# Spatial analysis of the urban expansion impact on traffic accidents
# ~ Case study in Kagawa Prefecture ~

Masanobu Kii, Visiting Researcher, Research Division

## 1. Introduction

The motorization that has spanned the past half century has simultaneously increased in traffic accidents and the urban expansion, though the connection between these two issues is not clearly understood. The increased mobility by the motorization has enabled people to live in and access to suburban areas, which has led an urban expansion. This expansion of cities predicated on the use of automobiles has engendered a dependence on automobiles and is causing travelling distances to grow as well. Conversely, the rise in automobile travelling distances is raising the potential for accidents. Therefore, it is hypothesized that traffic accidents will increase in cities with growing urban suburbs where the other means of transportation except automobiles are not provided. Past studies[1)] focusing on US cities statistically denoted the connection between sprawl and the increased risk of accidents by comparing among cities, presumably establishing this hypothesis regarding the connection between accidents and the expansion of cities. Yet at any rate, Japan has not taken measures to curb the expansion of cities from the perspective of traffic accidents, and in fact no special measures to combat accidents have been taken for the expanding urban areas. This situation is due to insufficient evidence that would prompt such measures to be taken.

The objective of this study is to analyze the connection between changes in the population, the expansion of cities, and the occurrence of accidents in a spatial statistical manner to clarify the impact of urbanization on the risk of accidents, as well as to find the characteristics of urban areas that elevate the risk of accidents. I focus on Kagawa Prefecture, in which the expansion of cities is proceeding apace as its population declines. In particular, there has been significant growth in urban areas in Kagawa Prefecture since a part of land use zoning regulations were abolished throughout the prefecture in 2004. In addition, it is considered to be a region that is suitable for analyzing the impact of urbanization on accidents since there are forceful demands for traffic accident countermeasures there, as evidenced by the fact that it consistently ranks among the top spots nationwide in terms of the number of per capita traffic accidents and traffic accident fatalities.

In Section 2 below the past studies regarding the connection between traffic accidents and urban form will be arranged, while in Section 3 the characteristics of traffic accidents and land use in Kagawa Prefecture (which is the target region) will be indicated. A statistical model for the impact that the expansion of urban areas has on traffic accidents will be created in Section 4, and in Section 5 this will be used to perform a spatial analysis of the risk of accidents. In Section 6 suggestions for urban policies and traffic policies will be considered based on the results of the analysis, followed by a conclusion in Section 7.

## 2. Past studies

A number of studies on the connection between urban form and the risk of traffic accidents have been seen. In the 1970s, which is when motorization gained momentum in Japan, a study by Wakita[2)] was seen in which prefectural traffic accident statistics were used. Using statistics from the 1950s – 1960s, Wakita indicated that there is a high concentration of traffic accidents in major urban areas based on the number of traffic accidents that occur per road area. Based on this and changes over time, he argued that accidents in urban areas were growing increasingly less severe as a result of traffic congestion, with serious accidents shifting out to suburban areas as a result of the rise in automobile traffic and increased travelling speed in peripheral prefectures. However, this study perceived the situation during the initial stages of motorization. It was also based on statistics from the prefectural level, and so its argument concerning the connection between the suburbanization of cities and traffic accidents is empirical.

In recent years, the accumulation of data on urban structures and spatial data on traffic accidents has led to studies that have statistically verified the connection between the two. Dumbaugh and Li[3)] statistically analyzed the connection between road conditions and traffic accidents by focusing on Bexar County in San Antonio between the years of 2003 and 2007. Their results brought to light the fact that commercial districts located along major roadways and suburban big box stores were major factors impacting traffic accidents. Conversely, they posited that the presence of commercial districts that can be accessed by walking is a factor that reduces accidents.

Marshall and Garrick[4)] analyzed the connection between the conditions under which traffic accidents occurred and road networks between the years of 1997 – 2007 with a focus on 24 cities in California. They quantitatively demonstrated that the greater the number of intersections in an area the more traffic accidents it experienced, though fatal accidents were rare. Since the density of intersections increases the closer one gets to a city’s downtown area, this suggests that while the downtown areas of cities experience a large number of accidents, fatal accidents and other serious accidents are more common in suburban areas.

Ewing et al.[1)] used structural equation modelling to analyze the connection between traffic accidents between the years of 2008 and 2011 and regional characteristics from 2010 by focusing on 994 metropolitan counties in the United States. With regards to fatal accidents, the results of this indicated that household income, the proportion of Caucasians, fuel prices, as well as the compactness of cities had the effect of curbing said accidents. On the other hand, when it came to non-fatal accidents, they posited that compactness had the effect of increasing the number of these accidents. In other words, this hints at the possibility that since traffic is concentrated in high-density cities, this increases the number of accidents, while conversely decreasing the number of serious accidents since speed is curtailed.

In addition, Kitano[5)] performed a statistical analysis of the impact that land use characteristics have on accidents involving pedestrians. This indicated a number of findings, like the high impact from the number of convenience stores in rural areas, as well as the strong impact that the size of the areas for commercial districts and the area of building sites have on accidents.

In a series of studies[6-8)] by IATSS on factors that give rise to traffic accidents focusing on Kagawa Prefecture, the organization surveyed the human factors concerning attribution for the causes of accidents via a questionnaire survey, and attempted to evaluate the risk of accidents in the area. The findings indicated that in urban areas community roads pose a particularly high risk, that low population density is a risk factor when it comes to fatal accidents, and that there is a significant impact from changes regarding building sites. This suggests that sprawl engenders risk.

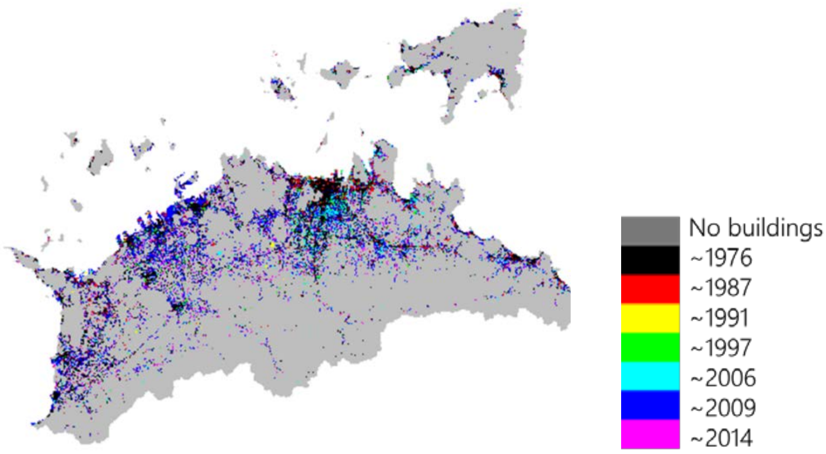
All of the aforementioned studies from Japan and the United States indicate that while the risk of accidents is higher in high-density cities, the risk of fatal accidents is higher in low-density cities. This study will focus in particular on the expansion of cities to perform an analysis in which population and building sites are used as explanatory variables in order to get a grasp of the impact from both density and land use changes.

## 3. Characteristics of the target region

According to the Traffic Master Plan for the Takamatsu Extended Metropolitan Region, the rate of people with driver’s licenses in 2012 had risen substantially compared with 1989, with notable increases in the rate of licensed drivers among women and elderly people in particular. As a reflection of this increase in the rate of licensed drivers, the share of automobiles rose from 46.3% to 66.7% during this same period, while the share of walking and bicycling both fell substantially. Looking at land use reveals that residential areas increased by roughly two-fold between the years of 1991 and 2009, with progress seen in the suburban development of residential areas accompanying the increase in automobile use.

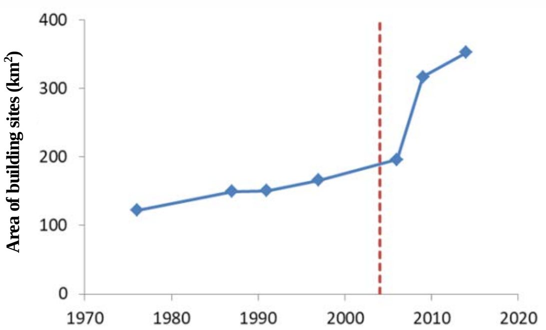
However, the suburban development of residential areas did not come about solely due to the popularization of automobiles. In 2004 Kagawa Prefecture became the first prefecture throughout Japan to abolish its area division system, or so-called demarcation system, which regulated suburban development, throughout the prefecture as a whole. As a result of this, the size of residential areas increased substantially.

Fig. 1 shows building sites by development period. The growth in residential areas between 2006-2009 indicated in blue can be read as being particularly striking in suburban areas. What is more, Fig. 2 shows trends in the area of building sites, which naturally reveals that said area rose substantially between 2006 and 2009. According to this same figure, building sites have continued to increase since 2006, with the rate of increase between 2006 and 2009 substantially outpacing the rate of increase from prior to that period. Over a mere three-year period, the area of building sites increased to 121km$^2$ to account for 61% of the urban area, which can be read as having been impacted by the abolishment of demarcation to a remarkable degree.




Source) Created by the author based on the National Land Numerical Information

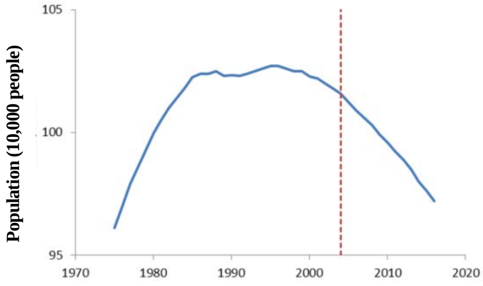
Fig. 1. Building sites by development period




Source) Created by the author based on the National Land Numerical Information

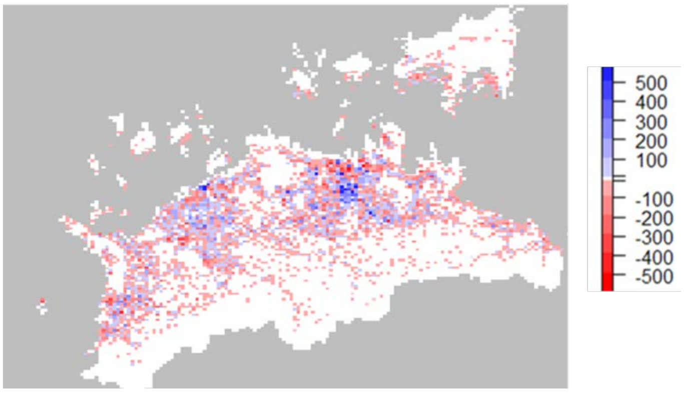
Fig. 2. Trends in the area of building sites in Kagawa Prefecture

While the area of building sites is increasing, the population is already in decline. Fig. 3 shows trends in the population of Kagawa Prefecture. The population had already begun to decline starting in 1998, and the rate of decrease has risen since 2004 when demarcation was abolished. While the population is decreasing, conversely building sites are on the rise. Looking at the population density of residential areas for the prefecture as a whole reveals that this is falling significantly.




Source) Created by the author based on regional mesh statistics

Fig. 3. Trends in the population of Kagawa Prefecture

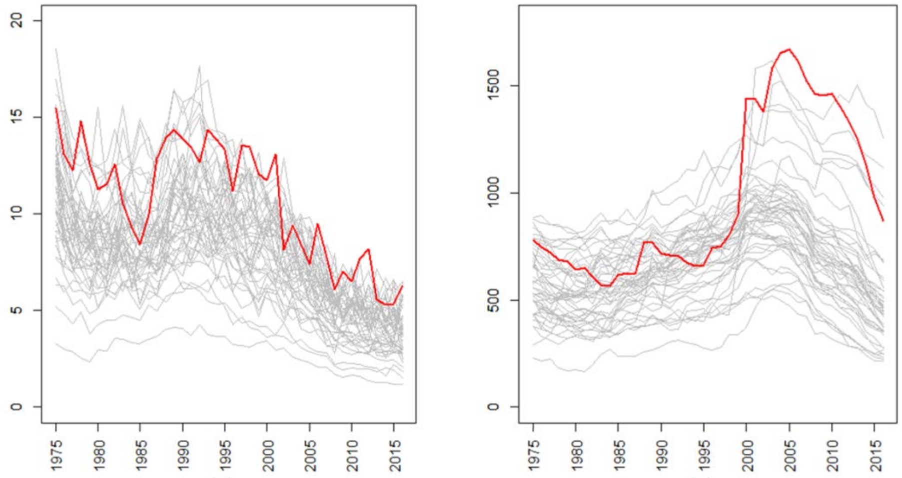



Source) Created by the author based on regional mesh statistics

Fig. 4. Mesh population changes (2000 – 2010)

Fig. 4 shows the regional distribution of population changes between 2000 and 2010. This reveals that the population is not necessarily declining in a uniform manner. The main trend that can be read into the graph is that while the population is falling in downtown urban areas and mesomountainous areas, it is conversely on the rise in the suburban areas around cities.

Looking at the number of traffic accident casualties per 100,000 people (Fig. 5) shows that Kagawa Prefecture is consistently ranked among the top spots nationwide in terms of both its number of fatalities and number of casualties.

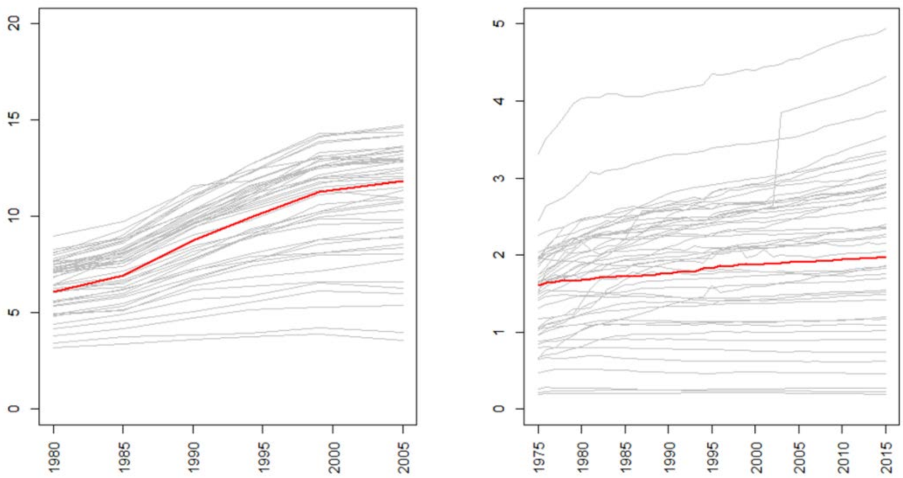



Red line: Kagawa Prefecture, Gray lines: Other prefectures

Source) Prefectural data from the System of Social and Demographic Statistics

Fig. 5. Number of traffic accident fatalities (left) and casualties (right) per 100,000 people

Yet as Fig. 6 indicates, Kagawa Prefecture does not necessarily have a particularly large volume of automobile traffic for its population, nor a particularly large volume of road infrastructure in place, compared with the national averages. In other words, it is difficult to imagine that prefectural residents have a particularly high exposure to traffic. What is more, the aforementioned Kagawa study by the IATSS pointed out that there were no clearly apparent indications of any qualities unique to the prefectural residents concerning causal attributions for accidents. Therefore, it is conceivable that a more multifaceted examination will be required when it comes to the causes behind the occurrences of accidents.




Red line: Kagawa Prefecture, Gray lines: Other prefectures

Source) Prefectural data from the System of Social and Demographic Statistics

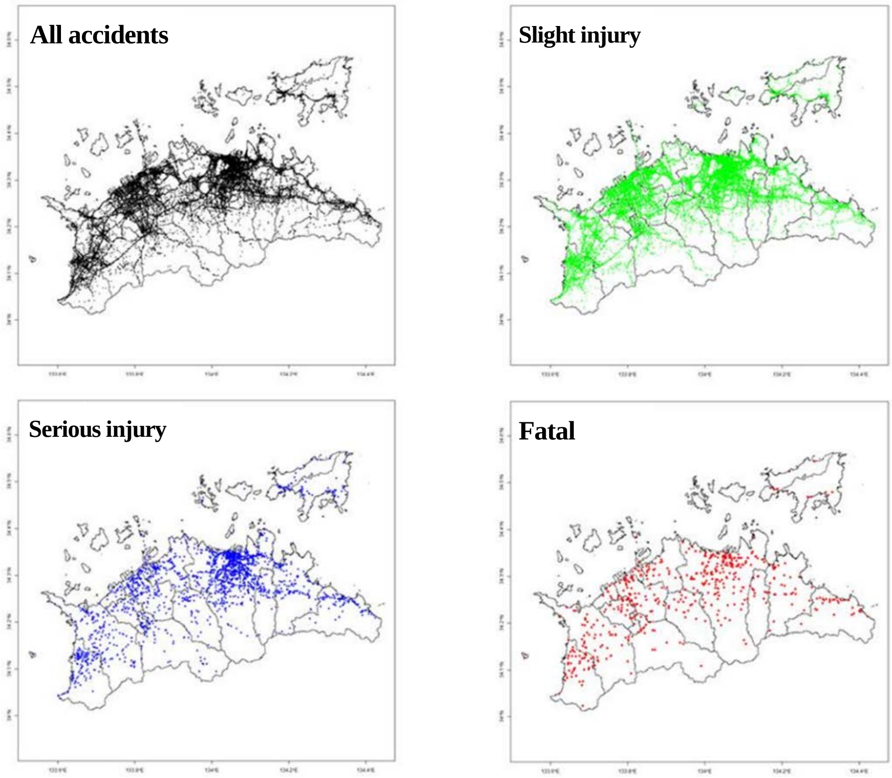
Fig. 6. Kilometers travelled by automobile per capita (left) and extension of paved roads per capita (right)

## 4. Impact from the expansion of building sites on traffic accidents

The purpose of this study is to perceive the impact that population changes and the expansion of building sites in particular have had on the occurrence of accidents in a spatial statistical sense. In general, increases in building sites are accompanied by a rise in the population, which in turn increases the volume of traffic. In addition, the installation of roads and development of building sites alter the traffic environment, with it assumed that there is the possibility that these operate in concert to increase the risk of accidents. On the other hand, it is also presumed to be possible that once a certain period of time has elapsed following the development of building sites, the risk of accidents declines as the residents adapt to the traffic environment. Therefore, this study will seek to verify the hypothesis that the time in which building sites were developed affects the risk of accidents.

A Poisson regression model will be used for the analytical method. In other words, the probability distribution for the number of accidents occurring each year will be assumed to be a Poisson distribution, with the expected values verified by whether or not they can be explained via variables related to population and land use. The accident data, which serves as the explained variable, is the number of accidents per year within 500m meshes, and is provided for all accidents, slight injury accidents, serious injury accidents, and fatal accidents for each year between 2009 and 2017. In addition, separate analyses will be performed for accidents involving pedestrians or cyclists in particular as one of the parties. It must be kept in mind that the number of accidents used here has not been standardized according to the volume of traffic or other factors, but instead represent the straightforward number of accidents. The explanatory variables include the share of building sites for each development period, the mesh population for the year 2000, the change in the population between 2000 and 2010, the population of people age 65 and older in 2000, the change in the population of people age 65 and older between 2000 and 2010, and the road extensions within the mesh from the year 2017. The accident data was prepared based on publically available information from the Kagawa Prefectural Police’s Traffic Accident Information Service System. Furthermore, census mesh information from regional mesh statistics was used for the population data, while the share of building sites for each development period were provided based on the National Land Numerical Information.

Fig. 7 shows the sites at which accidents occurred. From this, the viewer can discern a trend whereby the greater the population of a location, the higher the likelihood of accidents occurring there, with this holding true for all of the accident types. However, compared with slight injury accidents, the trend observed with serious injury accidents and fatal accidents was for these to not be concentrated in any particular sites to any great degree, but rather to occur in a relatively dispersed manner.




Source) Prepared based on the Kagawa Prefectural Police's Traffic Accident Information Service System

Fig. 7. Distribution of sites where accidents occurred

The results of a Poisson regression analysis using the above data is shown in Table 1. The table indicates the impact that each variable has on the risk of accidents occurring. Positive values are factors that increase the risk of accidents, while negative values are factors that decrease the risk of accidents. The variables were selected using a stepwise method, with those marked "NA" representing factors that were determined to have no impact on the risk of accidents. Through this, the parameter sign for each type of accident is identical, with the risk of accidents being low in meshes with large populations. What is more, for meshes where the population is on the rise, the risk of accidents is increasing for all types except for fatal accidents. Moreover, the greater the population of people age 65 or older, the higher the risk of accidents for all types except for serious injury accidents. In meshes where the population of people age 65 or older is on the rise, the risk of slight injury accidents is shrinking. The parameters for the share of building sites are all positive, indicating that the greater the number of building sites, the higher the risk of accidents. Looking at the size of the parameters reveals that the impact of building sites is greatest within ten years from when they were developed for both slight injury and fatal accidents. Conversely, old building sites have a greater impact when it comes to serious injury accidents. When viewed for all accidents, the highest impact was from building sites that were less than ten years old. Moreover, the longer the extension of roads, the higher the risk of accidents.

Similarly, the results of an analysis that focused solely on accidents including pedestrians and cyclists among the parties are shown in Table 2. Looking at this reveals that population only affects the risk of all accidents and slight injury accidents, with the sign differing for cases that include all parties. In other words, the results indicate that the greater the population, the higher the risk of accidents involving pedestrians and cyclists. To reiterate, the risk of accidents used here is the number of accidents. If we assume that a larger population means a larger number of pedestrians and cyclists, then presumably it is only natural that the risk of accidents involving them will increase. On the other hand, the parameter regarding fatal accidents is negative, so it can be conjectured that the greater the population, the lower the risk of fatal accidents.

Table 1. Poisson regression analysis results (all parties)

| | | All accidents | | Slight injury | | Serious injury | | Fatal | |
|---|---|---|---|---|---|---|---|---|---|
| | | Parameters | t-value | Parameters | t-value | Parameters | t-value | Parameters | t-value |
| Constant term | | -1.86 | -199.18 | -1.95 | -200.49 | -5.12 | -102.85 | -6.14 | -66.87 |
| Population (2000, $10^4$ people) | | -0.547 | -3.70 | -0.490 | -3.22 | NA | NA | -5.55 | -2.67 |
| Population change (2000-2010, $10^4$ people) | | 0.554 | 23.76 | 0.550 | 22.86 | 0.436 | 3.19 | NA | NA |
| Population of people age 60+ (2000, $10^4$ people) | | 7.61 | 10.47 | 7.42 | 9.89 | NA | NA | 29.7 | 2.96 |
| Change in population of people age 60+ (2000-10, $10^4$ people) | | -19.5 | -17.58 | -19.5 | -16.97 | NA | NA | NA | NA |
| Share of building sites by development period | 30 years or more | 3.41 | 133.24 | 3.43 | 129.79 | 3.43 | 32.48 | 1.94 | 5.33 |
| | 20-30 years | 3.70 | 89.01 | 3.72 | 86.37 | 3.26 | 13.18 | 2.89 | 5.09 |
| | 10-20 years | 1.87 | 32.22 | 1.89 | 31.46 | 2.48 | 7.58 | NA | NA |
| | Less than 10 years | 4.14 | 213.16 | 4.19 | 208.59 | 2.82 | 22.22 | 2.98 | 11.77 |
| Road extensions | | 0.19 | 80.73 | 0.19 | 77.88 | 0.18 | 12.84 | 0.19 | 6.81 |
| Extensions of major roads | | 0.05 | 8.57 | 0.05 | 8.15 | 0.12 | 3.14 | NA | NA |
| Sample size | | 63513 | | | | | | | |

Table 2. Poisson regression analysis results (accidents including pedestrians / cyclists among the parties)

| | | All accidents | | Slight injury | | Serious injury | | Fatal | |
|---|---|---|---|---|---|---|---|---|---|
| | | Parameters | t-value | Parameters | t-value | Parameters | t-value | Parameters | t-value |
| Constant term | | -3.74 | -165.55 | -3.85 | -162.61 | -6.43 | -70.78 | -6.98 | -52.70 |
| Population (2000, $10^4$ people) | | 1.20 | 4.35 | 1.29 | 4.55 | NA | NA | -5.09 | -2.03 |
| Population change (2000-2010, $10^4$ people) | | 6.51 | 14.85 | 6.65 | 14.77 | 3.97 | 1.97 | NA | NA |
| Population of people age 60+(2000, $10^4$ people) | | 14.7 | 10.99 | 15.0 | 10.93 | 7.68 | 1.77 | 23.1 | 1.92 |
| Change in population of people age 60+ (2000-10, $10^4$ people) | | -9.29 | -4.24 | -9.32 | -4.12 | NA | NA | NA | NA |
| Share of building sites by development period | 30 years or more | 3.77 | 71.21 | 3.79 | 68.92 | 4.09 | 18.18 | 2.83 | 6.38 |
| | 20-30 years | 3.84 | 43.75 | 3.85 | 42.37 | 4.04 | 11.33 | 2.91 | 3.90 |
| | 10-20 years | 1.78 | 14.38 | 1.73 | 13.44 | 3.12 | 6.41 | NA | NA |
| | Less than 10 years | 4.17 | 94.61 | 4.24 | 92.85 | 3.30 | 16.32 | 3.34 | 10.03 |
| Road extensions | | 0.18 | 35.88 | 0.18 | 34.87 | 0.16 | 6.96 | 0.20 | 5.41 |
| Extensions of major roads | | 0.03 | 2.09 | 0.02 | 1.62 | 0.17 | 3.00 | NA | NA |
| Sample size | | 63513 | | | | | | | |

To summarize the above data, looking at all parties reveals that risk decreases as the population increases. However, there is a tendency for risk to increase the larger the area of building sites becomes, with risk being higher with new building sites in particular. In other words, it appears that when population density is low, sprawl that gives rise to the spread of new building sites increases the risk of accidents.

## 5. Traffic accident risk from the expansion of building sites

The aforementioned Poisson regression model was used to estimate changes in the risk of traffic accidents due to the expansion of building sites. For this, the share of building sites by development period was adopted as the variable for the Poisson regression model. The corresponding variables from 2009 and 2017 were inputted, and the estimated difference in the risk of accidents was calculated as the change in the risk of accidents due to the expansion of building sites. Since the population is inputted in a fixed manner, consideration was not given to changes in this. The results are shown in Fig. 8.

From this, we see that the risk of accidents declines in Takamatsu City's suburban areas, while the risk of accidents increases in the western area stretching from Marugame City to Zentsuji City. The urban areas developed through land readjustments in the suburban areas of Takamatsu City are mature, having been built more than ten years ago, and therefore the risk of accidents there has declined. Yet conversely it is presumed that the new urban areas being developed in the western area are causing the risk of accidents to increase.

Therefore, by filtering the above areas they were divided up into an area where the risk of accidents has decreased and an area where this has increased (Fig. 9), with the occurrence status of accidents in these areas aggregated using data from ITARDA.

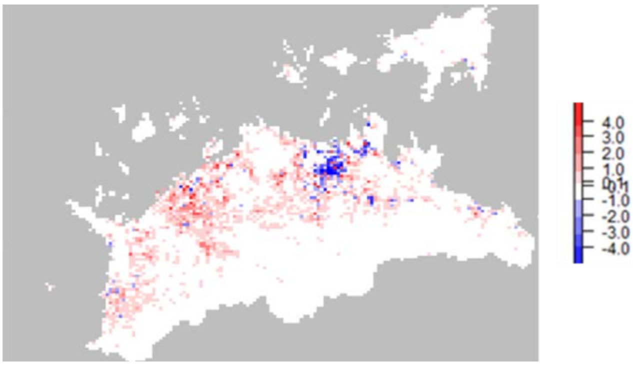



Fig. 8. Changes to the risk of traffic accidents from the expansion of building sites (All accidents: Difference between 2009-2017)

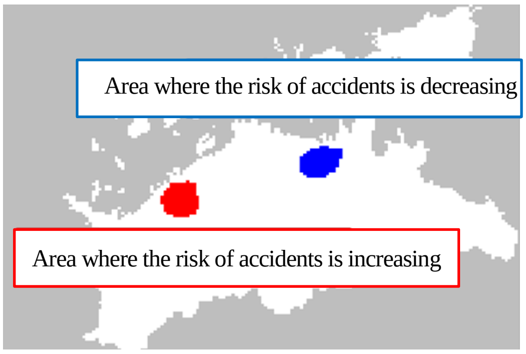
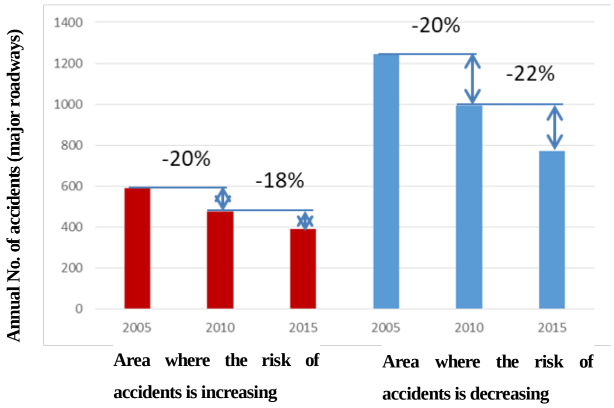



Fig. 9. Area where the risk of accidents is increasing and area where this is decreasing

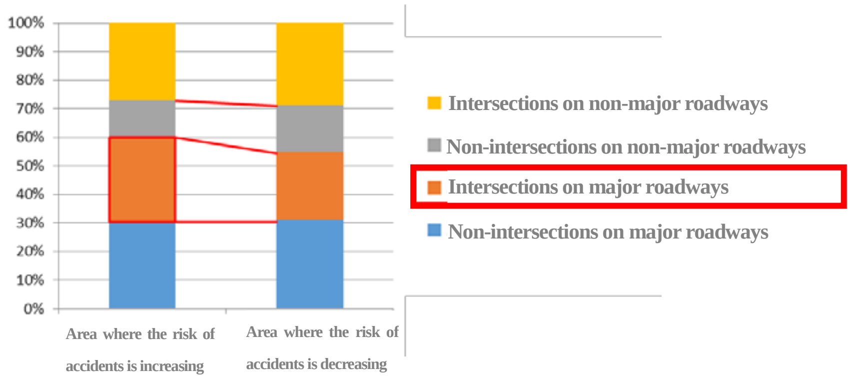
The numbers of accidents that occurred along major roadways in the years 2005, 2010, and 2015 in both areas are shown in Fig. 10. This indicates that the number of accidents per year is trending downward in both areas. What is more, for both areas the rate of change has stayed the same from 2005 through 2010, with the rate of change from 2010 through 2015 being larger in the area where risk is declining. In other words, as was conjectured based on the Poisson regression model, it is possible that as this urban area matured, the risk of accidents fell. Conversely, new building sites are being developed in the area where risk is increasing, and thus there is a conceivable possibility that changes to the traffic environment and changes in the residents are increasing the risk of accidents.

Next, comparing the sites where accidents occurred in both areas (Fig. 11) reveals that a high share occur at intersections along major roadways in the area where risk is increasing, while in the area where risk is decreasing non-intersections of non-major roadways account for a high share of these. As such, differences were seen in the trends for the sites where accidents occurred.



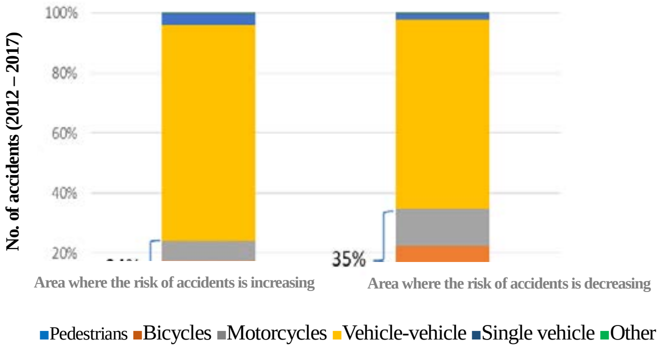

Source) Prepared based on Road Traffic Accident Statistics

Fig. 10. Trends in the number of accidents in the area where the risk of accidents is increasing and area where this is decreasing




Source) Prepared based on Road Traffic Accident Statistics

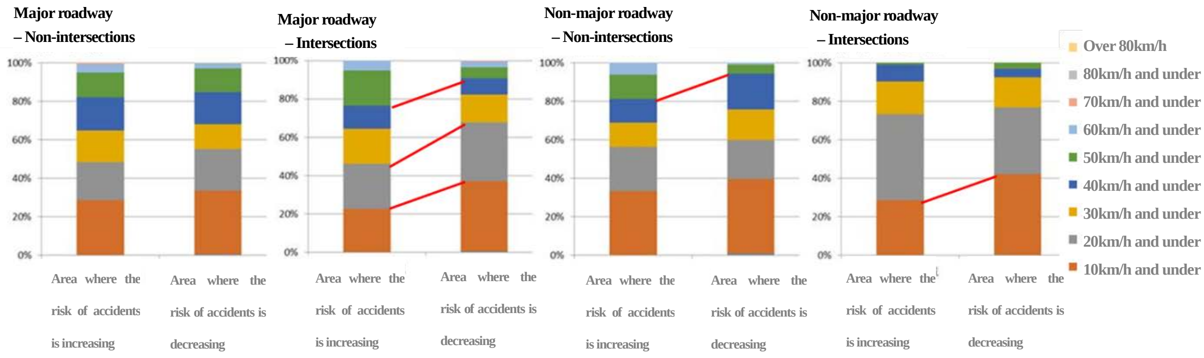
Fig. 11. Comparison of the sites where accidents occur




Source) Prepared based on Road Traffic Accident Statistics

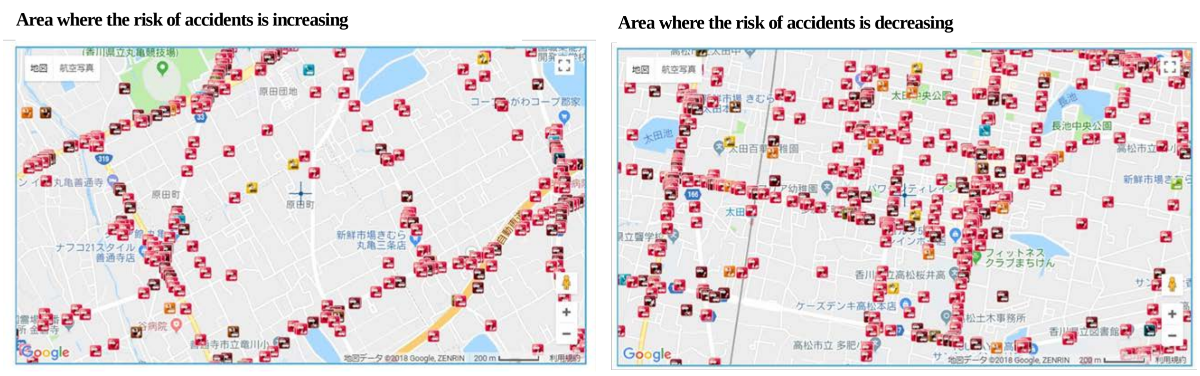
Fig. 12. Comparison of the parties to accidents

Next, looking at the parties to accidents (Fig. 12) reveals that cyclists and motorcyclists account for a large share of these in the area where risk is decreasing compared to the area where it is increasing. This is believed to be a reflection of the fact that, given the comparatively high population density, many trips taken by bicycle or motorcycle are over short distances.




Source) Prepared based on Road Traffic Accident Statistics

Fig. 13. Danger perception speeds




Source) Prepared based on the Kagawa Prefectural Police's Traffic Accident Information Service System

Fig. 14. Conditions of sites where accidents occur

The danger perception speeds (Fig. 13) are largely identical for both areas at non-intersections on major roadways, and a trend can be read into this whereby this tends to be higher in the area where risk is increasing at intersections along major roadways and on non-major roadways. This is suggestive of not only the high level of risk as seen in the number of accidents, but also the higher likelihood of more serious accidents occurring in the area where risk is increasing.

What is more, looking at the sites where accidents occurred in both areas shown in Fig. 14 allows us to spatially determine that, as can be seen from Fig. 11, accidents occur relatively frequently on non-major roadways in the area where risk is decreasing. As opposed to this, we can determine that in the area where risk is increasing accidents are concentrated on major roadways and intersections along major roadways.

## 6. Considerations

The results of the Poisson regression model from the previous section indicated that the risk of traffic accidents falls the higher the population density is. Conversely, it also indicates that a high share of building sites increases the risk of accidents, with the risk of accidents being particularly high in urban areas that are less than ten years old. This suggests that urban areas featuring new sprawl where the population density is low will suffer from a high risk of accidents. The area where risk is increasing mentioned above is precisely one such region in which sprawling development is proceeding apace. The claim could be made that it has been statistically shown that there is a likelihood that this sort of building site development is increasing the risk of traffic accidents. On the other hand, while the area where risk is decreasing is a suburban area of Takamatsu City, it is an area where land readjustment has been carried out. As such, it has a relatively high population density.

Since land readjustments were carried out in the area where risk is decreasing, it has well-developed transportation infrastructure, excellent visibility, and a high installation rate for sidewalks. As opposed to this, the area where risk is increasing is an area where farmland has slowly but steadily been converted to residential areas, its transportation infrastructure has not been able to adequately keep up with this conversion to residential areas, and it has a low installation rate for sidewalks. This is believed to be constraining vehicles from taking community roads, potentially manifesting itself in the form of the low share of accidents along non-major roadways. On the other hand, it is believed that there is the possibility that the fact that major roadways and their intersections have not been able to adequately accommodate the conversion of the surrounding region to residential areas is accounting for the high share of accidents at the intersections along major roadways. For intersections along major roadways in particular, the difference in the danger perception speeds for the area where risk is increasing and that where it is decreasing is striking, as can be observed in Fig. 13. It is presumably possible that the road infrastructure and drivers have both been unable to accommodate the changes to the traffic environment at intersections along major roadways, such as the increased volume of traffic and changes in visibility. Comparing the two areas mentioned above indicates that the development of building sites has brought about changes in their traffic environments. But the thinking is that in cases where the traffic infrastructure has been able to accommodate these changes, the risk of traffic accidents can be curbed.

When it comes to the abolishment of the Kagawa Prefecture demarcation system, from the outset one of the reasons for its adoption was due to the fact that the population was declining and the expectation was that little progress would be made with the development of new residential areas in the suburbs. Yet despite the fact that the prefecture is faced with a declining population, a substantial increase in the area of building sites was seen as indicated in Fig. 2. The majority of this consisted of sprawling development in which the conversion of land to residential areas proceeded slowly but surely without the development of new transportation infrastructure. As was seen in this study, this sort of sprawling development could potentially be a major factor in increasing the risk of accidents, with the thinking being that urban development must be managed from the perspective of curbing traffic accidents.

At present, many cities and towns are working on various policies to achieve the “Compact Plus Network” concept,[9)] and are aiming for urban development that is not overly reliant on automobiles. This aims to maintain urban functions by concentrating the supply of and demand for municipal services to core areas. The concept is also an attempt to ensure accessibility for the mobility-impaired, who are restricted when it comes to automobile use, by enhancing public transportation services between these core areas. Through this, existing urban areas will be maintained and upgraded while still maintaining population density despite the decline in the population. In addition, it also aims to improve the quality of road spaces and ensure alternate means of transportation other than automobiles by curtailing the development of new urban areas and concentrating infrastructure investments in a spatial sense. The thinking is that this may potentially be effective at reducing the risk of accidents.

However, the current initiatives related to the “Compact Plus Network” concept are limited to inducing urban facilities and functions to take root in core regions, with insufficient initiatives when it comes to curbing suburban development. Instead, there are strong demands for the development of roads due to the growing traffic demand in suburban residential areas where sprawling development is advancing, with road development that is performed in a sequential and trailing manner in response to such demands fostering further sprawl.

As a long-term outlook is considered to be necessary for guiding urban development, traditionally little consideration has been given to macro perspectives, including urban structural factors, when it comes to traffic safety measures that require urgency. In addition, adequate consideration has not been given to the impact that the formulation of land use plans has on traffic safety. Consideration has been given to traffic accident countermeasures when it comes to road development and traffic management, but it is assumed that this must be done in coordination with land use plans in order to enhance their effectiveness.

## 7. Conclusion

This study applied a Poisson regression model to capture the impact of population changes and the expansion of building sites on the occurrence of accidents considering the spatial heterogeneity in the urban sphere, taking the case of Kagawa Prefecture. The results indicated a trend whereby the larger the population, the lower the risk of traffic accidents. They also indicated a trend whereby the larger the area of building sites the higher this risk becomes, with the risk being particularly high in new urban areas that are less than ten years old. Based on these outputs, it was conjectured that increasing sprawl, which features expanding building sites with low population density, is raising the risk of accidents.

Moreover, based on the estimated results from this model, an area in which the risk of accidents is increasing and one where this is decreasing were selected, and the number of accidents in both areas and the characteristics of the traffic accidents there were organized. The results showed that the rate of decline for traffic accidents in the area where the risk of accidents is declining has exceeded that of the area where this risk is increasing between 2010 and 2015, indicating the possibility that the occurrence of accidents has been curtailed as a result of the maturation of its urban areas. The results also brought to light a number of other findings, such as the fact that intersections along major roadways account for a high share of the accidents in the area where the risk of accidents is increasing, whereas non-intersections along non-major roadways account for a high share of the accidents in the area where the risk is decreasing. It also revealed that the share of accidents involving cyclists and motorcyclists is high in the areas where risk is decreasing, and that while the danger perception speeds at non-intersections along major roadways are largely the same for both areas, it is higher in the area where risk is increasing at intersections along major roadways and on non-major roadways.

Finally, based on these analytical results, this paper has raised the possibility that growing urban sprawl increases the risk of traffic accidents. It has also argued that measures based on the “Compact Plus Network” concept can potentially contribute to curtailing traffic accidents, but that at the same time the current initiatives are insufficient and must be instituted in coordination with land use plans and traffic safety measures.

However, this study is still not enough when it comes to analyzing the impact that population and land use have on the risk of traffic accidents, and so further study is required. For example, this study took into consideration the course of land use over the years, but did not factor in population trends. As such, it was restricted to using the population from the year 2000 and the change between the years 2000 and 2010. What is more, the risk of accidents was not standardized based on the traffic volume, but focused on the number of accidents in themselves. In addition, it failed to take into consideration other macro factors with respect to the risk of accidents, such as vehicle safety and advances in medical care. In addition, the analysis from this study was limited to the interconnection between traffic accidents and urbanization, and failed to adequately inspect the mechanisms by which these accidents occur. The accumulation of spatial data on traffic accidents from over a longer time period and the indexing of this with micro data will be needed in order to advance such studies, and pose challenges for the future.

**Acknowledgment**: I received a great deal of advice and support regarding matters like preparing data from everyone in Research Section II, Research Division of the Institute for Traffic Accident Research and Data Analysis regarding the execution of this study, for which I would like to express my gratitude.

## References

1) Ewing, R., Hamidi, S., Grace, J.B.（2016） Urban sprawl and a risk factor in motor vehicle crashes, Urban Studies, 53-2, 247-266.

2) 脇田竹光：traffic accidents の地理学的研究，地理学評論，43-4，pp.223-243, 1970.

3) Dumbaugh, E., and Li, W.（2010） Designing for the Safety of Pedestrians, Cyclists, and Motorists in Urban Environments, Journal of the American Planning Association, 77-1, 69-88.

4) 4）Marshall,W.E., and Garrick, N.W. (2011) Does street network design affect traffic safety?, Accident Analysis & Prevention, 43-3, 769-781.

5) 北野朋子(2017) land use の特徴と歩行者事故との関連分析，イタルダインフォメーション No.120

6) 蓮華一己，他（2014）香川研究―事故発生要因の分析と対策への提言，国際交通安全学会，平成 25 年度研究調査プロジェクト（H2536）報告書

7) 赤羽弘和，他（2016）香川研究―事故発生要因の分析と対策への提言，国際交通安全学会，平成 27 年度研究調査プロジェクト（H2754）報告書

8) 赤羽弘和, 蓮華一己（2016）香川研究―事故発生要因の分析と対策への提言―中間報告, IATSS Review, Vol. 41, No.2, 59-67.

9) 国土交通省 都市局 都市計画課（2017）コンパクト・プラス・ネットワークの推進について―生活利便性の維持・向上のための居住の誘導―，http://www.mlit.go.jp/common/001170865.pdf （アクセス日 12018 年 11 月 27 日）