Impact of Rainfall on Urban Traffic Flow based on Probe Vehicle Data in Bangkok

Tsuyoshi Takano[*1], Hiroyoshi Morita[*2], Shinichiro Nakamura[*3],

Hiroyuki Miyazaki[*4], Wasan Pattara-atikom[*5], and Napaporn Piamsa-nga[*6]

Abstract—Adverse weather frequently affects the capacities and travel speeds on roadways, which result in worsened traffic congestion and incurred productivity loss. Further, with climate change predicted to increase rainfall in various cities in Southeast Asia, the risk of flood damage in this region is not only anticipated to increase and affect urban function but may also significantly aggravate daily traffic flow. This study highlighted an analysis of the effect of rainfall on urban traffic flow through the use of probe vehicle data and rainfall data in the center of Bangkok, which is known in Southeast Asia for problems with respect to maintenance of pumps and drainage channels and for many flooded roads after heavy rainfalls. The experimental result demonstrates that the average travel speed is decreased by 0.02 km/h per 1 mm of daily rainfall. In particular, at the time of peak traffic demand, the travel speed is notably reduced when passengers preferred automobile traffic. In 2018, the economic loss estimate in central Bangkok due to annual rainfall was approximately 0.01% of the city's GDP. Future rainfall forecast data makes it possible to assess the risk of climate change on urban traffic flow.

Index Terms— *Rainfall impact, Climate change, Probe vehicle data, Travel speed, Regression model.*

I. INTRODUCTION

DUE to climate change, many urban areas in Southeast Asia may be faced with the concern of increasingly frequent flood damage associated with rainfall [1]. Thus, the number of research focusing on the impact of climate change from a citywide viewpoint has recently increased to investigate the appropriate adaptation measures for climate change [2] [3].

The fact is rainfall occurrences in urban areas do not only bring inundation damage due to river inundation but also worse traffic congestion [4], increase traffic accidents [5], and cause changes in traffic behavior [6] (changes in transportation methods and destinations, trip schedules, etc.). More importantly, in Asia megacities where traffic congestion has become a very considerable issue [7], more frequent rainfall brought about by climate change can create a significant impact on daily urban traffic. Thus, when planning and establishing countermeasures for cities, their resistance to meteorological disasters such as heavy rains and floods should be considered, along with plans to reduce greenhouse gas (GHG) emissions. However, the impact of climate change on urban traffic has not been quantitatively evaluated.

On such basis, this study quantifies the impact of future rainfall increases on urban traffic in central Bangkok, which, among the many countries in Southeast Asia, has many problems in terms of maintenance of pumps and drainage channels and has many flooded roads after heavy rains.

II. LITERATURE REVIEW

With the relevance of climate change on today's community aspects, many researches have strengthened their focus on the influence of rainfall intensity on traffic flow. For instance, to improve highway operation in bad weather, previous studies have examined the effects of different rainfall intensities on urban highway traffic flow [4] [8] [9] mainly to prove the deterioration of traffic congestion by reduced road friction and driver visibility after rainfall in highways. Refs. [10] and [11] conducted an analysis of the impact of rainfall on traffic in units of areas but in developed countries with well-equipped drainage facilities; they have not performed an analysis under assumption of future climate change.

Moreover, focusing on research on general roads in developing countries, Ref. [12] conducted a microsimulation considering the flood risk under climate change for a specific section and computed the loss time due to changes in rainfall intensity. However, in the city center of Asian megacities, traffic congestion is visible in wide area, where certain traffic congestion factors (i.e., flooding) could also be assumed to affect spatially separated sections.

Objectively, this study highlights an analysis of the impact on the whole region in central Bangkok of estimating the travel speed drop due to rainfall.

III. DATA COLLECTION AND EXTRACTION

A. Target Area

The target area is center of Bangkok, Thailand, which features an advancing economic growth relative to ASEAN standards. Bangkok is known for extreme car traffic. Worldwide indeed, traffic congestion here is the eighth worst, whereas accident mortality is the second worst; both concerns could be considered risks hindering the city's future economic progress. To mitigate the worsening of both situations, countermeasures have been developed, including the separation of logistics traffic with the development and promotion of expressways and public transport such as

Bangkok Skytrain and Mass Rapid Transit (MRT), along with gaining momentum in urban development.

It should also be observed that the urban area extends to the lowlands (Fig. 1). In 2011, the Chao Phraya River was flooded and suffered enormous damage, especially in the north of Bangkok. Additionally, there were frequent reports of road flooding in various areas even in rainfall circumstances that do not cause major floods. Thus, estimation of damage due to increased rainfall and planning of adaptation measures for climate change have recently become urgent issues.

B. Probe Vehicle Data

Probe vehicle data (observed in 2018) were obtained from open data (historical raw vehicles and mobile probe data in Thailand) provided by the Thai Intelligent Traffic Information Center Foundation [13]. This data consists of Vehicle ID, GPS location collected every minute, time stamp, and speed. The data collection range is within the Center of Bangkok shown in Fig. 1. The GPS locations of about 4,000 cars traveling in the center of Bangkok covered most of the road network in the area (Fig. 2). The average travel speed is calculated from the travel distance and travel time in the area.

C. Rainfall Data

Rainfall data were a 5-minute unit data obtained (in 2018) from the Bangkok Metropolitan Flood Control Center. This center is located at the center of Bangkok (Fig.1). The number of rainy days in 2018 (≥ 0.5 mm/day) was 139 days, and the average rainfall on rainy days was 13.2 mm/day. There were more rainy days in May to October, as depicted in Fig. 3.

IV. MODEL DEVELOPMENT

A. Analysis of Relationship Between Rainfall and Travel Speed

To understand the effect of rainfall on travel speed, an independent t-test was first conducted to determine whether there was a difference in travel speeds between the rainy and non-rainy days (Figs. 4 and 5).

As shown in Fig. 4, the average daily travel speed was low on rainy days for both weekdays and holidays. During weekdays, the travel speed was decreased by 0.52 km/h on an instance of a rainfall, while it was decreased by 1.20 km/h during a rainfall on holidays. When traffic demand was high, the average daily travel speed on weekdays was 3.51 km/h (average without rainfall), which was lower than on holidays. This result explains that the decrease in travel speed due to rainfall is not lower compared to the decrease in travel speed due to increased traffic demand.

Fig. 5 illustrates the travel speed difference due to the rainy or non-rainy days at different times on weekdays. In any time
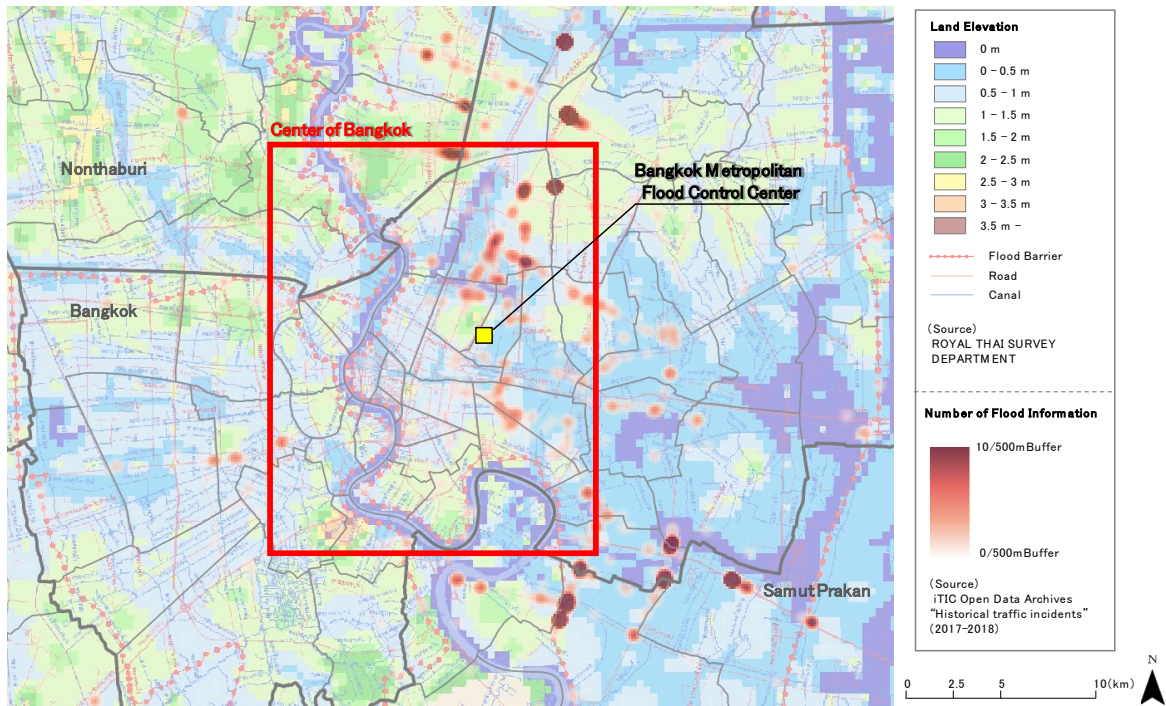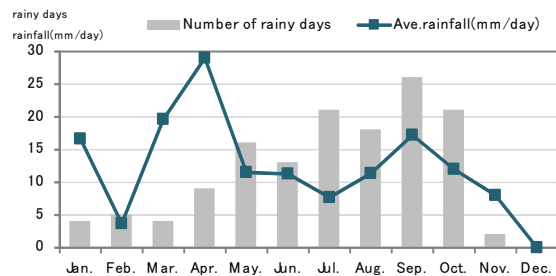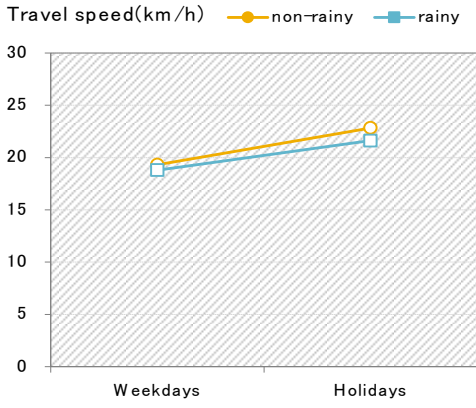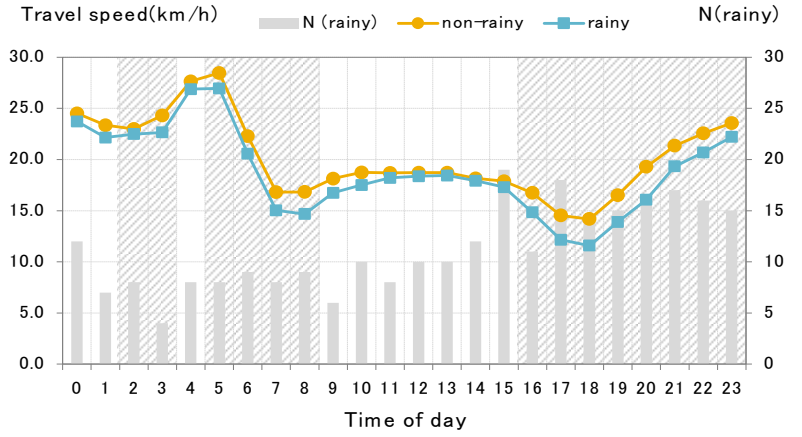

Fig. 1   Target area

Fig. 2   Probe data

Fig. 3   Rainfall data

Notes: Independent t−test 'hatching' p＜0.05

Fig. 4 Comparison of travel speed between rainy days
and non-rainy days

Notes: Independent t−test 'hatching' p＜0.05

Fig. 5 Comparison of travel speed between times of rainy and non-rainy (weekdays)

zone, the average travel speed was lower during instance of a rainfall compared to when there was no rain. In particular, the influence was large at the peak of the evening, where there was a significant difference of 2.6–3.2 km/h. Even when the peak was in the morning, there was an observable considerable difference of 1.8–2.2 km/h. This indicates that even when traffic demand appears concentrated, it may be more affected by rainfall.

Meanwhile, the number of samples on rainy days during the daytime was lower; thus, there was no significant difference obtained.

B. Relationship Between Daily Rainfall Intensity and Travel Speed

A regression model was developed to explain the relationship that exists between rainfall intensity and travel speed. The model could be expressed linearly by

$$y = \beta_0 + \beta_1 x + DOW, \qquad (1)$$

where y is the daily average travel speed, x the daily rainfall intensity, β_0 the intercept (travel speed when there is no rain on holidays), β_1 the parameter, and DOW the day-of-the-week dummy (Monday, Tuesday, Wednesday, Thursday, and Friday). The day-of-the-week dummy was included to understand the fluctuations in traffic demand.

Table I summarizes the results for this regression analysis, which describes that the travel speed on weekdays was lower than on holidays, with the travel speed exhibiting a tendency to decrease with increased rainfall intensity. Relative to rainfall intensity, the average daily travel speed in this area was decreased by 0.02 km/h for every 1 mm of daily rainfall.

C. Relationship Between Rainfall Intensity and Travel Speed by Time-of-Day

To analyze in detail the differences caused by fluctuations in traffic demand, a regression model for each time zone was also developed. The model was almost the same as the daily model and considered 6 hours of rain, due to the fact that the drop in travel speed caused by road flooding was believed to be affected by the previous rainfall. The regression model is a linear expression:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + DOW, \qquad (2)$$

where y being the average travel speed for 1 hour, x_1 the rainfall intensity for 1 hour (short-term impact), x_2 the rainfall intensity for 6 hours (long-term impact), β_0 an intercept (The travel speed when there is no rain on holidays.), β_1 and β_2 parameters, and DOW the day-of-the-week dummy (Monday, Tuesday, Wednesday, Thursday, or Friday).

Table II shows the results of this regression analysis, which clarifies that the travel speed was decreased from 0.056 to 0.555 km/h for every 1 mm of hourly rainfall (at the significance level of 0.05). Results also indicated that 6 hours of rain affects the travel speed, especially in the morning and evening peak hours, where the parameters of 1-h and 6-h rainfall were large and R^2 values were likewise relatively high. During the day, the rain parameters had lower values, and the model demonstrated poor accuracy, probably because of differences in traffic demand, including vehicles other than automobiles. Consequently, peak rainfall not only reduced driver visibility and road friction but also promoted people walking or transferring to motorcycle or taxi rides (increasing demand for car traffic).

V. DISCUSSION

The above analysis results suggest the possibility to derive a relationship where travel speed decreases as rainfall increases. Nevertheless, how do we gauge the impact on the economy of the average travel speed decreasing by 0.02 km/h for every 1 mm of daily rainfall?

To understand the impact of such event on daily traffic, the loss time due to rainfall was estimated using the parameters of the day model. Particularly, the loss time was calculated by multiplying the travel speed reduction due to rainfall and total trip distance in the area. Here, the total mileage of the car was calculated by multiplying the traffic volume and extension for each link, as detailed in Ref. [14]. For comparison, the loss time due to travel speed reduction caused by differences in traffic demand on holidays and weekdays was computed in the same way.

Table III shows the estimated results of the loss time due to rainfall in 2018. The loss time due to rainfall in the target area was estimated to be about 4 million hours/year, which is equivalent to 5% of the loss time due to traffic demand (difference between weekdays and holidays). Assuming a time value of $2.68/h [15] [16] and an average passenger

TABLE I. RESULT OF THE REGRESSION MODEL (DAY MODEL)

(Intercept)	Rainfall(mm)	Mon.	Tue.	Wed.	Thu.	Fri.	Multiple R-squared	Adjusted R-squared
22.458 ***	-0.020 ***	-2.407 ***	-3.342 ***	-3.379 ***	-3.312 ***	-3.709 ***	0.61	0.61

Signif. codes: '***' p<0.001, '**' p<0.01, '*' p<0.05, '.' p<0.1, ' ' p<0.2

TABLE II. RESULT OF THE REGRESSION MODEL (TIME-OF-DAY MODEL)

Time of day	(Intercept)	Rainfall(mm) 1 hour	Rainfall(mm) 6 hours	Mon.	Tue.	Wed.	Thu.	Fri.	Multiple R-squared	Adjusted R-squared
0	25.056 ***	-0.222 .	-0.009 *	0.567 **	-0.633 **	-0.942 ***	-0.758 ***	-0.695 ***	0.17	0.15
1	25.227 ***	-0.285 .	-0.010 *	-0.858 ***	-2.002 ***	-2.320 ***	-2.010 ***	-1.932 ***	0.37	0.36
2	25.304 ***	-0.291	-0.010 .	-1.410 ***	-2.317 ***	-2.733 ***	-2.545 ***	-2.453 ***	0.45	0.44
3	26.286 ***	-0.112 .	-0.009	-0.931 ***	-2.222 ***	-2.379 ***	-2.174 ***	-2.124 ***	0.43	0.42
4	28.092 ***	-0.165 .	-0.021 *	1.213 ***	-0.306	-0.968 ***	-1.063 ***	-0.858 ***	0.27	0.26
5	29.176 ***	-0.148 ***	-0.023 **	0.355 .	-0.771 ***	-0.933 ***	-1.022 ***	-1.072 ***	0.22	0.21
6	28.372 ***	-0.040	-0.034 *	-5.742 ***	-6.316 ***	-6.301 ***	-6.153 ***	-5.870 ***	0.74	0.73
7	26.269 ***	0.038	-0.041 **	-9.421 ***	-9.779 ***	-9.643 ***	-9.385 ***	-8.978 ***	0.84	0.83
8	24.593 ***	-0.555 *	-0.022 *	-7.757 ***	-8.093 ***	-7.961 ***	-7.752 ***	-7.209 ***	0.83	0.83
9	22.995 ***	-0.198 **	-0.020 *	-4.287 ***	-5.251 ***	-5.063 ***	-4.889 ***	-4.629 ***	0.62	0.61
10	21.660 ***	-0.075	-0.017 *	-2.064 ***	-3.123 ***	-3.180 ***	-3.031 ***	-3.054 ***	0.44	0.43
11	20.629 ***	-0.071	-0.008	-0.968 ***	-2.101 ***	-2.094 ***	-2.063 ***	-2.317 ***	0.32	0.30
12	19.875 ***	-0.073	-0.009	-0.180	-1.329 ***	-1.267 ***	-1.197 ***	-1.595 ***	0.18	0.16
13	19.815 ***	-0.056 *	-0.008	-0.083	-1.199 ***	-1.078 ***	-1.225 ***	-1.649 ***	0.19	0.17
14	19.853 ***	-0.053	-0.003	-0.817 **	-1.677 ***	-1.495 ***	-1.869 ***	-2.474 ***	0.28	0.27
15	19.936 ***	-0.061 *	0.001	-1.202 ***	-1.960 ***	-1.987 ***	-2.057 ***	-3.147 ***	0.36	0.35
16	20.023 ***	-0.181 ***	0.005	-2.236 ***	-3.269 ***	-3.256 ***	-3.413 ***	-4.401 ***	0.53	0.52
17	19.719 ***	-0.190 ***	0.001	-4.340 ***	-5.250 ***	-5.280 ***	-5.286 ***	-6.280 ***	0.68	0.67
18	20.067 ***	-0.100 **	-0.003	-5.225 ***	-6.057 ***	-5.942 ***	-5.724 ***	-6.812 ***	0.71	0.70
19	21.473 ***	-0.118 ***	-0.017 ***	-4.143 ***	-5.107 ***	-5.068 ***	-4.750 ***	-5.834 ***	0.68	0.68
20	22.310 ***	-0.210 ***	-0.027 ***	-2.063 ***	-3.143 ***	-3.079 ***	-3.017 ***	-3.806 ***	0.55	0.54
21	22.715 ***	-0.318 **	-0.022 ***	-0.429 .	-1.173 ***	-1.434 ***	-1.425 ***	-2.110 ***	0.32	0.31
22	23.388 ***	-0.084 *	-0.014 **	0.037	-0.582 *	-0.995 ***	-0.843 **	-1.781 ***	0.17	0.16
23	24.345 ***	-0.125 *	-0.009 *	-0.540 *	-0.807 ***	-0.704 **	-0.714 **	-1.114 ***	0.12	0.11

Signif. codes: '***' p<0.001, '**' p<0.01, '*' p<0.05, '.' p<0.1, ' ' p<0.2

TABLE III. RESULTS OF THE LOST TIME ESTIMATION

Travel Distance [PCU · km/day]	Lost Time [hours/year]	
	By Rainfall	By Traffic Demand
44,316,675	4,037,032	81,615,202

capacity of 1.4 passengers/vehicle, the economic loss due to rainfall in the target area could be an approximate $15.1 million/year or 0.01% of Bangkok's GDP [17] [18].

Nevertheless, note that such estimate does not include opportunity loss due to heavy rains and associated floods. With this, it could be inferred that even during daily rainfall, such rain accumulation created enormous economic losses. In expectation, rainfall may likely increase as a result of climate change, and if measures are not advanced, future economic losses may further increase.

VI. CONCLUSION

This study presented an analysis resolving the relationship between travel speed and rainfall by probe vehicle data and rainfall intensity data in the central area of Bangkok. These analyses clarified that the average daily travel speed in the area decreases by 0.02 km/h for every 1 mm of rainfall per day. By time zone, rainfall during peak hours of traffic demand not only decreased the driving performance but also promoted the preference for automobile traffic that may aggravate traffic congestion. Even in daily rainfall, the economic loss (time loss) estimate accounted for about 0.01% of Bangkok's GDP. Future climate change measures in urban areas in East Asia will be established to improve road drainage and secure alternatives to cars.

As limitation, this study excluded road network, as it was not possible to determine which section was vulnerable to rainfall. It would remain as a subject of further research, which includes analysis of changes in traffic behavior and opportunity loss due to rainfall.

REFERENCES

[1] ICHARM, *SOUSEI : program for risk information on climate change*, pp.142, 204, 209, 213, 2017.

[2] Richard T.Cooper, "Projection of future precipitation extremes across the Bangkok Metropolitan Region," Heliyon, Vol. 5, Issue 5, e01678, 2019.

[3] Shrestha, A., T. Chaosakul, D. P. M. P. Priyankara, L. H. Chuyen, S. S. Myat, N. K. Syne, K. N. Irvine, T. Koottatep and M. S. Babel", Application of PCSWMM to Explore Possible Climate Change Impacts on Surface Flooding in a Peri-Urban Area of Pathumthani, Tailand", Journal of Water Management Modeling, ISSN 2292-6062, 2014.

[4] M. Agarwal, T. H. Maze and R. Souleyrette, "Impacts of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity," Proceedings of the Mid-Continent Transportation Research Symposium 2005: Ames, Iowa, August 18-19, 2005.

[5] D. Jaroszweski and T. McNamara, "The influence of rainfall on road accidents in urban areas: A weather radar approach," Travel Behaviour and Society, Vol. 1, Issue 1, pp.15-21, 2014.

[6] M. Cools, E. Moons, L. Creemers and G. Wets, "Changes in Travel Behavior in Response to Weather Conditions Do Type of Weather and Trip Purpose Matter?," Journal of the Transportation Research Board, Vol. 2157, Issue 1, 2010.

[7] OECD, Economic Outlook for Southeast Asia, China and India 2019: Towards Smart Urban Transportation. Paris: OECD Publishing, 2018.

[8] W. Yuan-qing and L. Jing, "Study of Rainfall Impacts on Freeway Traffic Flow Characteristics," Transportation Research Procedia, Vol. 25, pp. 1533-1543, 2017.

[9] W. Zhang, R. Li, P.Shang and H. Liu, "Impact Analysis of Rainfall on Traffic Flow Characteristics in Beijing," International Journal of Intelligent Transportation Systems Research, 2018.

[10] Wang, L., Yamamoto, T., Miwa, T. and Morikawa, T., "An analysis of effects of rainfall on travel speed at signalized surface road network based on probe vehicle data," Proceedings of ICTTS 2006, pp. 615 - 624, Xi'an, China, August 2006.

[11] I. Tsapakis, T. Cheng and A. Bolbol, "Impact of weather conditions on macroscopic urban travel times," Journal of Transport Geography, Vol.28, pp. 204-211, 2013.

[12] E.Hussain, S.I.Ahmed, M.S.Ali, "Modeling the effects of rainfall on vehicular traffic," Journal of Modern Transportation, Vol. 26, Issue 2, pp.133-146, 2018.

[13] iTIC foundation, "Historical raw vehicles and mobile probes data in Thailand," 2018.

[14] Travel Demand Freight Movement Survey For National Transport Planning.

[15] International Labour Organization, ILOSTAT, "Mean normal monthly earnings of employees by sex and occupation - Annual", 2018.

[16] International Labour Organization, ILOSTAT, "Mean weekly hours actually worked per employed person," 2018.

[17] National Economic and Social Development Board, "GDP per capita in Bangkok Metropolis," 2016.

[18] Department of Provincial Administration, "Population of Bangkok Metropolis," 2016.