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Re-Evaluating Elements of an Existing Multi-Level Intersection: Na`ur Interchange as a Case Study

Feras Al adday

Middle East University, Amman, Jordan,

ABSTRACT

Multi-level intersections (Interchanges) are very effective in reducing crashes by removing a conflicts points. Na`ur interchange is considered a very important interchange that link some of the important destinations in Amman the capital of Jordan. Due to the importance of this intersections, it carries a heavy daily traffic movements that causes traffic congestion during peak hours in addition to traffic accidents produced from the conflicts of vehicles in weaving section in expressway (Airport highway). This project aims to propose an efficient, economic solution through a certain design criteria. The research project basically relied on the specifications of the American Association of State Highway and Transportation Officials (AASHTO) Code through which have determined the side friction factor, maximum super elevation, pavement width of turning movement on ramps, the appropriate acceleration, deceleration and taper lanes and minimum radiuses of the curvatures for all the interchanges ramps and loops after estimating a proper design speed for each curvature for all interchanges. Based on the set of criteria defined by the research, the research has concluded to a re-design of some parts of Na`ur interchange in accordance with the codes applicable in road engineering.

Keywords*:* Interchanges, Conflicts Points, Minimum Radius, and Superelevation.

1. INTRODUCTION

Intersections are generally the areas where streets connect to one another and this leads to the convergence of different traffic together [1]. Intersections are divided into three main groups, each of which differs from the other according to the function performed, as follows: (1) At-Grade Intersection, it is on one level and is the most dangerous intersection in terms of accidents, (2) Grade-separated intersection without ramps, where different traffic never meets, and the movements are separated by the bridge, (3) Grade-separated intersection with ramps (Interchanges), bridges are used but the different levels are connected by ramps [2].

Interchanges are almost used on the high volume highway such as expressways and freeways, where the entry and exit of these is just across ramps, all access are under control. Interchanges can be used on other categories of highways, as congestion problems cannot be solved without them [3][4].

Access control is often carried out by an ideal engineering design, driveway controls, by imposing laws of rotating and parking, and define areas of cross, separation and merger [5]. The highway users generally encounter some types of traffic jam and delay particularly at intersections. The traffic jam can be reduced by applying the appropriate designs of interchanges [6]. Sometimes these interchanges may not help solve critical traffic problems [7]. On an interchange, traffic jams are often bottleneck [8]. Several cloverleaf interchanges suffering from problems of delay and traffic safety at the weaving section between exits and enters of cloverleaf within short spaces [9]. Traffic jam has developed as one of main strategic concerns facing a large cities because the lack of space in urban areas [10]. Especially with the large increase in the number of vehicles in recent times, which constitutes a huge burden on the transportation system in general. This requires the search for strategic alternatives to old traffic facilities [11].

Statistical data indicate that the number of cars will increase significantly, which increases the need to make future development decisions that reduce the negative effects of this increase [12][13]. There have been many efforts made to find new designs to upgrade the operation of old and failing service interchanges. Finding emergency and useful solutions is not that easy. Efforts must be made to achieve traffic safety, reduce delay, establish a new traffic system or upgrade it, and eliminate the old traffic system [14]. In general, an interchange increases traffic safety and enhance traffic operation at a location by eliminating conflict points occur between main and minor movements of traffic [15].

The selection of the proper category of interchanges is influenced by several issues, such as classification of roads, design speed of roads, amount the access and control mode, and features and characteristics of the traffic. As well as the need for traffic signs, economic analysis, land topography, and right-of-way is one of essential criteria in deigning/planning facilities with satisfactory demanded capacity [16]. Critical interchange components comprise the freeway, median, cross road, supplementary lanes, and ramps [17].

To facilitate a turning traffic travels at a grade-separation crossing a many interchange arrangements (configurations) are used. These configurations are involve two classes, first, system interchanges are one must be connected two, three,

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four or more freeways. Second, service interchanges indicate to one that join a freeway to less important facilities. System interchange connections have to a high traffic speed as well free flow to facilitate all turning or through movements [18].

Basic interchange arrangements have been established may be operate in an existing and improved situations or combined to increase traffic efficiency more. Selection one of arrangements for the finishing design is established on a study of estimated volumes of traffic, designed code, location conditions, standards for crossing legs with the turning roads, expectation of motorists, consistent ramp arrangements, Continuity of effective performance, and preliminary cost [19].

Irrespective of the facility category, it is important the basic style of the interchanges serves its function which is anticipated to achieve. Incorrect uses may cause to premature uselessness and safety problems [15].

With regard to the secondary classifications of interchanges, emanating from system and service interchange patterns. System interchange include the directional "Y" (two level}, four level directional stack (one entrance and exit), and directional "T" (3 level). These interchanges are often complex forms and requirement to be modified to local situations.

Service interchange involve the standard diamond, split diamond, folded diamond, partial cloverleaf, and full cloverleaves, these interchanges are called basic forms. The compact forms are also service interchanges such as the diverging diamond, tight diamond, and single point diamond. There are also other forms of interchanges called specialized type such as trumpet and three level diamond [20]. Nevertheless, diamond and cloverleaves are the common class. Exit and entry ramps are generally single lane, double lane (two lane pavement width) ramps considered low use and rare. Each of these class be able to accommodate a wide-ranging of volume demands of traffic and these classes have great flexibility in adapting to the neighboring buildings and are less destructive to the surrounding environment [21]. In this research, the interchange of Na`ur will be the study topic, and it is closely related to full interchange. These interchanges removes all intersection movement encounters by the traveling in a weaving sections, where a critical part in designing cloverleaf is weaving sections. It replaces an intersection points with a merging as shown in figure 1[22]. Full cloverleaf can be removed all left-movement conflicts by creation of a two-level intersection. Figure 2 shows the Na`ur interchange, which is an intersection of the airport highway with AL Quds Street.

The Na`ur interchange was chosen due to the importance of this road, where it is linking points between the airport road (north south) and Al Quds Street (east-west). Na'ur Interchange is located in the west of the capital Amman 27 km from queen alia international airport. This interchange links some of the important destinations of Amman streets.

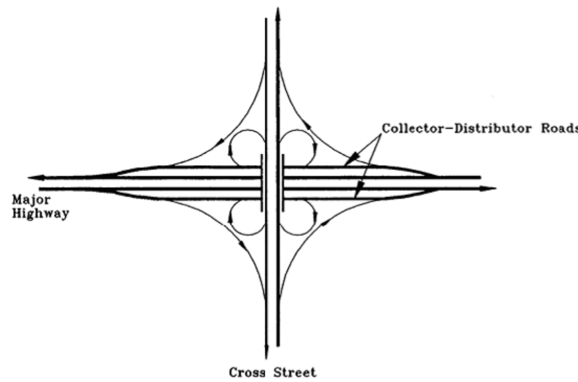

Figure 1. Represent typical full-cloverleaf interchange [22]

Figure 2. Na`ur interchange [23]

2. OBJECTIVES

The main goal in designing any intersection is to reduce dangerous collision points between different traffic movement, which leads to reduce delays, traffic accidents and environmental pollution resulting from CO_2 emissions, while preserving the damage to personal property. It is noted that the Na`ur Interchange suffers from a traffic congestion, especially during peak hours, and the delay in the remaining hours of the day, this is shown by Google Maps, which was taken at regular and continuous periods during daylight hours, as shown in Figure 3. This research aims to evaluate the basic design elements of the intersection, compare it with the AASHTO code, and propose alternative solutions to eliminate the current delays and improve mobility at the interchanges. Furthermore, avoid the drivers' confusion in the weaving section between the vehicles.

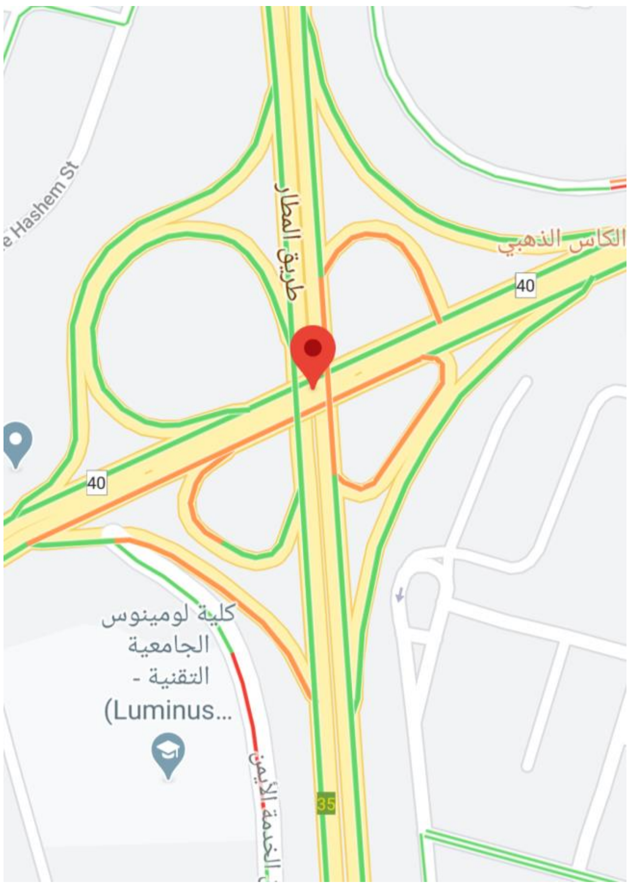

Figure 3. Na`ur interchange during the traffic congestion [23]

3. METHODOLOGY.

The methodology used in the research is simple and direct, as it was relied mainly on Google Mbps to take the plans for the Na`ur interchange as well as the plans of the interchange during the traffic congestion peak hour. As the green lines on the figure represent the light traffic, there is no delay. As for the red lines, there is a traffic congestion at the interchange. Also, the AASHTO code was used to find the dimensions of the main elements of interchange. Adopt the idea of redesigning the interchange without damaging any part or bridge. This stage started with the determination of design speed, and then determine the maximum super elevation, side friction value, deceleration and acceleration lane and maximum radiuses of loop and ramps according to the AAHTO code. Each part of the Na`ur interchange has been coded to facilitate the process of referring to the calculations as shown in Figure 4.The final stage represents drawing new plans through the AutoCAD 2020 program.

Figure 4. The coding of each part of the Na`ur interchange [23]

4. RESULTS

4.1 Determination of Existing Radii of Na`ur interchange

Through the use of the AutoCAD programs and Google Maps, the radii of the interchange were determined as shown in Figurer 4.

4.2 Determination of Ramp Design Speed (RDS)

Increased speed in cloverleaf design is a main benefit while increasing each of travel time, necessary right-of-way, and distance are some difficulties. The suggested loops radii of slight highway movements between 30 m - 50 m for design speeds up to 50 mph, while loops radii is 45 to 75 m for main highway movements for the design speeds greater than 50 mph [24]. RDS usually equal to the running speed of low volume on the crossing highways. This RDS is not applied at all times, and lower RDS may be designated, but RDS would not be a smaller value than the low value showed in Table 1 [16].

Table 1: RDS with Highway Speed (AASHTO, A Policy on Geometric…, 6th ed, 2011) [16]

Metric								
Highway design speed (km/h)	50	60	70	80	90	100	110	120
Ramp design speed (km/h)								
Upper range (85%)	40	50	60	70	80	90	100	110
Middle range (70%)	30	40	50	60	60	70	80	90
Lower range (50%)	20	30	40	40	50	50	60	70

Depending on the previous two references, it can be considered that the design speed of the loop is 50 Km/h (lower rang) as shown in Table 1. As the design speed and posted on Airport Highway is 100 km per hour. As for the design speed of the ramp. For right movements usually is taken for upper value of design speed, but can be taken a middle value of speed as typically practical, it also takes 70 km per hour, depending on the same cafeteria.

4.3 Determination of Superelevation *e* and side fraction *f*

Coefficient of side friction f varies depending on the speed and Superelevation, AASHTO provides recommended values according design speed of highway, for design speed of 50 Km/h (30 mph), the f equal to 02, and for design speed of 70 Km/h (45mph), the f equal to 0.15 [25][26].

The superelevation value, e considered a critical value for the reason that high superelevation value can lead to problems in maneuver on the horizontal curve such as steering difficult in icy climates, in this case f reduced, and then leading to the exit of vehicles from the curve because of centrifugal force. AASHTO delivers common recommendations for the selection of e at curves dependent on the road type (maximum e's are acceptable on freeways type than on arterials, collector and local types) and native design experience [27].

Some agencies specialized in traffic engineering have approved a maximum e of 8% as a logical maximum e, Regardless of bad weather, such as snow and frost. There are other opinions on the possibility of reducing e to 4 or 6%, where slow motorists will suffer a negative f, which cause extreme steering energy of motorists. Where this situation can be caused by a traffic congestion on entrenching interchange that restrict speeds, a lower e can be used as a common practice, generally 4 to 6% taken as a practical applied value. Maximum e or e equal to 0 can be used in important crossing zones or at turning and intersection traffic movements, where slow speed occurs as a result of control devices [16]. According to the aforementioned Criteria (AASHTO). In this paper, the value of e will be 6%.

4.4 Determination of the minimum radius (Rm) for loops and ramps

The appropriate Rm of curvature is defined from the design speed of ramp or loops, maximum e, and the f, Rm can be expressed according to AASHTO as following equation [16][17][25][26].

$$R_m = \frac{v^2}{127(e+f)} \ldots\ldots\ldots\ldots \text{Eq (1)[16]}$$

Where *V* is design speed of vehicles on the curve. If the *e* and *f* values were determine, it can be conceivable to conclude the R_m for loops and ramps. The table 2 represent R_m for these elements according to AASHTO (A Policy on Geometric…, 6th ed, 2011) [16]. The second and third column of this table represents existing and proposed Rm, respectively.

Table 2: Calculated, proposed and existing design Rm of Na`ur interchange

	Calculated design Rm (m)	existing design Rm (m)	proposed design Rm (m)
Part 1	75	30	60
Part 2	75	15	60
Part 3	75	35	60
Part 4	75	65	60
Part 5	180	160	100
Part 6	180	220	120
Part 7	180	150	100
Part 8	180	40	120
Part 9	180	70	120

4.5 Determination of Acceleration and Deceleration Lanes length

The adding of axillary lanes such as the deceleration or acceleration during design process of cloverleaf interchanges is an ideal alternative solution to collector-distributor highways [16][17][28].

Deceleration Lanes: Appropriate deceleration space is required to provide a comfortably and safely to drivers and allow them to get off their vehicles from the freeway. The deceleration lane distance will based on the design speed freeway and the design speed of exit ramp [28]. Parallel type of exits (PTE) can be adapted in this research. It is commonly starts with a taper, an auxiliary lane followed this taper and is parallel to the freeway lanes. The PTE terminal is revealed in Figure 5. This form of end zone gives a safe and attractive area, since the foreshortened vision of the taper and an extra breadth are very obvious. The length of parallel deceleration lanes is typically calculated from the extra width lane of 3.6 m to the exit point, which is represented spilt the ramp from the freeway alignment. Maximum parallel deceleration lanes are desired the motorists than lesser lanes. Deceleration lane with length of 240 m are suitable. [16][17]. Using Table 10-5 from AASHTO code (A Policy on Geometric…, 6th ed, 2011) [16]. The minimum length of deceleration lanes is 135 m., where freeway speed and loop speed was 100 and 50 Km/h respectively. Based on the above about the best length of the deceleration lane, a value of 240 meters was taken as a better solution for the deceleration lane. As for the taper length, the minimum taper of 75 m. in this research, A 90 m will be adapted. The taper of a PTE lane would have a gradual slope about 15:1 to 25:1.

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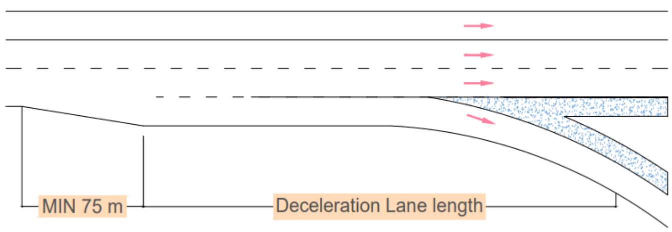

Figure 5. PTE with Deceleration Lane

Acceleration Lanes

Acceleration lane consider one of important elements to assist driver to enter freeway with comfortable, safety and regulated traffic operations if it designed properly. The acceleration lane length mainly governed by the design speed both the entry ramp and the freeway [28]. Parallel type of entrances (PTN), it is help a vehicle to increase speed adjacent freeway lanes before to merging by adding of sufficient length lane. A taper is provided at the end of the added lane. The motorist can see the surrounding area and all traffic via the side and rear car mirrors 16][17].

A classic design of a PTN is revealed in Figure 6. A curve radius of 300 m or more is suitable, while a curve length of 60 m or more also is preferable. This curve should be setting in prior the Acceleration lane. The importance of adding curve in beginning and with radius greater than 300 m to avoid entering the vehicles directly on top of the freeway lanes without entering and driving on the acceleration lane. When placing the PTN lane, a taper must be placed at the end of that lane to leader the drivers progressively onto the through freeway lane. A desired taper length of about 90 m is appropriate for design speeds of freeway up to 110 km/h. The length of a PTN lane is commonly calculated from the connection point between the left sides of the ramp lane and the traveled right side of the freeway lanes to the start of the downstream taper. [15][16][20][21].

Minimum PTN lengths governed by freeway speed and entering loop speed. Using Table 10-4 from AASHTO code (A Policy on Geometric…, 6th ed, 2011) [16]. The minimum length of PTN lanes is 255 m., where freeway speed and loop speed was 100 and 50 Km/h respectively. In practice, the minimum length for an accelerated traffic lane is 360 m, in addition to the length of the taper, this is due to the fact that traffic forecasts for freeway and ramp will increase and reach of the maximum capacity of the merging zone. In this research, and based on the above, the value of the accelerating lane length can be 360 + 90 = 450 m. a required gradual slop of taper of about 50:1 to 70:1 (horizontal to vertical).

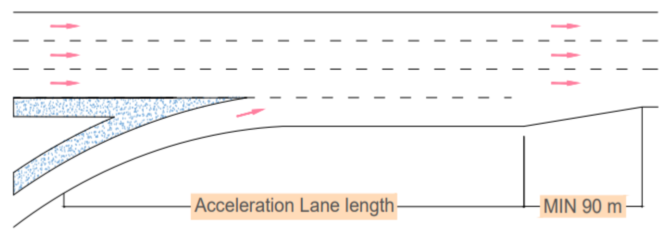

Figure 6. PTN with Acceleration Lane

4.6 Determination of weaving section length

The close and successive loop ramps of full-cloverleaf interchange initiate a weaving area neighboring to the external through lane, which helps in the occurrence of acceleration and deceleration at the same time in the lane traffic straight neighboring. Because of this problem, there must be sufficient distance between the entrance and exit of the loops. In urban areas, it is possible to find two or more loop ramps placed in successive close range. A practical space should be added between sequential loop ramps. This space is influenced by the interchanges classification, the consecutive ramp function, loops radii, and weaving possible. When the following noses space is fewer than 450 m, there is needed to prove the speed change lanes. In this research. The lengths each of acceleration and deceleration lane were 780 m (360+90+240+90), initially, this length will form the weaving space, before the final design of the Na`ur interchange.

4.7 Determination of Minimum Widths of Turning ramps and Roadways

The airport highway and ramps speeds are more than 25 Km/h, it is needed to increase the widths of pavement for the turning movements. These roads are often designed with flexible pavement, which makes up the bulk of road construction projects, which are contained of asphalt and aggregates [29][30]. According to the operational conditions of the airport highway, the second case of the design of ramps could be considered the ideal case, which one-way, one-lane operation with capability for passing a stalled car, The pavement width based on the turning roadway radius and the features of the design vehicle. Traffic Condition B can be adapted: Percentage of SU trucks permits to be the design trucks. But it permits for 5 to 10% of tractor-trailer combination trucks, the pavement width for ramps 5, 6, 7, 8, 9 will be 6.5 m, rounded to 7m [26]. This requires that there be two traffic lanes for the ramps entering and exiting the freeway. As for loops as recommended by AASHTO, there should be one traffic lane for freeway entry [16]. Table 3 presents a summary of the proposed, existing and calculating for the Naour interchange elements. Based on the geographical nature of the region and the surrounding residential buildings, it has been proposed a simple design that fits with these conditions and is shown in the figure 7. As for the dimensions, they are shown in the third column in table 2. Figure 8 shows a comparison between the existing and proposed design.

Table 3: Calculated, proposed and existing design elements of Na`ur interchange

	Calculated	Existing design (m)	Proposed design (m)
Acceleration Lanes length	360 m	There is no	110 m
Deceleration Lanes length	240 m	There is no	110 m
weaving section	780 m	165 m	220 m
pavement Widths	6.5 m	7 m	7.5 m
Number of loop lanes	1 lane	1 lane	1 lane
Number of Ramp lanes	2 lane	2 lane	2 lane
Taper	90 m	There is no	90 m

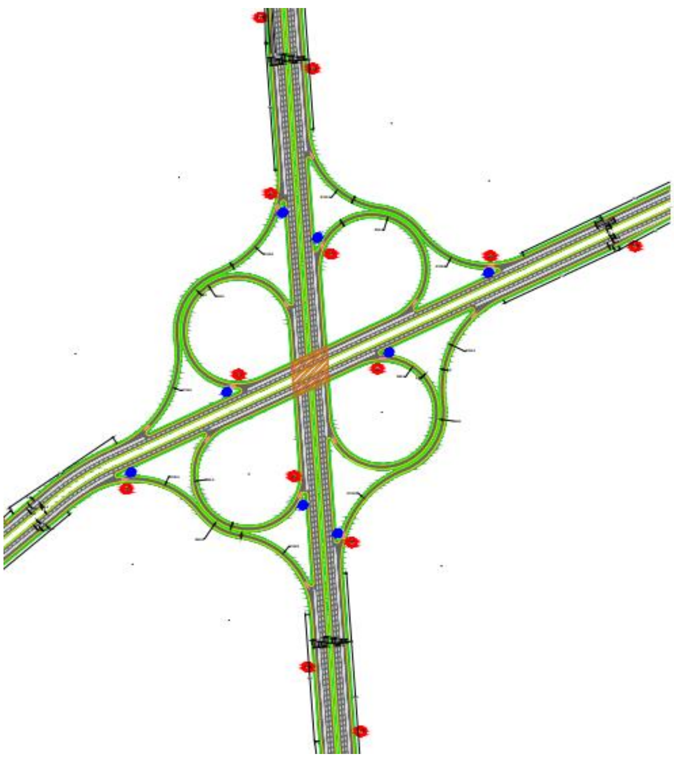

Figure 7. Proposed a simple design interchange

Figure 8. Comparison between the existing and proposed design

5. CONCLUSION

This research constitutes a practical and realistic study of a traffic problem that leads to traffic congestion on the Naour interchange. The study concluded a set of results that can avoid this traffic congestion. The design speed of the loop is 50 Km/h. As for the design speed of the ramp. For right movements usually is taken for upper value of design speed, but can be taken a middle value of speed as typically practical, it also takes 70 Km/h.

According to the aforementioned Criteria (AASHTO), the value of superelevation e will be 6%, coefficient of side friction is 0.2 for loops, and 0.15 for ramps. It is possible to change the current shape of the loops and ramps interchange, and to design them in radii of 75 m for the loops and 180 m for the ramps as a minimum values. The study recommended adding a lane for acceleration and deceleration movements with a length ranging from 780 m. As for the width of the width lanes, it will be 7.5 m. The number of traffic lanes is two traffic lanes for ramps and one traffic lane for entering the airport highway.

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