Energy and Cost Benefit Evaluation of a Urine Diversion System –A Case Study at Highway Service Areas in Japan

Naoko NAKAGAWA[1], Akira KAWAMURA[1] and Hideo AMAGUCHI[1]

[1]Department of Civil and Environmental Engineering, Tokyo Metropolitan University,1-1 Minami-Ohsawa, Hachioji, Tokyo 192-0397, Japan

ABSTRACT

In this study, the reduction on the environmental load by the replacement of conventional toilets with low environmental load toilets such as water recycling urine-diverting toilet newly developed at highway service areas in Japan was quantified and a cost-benefit analysis concerning introducing low environmental load toilets were performed. Moriya service area which is one of the large–scale service areas and Minori service area which is the middle–scale one were selected for the case study. As for the results, the pollution load, especially, total nitrogen and phosphorous were expected to be reduced by 94% and 79 % from existed system, respectively, in the Minori service area. Concerning the burden of energy and cost, the payback periods by introducing the urine diversion system were 0.3 and 0.8 years for energy, and 2.8 and 12.6 years for cost at Moriya and Minori service area, respectively.

INTRODUCTION

It has become more common to view wastewater as a resource. There is increased recognition that water itself is regarded as a limited resource and the nutrients in wastewater can be recycled through agriculture if it can be properly treated. This has led to the development of new wastewater technologies, including source-separating systems in which urine is collected separately.

On the other hand, Japanese highway service areas that have the basic facilities, such as car parking lots, toilets, and restaurants are required to be comfortable, clean, safe, and environmentally friendly. The Japanese highway management and maintenance company, NEXCO, owns about 300 service areas, where 80 toilets are installed on average. They are considering replacing some of these conventional toilets with low environmental load ones not only to save on water and energy usage costs but also to contribute to ecological conservation.

Therefore the newly urine diversion system(UDS) such as water recycling urinals and urine diversion toilets that are comfortable to use as pre-existing toilets have been developed. The aim of this paper is to perform the environmental assessment by introducing the UDS, and to estimate the environmental load reduction at highway service areas in Japan. The Moriya service area, which is one of the large–scale service areas, and the Minori service area, which is one of the middle–scale ones in Ibaraki prefecture, were selected for the case study.

MATERIALS AND METHODS

Newly developed Urine Diversion System (UDS)

UDS installed in the highway service area are required the following conditions such as having no unpleasant smells, being comfortable to use and being easy to maintain. Therefore, we developed the following UDS consisted of a water recycling urinal and a water recycling urine-diverting toilet that can save water significantly with minimal energy consumption to be installed in the highway service area.

Figure 1 shows a water recycling urinal. The disposed flushing water was reduced up to 0.25 L per use by the sensitive electromagnetic switch, which controls the flushing water for the urine or for washing the toilet bowl. The 1.7 L of the flushing water isn't mixed with the urine and recycled many times. The electricity is 3.3 W at standby and 10 W at flushing. Figure 3 shows the schematic of water recycling urinal. Figure 2 shows the newly developed water recycling urine-diverting toilet by combining the existed urine-diverting toilets and the water recycling toilets (Nakagawa *et. al.*, 2009). The appearance is almost the same as the existed water recycling toilet. Figure 4 shows the schematic figure of the water recycling urine-diverting toilet. Urine can be trapped under the toilet bowl by an electromagnetic sensitive switch. The disposed flushing water is 0.6 L per use by the switch which controls the flushing water. The 2.2 L of the flushing water for the toilet bowl isn't mixed with the black water and it is recycled many times. The electricity is 3.3 W at standby and 45.3 W at flushing. The captured urine is sent to a container where it can be collected and stored for further use.

Feature of the Moriya and Minori Service Area in Ibaraki prefecture

The feature of the Moriya service area and Minori service area are shown in Table 1. The Moriya service area (Figure 5) is located about 30 km northeast of Tokyo, Japan and one of the large–scale service areas. The effluent from this service area is treated by the sewage treatment system. Figure 6 shows the restroom at the Moriya Service Area. The toilets are 8 L-type flush toilets with a bidet and a fountain of warm water.

The Minori service area (Figure 7) is located about 100 km northeast of Tokyo, Japan and is one of the middle–scale service areas. The effluent from this service area is treated by the domestic wastewater treatment system (Figure 8). The average water quality of the domestic wastewater treatment facility in the Minori service area is shown in Table 2 based on the data obtained from April 2009 until March 2010. As shown in Table 1, water use for the toilets accounts for 53.4 % and 43.8 % of the total water used in the Moriya and Minori service area, respectively. The water used by the toilets in the Moriya service area totals to a huge amount of 70,794 m^3 per year and costs 170,862 dollars per year. Because the wastewater of the Moriya service area is sent to a public sewage treatment plant, the electricity related water is just dedicated to the water supply. However, the payment for using the public sewage system is quite large in the Moriya service area.

Figure 1. Water recycling urinal.

Figure 2. Water recycling urine-diverting toilet.

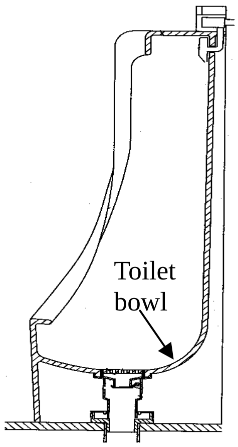

Figure 3. Schematic of water recycling urinal .

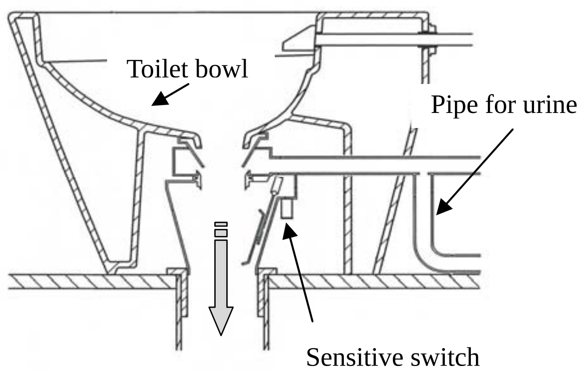

Figure 4. Schematic of water recycling urine-diverting toilet .

Figure 5. Moriya service area in Ibaraki prefecture.

Figure 6. Existed Toilet in Moriya service area.

Figure 7. Minori service area in Ibaraki prefecture.

Figure 8. Domestic wastewater treatment facility in Minori service area.

Table 1. Feature of Minori and Moriya service area (SA).

Case Study			Moriya SA	Minori SA
Size of service area			Large	Medium
Wastewater treatment			Sewage	*DWTF
Number of Users		/ Year	8,080,000	560,000
	Men	/ Year	4,202,000	351,000
	Women	/ Year	3,878,000	214,000
Number of Toilets	For Men		*U 64/ R 28	U 30/ R 10
	For Women		For kids 5/ R 80	For kids 0/ R 32
	For Handicapped		2	2
Amount of Water Use	Total Amount	m^3/Year	132,670	16,138
	Total Cost	Dollar/Year	320,200	37,200
	For toilets	m^3/Year	70,794	7,063
	Cost for toilets	Dollar/Year	170,862	16,281
	Ratio of toilet water use for entire facility	%	**53.4%**	**43.8%**
Amount of Effluent		m^3/Year	134,249	16,548
Cost for sewage system		Dollar/Year	219,800	--
Electricity	Total	kWh/Year	3,250,368	233,681
	Total Cost	Dollar/Year	426,900	35,200
	For water treatment	kWh/Year	39,192	93,641
	Cost for water treatment	Dollar/Year	5,200	14,100
	Ratio of water treatment for entire facility	%	**1.2%**	**40.1%**

* DWTF : Domestic Wastewater Treatment Facility

*U 64/ R 28 : Number of Urinals is 64,Number of Regular Toilets is 28.

Estimation of environmental load reduction

In order to consider the advantage of introducing the UDS, we calculated the water consumption, energy consumption, and cost from when the previous toilets were replaced with low environmental load ones. In this case, we assumed replacing all old-type toilets with the water recycling urinals and the water recycling urine-diverting toilets newly developed as written above. The basic data required for the calculation were obtained from NEXCO LTD and Reinforce LTD. Table 3 shows the amount of the pollution loads included in the urine and excrements per person per day. These are calculated from the ratio of feces and urine in the excrement (Lens P. *et al.*, 2001) and the pollution loads including black and gray water (Matsuo *et. al.*, 1999), assuming the intervals of urination are five times per day and the excretion of feces are once per person per day. Table 4 shows the flush volumes of the toilets in the case of introducing the water recycling urinal and urine-diverting toilet. The change in energy load and cost that occurred were calculated. Table 5 shows the cost for introducing the UDS. To calculate the energy load, a life cycle assessment (LCA) was adopted. Table 6 shows the energy consumption rate used for the LCA. Other data used for the LCA were obtained from Reinforce LTD.

Table 2. Average water quality of the domestic wastewater treatment facility in Minori service area.

	Influent	Effluent
BOD (mg/L)	155	0.6
COD (mg/L)	118	4.1
T-N (mg/L)	65	8.1
T-P (mg/L)	12	0.5

Table 3. Amount of the pollution load in black water.

	Feces	Urine
BOD (g/use)	14.4	0.7
COD (g/use)	8.0	0.4
T-N (g/use)	0.8	1.6
T-P (g/use)	0.3	0.1

Table 4. Flush volume of the toilets.

	Existing toilets				Low environmental load toilets	
	Minori PA		Moriya SA			
L/flush	Men	Women	Men	Women	Men	Women
For feces	10	10	8	8	0.6	0.6
For Urine	6		4		0.25	

Table 5. Cost for introducing the low environmental toilets.

Case Study		Moriya SA	Minori SA
Cost for introducing the urine diversion system (dollar/Year)	Water recycling Urinals	276,500 (64 units)	107,500 (30 units)
	Water recycling urine-diversion toilets	106,200 (108 units)	49,800 (42 units)
	Urine storage tanks	7,000 (21 units)	6,600 (20 units)

Table 6. Energy consumption rate used for the LCA.

Item	Energy consumption rate	Data source
Demolition and removal work	Disposal of waste matter 34,500 (MJ/mill.)	(Nansai,K. *et al.*,2010)
Installation work	Civil engeering & Construction 18,400 (MJ/mill.)	
	Non-wood building construction 39,400 (MJ/mill.)	
	Repair & Maintenance works (MJ/mill.)	
Polypropylene	55.55 (MJ/kg)	NIAIST,JEMAI-LCA software
ABS resin	81.12 (MJ/kg)	
Stainless steel plate	52.38 (MJ/kg)	
Plain steel	20.21 (MJ/kg)	
Styrene-btadiene rubber	83.17 (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)	

(MJ/mill.) : (MJ/million yen)
NIAIST:National Institute of Advanced industrial Science and Technology

RESULTS AND DISCUSSION

In both cases at Minori and Moriya, urine removed by the UDS was assumed to be used effectively as fertilizer. The results of the estimation concerning the environmental loads by assuming the installation of water recycling urinals and water recycling urine-diverting toilets are shown in Figure 10 and Figure 11. The amount of water use was reduced by about 50 % through introducing UDS in both SA. Especially the amount of the water consumption reduced is significant in the Moriya service area which is a large-scale service area. The influent volume to the sewage pipe and domestic wastewater facility is reduced by the reduction of flush water volume, and along with it, the cost for the public sewage system and the electricity concerning the domestic water treatment facility are also reduced in the Moriya and Minori service area respectively. As shown in Figure 11, in Minori service area, the pollution load, especially total nitrogen and phosphorous were expected to be reduced by 94% and 79 % from existed system, respectively. This is because urine was removed by the water recycling urine-diverting toilets and the water recycling urinals. Thus, it was found that the environmental load can be reduced greatly by introducing the UDS.

Figure 12 and Figure 13 shows the energy and cost, respectively, for introducing of the UDS and the reduced energy per year after introducing it. Regarding the part of the introduction, the ratio of the energy and cost for manufacturing and installation were large. Regarding the reduced energy after introducing the UDS, the energy reduction of water supply system and sewage system were large because the amount of the water use and effluent were reduced greatly in Moriya SA. On the other hand, in the case of Minori SA, which fewer UDS were installed, the amount of the energy reduction was small. Regarding the cost, as shown in Figure 13, the reduction of the cost for water use and effluent charge were large in the case of Moriya SA because the effluent from this service area is sent to the public sewage treatment system.

In order to consider the advantage of the UDS, the payback period by introducing UDS was calculated from the view point of energy and cost. Consequently, it was demonstrated that the payback period by introducing the UDS was 0.3 and 0.8 years regarding the burden of the energy, and 2.8 and 12.6 years regarding the cost for the Moriya and Minori service area, respectively. This result is valuable for considering the cost of treatment for the removed urine in this system. Concerning the removed urine, so far, using it as a fertilizer in the rape blossoms field in the vicinity is considered for recycling nutrients back into the environment with low cost and energy as possible.

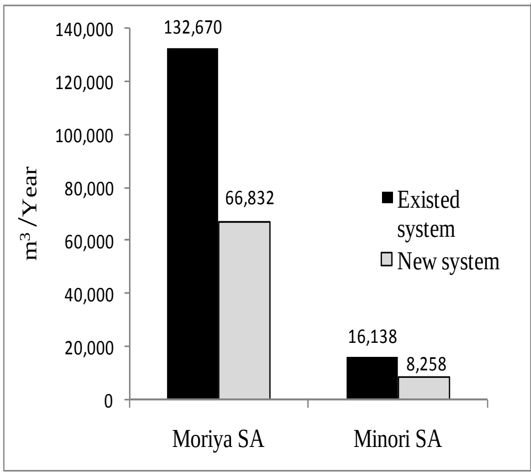

Figure 10. Change of the amount of water use.

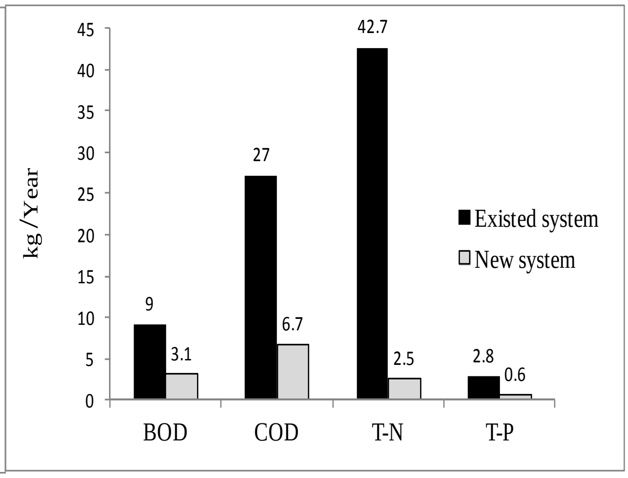

Figure 11. Amount of pollution load from Minori SA.

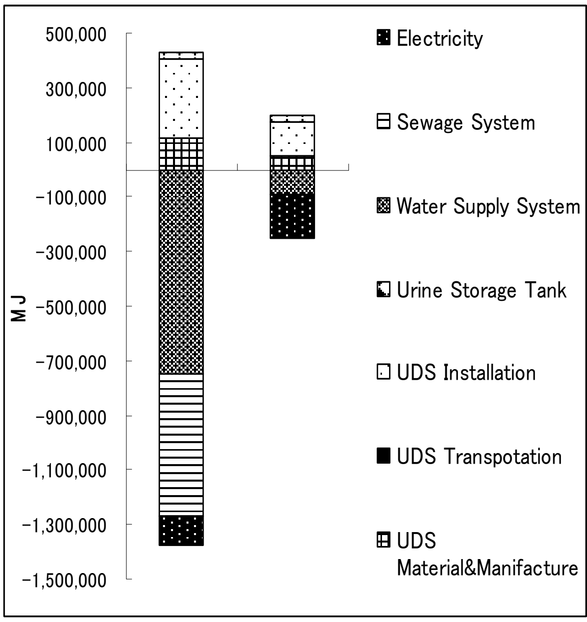

Figure 12. Energy for introducing of the UDS and the reduced energy per year.

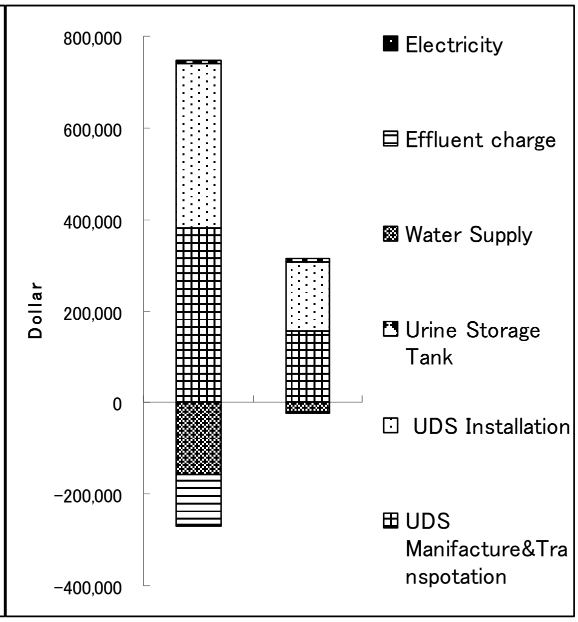

Figure 13. Cost for introducing of the UDS and the reduced cost per year.

CONCLUSIONS

In this study, the reduction of the environmental load by the replacement of conventional toilets with urine diversion system at highway service areas in Japan was estimated. The Moriya service area, which is one of the large–scale service areas and the Minori service area, which is one of the middle–scale areas, were selected for the case study. As for the results, the pollution load, especially, total nitrogen and phosphorous were expected to be reduced by 94% and 79 % from existed system, respectively, in the Minori service area. Concerning the burden of energy and cost, the payback periods by introducing the UDS were 0.3 and 0.8 years for energy, and 2.8 and 12.6 years for cost at Moriya and Minori service area, respectively.

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