Mobile phone placement during lectures and dependency on LINE and text messaging: Survey of students at a women's university in Japan

Keywords:
LINE messaging, text messaging, mobile phone dependency, classroom behavior, higher education

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Abstract

This study measured the dependency on text messaging of students in lectures at a women's university in Japan, comparing students who placed their mobile phone on their desk during lectures with those who did not do so. Dependency was measured by using a text-message dependency scale. Dependency on LINE messaging was measured by the same scale with "text" replaced by "LINE" in each question. The results of the questionnaire survey showed a significant difference in "emotional reaction," one of the three subscales of the scale used in the study, between students who placed their mobile phone on their desk and those who did not: the LINE messaging dependency score was higher among those who did. Also, in each subscale score and in the total of those scores, dependency on LINE messaging was significantly higher than dependency on text messaging for both students who placed their mobile phones on their desks during lectures and those who did not do so.

1. Introduction

Previous studies discussed the use of personal laptop computers during university lecture. Although these studies pointed out the negative effect of student laptop use during lectures, finding that it was a distraction from the lectures (Fang 2009; Fried 2008; Hembrooke and Gay 2003), different studies showed increased learning effectiveness through the appropriate use of laptops during lectures (Barak et al. 2006; Demb et al. 2004; Gay et al. 2001). In modern university lecture halls, the use of not only laptop computers but also of mobile phones (including smart phones) by students in lectures has also been frequently observed (Amali et al. 2012; Campbell 2006; Hammer et al. 2010; McCoy 2013; Wei and Wang 2010; Wei et al. 2012).

In the past, we saw almost no use of laptop computers by students in lectures at Japanese universities, as is seen in other countries, but the personal use of mobile phones by students during lectures was a common sight (Tachino et al. 2012). In the past, use of mobile phones by students during lectures was conducted "under the desk," that is, out of sight of the instructor (Matsushita 2007). However, we observed that the personal use of mobile phones by students during lectures has changed owing to the widespread use of smart phones, which was sparked in Japan by the introduction of the iPhone in 2008. In other words, the shift in the personal use of mobile phones to easy "on the desk" use was made possible by the fact that the backs of smart phones are flat and that the phones are usually operated by touchscreen. It cannot be said that the shape and design of smart phones is the sole cause for the change from hiding one's phone under the desk to using it on top, but it can be said that, at least as a background to this study, it is not difficult to find students using mobile phones on desks during lectures at Japanese universities in the present day.

Accordingly, we undertook an investigation of the use of mobile phones during lectures. In a preliminary investigation in which 21 Japanese university students participated, 52.4% of students responded that they "use mobile phones during lectures," and 42.9% of students said that they "don't feel embarrassed about operating mobile phones during lectures (Tachino et al. 2012)." In a study by Tachino et al. (2013a), a questionnaire was distributed to 20 students who placed their mobile phones on their desks during an exercise class in a computer lab room. The students were asked to answer two questions: a free response regarding the "reason for placing the mobile phone on the desk," and a yes or no question as to the "sense of guilt about placing a mobile phone on the desk." The results showed that the most common reason for placing a mobile phone on the desk, given by 7 students, was "for the purpose of receiving contact," and 9 of the students responded that they felt no sense of guilt about placing their phone on their desk (Tachino et al. 2013a). Also, in Tachino et al. (2013b) and Tachino et al. (2014), a yes/no questionnaire was given to 237 students, asking about their "experience of placing a mobile phone on the desk during lectures." Among respondents, 67.9% said that they placed their phone on their desk during regular lectures, and 30.8% said that they did so even in lectures where mobile phone use was prohibited (Tachino et al. 2013b; Tachino et al. 2014). The common finding of these preliminary investigations is that most university students who use mobile phones during lectures place their phones on their desks for the purpose of using their phone as a communication tool.

Building on the preliminary investigations mentioned above, our current investigative study (Kato and Kato 2016) surveyed university about the use of mobile phones in lecture. The questionnaire began with a question regarding whether the student had their mobile phone placed on their desk "now" (from the time of distribution of the questionnaire to about 30 minutes after the beginning of the class). The analysis proceeded by grouping students according to the answer on that question and comparing the other responses between groups. The results of this study are given below. It was seen that the ratio of students who placed their mobile phone on their desk was 64.5% and that there was a higher probability among those who did so to use their phones during lessons to check phone, text, and LINE message content and to respond (by replying, etc.) to those messages; further, those who placed their phone on their desk felt more unease when rules restricting the use of mobile phones during classes were in place (Kato and Kato 2016). An additional pattern was seen: in mobile phone communication by students during classes, text-based communication was an easy choice. In particular, the LINE application, which is a (primarily smart phone-based) communication tool for free chat and voice over IP telephone calls, was used more often than standard mobile text messaging (Hereafter, "LINE messaging" will refer to LINE's chat function, called "Talk" in-app) (Kato and Kato 2016).

Although personal communication using mobile phones during classes differs from standard class behavior (Ling 2004), one reason this behavior occurs is because students desire the rapid exchange of mobile text messages (Kato et al 2012, 2013; Kato et al. 2013). Typically, a speedy response is desired in mobile text message communications. Students are aware that this expectation should be modified during classes. However, when there is pressure to not wait, or to keep others from waiting, until class has finished, and in situations where there are rules restricting the use of mobile phones, a sense of unease among students demonstrates a clear dependency on mobile text message communication. Yoshida et al. (2005) writes, (translated from Japanese) : "In recent years, the use of mobile phones without respect of time or place, and the prioritization of mobile text messaging over communication with others right in front of them, is becoming a significant dependency issue with mobile text messaging among young people."

Long hours of use was named as the primary cause of "Internet dependency" according to a 2013 Ministry of Internal Affairs and Communications survey targeting participants between upper primary school age and age 25 (Ministry of Internal Affairs and Communications, Japan 2014). According to the survey, 68.8% of high school students and 65.6% of university students responded that they had taken away from time dedicated for other activities in order to make more time for Internet use, mainly from sleeping (48.1% of high school students and 47.5% of university students) and study (46.6% of high school students and 34.6% of university students) (Ministry of Internal Affairs and Communications, Japan 2014). Many related studies point out that the existence of adverse effects on normal life activities is one possible indicator of dependency (Okada 2014). It has been noted that women are far more likely to use their mobile phones more than a PC, and that more women use mobile text messaging and LINE (Ministry of Internal Affairs and Communications, Japan 2014). LINE, in particular, has been reported to be the most-used mobile communication tool (LINE Corporation 2013), particularly its chat, which is faster and easier to use for long periods of time than mobile text messaging (Kato 2015). Also, because LINE displays read receipts (a function that lets the sender know when his/her message has been read by the recipient), many young people continually check their phone to see if their messages have been read by the other party, in addition to normal use to send and receive messages. A previous study (Kato and Kato 2016) showed that LINE messaging is used more than text messaging in class, and as a result it is thought that dependency on LINE messaging is greater among students than dependency on other forms of text messaging. Because of the above, it is necessary to examine the degree of student Internet dependency as a factor in considering the personal use of mobile phones during lectures. Furthermore, consideration should be given to the main communication tools used in mobile text-based communication (mobile text messaging and LINE) within the overall scope of Internet dependency.

This study takes the student factor (dependency) into consideration in the personal use of mobile phones in lectures, but there are a variety of influences on student behavior. Many factors other than the student factor can be considered, such as lecture content, form of the lecture, the lecturer, and the classroom. However, moving students to an experimental setting wherein all of these factors are controlled for could cause students to alter their normal behavior. Therefore, the present study was conducted during a lecture at an actual university. Although in a real-life setting, students will be influenced by these various factors, intra-class comparison of students should allow for discernment of individual differences.

In certain types of classes, such as sports classes, multiple seminars, or classes where the lecturer strictly prohibits or punishes cell phone use in-class, external influences are too strong to confirm student factor. A survey by Terao and Ito (2014) reported that 40% to 60% of students used their mobile phones in lectures for personal reasons when no particular rules about mobile phone use in class were made. Because this is about the same as our abovementioned preliminary research, even though the classroom conditions may be different, the observation that about 50% of students are using their mobile phones during lectures (especially those in which no rules regarding phone use have been set) suggests that the relationships between the in-class factors and the students' behavior can be elucidated. Against this background, the present study was done in a class at a women's university confirmed to meet the above preliminary study requirements (Kato and Kato 2016). An all-female class was chosen to exclude the effects of gender.

Given the above, the present study examined the following two hypotheses.

Hypothesis 1: Due to the high probability of use of mobile phones during class by students who place their phone on their desk as compared with those who do not do so, there is a high degree of dependency on mobile text message communication among students who place their mobile phone on their desk during classes.

Hypothesis 2: Due to the trend for LINE text messaging to be used during classes, the degree of dependency on LINE text messaging among present-day female university students is greater than that on mobile phone text messaging, another text communication tool.

2. Purpose

This study examined the relationship between the behavior of placing mobile phones on desks during university lectures and the dependency of university students on mobile text messaging and LINE. The dependency of students who placed their mobile phones on their desks during lectures was compared to students who did not. The aforementioned Hypothesis 1 and Hypothesis 2 were also examined.

3. Method

(1) Participants and Class Surveyed

This study was performed at a women's university in a liberal arts class on understanding media. This is an elective course, taken by first- to fourth-year students from various schools within the university. As a result, although small groups of three to five friends were seen, there was little overall social cohesion as is frequently seen in courses intended for specific majors. Enrolled students perform investigations on self-selected topics related to media and compile their findings into a PowerPoint presentation. In addition to general lectures, in each class approximately 10 of these presentations are randomly selected for the respective students to give 5-min presentations, which are then critiqued by the instructor and the rest of the class. This class was the same class surveyed in Kato and Kato (2016).

There were 101 students enrolled in the course, and the 80 participants (all Japanese women 18-21 years old, mean age 18.98 years ± SD 0.63 years) were the enrolled students in attendance on the day of the questionnaire.

The survey was performed in December 2013 during the eleventh class meeting, approximately 30 minutes after the class began. Students required approximately 15 minutes to complete the questionnaire. At the time of the questionnaire, no class rules were in place regarding the use of mobile phones.

(2) Questionnaire

The questionnaire distributed to student survey participants first required a "Yes or No" response to the question, "Is your mobile phone on your desk at the present moment?"

For the rest of the questionnaire, questions were used to measure dependency on mobile text messaging and LINE messaging. The text-message dependency scale of Yoshida et al. (2005) and Igarashi et al. (2008) was used to measure dependency on mobile phone text messaging. This scale incorporated an element of dependency on communication, taken from previous studies on Internet, computer, and mobile phone addiction (e.g., Armstrong et al. 2000; Block 2008; Caplan 2005; Griffiths 2000; Kandell 1998; Morahan-Martin and Schumacher 2000; Park 2005; Young 1998), and created from a comprehensive viewpoint of dependency on communication media (Igarashi et al. 2008; Yoshida et al. 2005). The full scale contains 56 items, but there is also a 15-item short-version scale (Igarashi et al. 2008, p.2318), and it was this short-version scale that was used in this study.

This scale is composed of 3 subscales. There are 5 questions in the "emotional reaction" subscale, such as "I feel disappointed if I don't receive any text messages," and "I often check my mailbox to see if I have a new text message."

There are 5 questions in the "perception of excessive use" subscale, such as "I sometimes send text messages while engaging in a conversation with another person," and "I sometimes spend many hours on text messages." There are also 5 questions in the "relationship maintenance" subscale, such as "I cannot maintain new friendships without text messages," and "I can't form any new relationships without using text messages." The questions require responses on a 5-point scale: not at all applicable, not very applicable, can't say either way, somewhat applicable, and very applicable.

To measure dependency on LINE text messaging, the phrase "text messages" was replaced by the phrase "LINE messages" in each of the 15 questions in the text-message dependency scale. For example, the phrase "I feel disappointed if I don't receive any text messages" for text-message dependency was changed to "I feel disappointed if I don't receive any LINE messages" for LINE text messaging.

Permission was obtained from the creators of the text-message dependency scale for the replacement of "text messages" with "LINE messages" in the text of each question.

4. Results

Responses to the question, "Is your mobile phone on your desk at the present moment?" showed that 67.5% (54 students) had their mobile phone placed on their desk (Figure 1). This group of 54 students is referred to as the "on-desk group" hereinafter, and the group of 26 students who answered negatively is called the "not-on-desk group."

Next, to compare the score for dependency on text messaging and LINE messaging between

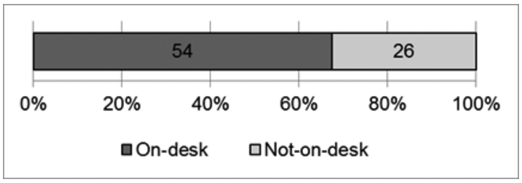

Figure 1 Number of students who placed their mobile phones on the desk during class

the two groups, an analysis of variance was performed with 2 factors, membership in the on-desk group (an intersubject or "group" factor) and dependency on mobile text messaging / LINE messaging (an intrasubject or "tool" factor).

Responses to the two dependency scale questions were on a 5-point scale and were analyzed as Likert items, with "Not at all applicable" given a value of 1 and "Very applicable" a value of 5. Additionally, there was 1 student in each group who reported that they do not use LINE messaging, and data for these 2 students were omitted from the analysis.

In the results of the analysis of variance using the total score of all 15 questions, the tool factor had a significant main effect (F (1, 76) = 45.50, p < .001), the group factor did not (F (1, 76) = 2.05), and the interaction was not significant (F (1, 76) = 0.95). Figure 2 shows that in both groups the dependency on LINE messaging was greater than the dependency on mobile text messaging.

An analysis of variance was also performed for the 3 subscale scores. Additionally, Cronbach's alpha was calculated for each subscale with the following results for text messaging and LINE messaging, respectively: 0.84 and 0.90 for emotional reaction, 0.73 and 0.83 for excessive use, and 0.91 and 0.85 for relationship maintenance.

In the results for the emotional reaction subscale, there were marked differences between

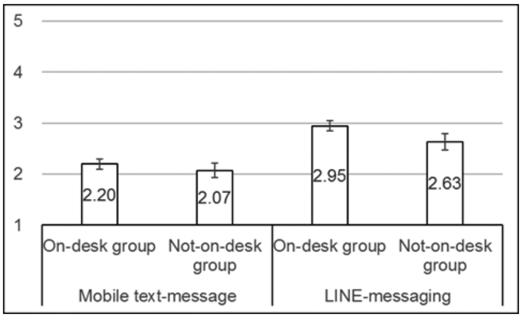

Figure 2 Comparison of average dependency scores between on-desk and not-on-desk groups

significances of the tool factor main effect (F (1, 76) = 30.58, $p < .001$), the group factor main effect (F (1, 76) = 3.30, $p < .10$), and the interaction effect (F (1, 76) = 3.03, $p<.10$). Figure 3 shows that in both groups, LINE-messaging dependency was higher than mobile text-message dependency, but that LINE-messaging dependency was even higher in the on-desk group.

For the perception of excessive use subscale, the tool factor main effect was significant (F (1, 76) = 58.63, $p < .001$), but the group factor main effect was not (F (1, 76) = 0.49) and there was no significant interaction (F (1, 76) = 0.00). Figure 4 shows that in both groups LINE-messaging dependency was higher than mobile text-message dependency.

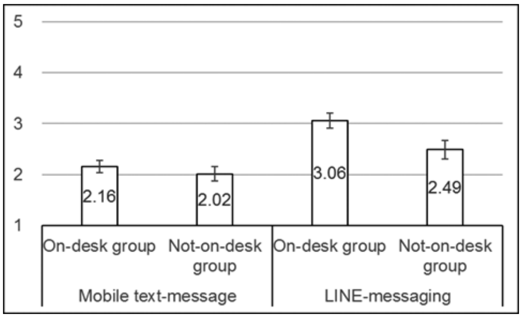

Figure 3 Comparison of average emotional reaction subscale scores between on-desk and not-on-desk groups

For the relationship maintenance subscale, the tool factor main effect was significant (F (1, 76) = 13. 30, $p < .001$), but the group factor main effect was not (F (1, 76) = 0.63) and there was no significant interaction (F (1, 76) = 0.75). Figure 5 shows that in both groups LINE-messaging dependency was higher than mobile-text message dependency.

Finally, an analysis of variance was performed using the scores of each of the 5 questions for emotional reaction, where a difference in the group factor was observed. Significance was observed for each of the following 3 items. For "I

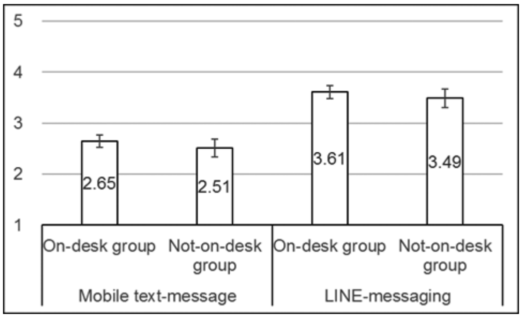

Figure 4 Comparison of average excessive use subscale scores between on-desk and not-on-desk groups

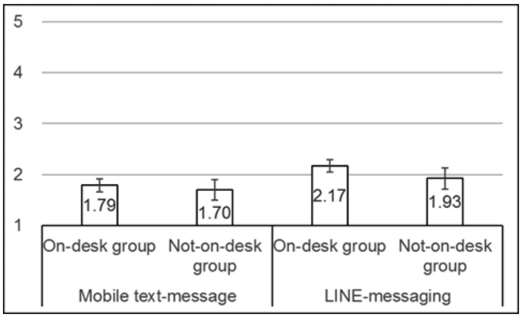

Figure 5 Comparison of average relationship maintenance subscale scores between on-desk and not-on-desk groups

feel disappointed if I don't receive any text messages / LINE messages", the interaction was significant (F (1, 76) = 4.90, p < .05) as were the tool factor main effect (F (1, 76) = 24.57, p < .001) and the group factor main effect (F (1, 76) = 3.48, p < .10). Figure 6 shows that for both groups LINE-messaging dependency was higher than mobile text-message dependency, but that LINE-messaging dependency was even higher in the on-desk group. For "I feel disappointed if I don't get a reply to my text message / LINE message immediately," the tool factor main effect was significant (F (1, 76) = 17.96, p < .001) as was the group factor main effect (F (1, 76) = 5.63, p < .05), but there was no significant interaction (F (1, 76) = 1.69). The item "I feel anxious when people don't immediately reply to my text message / LINE message" had the same pattern: a significant tool factor main effect (F (1, 76) = 14.22, p < .001) and group factor main effect (F (1, 76) = 5.38, p < .05), but an insignificant interaction (F (1, 76) = 0.85). The LINE-messaging dependency score was higher than the mobile text messaging dependency score, and both scores for the on-desk group were higher than those for the not-on-desk group (Figures 7 and 8).

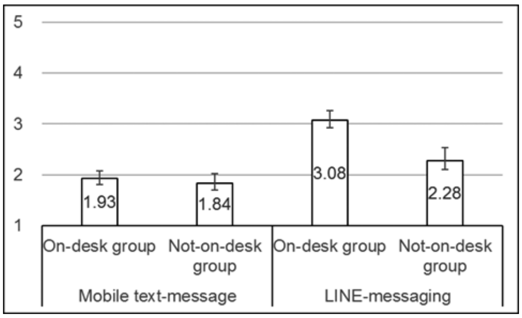

Figure 6 Comparison of average scores between on-desk and not-on-desk groups for the statement "I feel disappointed if I don't receive any text messages / LINE messages."

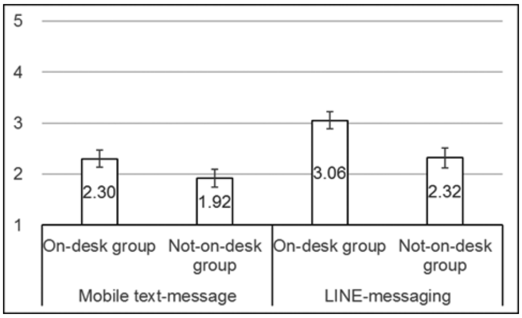

Figure 7 Comparison of average scores between on-desk and not-on-desk groups for the statement "I feel disappointed if I don't get a reply to my text message / LINE message immediately."

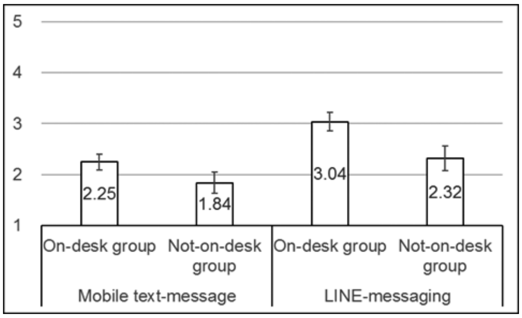

Figure 8 Comparison of average scores between on-desk and not-on-desk groups for the statement "I feel anxious when people don't immediately reply to my text message / LINE message."

5. Discussion

Using a questionnaire delivered to students of a women's university in Japan, dependency on LINE and text messaging was measured for students who placed their mobile phones on their desk during class and those who did not do so, and two hypotheses were examined.

The first hypothesis, that there is a high degree of dependency on mobile text message communication among students who place their mobile phone on their desk during classes, is partly supported. A difference in score was observed between the on-desk and not-on-desk groups in only the emotional reaction subscale of dependency on LINE messaging, with the on-desk group having a higher score. Among the 3 subscales, the score for perception of excessive use was highest in both groups for both mobile phone text messaging and LINE messaging. Excessive use indicates extended periods of continuous mobile text messaging and LINE messaging, and the use of mobile text messaging and LINE messaging in communicating back and forth with people as well. In contrast, the relationship maintenance subscale, which asked about the necessity of mobile text messages and LINE messages to create and maintaining personal relationships, was lowest among the subscales for both groups. Taken together, these imply that university students use mobile text messaging frequently but do not think that personal relationships are impossible to create and maintain without mobile text and LINE messaging. It was also observed that students who place their phone on their desk during class have a marked tendency to feel lonely or uneasy when they do not receive a quick reply from the other party during their communication, but this emotional reaction was more apparent for LINE messaging than in mobile text messaging.

The second hypothesis, that the degree of dependency on LINE text messaging among university students is greater than that on mobile phone text messaging, is supported. LINE text communication is a form of chatting. That is, because LINE messages are regarded as more casual, daily conversation (with messages exchanged simultaneously and continuously), the perception of excessive use score was higher for LINE messaging than for mobile text communication. As regular conversation creates and maintain personal relationships, it was expected that the relationship maintenance score would be slightly higher for LINE messaging, which enables conversation-style exchanges more readily than mobile text messaging does. Additionally, LINE messaging notifies the sender when a message has been read. This means that, in addition to waiting for a reply that is not arriving quickly, which occurs with mobile text messaging, LINE messaging also causes users to wait for a reply that is not arriving quickly even though the sender that knows the recipient has read the message. Thus the emotional reactions of loneliness and unease arise more easily with LINE messaging.

According to LINE Corporation (2013), most LINE users are in their teens and twenties, with the amount dropping for those 30 and older. While most university students use LINE to communicate with students of the same generation, most members of the older generation use standard mobile text messaging, mainly because they are not as accustomed to the newer communication tool as younger students (Kato 2015). Thus, the parties involved when communicating by LINE are different from those in mobile text messaging. Because for most university students, familiar people such as friends, significant others, and so on are generally in the same generation, it is assumed that they use LINE to communicate with these parties and mobile text messaging to communicate with out-of-generation individuals such as superiors at work or parents. If parties are different, the message content will also differ: in LINE, the content is mainly conversation that includes a variety of emotional expressions, while in mobile text messaging the content is more likely to be mainly business-like exchange. Compared with mobile text messaging, the use ratio of LINE is therefore increasing, with LINE taking on an important role in the deepening of relationships such as friendships. Because of this, it is thought that there are many more messages received in LINE and that the attention paid to replies and whether messages have been read or replied to has contributed to increased dependency on LINE.

This study was conducted in a classroom where no rules had been set regarding mobile phones. However, this didn't completely remove differences in influence between students. For example, we assume that differences in student's seating were influential. Generally speaking, if the seat in front of you is occupied, it's easier to take out your mobile phone without being seen by the lecturer. This can be described as an external influence on the placing of a phone on the desk. However, several student factors other than dependency can also be considered, such as difference in student age. First-year students may still experience residual influences from mobile phone rules in high school, which are generally very strict. Also, individual differences between students may also become factors, such as student relationships and events taking place that day (such as an emergency call, or having just received a romantic confession). This study, however, demonstrated and clarified that there are a number of correlations between the behavior of setting phones on desks in lectures and dependency scale score, although it goes without saying that future studies should investigate the various external and internal influences on phone behavior.

6. Conclusions

This study examined the relation between dependency on mobile text messaging and LINE messaging and the act of placing a mobile phone on the desk during classes, focusing on students at a Japanese women's university.

1) Students who place their mobile phone on their desk have a particularly high dependency score for LINE messaging for emotional reactions, including feelings of uncertainty and loneliness in waiting for a slow reply.

2) There is a higher dependency score for LINE messaging than for mobile text messaging.

This study focused on the act of university students placing their phone on their desk during classes. Our previous study showed that the act of placing a mobile phone on one's desk is a sign that shows the potential for mobile phone use during classes (Kato and Kato 2015). According to this study, this action also suggests a high degree of dependency on mobile phone use by the student.

7. Limitations and future research

The number of samples in this study was 78, so consideration remained focused on classification of whether students did or did not place their mobile phones on their desk. In the future, it will be necessary to conduct this same survey under the same conditions, but with an increase sample size, to improve the quantity of data. By doing so, it will become possible to classify phone use according to common student attributes (e.g. academic year, major, seat that day, frequency of mobile text messaging / LINE use, purpose of use) and consider the influence of these attributes in more detail. Furthermore, adding data on various lecture factors will enable multivariate analysis to include external attributes, improving our understanding of the relative strengths and weaknesses of a variety of influences.

Modern university students are often called "digital natives," indicating a generation that has been born and educated in an environment where they are surrounded by computers and mobile phones, and it is said that they are skilled at multitasking (Prensky 2001a, 2001b). A detailed examination of the effects of mobile phone use during classroom lectures should be conducted to test this assertion (Baron 2008).

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An Evaluation of Measures against the Urban Heat Island from the Viewpoint of Artificial Exhaust Heat of Road Traffic*
– An Evaluation Using GIS in the Tokyo 23-Ward Area –

Keywords:
Urban Heat Island, Artificial Exhaust Heat, Road Traffic, Geographic Information Systems (GIS), Tokyo 23-Ward Area

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Abstract

This study aims to evaluate measures against the Urban Heat Island (UHI) from the viewpoint of artificial exhaust heat of road traffic using Geographic Information Systems (GIS) in the Tokyo 23-Ward Area where the degree of UHI is particularly strong. We developed a GIS database that reflects road traffic conditions and calculated the volume of artificial exhaust heat of road traffic to evaluate measures against the UHI.

The findings of this study can be summarized in the following three points.

(1) Artificial exhaust heat volume for moving targets was remarkably higher than that of stationary targets and, in particular, artificial exhaust heat volume was high on roads with remarkable numbers of vehicles and running speeds such as expressways and ring roads. Artificial exhaust heat volume was particularly high for cars and regular trucks by model, and for weekdays and holidays, and daytime and night-time, artificial exhaust heat volume was mainly high during the day on weekdays.

(2) In UHI-related policy for moving targets, the suppression of waste heat through choice of fuel burned, improvement of traffic flow by securing space for cyclists and pedestrians, development of bypasses, and upgrading signal control managed to reduce artificial exhaust heat volume even though there were differences in degree of reduction. However, roads with high artificial exhaust heat volume reduction ratio differed with each UHI-related policy.

(3) In UHI-related policy for stationary targets, special road surfaces and the increase in efficiency of energy consumption equipment achieved a reduction ratio of around 30% in artificial exhaust heat volume, more than moving targets as well as making it possible to expect a reduction in artificial exhaust heat volume on a wide scale.

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1. Introduction

1.1 Point of view and purpose of research

Due to global warming in recent years, Urban Heat Islands (UHI) have become a serious problem for major urban areas in every country of the world. Japan's Inter-Ministry Coordination Committee to Mitigate Urban Heat Island developed the Outline of the Policy Framework to Reduce Urban Heat Island Effects in 2004. The Ministry of Economy, Trade and Industry (2007) reported that Japan's energy consumption in the private consumer, transportation and industrial sectors increased by approximately 2.6, 2.1 and 1.0 times respectively from 1973 to 2005. The Ministry of the Environment (2003a) also reported an increasing trend in artificial exhaust heat due to energy consumption in the Tokyo 23-Ward Area, and suggested that the proportions of artificial exhaust heat were approximately 50% buildings, 40% automobiles and 10% factories.

Mikami (2005) suggests changes in urban structure and artificial exhaust heat as causes for UHI, while the Japanese Meteorological Agency (2007) suggests changes in land use, the effects of buildings and the effects of artificial exhaust heat. Though the highest proportion of artificial exhaust heat is caused by buildings, measures to increase natural ground cover and greenery have already been implemented, and there are many examples of UHI research related to city green zones and increasing greenery for buildings and their grounds represented by Hirano et al. (2004) and Hoyano (2005). However, the proportion of artificial exhaust heat caused by road traffic in the field of transportation, in particular automobiles, is high and despite this being one of the major causes of UHI, there has been little focus on this issue.

Based on the above, this study targets the Tokyo 23-Ward Area where UHI intensity is particularly high, using a Geographic Information System (GIS) [(1)] with the aim of evaluating UHI-related policies focusing on artificial exhaust heat from road traffic. According to the Tokyo Metropolitan Heat Island Mitigation Committee (2003), recorded temperatures in the Tokyo 23-Ward Area have risen by approximately 3℃ in the past 100 years, and due to the fact that this rise is high in comparison with other large cities in Japan and other countries, it is understood that UHI intensity as urban warming is remarkably high in addition to the effects of global warming.

1.2 Related Work

The first study on UHI to be published in Japan was Tyson et al. (1973), and the number of studies began to increase dramatically from around the year 2000. Based on the results of a review of prior research targeting the relationship between UHI and artificial exhaust heat in the same way as this study, the following 16 major studies were divided into 4 groups depending on their research targets.

(1) Phenomenon / characteristics (3 studies): Mikami (2002), Ashie et al. (2004), Ishimaru (2004)
(2) Causes / mechanism (1 study): Mikami (2005)
(3) Effects / issues (7 studies): Mochida et al. (2001), Yoshida et al. (2002a, 2002b), Kamishige (2004), Sugahara (2005), Tamura et al. (2006b), Narumi (2006)
(4) Measures / effects (5 studies): Ota (2001), Tamura et al. (2003, 2005a, 2005b, 2006a)

As shown by the above prior research in related fields, though (3) Effects / issues have been most frequently studied, there have been few studies on the relationship between UHI and the artificial exhaust heat from road traffic. Only Ashie et al. (2004) discussed the differences between sensible heat and latent heat, and calculated artificial exhaust heat output for road traffic in 500m grid units in the Tokyo 23-Ward Area using GIS to obtain an understanding of the output characteristics of artificial exhaust heat. Though Ashie et al. (2004) conducted analysis in 500m grid units, it did not specifically investigate to propose UHI mitigation, or a detailed understanding of artificial heat volume considering road traffic status.

Accordingly, this study refers the results of the above-mentioned prior research as a foundation, and highly effective GIS as a database development and information analysis tool to develop a digital map database reflecting the status of road traffic. Furthermore, using this, specific evaluation of UHI-related policy is conducted after calculating artificial exhaust heat volume from road traffic for each road unit using GIS.

2. Evaluation method

2.1 Evaluation framework and method

This study began with a review of prior research to gather UHI-related policy with reference to artificial exhaust heat from road traffic in the Tokyo 23-Ward Area, and organized this information focusing on the characteristics of each policy target. Effect functions were set in order to analyze the effects of UHI-related policy after implementation, taking road traffic status into account, and road traffic status data and function coefficients used government data, experiment results and estimated values.

Using the above method, if all data and research information is updated using future technology developments and advances in research, it will be possible to update and provide even more accurate information. In addition, though this study targeted the Tokyo 23-Ward Area, if it were possible to obtain the same kind of data and information, it would be possible to conduct evaluation by applying this evaluation method to other urban areas. Due to this, we can expect the evaluation method proposed in this study to be temporally and spatially general-purpose and duplicable.

Next, this study set initial functions prior to the implementation of each UHI-related policy and effect functions for post-policy implementation, suggested respective methods of calculating artificial exhaust heat volume before and after policy implementation using GIS, and used these to calculate artificial exhaust heat volume. Furthermore, by comparing artificial exhaust heat volume before and after the implementation of each UHI-related policy, evaluation was conducted by investigating the effects of implementation of each policy. Though it should be noted that Ashie et al. (2004) conducted analysis in 500m grid units as mentioned above, this study used a digital base map that expresses roads in line format as detailed in the section below to add diverse data, and develop an integrated database to analyze and evaluate. By doing this, it was possible to calculate artificial exhaust heat volume by road unit and evaluate UHI-related policy, taking road traffic status characteristics into account.

2.2 GIS database development / usage process

Figure 1 shows the development / usage process for the GIS database in this study. First of

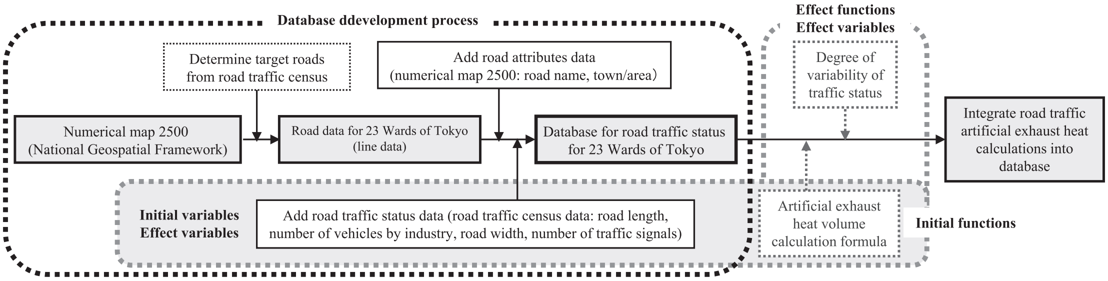

Figure 1　GIS Database Development / Usage Process

all, road data was developed in digital map format from 42,461 lines with numerical map 2500 (National Geospatial Framework)(2). Next, this data was added to / integrated with data relating to the road attributes and road traffic status on road traffic census (3) and numerical map 2500 to develop a database of road traffic status in the Tokyo 23-Ward Area.

Furthermore, from the next section onwards, following the framework and method explained in the previous section, the volume of artificial exhaust heat before and after implementation of each UHI-related policy was calculated using GIS, and this data was also integrated into the road traffic status database. It should be noted that initial and effect variables for road traffic status data, effect variables for degree of variability of traffic status and the artificial exhaust heat volume calculation formula included in initial and effect functions in Figure 1 are shown in section 3. Section 4 shows the concrete artificial exhaust heat volume calculation method using GIS in a flow chart and calculates artificial exhaust heat volume.

3. Organization of UHI-related policy and setting of functions

3.1 The relationships between the organization of UHI-related policy and functions

All policies listed by the Ministry of the Environment (2003b), the Tokyo Metropolitan Heat Island Mitigation Committee (2003), and the Ministry of Land, Infrastructure, Transport and Tourism (2007) were researched, and the nine policies shown in Table 1 are the result of extracting only UHI-related policies that were implemented or under consideration for the mitigation of artificial exhaust heat from road traffic in the Tokyo 23-Ward Area. Furthermore, the authors focused on the characteristics of each policy target, and divided to organize these into three groups: A. Transport framework / fuel, B. Road / road surface construction, and C. Road equipment. It should be noted that UHI-related policies No.3, 4, 5, 7 and 8 aimed to improve running speed by alleviating and reducing traffic congestion during the day.

Though the effects of implementation of related policies are diverse, they do permit eventual effects that inhibit artificial exhaust heat (main effects). Accordingly, primary factors directly before achieving main effects were defined as supplementary effects, and the determinants of supplementary effects were determined as effect variables. Effect functions were set and calculations were made for artificial exhaust heat volume affected by the supplementary effects of each related policy using these effect variables. As shown in the previous section, initial functions were also set before the implementation of these policies in order to obtain an understanding of the implementation effects of each UHI-related policy.

It was possible to divide supplementary effects into four categories: improvements in fuel consumption, improvements in running speed, reduction in heat storage volume, and increase in efficiency of equipment. Furthermore, the targets of supplementary effects were divided into two groups: moving and stationary depending on whether the target is traffic flow data (number of vehicles, running speed) or traffic facility data (road length or width, number of traffic signals).

Using the above-mentioned method, it was possible to specify how effects are emphasized by the supplementary effects of each related policy, and to organize data categories in road traffic status data which is an effect variable and degree of variability of traffic status for each UHI-related policy. As moving targets were mainly affected by sensible heat and stationary targets by latent heat, it can be said that the categories in

Table 1 UHI-Related Policy and Effect Variables

Policy target		Policy	UHI-related policy	Supplementary effects	Effect Target	Effect variables (road traffic status data / degree of variability in traffic status)				
						Road Length	Number of Vehicles	Running Speed	Road Width	Number of Traffic Signals
A.	Transport framework/Fuel	No.1	Spread of low-emission vehicles (hybrid)	Improvements in fuel consumption	Moving Targets	○	Diffusion rate	○	×	×
		No.2	Suppression of waste heat through choice of fuel burned (bioethanol)	Improvements in fuel consumption		○	Diffusion rate	○	×	×
B.	Road/Road surface construction	No.3	Improvement of traffic flow by securing space for cyclists and pedestrians	Improvements in running speed		○	○	Progress rate	×	×
		No.4	Development of bypasses	Improvements in running speed		○	○	Progress rate	×	×
		No.5	Improvement of access roads to airports and ports	Improvements in running speed		○	○	Progress rate	×	×
		No.6	Special road surfaces (water-holding surfaces)	Reduction in heat storage volume	Stationary Targets	○	×	×	○	×
C.	Road equipment	No.7	Increase in efficiency of energy consumption equipment (changing signal lights to LED)	Increase in efficiency of equipment		×	×	×	×	Diffusion rate
		No.8	Upgrading signal control	Improvements in running speed	Moving Targets	○	○	Progress rate	×	×
		No.9	Diffusion of ETC	Improvements in running speed		○	Diffusion rate	Progress rate	×	×

1) The ○ symbol in the table represents road traffic status data which is an effect target for supplementary effects in each UHI-related policy, and each value for road traffic status data and degree of variability in traffic status (diffusion and progress rates) marked with ○ is used to calculate artificial exhaust heat volume. The × symbol represents road traffic status data which is not an effect target for supplementary effects in each UHI-related policy.
2) UHI-related policies No.1 and No.2 are both UHI policies related to automobiles. According to the Ministry of the Environment (2003b), the Tokyo Metropolitan Heat Island Mitigation Committee (2003), and the Ministry of Land, Infrastructure, Transport and Tourism (2007), hybrid vehicles with two sources of power in the engine and in the motor, and driven using a combination of their respective benefits are defined as vehicles that can achieve both energy conservation and low emissions. Policy No.1 targets only hybrid vehicles, whereas policy No.2 targets vehicles that run on gasoline, excluding hybrid vehicles.

this study considers the effects of both sensible and latent heat.

3.2 Setting initial functions

Table 2 provides an overview of initial functions, while Table 3 provides an overview of initial variables. A formula for calculating artificial exhaust heat volume in initial functions such as those in Table 2 was developed according to the two categories mentioned above, moving and stationary targets. Using this formula, a basic structure was formed to group effect functions calculating artificial exhaust heat volume after the implementation of each UHI-related policy. It should be noted that, as elements of effect functions were designated as effect variables, in the same way, elements of initial functions were designated as initial variables. Initial variables are: road traffic census road traffic status data, waste heat coefficients by model and speed converted from the energy consumption coefficients by model and speed which are provided by Ministry of Land, Infrastructure, Transport and Tourism / Ministry of the Environment [(4)], road surface waste heat coefficients in the results of Kanto Regional Development Bureau, the Ministry of Land, Infrastructure, Transport and Tourism [(5)] project, and traffic signal waste heat coefficients converted to one day's worth of heat volume from electricity consumption by light bulb and LED from the National Police Agency [(6)].

Table 2 shows each data category for road traffic status data used as initial variables, and these are also used in the same way in effect functions detailed in the next section. Road traffic census values were used in each of the above-mentioned categories, and values for numbers of cars, buses, and small and regular trucks were input by model and running speed values for both weekdays and holidays in FY2005 were input. For the number of traffic signals, the number of intersections with traffic signals was calculated by dividing them into two types depending on the width of the road: main roads and minor roads, and the number of traffic signals was set at four as the average number found at a regular cross-shaped intersection and

Table 2　Initial Functions

Initial target	Initial function (Artificial exhaust heat volume calculated formula) Q_{α}, Q_{β}[J]
Moving target	Q_{α}=road length L[km]×number of vehicles by model M[number]×waste heat coefficient by model/speed C_V[J/(km・number)]
Stationary target	Q_{β}=(road length L[km]×road width W[km]×road surface waste heat coefficient C_{lw}[J/km^2])+ (number of traffic signals S[number]×traffic signal waste heat coefficient C_s[J/number])

Table 3　Outline of Initial Variables

Effect target	Initial variables	Explanation	Source
Moving target	Waste heat coefficient by model speed C_v [J/(km・number)]	Convert with waste heat by model 4.1858[kJ/kcal] per source speed	Ministry of Land, Infrastructure, Transport and Tourism / Ministry of the Environment (2004) Survey of Heat Island Mitigation through Artificial Exhaust Heat Control in Urban Areas 2003 <http://www.mlit.go.jp/sogoseisaku/heat_island/05.pdf>
Stationary target	Road surface waste heat coefficient C_R[J/m^2]	Asphalt road surface temperature set at 63[℃]【Test value】(1 day's worth of waste heat volume 6.24×10^4[kJ/m^2] according to the Stefan-Boltzmann Constant)	Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism (2004) The Challenge of alleviating the Heat Island Phenomenon on Roads - Results of the Tokyo Environmental Surface Project (press conference documents, 25th May, 2004)
	Number of traffic signals S[number]	Number of traffic signals per intersection set at 4	Japan Society of Traffic Engineers Results of Responses to Enquiries to Road Traffic Census Support Staff 2005
	Traffic signal waste heat coefficient C_L[J/number]	Bulbs used determined as 70W【Document value】(1 day's worth of waste heat 6.0×10^3[kJ/number])	National Police Agency Conversion of Traffic Signals to LED <https://www.npa.go.jp/koutsuu/kisei/shisetu/led.pdf>

calculations were made.

3.3 Setting effect functions

Table 4 provides an overview of effect functions, while Table 5 provides an overview of effect variables. Effect functions such as those in Table 4 were composed using effect variables and in effect variables, there were functions for which degree of variability of traffic status was added to road traffic status data as shown in the previous section as a correction factor after the implementation of each UHI-related policy. Moreover, there were also functions for which heat waste coefficient by model / speed, road surface waste heat coefficient, and traffic signal waste heat coefficient were each converted respectively.

Degree of variability of traffic status effect variables was set as a correction factor in order to reflect the effects of the implementation of each UHI-related policy in each data category of road traffic status data. These are the actual changing values at the time of setting effect functions in order to calculate artificial exhaust heat volume after the implementation of each policy. If there are changes to the expected implementation effects of UHI-related policies, it is possible to recalculate artificial exhaust heat volume by re-setting this degree of variability for traffic status.

Moreover, waste heat coefficients by model / speed in initial functions were re-set in moving target UHI-related policies No.1, 2, 3, 4, 5, 8 and 9 as waste heat coefficients by model / speed in effect functions. This is because the policy target in UHI-related policies No.1 and 2 is related to A. Transport framework / fuel, and there is potential for future change in goal values for waste heat volume, waste heat rate and rate of spread of target vehicles. This is because, in UHI-related policies No.3, 4, 5, 8 and 9, corrected values for running speed in road traffic status data through improvement of degree of variability in traffic

Table 4　Effect Functions

Policy	UHI-related policy	Effect target	Effect function (Artificial heat exhaust volume calculation formula) Qn[J]
No.1	Spread of low-emission vehicles (hybrid)	Moving targets	Q_1＝road length L[km]×〔(diffusion rate d_1[%]×number of vehicles by model M[number]×waste heat variables by model/speed X_{Cv1}[J/(km・number)])＋{（100-diffusion rate d_1[%]）×number of vehicles by model M[number]×waste heat coefficients by model/speed C_v[J/(km・number)]}〕
No.2	Suppression of waste heat through choice of fuel burned (bioethanol)		Q_2＝road length L[km]×〔（diffusion rate d_2[%]×number of vehicles by model M[number] waste heat variables by model/speed X_{Cv2}[J/(km・number)])＋{（100-diffusion rate d_2[%]）×number of vehicles by model M[number]×waste heat coefficients by model/speed C_v[J/(km・number)]}〕
No.3	Improvement of traffic flow by securing space for cyclists and pedestrians		Q_3＝road length L[km]×noumber of vehicles by model M[number]×waste heat variables by model/speed X_{Cv3}[J/(km・number)]
No.4	development of bypasses		Q_4=road length L[km]×number of vehicles by model M[number]×waste heat variables by model/speed X_{Cv4}[J/(km・number)]
No.5	Improvement of access roads to airports and ports		Q_5＝road length L[km]×number of vehicles by model M[number]×waste heat variables by model/speed X_{Cv5}[J/(km・number)]
No.6	Special road surfaces (water-holding surfaces)	Stationary targets	Q_6＝road length L[km]×road width W[km]×road surface waste heat variables X_{C1W}[J/km^2]
No.7	Increase in efficiency of energy consumption equipment (changing signal lights to LED)		Q_7＝number of traffic signals S[number]×〔{LEd diffusion rate d_7[%]×traffic signal waste heat variables X_{CL}[J/number]}＋{(100-LED diffusion rate d_7[%])×traffic signal waste heat coefficients C_L[J/number]}〕
No.8	Upgrading signal control	Moving targets	Q_8＝road length L[km]×number of vehicles by model M[number]×waste heat variables by model/speed X_{Cv8}[J/(km・number)]
No.9	diffusion of ETC		Q_9＝road length L[km]×〔（diffusion rate d_9[%]×number of vehicles by model M[number]×waste heat variables by model/speed X_{cv9}[J/(km・number)])＋{（100-diffusion rate d_9[%]）×number of vehicles by model M[number]×waste heat coefficients by model/speed C_v[J/(km・number)]}〕

Table 5　Overview of Effect Variables

Policy	Effect variables	Explanation	Source
No.1	Waste heat variables by model/speed X_{Cv1}[J/(k・number)]	cars/buses: waste heat ratio of 75% as hybrid vehicles【Assumed value】 small/regular trucks: waste heat ratio of 74% as CNG trucks【Assumed value】	Ministry of Land, Infrastructure, Transport and Tourism (2005) Ranking by Vehicle Weight <http://www.mlit.go.jp/kisha/kisha05/09/090223/02.pdf>
	Diffusion rate d_1[%]	Target vehicles are 0.87% of all vehicles (figures from the year 2000)	Japan Automobile Manufacturers Association (2001) Special Report on the Development and Spread of Low-emission Vehicles <http://www.jama.or.jp/lib/jamagazine/200109/01.html>
No.2	Waste heat variables by model/speed X_{Cv2}[J/(km・number)]	60% waste heat using E100【Assumed value】	Council for Science, Technology and Innovation, Cabinet Office, Government of Japan Roadmap and Diffusion Scenario for Environmental Energy Technology <http://www8.cao.go.jp/cstp/siryo/haihu75/sanko2-1.pdf>
	Diffusion rate d_2[%]	Target vehicles are 42% of gasoline vehicles (gasoline vehicle ratios/cars: 88.7%, buses: 0.28%, small/regular trucks: 24.6%)	Daiwa Institute of Research (2007) New Industry Report 2007/summer: Trends in Automobile Technology borne by the Next Generation <http://www.dir.co.jp/souken/research/report/emg-inc/hitech/07060101hitech.pdf> Ministry of Land, Infrastructure, Transport and Tourism, Policy Bureau Information Management Division (2006) Outline of Traffic-related Energy <http://www.mlit.go.jp/toukeijouhou/energy/h18_energy.pdf>
No.3	Waste heat variables by model/speed X_{Cv3}[J/(km・number)]	Improve running speed for all vehicles by 10% except on national/urban expressways【Simulation value】	Yuichi Harumoto (2006) Understanding of the Current Status of Urban Traffic and Bicycle Use in Nagano City <http://taklab12.shinshu-u.ac.jp/contents/subjects/Others/pdf/B4_harumoto.pdf>
No.4	Waste heat variables by model/speed X_{Cv4}[J/(km・numner)]	For roads (congested roads) with running speed of 20[km/h] or less, running speed is set at 21[km/h] as a congestion solution value【Assumed value】	Inter-Ministry Coordination Committee to Mitigate Urban Heat Island (2004) Outline of the Policy Framework to Reduce Urban Heat Island Effects <http://www.env.go.jp/air/life/heat_island/taikou.pdf> Ministry of Land, Infrastructure, Transport and Tourism Kanto Regional Development Bureau Alleviating Traffic Congestion <http://www.ktr.mlit.go.jp/3kanjo/efficacy/traffic_jam.htm>
No.5	Waste heat variables by model/peed X_{Cv5}[J/(km・number)]	For roads with running speed of 20[km/h] or less, such as coastal roads (national highways 14 and 357, coastal expressways) and the Yokohama-Haneda Airport urban expressway, running speed is increased by 13% as a congestion alleviation value 【Current congestion alleviation value】	Tokyo Metropolitan Government (2000) Basic Aviation Policy (enhancement/strengthening of access to 4 airports) <http://www.toshiseibi.metro.tokyo.jp/kanko/ksk/03-4.pdf> Ministry of the Environment (2007) (Annex) State of Progress of Specific Policies recorded in the Outline of the Policy Framework (July, 2007 Ministry of the Environment press conference documents) <http://www.env.go.jp/press/file_view.php?serial=9863&hou_id=8588>
No.6	Road surface waste heat variable X_{CR}[J/km^2]	Set at 40℃ using water-holding surfaces 【Test value】 (1 day's worth of waste heat volume 4.70×10^4[kJ/m^2] according to the Stefan-Boltzmann Constant)	Ministry of Land, Infrastructure, Transport and Tourism, Kanto Regional Development Bureau (2004) The Challenge of alleviating the Heat Island Phenomenon on Roads - Results of the Tokyo Environmental Surface Project (press conference documents, 25th May, 2004)
No.7	Traffic signal waste heat variables X_{CL} [J/number]	Set at 15W using LED【Document value】 (1 day's worth of waste heat volume 1.3×10^3[kJ/number])	National Police Agency Conversion of Traffic Signals to LED <https://www.npa.go.jp/koutsuu/kisei/shisetu/led.pdf>
	LED diffusion rate d_7[%]	LED diffusion rate was set at 39.4% (Rate of use of LED in vehicles in Tokyo) (Number of traffic signals at 1 intersection was set at 4)	National Police Agency Number of Instances of Maintenance in Traffic Signals by Prefecture <https://www.npa.go.jp/koutsuu/kisei/institut/kazu.pdf>
No.8	Waste heat variables by model/speed X_{Cv8}[J/(km・number)]	Improve running speed for all vehicles by 10% excluding national expressways, urban expressways and minor roads with no traffic signals 【2007 Goal Values for the Policy Framework to Reduce Urban Heat Island Effects】	Ministry of the Environment (2007) (Annex) State of Progress of Specific Policies recorded in the Outline of the Policy Framework (July, 2007 Ministry of the Environment press conference documents) <http://www.env.go.jp/press/file_view.php?serial=9863&hou_id=8588>
No.9	Waste heat variables by model/speed X_{Cv9}[J/(km・number)]	For national and urban expressways which are roads (congested roads) with running speed of 20[km/h] or less, running speed is increased to 13% as a congestion alleviation value【Current congestion alleviation value】	Ministry of the Environment (2007) (Annex) State of Progress of Specific Policies recorded in the Outline of the Policy Framework (July, 2007 Ministry of the Environment press conference documents) <http://www.env.go.jp/press/file_view.php?serial=9863&hou_id=8588>
	Diffusion rate d_9[%]	75.8% of all vehicles are target vehicles (national figure as of December, 2008)	Ministry of Land, Infrastructure, Transport and Tourism (2008) Status of Usage of ETC (bulletin) (as of 18th December, 2008) <http://www.mlit.go.jp/road/yuryo/riyou.pdf>

status at the time of composing effect functions are inherent as heat waste variables by model and speed. Furthermore, road surface waste heat coefficients in initial functions were reflected in the implementation effects of each policy as road surface heat waste variables in effect functions, and traffic signal waste heat variables in the same way in traffic signal waste heat coefficients, and each artificial exhaust heat volume was re-defined. UHI-related policy No.3 was based on research results in the centre of Nagano City, and as a result of reviewing research such as data from governmental documents, experiment results and estimated values relating to the effect functions of the policies mentioned in 2.1, at present, this study determined that its own research target areas were the most appropriate.

4. Calculation of artificial exhaust heat volume using GIS

4.1 Artificial exhaust heat calculation method

Figure 2 shows the artificial exhaust heat volume calculation method using GIS in flow chart format. First of all, initial variables were set

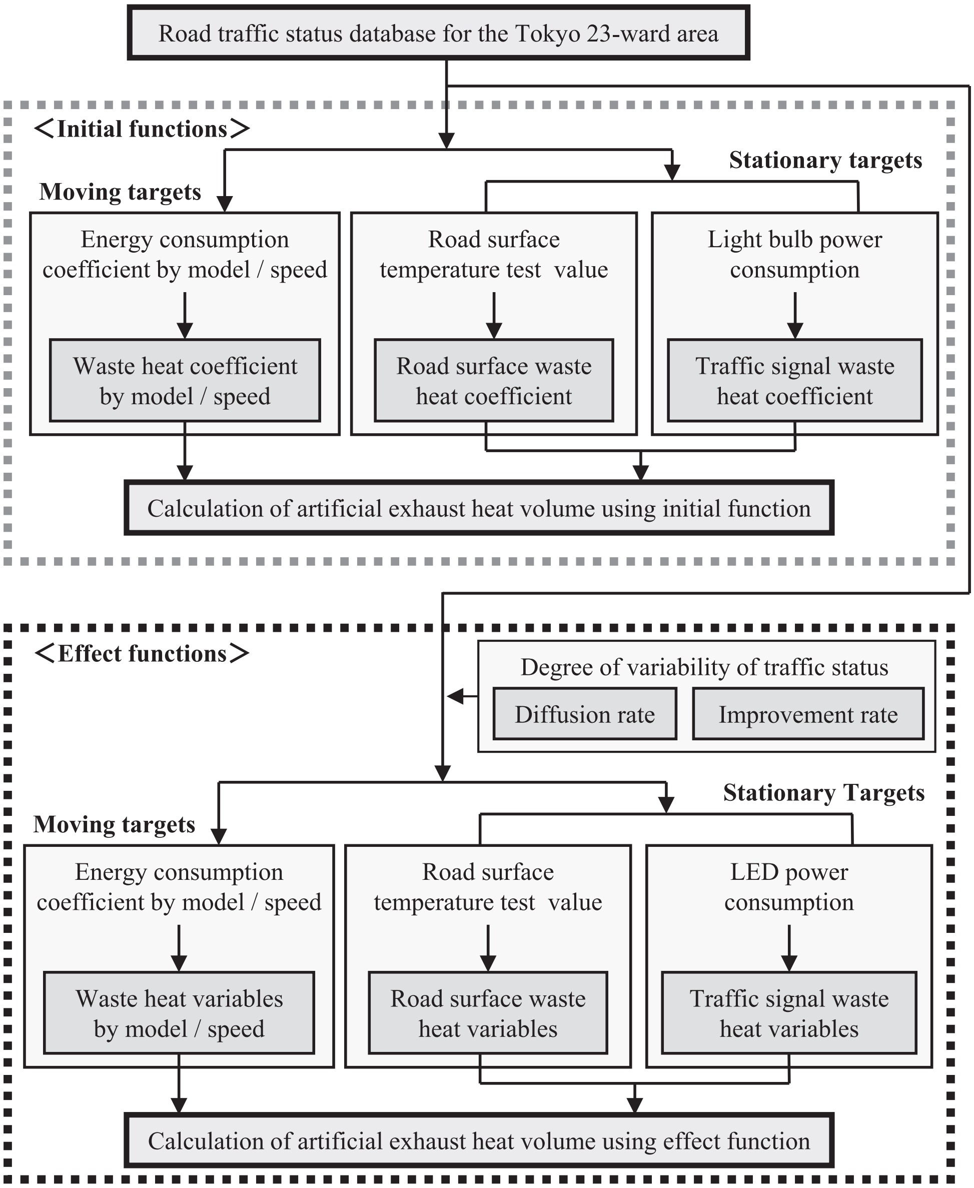

Figure 2 Calculation Method for Artificial Exhaust Heat Volume using GIS

as heat waste coefficients by model and speed for moving targets, and as road surface heat waste coefficients and traffic signal waste heat coefficients for stationary targets in initial functions. Artificial exhaust heat volume was calculated before the implementation of UHI-related policies. Road traffic status data corrected with degree of variability in traffic status, waste heat variables by model and speed in moving targets, and road surface waste heat variables and traffic signal waste heat variables in stationary targets were set as effect variables in effect functions and artificial exhaust heat volume was calculated after the implementation of UHI-related policies.

It should be noted that, as waste heat coefficients by model and speed differ in the daytime (9 am - 8 pm) and the night-time (9 pm - 8 am), artificial exhaust heat volume for moving targets was calculated for both daytime and night-time in addition to calculations for weekdays and holidays, and four types of vehicles in accordance with the categories in the road traffic census. However, as moving target UHI-related policies No.3, 4, 5, 8 and 9 aimed to improve running speed by alleviating and reducing traffic congestion during the day, artificial exhaust heat volume after the implementation of these policies was calculated in the daytime. In addition, as stationary target artificial exhaust heat volume is calculated with one day's worth of waste heat volume, artificial exhaust heat volume after the implementation of stationary target UHI-related policies No. 6 and 7 was calculated by day.

4.2 Results of calculations of artificial exhaust heat volume for moving targets

Using the calculation method shown in the previous section, artificial exhaust heat volume was calculated for both moving and stationary targets. Table 6 shows artificial exhaust heat volume for moving targets which was remarkably

Table 6 Results of Calculation of Artificial Exhaust Heat Volume for Moving Targets by Model (%, top value: daytime, bottom value: night-time)

Area	Road	Car		Bus		Small truck		Regular truck		Total for each road (10,000 kJ)	
		Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday
Centre	Metropolitan Expressway No.4 (Shinjuku)	40.0	44.3	3.1	3.2	11.0	11.5	46.0	41.0	18,525.5	19,263.0
		40.0	42.5	3.1	3.1	11.0	11.9	45.9	42.4	17,175.6	18,596.3
	Metropolitan Expressway (ring road)	34.2	33.9	2.2	2.3	8.6	8.6	55.0	55.2	27,567.4	23,664.4
		34.2	33.9	2.2	2.3	8.6	8.7	55.0	55.2	25,553.7	21,929.0
North	Metropolitan Expressway No.5 (Ikebukuro)	30.4	24.1	1.5	1.3	8.1	7.2	60.0	67.3	65,718.4	54,310.9
		29.1	26.2	1.4	1.5	7.7	7.9	61.8	64.5	63,803.3	46,328.1
East	Metropolitan Expressway No.7	42.4	42.4	0.9	0.9	9.5	9.7	47.3	47.0	15,004.4	11,796.6
		42.4	42.5	0.9	0.9	9.5	9.7	47.3	46.9	13,905.7	10,945.2
	Metropolitan Expressway No.9	24.2	23.6	3.7	3.9	7.8	8.0	64.3	64.5	8,692.3	6,431.9
		24.2	23.7	3.7	3.9	7.8	8.0	64.3	64.3	8,057.0	5,965.7
West	Chuo Expressway	44.3	43.2	3.8	4.1	9.9	10.2	42.0	42.5	5,016.0	3,225.7
		44.3	43.3	3.8	4.1	9.9	10.2	42.0	42.4	4,650.6	2,992.6
Northeast	Metropolitan Expressway No.6	23.6	23.1	1.8	1.8	6.9	6.9	67.7	68.3	25,894.5	24,716.8
		23.6	23.1	1.8	1.8	6.9	6.9	67.7	68.2	24,004.1	22,912.8
Southeast	Metropolitan Road No. 482 (Daiba/Ome)	41.3	41.3	3.9	3.9	15.5	15.5	39.3	39.3	43,851.8	43,851.8
		41.3	41.3	3.9	3.9	15.5	15.5	39.3	39.3	40,656.0	40,656.0
	Metropolitan Expressway (coastal route)	17.7	17.2	3.3	3.3	6.5	6.5	72.5	72.3	17,210.4	17,075.9
		17.7	17.4	3.3	3.3	6.5	6.5	72.5	72.3	15,944.7	15,810.1
Southwest	Tokyo-Nagoya Expressway	24.7	25.5	1.2	1.1	4.5	4.4	69.6	68.9	27,915.1	30,333.7
		24.9	25.5	1.2	1.1	4.5	4.5	69.3	68.9	25,907.1	28,105.9
Total for roads in the Tokyo 23-ward area		35.8	35.5	2.4	2.4	12.2	12.4	49.6	49.7	33,374,492.9	31,197,133.8
		35.8	35.5	2.4	2.4	12.2	12.4	49.6	49.7	30,939,244.8	28,921,064.8

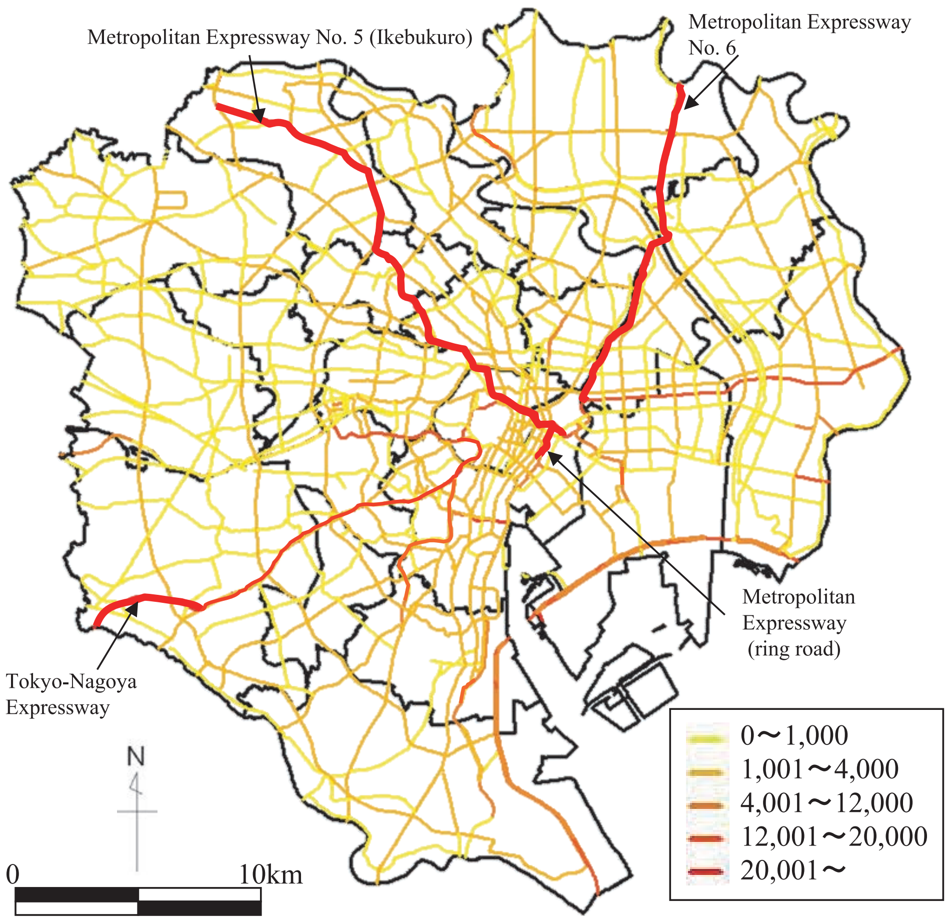

Figure 3　Status of Artificial Exhaust Heat Volume in Daytime on Weekdays (10,000 kJ, total of all vehicles)

high in comparison to that of stationary targets. Figure 3 shows the weekday daytime status where artificial exhaust heat is at its highest. In addition, as artificial exhaust heat volume was high for all vehicles, regardless of the time, on the same roads with remarkable vehicles numbers and running speed such as expressways and ring roads, Table 6 shows artificial exhaust heat volume for all these roads. It should be noted that artificial exhaust heat volume for stationary targets was 1,336,070,000 kJ from road surface and 6,939,200,000 kJ from traffic lights for one day on all roads in the Tokyo 23-Ward Area. Total artificial exhaust heat volume for these stationary targets was not more than around 1.3% of total artificial exhaust heat volume for both daytime and night-time for moving targets on both weekdays and holidays.

The greatest characteristic of vehicles by model was that artificial exhaust heat volume for cars and regular trucks on all roads was high on both weekdays and holidays, during the day and at night. If these values are amalgamated, they account for more than 80% of artificial exhaust heat volume for each road. Artificial exhaust heat volume was high on weekdays for all roads excluding those in central and south-western areas in the weekday / holiday category, and it was high in the daytime for all roads in the daytime / night-time category. Metropolitan Expressway No.5 (Ikebukuro) in the northern area in particular had higher disparity between daytime and night-time on holidays than other roads.

5. Evaluation of UHI-related policy

5.1 Evaluation of UHI-related policy for moving targets

A comparison was made between artificial exhaust heat volume after the implementation of policies using effect functions in UHI-related policies No.1, 2, 3, 4, 5, 8 and 9 for moving targets, and artificial exhaust heat volume before the implementation of policies using initial functions and related policies were evaluated. Table 7 shows the proportion of reduction of artificial exhaust heat volume after the implementation of UHI-related policy for roads with high artificial exhaust heat volume in the same way as Table 6.

It was understood that, for the Tokyo 23-Ward Area overall, the reduction ratio of No.2 (suppression of waste heat through choice of fuel burned) was high at over 10%, and that it was possible to reduce artificial exhaust heat volume, albeit slightly, in No.3 (improvement of traffic flow by securing space for cyclists and pedestrians), No.4 (development of bypasses), and No.8 (upgrading signal control). In addition, in No.2, apart from Metropolitan Expressway No.5 (Ikebukuro), the reduction ratios on weekdays and holidays were of a similar level, and it can be said that the effect of implementation was higher during the day in particular. However, after the implementation of No.1 (spread of low-emission vehicles), it was suggested that there is

Table 7 Reduction Ratio of Artificial Exhaust Heat Volume After the Implementation of UHI-Related Policies (excluding No.7) (%, top value: daytime, bottom value: night-time)

Area	Road	Moving targets														Stationary targets
		No.1		No.2		No.3		No.4		No.5		No.8		No.9		No.6
		Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	Weekday	Holiday	
Centre	Metropolitan Expressway No.4 (Shinjuku)	0.2	(+6.4)	11.5	5.7	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	24.7
		(+7.6)	(+10.2)	5.9	3.7	-	-	-	-	-	-	-	-	-	-	
	Metropolitan Expressway (ring road)	0.2	0.2	11.3	11.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.7
		(+7.6)	(+7.6)	5.6	5.6	-	-	-	-	-	-	-	-	-	-	
North	Metropolitan Expressway No.5 (Ikebukuro)	0.2	12.5	11.1	21.9	0.0	12.3	12.2	12.3	0.0	12.3	0.0	12.3	3.4	12.3	27.7
		(+2.7)	(+2.5)	9.7	9.7	-	-	-	-	-	-	-	-	-	-	
East	Metropolitan Expressway No.7	0.2	0.2	11.8	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7
		(+7.6)	(+7.5)	6.3	6.3	-	-	-	-	-	-	-	-	-	-	
	Metropolitan Expressway No.9	0.2	0.2	10.6	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.0
		(+7.6)	(+7.5)	4.8	4.8	-	-	-	-	-	-	-	-	-	-	
West	Chuo Expressway	0.2	0.2	11.6	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7
		(+7.6)	(+7.5)	6.1	6.0	-	-	-	-	-	-	-	-	-	-	
Northeast	Metropolitan Expressway No.6	0.2	0.2	10.7	10.7	0.0	0.0	6.4	1.9	0.0	0.0	0.0	0.0	3.4	3.7	27.7
		(+7.6)	(+7.6)	5.0	5.0	-	-	-	-	-	-	-	-	-	-	
Southeast	Metropolitan Road No. 482 (Daiba/Ome)	0.2	0.2	11.5	11.5	4.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7
		(+7.6)	(+7.6)	5.9	5.9	-	-	-	-	-	-	-	-	-	-	
	Metropolitan Expressway (coastal route)	0.2	0.9	10.3	10.8	0.0	0.6	0.0	0.6	0.0	0.6	0.0	0.6	0.0	0.6	27.7
		(+7.7)	(+7.0)	4.4	4.9	-	-	-	-	-	-	-	-	-	-	
Southwest	Tokyo-Nagoya Expressway	0.2	0.2	10.8	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.7
		(+7.5)	(+7.6)	5.2	5.1	-	-	-	-	-	-	-	-	-	-	
Total for roads in the Tokyo 23-ward area		0.2	0.2	11.3	11.3	2.9	3.0	5.4	3.2	0.1	0.0	2.8	2.9	0.4	0.3	27.7
		(+7.6)	(+7.6)	5.7	5.7	-	-	-	-	-	-	-	-	-	-	

Note: UHI-related policies No.3, 4, 5, 8 and 9 for moving targets had the aim of improving running speed by alleviating and reducing daytime traffic congestion therefore only daytime artificial exhaust heat volume after the implementation of these policies was calculated, and as values for night-time were not calculated, the relevant cells for night-time reduction ratios are marked with a -.

Table 8 Reduction Ratio of Artificial Exhaust Heat Volume after the Implementation of UHI-Related Policy No.7 (%)

Area	Road	No.7
Centre	Major Regional Road No.302 (Shinjuku/Ryogoku)	30.9
North	Metropolitan Road No.455 (Hongo/Akabane)	30.9
East	Metropolitan Road No.465	30.9
	Metropolitan Road No.474	30.9
West	Major Regional Road No.3 (Setagaya/Machida)	30.9
Northwest	Major Regional Road No.9 (Ichikawa/Yotsugi)	31.5
Southeast	Metropolitan Road No.482 (Daiba/Ome)	30.9
Southwest	Major Regional Road No.426 (Kamiuma/Okusawa)	30.9
Total for roads in the 23 Wards of Tokyo		30.9

potential for an increase in artificial exhaust heat volume mainly at night. As shown in the previous section, this is because waste heat coefficients by model and speed differ between day and night, and values are set to increase according to improvements in running speed.

Meanwhile, it was discovered that roads with high reduction ratios for artificial exhaust heat volume differed for each UHI-related policy. For example, though the above-mentioned No.1, No.5 (improvement of access roads to airports and ports), and No.9 (diffusion of ETC) did not manage to reduce artificial exhaust heat volume much in the Tokyo 23-Ward Area overall, the Metropolitan Expressway No.5 (Ikebukuro) has a reduction ratio of more than 10% during the day on holidays.

5.2 Evaluation of UHI-related policy for stationary targets

In the same way as in the previous section, evaluation of UHI-related policies No.6 and 7 for stationary targets was conducted. Artificial exhaust heat volume reduction ratio for No.6 (special road surfaces) is shown in Table 7 above, and the reduction ratio for roads with high artificial exhaust heat volume among those installed with traffic signals for No.7 (increase in efficiency of energy consumption equipment) is shown in Table 8. Though differences in reduction ratios were observed for each road as shown in Tables 7 and 8, as discrepancies in road width in No.6 and number of traffic signals by unit length in No.7 were reflected, differences occurred.

By implementing these two related policies, it was discovered that it was possible to reduce artificial exhaust heat volume in the Tokyo 23-Ward Area overall by 27.7% and 30.9% respectively, and that it was possible to obtain the same level of effects in all areas. Consequently, as shown in section 4.2, though artificial exhaust heat volume for stationary targets was remarkably lower than that of moving targets, it can be said that reduction ratio was higher than that of moving targets in this related policy. As the two policies mentioned above are implemented in all Tokyo 23-Ward Area, it is expected that artificial exhaust heat volume will reduce over a wide area.

However, as policy No.7 targets roads installed with traffic signals, implementation effects were not obtained on expressways or ring roads with high artificial exhaust heat volume for moving targets as shown in the previous section. In addition, though this study does not target small-scale roads that are not published in the road traffic census, as it is thought to be possible to expect implementation effects for these with policy No.7, it is necessary to develop a more detailed road traffic status database and conduct evaluation.

6. Conclusion and Future Research

By using GIS as a database development and information analysis tool in this study, it was possible to develop a digital map database that reflects road traffic status, and to calculate artificial exhaust heat volume for road traffic in each road unit. Specific evaluation of UHI-related policies was then conducted, and artificial exhaust heat volume was able to be explained and displayed in an easy-to-understand manner on a digital map with spatial distribution status.

The conclusions of this study can be summarized by the following three points.

(1) Artificial exhaust heat volume for moving targets was remarkably higher than that of stationary targets, and, in particular, artificial exhaust heat volume was high on roads with remarkable numbers of vehicles and running speeds such as expressways and ring roads. Artificial exhaust heat volume was particularly high for cars and regular trucks by model and for weekdays and holidays, and daytime and night-time, artificial exhaust heat volume was mainly high during the day on weekdays.

(2) In UHI-related policy for moving targets, the suppression of waste heat through choice of fuel burned, improvement of traffic flow by securing space for cyclists and pedestrians, development of bypasses and upgrading signal control managed to reduce artificial exhaust heat volume, even though there were differences in degree of reduction. However, roads with high artificial exhaust heat volume reduction ratio differed with each UHI-related policy.

(3) In UHI-related policy for stationary targets, special road surfaces, and the increase in efficiency of energy consumption equipment achieved a reduction ratio of around 30% in artificial exhaust heat volume, more than moving targets as well as making it possible to expect a reduction in artificial exhaust heat volume on a wide scale.

The following five points require research in the future.

(1) By more effectively using the various functions of GIS and obtaining an accurate understanding of the spatial changes in road traffic status, the calculation of even more rational values. In addition, the calculation of artificial exhaust heat volume in each road unit taking reciprocal effects due to spatial positioning into account.

(2) Even more detailed evaluation of areas which have particularly high UHI density in the Tokyo 23-Ward Area.

(3) Development and evaluation of a detailed road traffic status database targeting small-scale roads.

(4) Understanding of the implementation effects of each UHI-related policy and proposals for effective policy implementation plans.

(5) Application of the evaluation methods in this study to other urbans areas with high UHI density and evaluation.

Notes

(1) The GIS used in this study was ESRI's Arc GIS Desktop Arc Info (Ver. 9.2).

(2) Geographical Survey Institute (issued 2003 (6 issues)), numerical map 2500 (National Geospatial Framework) Kanto - 3

(3) Japan Society of Traffic Engineers (2007) 2005 Road Traffic Census National Road / Street Traffic Status Survey

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