methods of calculating the environmental load reduction

The amount of water used before and after introducing the newly developed system was calculated from the data of Tables 1–3.

The pollution load included in the effluent from P1 goes to a river. The pollution load included in the effluent from P2 is sent to the public wastewater treatment plant and finally goes to a lake. The pollution load included in the effluent from P3 goes to an ocean.The pollution load to the water environment from P1 and P3 were calculated for scenarios 1–3. The pollution load for the existing system was calculated from influent and effluent water quality at the domestic treatment facility for P1

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and P3 (Table 4), the effluent amount (Table 1), and the pollution load rate of black and gray water per day per capita (Table 5) that was calculated from Tanaka *et* al. (2005) and Lens *et* al. (2001). The pollution loads in scenarios 1–3 were calculated from the annual number of users in Table 1 and the pollution load rate in Table 5, assuming that 9 times out of 10 the toilets were used for the purpose of urination, by subtracting the pollution load of the captured urine from the existing one.Following this, the projected annual reductions in pollution load were calculated. The pollution load to the water environment from P2 could not be calculated because the effluent from P2 was connected to the sewage pipes directly and treated by the public sewage treatment system.

To calculate the burden of the energy, the Life Cycle Assessment (LCA) method was used. LCA is a powerful method for comprehensive quantification of environmental loads. The load from many factors due to different kinds of environmental loads was evaluated with the LCA approach. The LCA method consists of process analysis and input–output analysis (Nansai *et* al. 2010). In the process analysis, the materials and energy resources for a given step in producing a product were itemized. The LCA support software, JEMAI-LCA Pro., was used in the process analysis. The scope of the LCA included the disposal of the existing toilets, the materials and manufacture of the super water-saving toilets' urine storage tanks, and the installation process, the operation of the newly developed system, and the transportation of captured urine from each service area to the rape fields existing near them. The data required for calculation were gathered from TOTO LTD., LIXIL LTD., and Reinforce LTD.

Moreover, the energy for water supply and sewage system was considered to be reduced because the amount of water supplied from waterworks was reduced under the three scenarios. Therefore, the reduced energy for the water supply and sewage system attributed to introducing the newly developed system was calculated using the energy rate of 2,706 kcal/m^3 (Sustainable Water System Association, 1993) and 1,889 kcal/m^3 (Imura *et* al., 1996), respectively. Urine collected by super water-saving toilets was assumed to be transported to the rape field near each highway service area by 10-t trucks. The distances from P1, P2, and P3 to the nearby rape fields were 65 km, 17 km, and 19 km, respectively. Tables 6 and 7 show the energy consumption rate and the material data used for the LCA. Table 8 shows the costs used in the LCA for the super water-saving toilets, the urine storage tank, and their installation per unit. The data were obtained from LIXIL LTD and Reinforce LTD. Regarding the cost of the transportation of urine, only cost of gasoline was included because NEXCO LTD. has its own trucks to transport the waste.

Table 4 Influent and effluent water quality of the domestic treatment facility in the P1,P3 (Tanaka *et*al. (2005) and Lens *et*al. (2001))

		Influent (mg/L)	**Effluent** (mg/L)	**Removal rate** (%)
BOD	P1	343	1.08	99.7
	P3	155	0.6	99.6
COD	P1	261	4.2	98.8
	P3	118	4.1	96.5
T-N	P1	107.9	4.25	96.1
	P3	65	8.1	87.5
T-P	P1	11.8	0.54	95.3
	P3	12	0.5	95.8

Table 5 Pollution load rate of faeces and urine per flush

	Faeces(g/flush)	**Urine** (g/flush)
BOD	14.4	0.7
COD	8.0	0.4
T-N	0.8	1.6
T-P	0.3	0.1

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Table 6 Energy consumption rate used for the LCA

Item	Energy consumption rate		Source
Demolition and removal work	Disposal of waste matter	3.45 (MJ/dollar)	(Nansai K *et* al.,2010)
Installation work	Civil engineering & Construction	1.84 (MJ/dollar)	
	Non-wood building construction	3.94 (MJ/dollar)	
	Repair & Maintenance works	3.74 (MJ/dollar)	
Polypropylene		55.55 (MJ/kg)	JEMAI-LCA software
ABS resin		81.12 (MJ/kg)	
Stainless steel plate		52.38 (MJ/kg)	
Plain steel		20.21 (MJ/kg)	
Styrene-butadienerubber		93.17 (MJ/kg)	
Vinyl chloride monomer		32.89 (MJ/kg)	
Sheet copper		28.62 (MJ/kg)	
Glass		15.04 (MJ/kg)	
Electric power		8.14 (MJ/kwh)	

Table 7 Material data of toilets used for the LCA

Materials		**Quantity** (g/set)
Toilet bowl	pottery	3283
	ABS	370
	carbon steel	135
	PE	10
	PP	105
	paper	50
	steel products	325
	corrugated cardboard	4500
	dodecanol	55
	butyl rubber	100
Peripheral	vinyl chloride	86
	brass	2
	steel products	214
	nickel plating	10
	stainless	82
	carbon steel	360
	low carbon steel wire rods	48
	butyl rubber	100

Table 8 Cost data of toilets used for the LCA

Materials	**Cost** (dollar/unit)
water recycling urine-diverting toilet	2000
water recycling urinal	1100
Tank for purifying rinse water	560
6L type saving flush toilet	1110
waterless urinal	1160
cartridge	52
urine storage tank	330
cost for installation	2080

3. RESULTS AND DISCUSSION

Figure 1 shows the results of the annual amount of water supplied from waterworks for the existing system and the systems under scenarios 1–3. From this figure, the reduction rates at P1 and P2 are similar, and the reduced amount of water supplied from waterworks, along with the accompanying cost reduction, is especially significant at P2, which is a large-scale service area. The amount of water supplied from waterworks at P3 is not changed because reclaimed water is used as flushing water there. Comparing scenarios 1–3, the reduction in the amount of water supplied from waterworks in scenario 1 is the largest; however, scenarios 1 and 3 are not so different.

To calculate the amount of pollution load to the water environment, Figures 2 and 3 show the result for the amount of pollution load at P1 and P3, respectively. The calculation was not performed for P2 because the wastewater from P2 is treated at the public sewage treatment plant. In scenarios 1 and 3, especially, the BOD, COD, T-N, and T-P are reduced greatly by introducing the newly developed system at both P1 and P3. In scenario 2, the reduction of T-N was small.

Moreover, Figures 4 and 5 show the calculation results regarding energy and cost. The energy required to introduce this system includes the energy for material and manufacture of newly installed super water-saving toilets and urine storage tanks, and their transportation and installation. The removal of the existing toilets is also included in this calculation.The ratio of the energy and cost for the manufacture, installation, and removal of the existing toilets, which are also included in the calculation is large. On the other hand, the ratio of the energy and cost for the manufacture and installation of the urine storage tank necessary for separating the urine is small.

After the introduction of the newly developed system, the energy for the water supply system, sewage treatment system, and domestic treatment facility is reduced compared to existing system because the amount of water supplied from waterworks is reduced. However, the amount of energy reduction differs greatly at each service area depending on its features. In fact, the energy reduction at P1 is small because of the small number of toilets and the amount of reduced water supplied from waterworks. On the other hand, the energy reduction at P2 is large because it has a large number of toilets and the energy reductions for the water supply system and the sewage treatment system are large. Besides, the amount of water supplied from waterworks and the energy for it are not reduced at P3, which uses reclaimed water to flush toilets. However, the energy of the domestic treatment facility is reduced greatly because the amount of the effluent is reduced. Furthermore, the cost does not decrease very much because the cost of electricity is cheap compared to the cost of manufacture and installation.

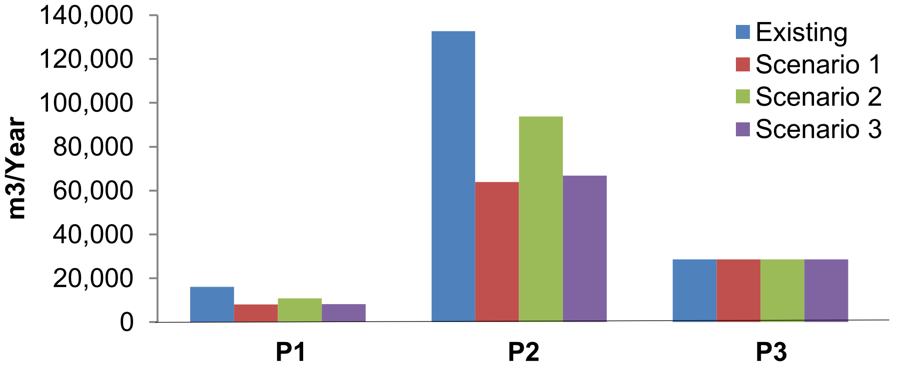


Figure1 Results of the annual amount of water supplied from waterworks for the existing system and the systems under scenarios 1–3

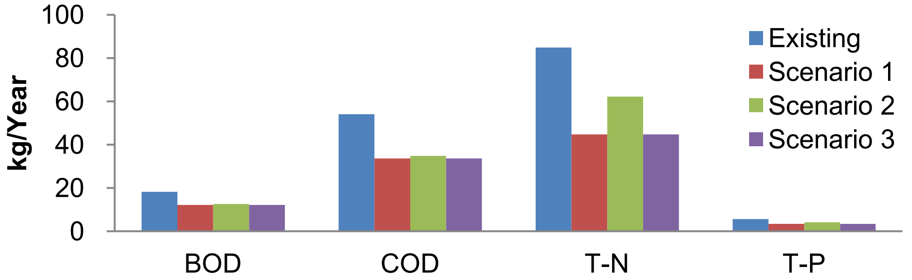


Figure 2 Result for the amount of pollution load at P1

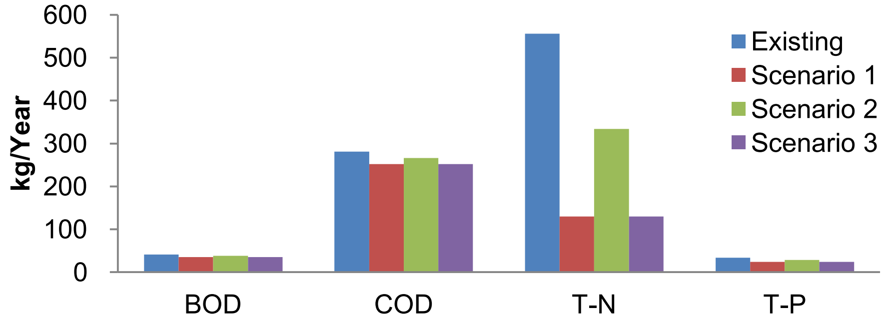
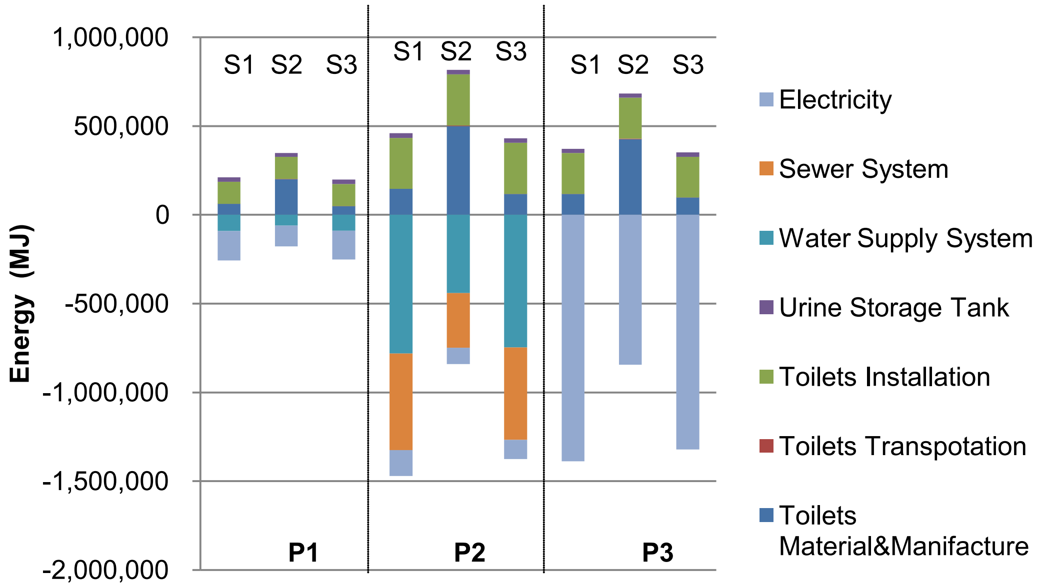


Figure 3 Result for the amount of pollution load at P3



S1: Scenario 1, S2: Scenario 2, S3: Scenario3

Figure 4 Calculation results regarding energy

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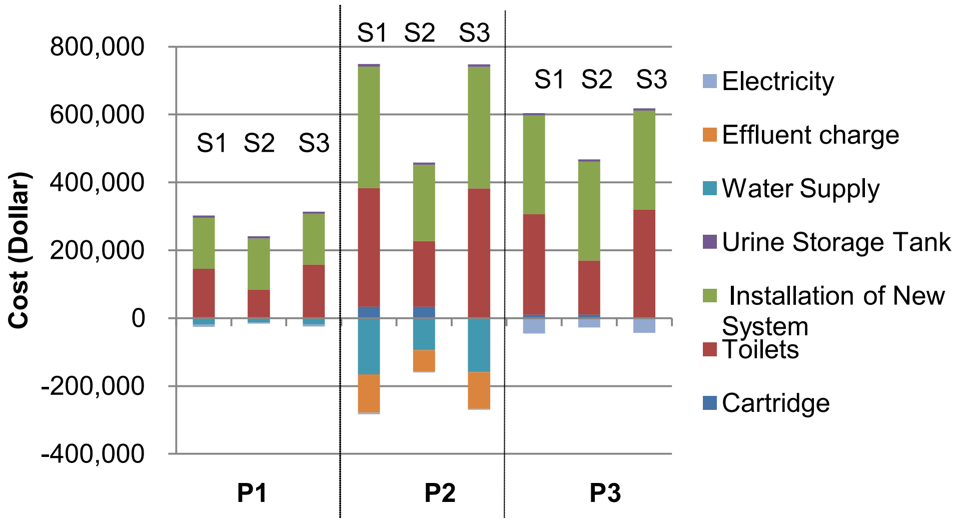

S1: Scenario 1, S2: Scenario 2, S3: Scenario3

Figure 5 Calculation results regarding cost

4. CONCLUSION

In this study, the reduction of environmental load by replacing conventional toilets with super water-saving toilets, such as waterless urinals and urine-diverting toilets, at highway service areas in Japan was quantified. Three different types of service areas were selected for the case study, and a simulation was performed under three scenarios. The results show that the environmental load from the service areas (i.e., water consumption and energy consumption) was reduced greatly by introducing super water-saving toilets. Especially, the burden of energy and costs for scenarios 1 and 3, which use the urine-diverting toilet as the sitting toilet, can easily be recovered when they are introduced into large service areas where the wastewater is treated by the sewage system.

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