

4D CAD MODEL FOR RISK ASSESSMENT OF ACCIDENTS IN INTERCHANGE MAINTENANCE PROJECT PLANNING

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Abstract

Interchange maintenance projects differed from general road maintenance projects in that there were differences in the elevation of the operation site and the operating machinery areas. Therefore, this research aimed to build a 4D CAD model which could show the area changes throughout the maintenance operation. The model would enable the accident risk prone areas caused by the operations of large machinery such as cranes and trucks to be visible over the operation time interval. It would project the horizontal and vertical areas required for the crane during operation whether they were redundant with the existing land use or neighboring traffic routes. It would also identify the need of specific place and time to close off any other traffic routes. The project planner could then foresee the accident risk prone areas caused by falling objects from higher operation elevation onto the lower elevation which was harmful to the operators and the commuters below the operation sites, or vehicles travelling on traffic routes close to the operation site. Moreover, the information from this 4D model would allow the planner to specify the site management plans and measures to eliminate the accident risk prone areas which was necessary to provide protective equipment to protect the operation area and traffic below from falling objects and for managing risk prone areas at truck entrances, etc. In summary, 4D CAD model could also be applied for better safety management of any project sites appropriately and efficiently.

Keywords: 4D CAD model, safety management, road maintenance projects

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Introduction

An Interchange was an important road network infrastructure because it helped eliminate the traffic congestion at intersections and allowed the smooth and safe traffic. There was necessary for maintenance operations to ensure that the interchange was in a good working condition after a long service life. Maintenance operations at an interchange were different from new road construction because there was traffic flow through the interchange during the operation. This created overlapping area between the commuting vehicles and the machinery required for the maintenance operation. Moreover, the differences of elevation for operation site and machinery site were also a limitation for the machine to operate properly, so it was necessary for the project planners to visualize these impacts. Route closure for road maintenance also created risks to accidents in many aspects such as creating a bottle-neck area where the road was close off or the machines were operating and risk off falling objects from higher elevation. These incidents on construction sites can cause severe damages to drivers. Therefore, the appropriate maintenance plan software for interchanges project planners were developed in this study. The new software was required to input data from the other road analytic software packages such as CORSIM®, VISSIM® or AIMSUN®, which was designed to analyze various parameters of the affected traffic (Fang and Elefteriadou, 2005; Moridpour *et al.*, 2015; Černický *et al.*, 2016; Junhua *et al.*, 2017). However, the software had limitations that they were unable to show the area changes while the maintenance was processing because of the overlapping use of the area. It was hard to specify appropriate maintenance plan and measures for safety during maintenance operations.

A 4D CAD was a 4-dimensional model created in this study to combine all the physical characteristics of the interchange into the maintenance operation plan. This model would be used for safety management in a project. For project planners, this was supposed to be a

tool for visualizing the area change according to the maintenance operation and the overlapping areas which were risk prone to accidents.

4D CAD

4D CAD was a model created through integration of 3D model using engineering area data with the construction schedule (Jongeling and Olofsson, 2007; Hartmann *et al.*, 2008). In the past, many construction projects had applied 4D CAD to both construction and maintenance projects in building and road work such as creating a model in the design phase, using as a communication medium for inspection phase, and estimating project cost for bidding preparations phase. (Hartmann *et al.*, 2008; Kassem *et al.*, 2015). It was also used as a project progress monitoring tools (Hartmann and Fischer, 2007), system maintenances in the construction sites (Chau *et al.*, 2004), for work scheduling purposes and area management planning (Jongeling and Olofsson, 2007), and for safety management planning (Junhua *et al.*, 2017; Benjaoran and Bhokha, 2010; Zhou *et al.*, 2013). This technique was used to visualize the impacts of highway construction to the surrounding residual areas along the project route (Zanen *et al.*, 2013). It could also visualize the new highway construction project at the intersections while traffic was flowing through the existing road during the project operation phase (Liapi, 2003), etc.

This research adopted the 4D CAD to visualize the area changes in the construction site of the road maintenance projects over the operation interval.

Safety Management

Safety management in construction was to determine measures that would eliminate risks of accidents during work operation. Accident, its frequency and magnitude, was caused by

modern technology, tools, equipment, and machinery used to ease the work and save time. Not only the safety technology in construction work had been overlooked, but also the ordinary safety practices were underestimated and not given serious attention from the relevant parties. In addition, it was found that workers lack of knowledge, understanding and awareness of safety which led to accidents. Safety at work composed of workplace safety, tools and machinery safety and personal safety. Past researches had studied the factors which caused accidents and the initial investments in managing risks for safety purposes (Behm., 2005; Carbonari *et al.*, 2011; Jazayeri and Dadi, 2017).

From the reviews of relevant literatures, 4D CAD had not yet been applied for the interchange maintenance projects. Thus, this research initiated the 4D CAD for modeling the interchange maintenance projects in order to identify risky areas and specify appropriate safety management measures.

Objective

1. Select the most appropriate interchange maintenance plan.
2. Create a 4D CAD model that could project the accident risk prone areas during the maintenance process according to the schedule for each operation time interval and showed the area utility profile throughout the maintenance operation.

Study Method

The research methodology was as follows.

Part 1 Selection of the most appropriate maintenance plan.

1. Survey and select the case study interchange, and then collect traffic data during normal hours for weekdays, weekends and special holidays which had different traffic characteristics.

2. Arrange a few different maintenance plans from construction activities.

3. Analyze the traffic flow characteristics in normal condition in comparison with the case scenarios where there were partial route closures in the interchange for each hour using Aimsun® program. Various parameters of the alternative plans were then compared and evaluated to select the most appropriate plan.

Part 2 4D CAD Development

1. Use engineering area data and land utility profile to create 3D model by Auto CAD® and SketchUp®. The 3D model used geometric shapes to represent the interchange, the buildings and infrastructures around the site.

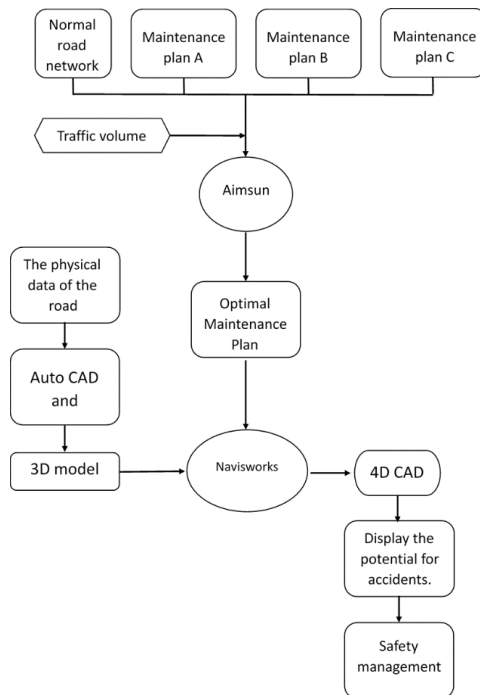
2. Integrate the 3D model with the most appropriate maintenance plan using Navisworks® so that the 4D CAD model could project the area changes at different time intervals according to the maintenance plan so the accident risk prone area could be visible. The 3D model of the interchange was input using the Append command which could open various file types. Then Time Liner command was used to specify the operation area according to the maintenance and activity schedule of the appropriate maintenance plan using the Add Task command. The starting and finishing dates of each activity could be specified at this step according to the plans. The program could also show the site area changes according to the maintenance plan which visualized the accident risk prone area. The research methodology is shown in Figure 1.

Case Study

The Nakhon Ratchasima Route 2 Interchange Maintenance Project in Nakhon Ratchasima province, Thailand was chosen as the case study interchange because there was high traffic volume during normal hours and was very congested during holidays. In addition, the physical characteristics of the project showed that there were multiple uses of the area, a lot of buildings were around the site. Unlike other interchange, there was also a railway running under the site as shown in Figure 2.

Table 1. Example of the holiday traffic data in each direction during 17.00-18.00 h. by manual count method

	N	S	W	E	SUM
N	-	5163	5737	1147	12047
S	2599	-	780	1949	5328
W	2649	530	-	2119	5297
E	1281	3629	4270	-	9180
SUM	6529	9322	10786	5216	31852

**Figure 1. Research methodology**

In the near future, the new interchange linking to the Motorway No. 6 Bang Pa-In - Nakhon Ratchasima would be constructed so that the Nakhon Ratchasima interchange will have to carry more traffic that come in and out to various directions while wearing and damaged surface were found in the interchange which had been in service for more than 20 years.

The maintenance project aimed to repair the surface which was damaged through the base layer. The maintenance process was complex and lengthy; therefore, it would impact both the commuters and people around the area. The researcher collected traffic data

**Figure 2. Geographical and land use characteristics around the Nakhon Ratchasima interchange**

at the different time intervals during weekdays, weekends and special holidays. Data collection was performed manually using manual counts method which collected the number of vehicles flowing in specific direction. The sample data is shown in Table 1.

The alternative maintenance options for the interchange were created by activity information in each maintenance process. This maintenance project required 125 days to finish. The 3 plans (Plan A, B, and C) were created based on different scenarios as shown in Tables 2, 3 and 4. The activities for every option were represented using the letters 'a' to 'i'. Plans A and B were created based on conventional maintenance operations of the highway, of which the construction starts from one end to the other end in one direction. Plan A was arranged to start the station from the west side of the route and move to the north, whereas Plan B was arranged in the opposite direction or starting from the north end to the west end. For Plan C, the work process was arranged unconventionally. Some activities were scheduled in the direction from the west

Table 2. Maintenance option A which scheduled to begin from West to North

Month	1	2	3	4	5
Activity					
a	■				
b	■				
c		■			
d		■			
e		■			
f		■			
g		■	■	■	■
h		■	■	■	■
i				■	■

Table 3. Maintenance option B which scheduled to begin from North to West

Month	1	2	3	4	5
Activity					
a	■				
b	■				
c		■			
d		■			
e		■			
f		■			
g		■	■	■	■
h		■	■	■	■
i				■	■

Table 4. Maintenance option C which scheduled to big in from West in the morning and North in the afternoon

Month	1	2	3	4	5
Activity					
a	■				
b	■				
c		■			
d		■			
e		■			
f		■			
g		■	■	■	■
h		■	■	■	■
i				■	■

Note: "a" was closing traffic route, "b" was specifying the damaged area, "c" was demolishing the existing reinforced concrete surface from Sta. 0+000 to Sta. 0+510, "d" was demolishing the existing reinforced concrete surface from Sta. 0+510 to Sta. 1+135, "e" was repairing the sub-base layer for Sta. 0+000 to Sta. 0+510, "f" was repairing the sub-base layer for Sta. 0+510 to Sta. 1+135, "g" was constructing the new reinforced concrete surface, "h" was working on construction joint, and "i" was painting traffic line.

to the north in the morning period and some were scheduled in the reverse direction from the north to the west in the afternoon. It is hypothesized that noncontinuous operations would be able to better reduce the impact on traffic traveling through the interchange.

The traffic data was then analyzed using the Aimsun® software where 3 parameters were used; 1) Delay Time, 2) Speed, and 3) Travel Time. The analyses were conducted on the 3 plans to determine the most appropriate

plan. The highest traffic volume of each day was used in the analyses because it would reflect the worst impact on traffic to be considered and handled.

The square shape was used in this 4D CAD model to represent the machinery such as cranes, concrete mixing trucks and other trucks, etc. The shape would show the area necessary for machines operations both in horizontal and vertical alignments. The 3D models would be combined with the most

appropriate maintenance plan afterward using the Navisworks® software to create the 4D CAD model.

Next, the accident risk prone areas would be displayed in the 4D CAD model specifying the place and time that may occur in order to create specific safety measures that were appropriate for each of the time interval.

The limitation of this study was the safety management plan could not be activated because the Nakhon Ratchasima interchange maintenance project is still in the future plan.

Study Results

The analysis results of the traffic volume data in the normal road network compared with the route closure condition according to maintenance options A, B and C using the 3 parameters derived from the software program are as shown in Table 5.

The 3 maintenance plans were compared for the normal road conditions which considered only the weekdays and weekends because the maintenance plan specified the working days to be Mondays - Saturdays. It was found that the parameters included 1) Delay Time 2) Speed and 3) Travel Time for the traffic around the interchange were analyzed to determine the appropriated plan. Considering the delay time parameter, it was

found that maintenance option C which the operation began from West to North caused delays in weekdays during 17.00-18.00 h. at 49.87 s/km and in weekends at 107.08 s/km during 11.00-12.00 h. This was less than option A which had a delay time in weekdays at 53.92 s/km during 17.00-18.00 h. and in weekends at 115.78 s/km during 11.00-12.00 h, while option B had a delay time in weekends at 62.11 s/km during 17.00-18.00 h and in weekends at 111.89 s/km during 11.00-12.00 h. The speed parameter showed that travelling through the interchange in option C was faster than option A and B. For option C the travel speed in weekdays during 17.00-18.00 h. was at 37.24 km/h and in weekends during 11.00-12.00 was at 26.23 km/h whereas the speed for option A was at 35.77 km/h and 25.22 km/h and the speed for option B was at 34.72 km/h and 25.56 km/h in weekdays and weekends, respectively. The travel time for option C was less than for options A and B. The travel time for option C in weekdays during 17.00-18.00 h was at 108.61 s/km, in weekends during 11.00-12.00 was at 165.40 s/km. A travel time for option A and B in weekdays during 17.00-18.00 h. was at 119.75 s/km and 127.95 s/km, and in weekends during 11.00-12.00 was at 181.76 s/km and 177.92 s/km, respectively. From the 3 parameters data, maintenance option C was considered the most appropriate plan for this activity.

Table 5. Analysis results of the traffic volume during the most congested time interval for the normal road network condition and for the road closures condition of maintenance options A, B and C

parameter	Time 5.00-6.00 pm. weekdays	11.00-12.00 am. Weekend	5.00-6.00 pm. The first day of public holidays	5.00-6.00 pm. The end date of a public holiday
In the case of normal road network conditions				
Delay Time (sec/km)	24.84	90.48	101.92	111.63
Speed (km/h)	44.00	30.46	21.47	28.65
Travel Time (sec/km)	90.63	156.18	167.70	177.43
In case of blocking road according to maintenance plan A				
Delay Time (sec/km)	53.92	115.78	132.28	127.89
Speed (km/h)	35.77	25.22	25.12	23.69
Travel Time (sec/km)	119.75	181.76	198.26	193.79
In case of blocking road according to maintenance plan B				
Delay Time (sec/km)	62.11	111.89	141.58	141.34
Speed (km/h)	34.72	25.56	22.69	22.19
Travel Time (sec/km)	127.95	177.92	207.39	207.26
In case of blocking road according to maintenance plan C				
Delay Time (sec/km)	49.87	107.08	121.69	117.66
Speed (km/h)	37.24	26.23	26.13	24.64
Travel Time (sec/km)	108.61	165.40	180.42	176.35

The created 4D CAD model could show the area changes on the site over the different time intervals of the maintenance operation according to the scheduled processes. Figure 3 shows the accident risk prone areas in each time interval under maintenance plan C which was the most appropriate option. From Figure 3, the 4D CAD model showed the accident risk prone area in different time intervals represented by squares. The accident risk prone areas were found overlapping with the area that road closure was required which was in higher elevation than the area for cranes and trucks operation, the traffic route under the operation sites, the traffic route where cranes and trucks were operating, and the traffic route under the interchange. On 15th day of the maintenance according to the scheduled operation in the plan, the activity scheduled for this day was demolishing the damage reinforced concrete surface. In this step, the jackhammer would be used since the interchange was a bridge structure which was different from normal road surfaces on flat land which heavy machinery could not be used as it might damage the bridge structure. Once the surface had been demolished, it was necessary to take them out of the site. However, due to the area limitations, it was not possible to send trucks in to carry out the materials as in general construction work. Therefore, route closure was required for the crane to be installed for operation and enable trucks to come into the area to take the materials out from the site. Figure 3 showed the area required by the crane and trucks for both vertical and horizontal operations. The left side of the figure showed the position of the crane and the area that the trucks would enter the site in the morning. The risk area was at Sta. 0+324 where there were 2 potential causes of risks including 1) risk of falling objects from higher elevation onto the site under the area where the crane and trucks were operating which was dangerous to workers, and 2) risk of accidents to the vehicles driving in the lanes next to the crane and truck area due to the crane turning or the truck tripping. On the right of the figure, the position of the crane and truck operating in the afternoon was

shown. Here, the risk area was predicted at Sta. 0+811 from 2 possibilities, 1) materials from the site that were being transported out might fall onto the area under where the crane and trucks were operating which was dangerous to the workers and a risk for vehicles driving through in the lanes under the operation site, and 2) accidents may occur to the vehicles driving by in the lanes next to the crane and truck area from the crane turning and the truck tripping.

Once the project planners were able to see the accident risk prone areas, it was possible for them to specify safety measures and perform cost estimates for the safety management purposes. This was in addition to the personal protective equipment as required by the Department of Highway including

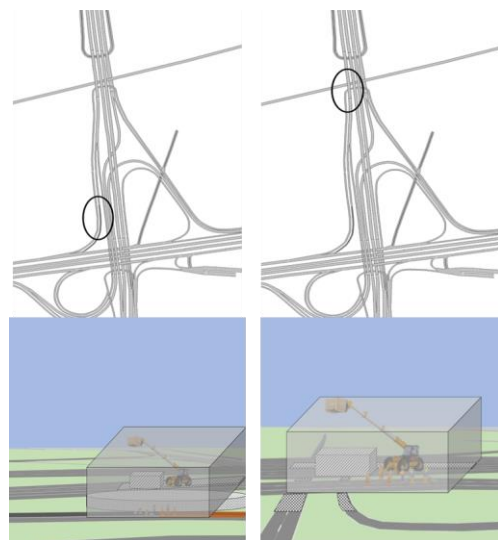


Figure 3. The 4D CAD model projecting 1) the accident risk prone areas from the scheduled maintenance plan of the Nakhon Ratchasima interchange processing West to North according to maintenance option C scenario. In this scenario, the work would begin in the morning on the West side and commenced on the North side in the afternoon, and 2) the changes in the operation area during the different time intervals according to the maintenance schedule

1) head protection devices for risk of falling objects or safety hats to protect the head from injuries, ear protection devices for working in loud noise environment of more than 40-120 dB over long periods of time, eye protection devices such as safety glasses to protect the eyes from dust and other materials during work, hand protection (gloves), and foot protection to prevent the impact of heavy materials falling on the foot and the sole of the shoe must be lined with metal to prevent sharp objects from piercing into the foot. Dust masks and safety vests were required for dust protection in the workplace in areas where there were excessive amounts of dust and glow-in-the-dark, and 2) equipment for preventing objects from falling onto the traffic below such as the safety net was mandatory. Safety nets had to be made of materials with specific qualifications and must be tough, durable and not easily torn. It was safety measures for preventing from falling in the workplace during operation or to prevent materials falling from higher elevations. Rubber padded slings should be woven through the middle of the nets for nets that were very long, or they might be used to reinforce at the corners of the nets in the cross shaped form to make the nets tighter. Slants were set up below the net lines as the interchange maintenance was a work site that has damaged reinforce concrete surface demolishing creating a lot of concrete debris during operation. In addition, traffic control equipment for the area was required including warning signs, barriers, traffic lane management equipment, lighting and signaling equipment. Equipment must be appropriately supplied for managing the accident risks from truck trips and other safety management measures on the maintenance site.

Summary

The analysis showed that the most appropriate option for maintenance plan of the interchange was plan C. According to this plan, work activity would be carried out on the West side of the interchange in the morning and on the

North side in the afternoon. The selection was based on the 3 parameters which showed that the delay for plan C was less than that of plans A and B. Likewise, usable speed for plan C was better than plan A and B and the travel time required for plan C through the interchange was less than plans A and B.

The created 4D CAD model was able to show the actual changes that occurred on the site for the different time intervals throughout the maintenance process. This enabled the visibility of the accident risk prone areas during the maintenance project and the changes in the risk locations during the scheduled operations. It was possible to specify safety measures appropriate to the risks at the different locations and time intervals. For example, it helped in providing the equipment for prevention of falling objects and road closure equipment adequately and accordingly to the requirements of the Department of Highways for risk areas that required road closure during operation. This also allowed the cost estimation for the project implementation to be more realistic and prevent losses that could occur. In conclusion, the 4D CAD model created in this study was an indicator for efficient and effective project safety management work.

It is noted that this proposed 4D CAD planning model for the interchange maintenance is superior to the traditional 2D planning. The 2D planning approach assesses risk of accidents via standards and requirements of the Department of Highways such as bridge repair and maintenance manual, road safety inspection manual during construction, highway maintenance repair manual, traffic control signage guide, manual for traffic control equipment in the construction area, and general maintenance manual, etc. However, the 2D approach is unable to effectively spotlight particular risk of accidents that change according to the various activities carried out at different project time and one related to spatial constraints of the particular construction site. Therefore, specific protective and preventive measures cannot be provided before the activities commencing. Instead, the 4D CAD planning model can help determine

preventive measures to reduce the risk of accidents particularly the ones associated with different elevations of the worksite and the machine working area, such as cranes which have a wide working radius. These spatial constraints affect the traffic passing through, the other structural parts of the intersection, and other infrastructures (such as electric poles) and buildings nearby. This also help to allocate budget appropriately and adequately.

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