An Analysis of a Partially Signalized Roundabout using SIDRA 6 Software

Hong Ki AN a*, Wen Long YUE b, Branko STAZIC c

a School of Natural Built and Environment, University of South Australia, South Australia, 5095, Australia; Email: hong_ki.an@mymail.unisa.edu.au
b Same as the first author; Email: Wen.Yue@unisa.edu.au
c School of Computer Science, Engineering and Mathematics, Flinders University, South Australia, 5001, Australia; Email: branko.stazic@flinders.edu.au

Abstract: Normally, under unbalanced traffic volumes, roundabout metering that operates with traffic signals on one (sub-dominant) approach is used to improve roundabout operating conditions. There are few reports of studies concerning roundabout metering that operates with traffic signals on two approaches. SIDRA INTERSECTION 6 is a widely used intersection evaluation software with a roundabout metering model which allows only one approach to be signalized. This paper reports a study of roundabout metering with signals on two approaches using a SIDRA INTERSECTION 6 network model, representing the roundabout as a four-node network. The model is applied to a real-life case on Old Belair Road in Adelaide for the morning peak period (08:00–09:00 AM). Calibration methods are suggested for this analysis. The results of the analysis indicate that the level of service (LOS) and the delay time on the dominant approach are C and 23.2 seconds.

Keywords: Double signal metering roundabouts, modelling, calibration, four-node intersection, SIDRA 6 software.

1. INTRODUCTION

Intersections are very complex and important areas in traffic engineering research due to the incidents of vehicle acceleration/deceleration and accidents occurring at or around the intersections. A recent study indicated that around 75 percent of injuries are related to car accidents from intersection convergence (Hydén and Várhelyi, 2000).

Simply, intersections can be categorized into three different control devices as signalized intersections, roundabouts, and stop or give-way intersections, and are arranged in accordance with daily traffic volumes (Ogden and Taylor, 1996). In general, signalized intersections are suitable for high volumes of traffic (arterial and sub-arterial roads), roundabouts are an appropriate option for medium traffic volumes (collector roads and local streets), stop or give-way controls are suitable for low levels of traffic (local streets). Among the above-mentioned control devices, roundabouts are being taken into consideration more seriously. This is because, compared with signalized intersections, roundabouts have several advantages such as capacity enhancement, increased safety levels and decreased pollutant emissions, in particular, when approach traffic volumes are balanced and at a low to medium level for the major part of the day (An et al., 2014).

Even though roundabouts have the merits mentioned above, they have disadvantages when traffic conditions are unbalanced. This means that although total daily traffic volume may be moderate for roundabouts, particularly during normal peak hour, some real world

* Corresponding author.
cases show that vehicles tend to be concentrated on one approach (Akçelik, 2004). Therefore, a queue from a dominant approach can affect the circulating flow and decrease a roundabout’s capacity.

In order to enhance the capacity of roundabouts, signalized roundabouts, with traffic signals installed on the sub-dominant approach, were developed by Millard and Bapat who in 1974 introduced a signalized roundabout in London, which led to increased capacity. In recent decades, in order to improve a roundabout’s capacity, a metering roundabout that is a type of signalized roundabout which can reflect dynamic traffic flows was developed. The concept of the metering roundabout originated from freeway ramp metering (Qian et al., 2008) and a basic principle of operation is described by Akçelik (2004, 2006a). As can be seen from Figure 1, the terms metered approach and controlling approach are explained as follows.

The term metered approach is used for an approach stopped by red signals (approach causing problems for a downstream approach), and the term controlling approach is used for an approach with a queue detector, which is an approach helped by metering signals.

(Akçelik, 2006a, Akçelik, 2006b)

In detail, when the queue length reaches the queue detector, the traffic signal on the metered approach changes to red, thus, vehicles at the controlled approach are able to obtain enough gaps to enter the roundabout. When the red signal ends, the metering roundabout operates as a normal roundabout.

Figure 1. A form of typical metering roundabout
Source: (Akçelik, 2006b)

In recent years, numerous studies have investigated and explored the effectiveness of metering roundabouts; however only a few studies have been attempted for double signal roundabouts so far. Therefore, this paper reports a study of roundabout metering with signals on two approaches using a SIDRA INTERSECTION 6 network model, representing the roundabout as a four-node network. The Old Belair Road/Blythwood Road roundabout in Adelaide, South Australia presents a unique and special case of roundabout metering which operates with two traffic signals during the morning peak periods. SIDRA INTERSECTION
6 is a widely used intersection evaluation software with a roundabout metering model which allows only one approach to be signalized.

2. LITERATURE REVIEW

In order to increase the capacity of and reduce delay and queue lengths at roundabouts, two methods have been widely discussed. One method relates to the changing of the geometric design including flare roundabouts and slip-lane roundabouts. According to Lim et al., (2010), when there is a high level of right turning vehicles (driving on the right side of the road), slip-lane roundabouts can increase roundabout capacity. Further, Kim et al., (2010) state that the flare roundabout is able to enhance roundabout level of service (LOS). The other method is a signal metering roundabout. Even though both methods can increase roundabout capacity and decrease delay time significantly, the geometric design changes need available land space which is often not possible or involves high cost. Thus, this review will focus on metering roundabouts in the following sections, as metering roundabouts seem a more suitable option to increase roundabout capacity.

2.1 Metering Roundabouts

A study of roundabout metering was conducted by Akçelik (2006a) where he selected the intersection of the Nepean Highway and McDonald Street in Melbourne as the subject for a case study to monitor the effect of metering signals on traffic delays and queues. In his study, five scenarios in accordance with signal time were compared and he drew the conclusion that metering signals can decrease queue length and delays.

Another research by Akçelik (2011) investigated capacity and signal timing with regards to roundabout metering signals. In his study, three-leg roundabouts with one, two and three lanes were studied in the UK, USA and Australia with SIDRA INTERSECTION software and the cycle time including red and blank time effect signal metering operations were assessed using eight scenarios. He concluded that the output of all the scenarios were better than for a normal roundabout and a short time cycle was more efficient than a long time cycle.

Azhar and Svante (2011) also stated that a metering roundabout can reduce delay time, and queue length can be managed by traffic signals which can prevent spill back to other intersections. They further mentioned that flare entry and exit approaches are more efficient for metering roundabouts.

A recent study by Ahn (2012) also studied metering roundabouts to solve unbalanced flow pattern problems. He studied a four-leg roundabout with one circulatory lane (diameter: 25 m, circulatory lane width: 5 m, entering speed: 20 km/h) using SIDRA software for the analysis. He found that when the traffic volume of the dominant approach is less than 50 percent, the signal metering was ineffective. In addition, when traffic volume of the controlling lane is at 60 percent and the entry volume is 1,000–1,800 pcph, the average delay and queue length is reduced slightly compared to a normal roundabout.

3. STUDY AREA AND DETAILS

In the southern part of the Adelaide metropolitan area, there is a metering roundabout on Old Belair Road which has two signals as shown in Figure 2. In the morning peak period,
commuters are using this roundabout, especially from the southern approach and the vehicle storage area on that approach is shorter than on other approaches. In addition, the south approach joins another local road close to the roundabout.

Thus, the objective of metering signals at this roundabout is to reduce queue length and delay time on the south approach for capacity and safety reasons. Furthermore, along the approach, there is a school entrance, and a long queue on the west approach blocks school visitors during the morning peak. Another aim is to avoid blocking the school access on the west approach. Therefore, this roundabout is operated as a metering roundabout with a queue detector installed 157 meters away from the stop line on the south approach so when the queue detector detects a queue, the two traffic signals on the north and east approaches change to the red phase.

3.1 Geometry

The Old Belair Road roundabout consists of four legs and each approach has two entering and exiting lanes except for the east approach which has one entry and exit lane only. The number of circulatory lanes in each direction is also different (i.e. south and north are 5.5 meters and east and west are 7.0 meters). As shown in Figure 2, the east and west sides have two circulatory lanes and the south and north directions consist of one circulation lane. Besides, the width of each approach is also varied i.e. east (3.6 m), west (3.7 m), south and north (3.55 m), and the width of the circulating lane is 3.5 m, and moreover, the island diameter is 18 meters. To make things more complex, the roundabout has a five percentage uphill road from north to south.

3.2 Traffic Volumes

The total traffic volume on March 4, 2009, was 28,051 vehicles and during the morning peak, the traffic volume from the south approach increased dramatically as shown in Figure 3. Between 08:00–10:00 AM, the traffic volume from the south approach was approximately
twice that of the other approaches, especially between 08:00–09:00 AM when it was around 1,000 vehicles as shown in Figure 3.

![Figure 3. Directional traffic volumes (08:00–09:00 AM)](image)

Table 1 describes the hourly traffic volume and the directional flow ratio of each approach on March 4 in 2009, and Jiban (2009) collected the directional ratio for the site during the morning peak period (08:00–09:00 AM). However, the data was collected across two days on 3 and 4 March in 2009 with each day covering two roundabout approaches. On the first day, north and south approaches were surveyed and the following day, east and west approaches were surveyed. Between 08:00–09:00 AM, a total of 2,097 vehicles passed through the roundabout and around 99 percent of vehicles from the south and 87 percent of the vehicles from the west were northbound.

<table>
<thead>
<tr>
<th>Traffic Volumes</th>
<th>Directional Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left turn</td>
</tr>
<tr>
<td>EAST</td>
<td>31 veh</td>
</tr>
<tr>
<td>WEST</td>
<td>424 veh</td>
</tr>
<tr>
<td>SOUTH</td>
<td>1019 veh</td>
</tr>
<tr>
<td>NORTH</td>
<td>623 veh</td>
</tr>
<tr>
<td>Total</td>
<td>2097 veh</td>
</tr>
</tbody>
</table>

Source: SCATS data from Adelaide DPTI

3.3 Signal Phases

The Old Belair Road roundabout is a unique metering roundabout because it has two traffic signals on sub-dominant approaches. When a queue is detected by the queue detector on the south approach, the two traffic signals change to red. According to the Department of Planning, Transport and Infrastructure (DPTI), cycle times at the Old Belair roundabout are a maximum of 120 seconds. Furthermore, during the morning peak period from 06:00 to 10:00 AM, the red and green phase duration changes depending on the queue lengths of every cycle as shown in Figure 4. Moreover, the busiest time during the morning peak hour is between 08:00 and 09:00 AM and the red phase duration in that period is 94 seconds maximum with an average of 91 seconds compared with the maximum 120-second cycle time.
3.4 Queue Length

A survey of maximum queue length was also conducted by Jiban (2009) as part of his Master thesis in 2009, and the traffic volumes and the maximum queue lengths were surveyed for two days. Also, the queue lengths of the north and east approaches were collected on the first day and the west and south approaches were surveyed on the following day. The results of the surveys show the maximum queue lengths of each approach to be 14 m (east), 294 m (west), 147 m (south) and 798 m (north) during the morning peak (08:00–09:00 AM).

4. MODELLING
The roundabout metering model in the current SIDRA INTERSECTION 6 software can assess operation with metering signals on one approach only. This research formulated a new method describing the roundabout as a network of four individual intersections ("sites") for modelling a roundabout with signals on two approaches.

4.1 Creation and Linkage of Four Individual Intersections

The Old Belair Road roundabout is comprised of four approaches and the north and east approaches are controlled by traffic signals during the morning peak hour. Thus, the roundabout is represented as a network of two signalized intersections (signals on north and east approaches) and two give-way intersections as shown in Figure 6.

![Figure 6](image)

Figure 6. Representation of the roundabout as a network of four intersections

After the creation of the individual intersections, a linkage is necessary using the network function in SIDRA INTERSECTION 6 and, at this stage, the linked four intersections can be seen as a roundabout.

4.2 Adjustment of Approach Geometry

For each intersection, the approach geometry is already set up as two-way which is a default value. However, the individual four-leg intersections can have a role as two different bound approaches, thus, in this step the modification of approach geometry into one way is needed. In addition, the circulation lanes in the linked roundabout also need a lane discipline modification due to the entry internal approach being a dummy approach whereas in a normal intersection vehicles can go in all directions. Thus, at the position of the entry internal approach (dummy), the approach needs to have the direction of traffic specified (as shown in Figure 7).
4.3 Modification of Lane Geometry

As mentioned in previous sections, the Old Belair Road roundabout has four legs and all approaches have two entry/exit lanes excluding the east approach which is comprised of one entry/exit lane. In the case of the west approach, one lane flares into two lanes (left turn lane and shared left/through/right lane) which starts 110 m away from the stop line. Figure 8 shows the amended lane geometry.

4.4 Priorities

The roundabout is operated with two phases; during peak hours, the north and east approaches are controlled by traffic signals and the west and south approaches operate by a give-way control as with a normal roundabout. For this four-node roundabout, a confirmation of priorities is necessary because each intersection operates individually. During phase A (green time) the circulating vehicles have the priority on all approaches as a normal roundabout, however, during phase B (red time) entering vehicles from the north and east approaches are stopped as shown in Figure 9.
4.5 Input Directional Traffic Volumes

The last step of modelling requires an input of the directional traffic volumes (turn volumes). If a roundabout has one signal, this step would not be necessary because SIDRA 6 can calculate these turning volumes automatically. However, since each intersection has a dummy approach (internal approach) in the linked intersection model, users need to input turning volumes manually as shown in Figure 10.

5. CALIBRATION
In order to calibrate the model, it was aimed to match the real-life observed maximum queue lengths as closely as possible. As mentioned earlier, on March 4, 2009, the observed queue lengths were 14 m (East), 294 m (West), 147 m (South), 798 m (North) between 08:00–09:00 AM. In this study, the calibration process was divided into two steps. In the first step, the calibration parameters can be confirmed roughly and in the second step, the parameters will be further adjusted in order to match the observed queue length.

5.1 First Phase Calibration

5.1.1 Critical Gap and Follow-Up Headway

For roundabouts, critical gap and follow-up headway parameters play a key role in determining the roundabout capacity. Normally, these values are collected from the field; however, due to the lack of data, the calculated values have to be applied. According to Jiban (2009), the critical gaps and follow-up headways can be calculated based on circulating flow and inscribed diameter. The results of the calculation are represented in Table 2 and the default values from SIDRA INTERSECTION 6 are applied for Blythewood Road (E) and Old Belair Road (N). This is because east and north approaches are operated by traffic signals.

<table>
<thead>
<tr>
<th>Approach Description</th>
<th>Critical gap</th>
<th>Follow-up headway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Belair Rd(S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant lane</td>
<td>5.2s</td>
<td>2.6s</td>
</tr>
<tr>
<td>Sub-dominant lane</td>
<td>5.2s</td>
<td>2.6s</td>
</tr>
<tr>
<td>Blythewood Rd(E)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant lane</td>
<td>Default value</td>
<td>Default value</td>
</tr>
<tr>
<td>Old Belair Rd(N)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant lane</td>
<td>Default value</td>
<td>Default value</td>
</tr>
<tr>
<td>Sub-dominant lane</td>
<td>Default value</td>
<td>Default value</td>
</tr>
<tr>
<td>Blythewood Rd(W)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant lane</td>
<td>4.8s</td>
<td>2.4s</td>
</tr>
<tr>
<td>Sub-dominant lane</td>
<td>6.4s</td>
<td>3.2s</td>
</tr>
</tbody>
</table>

5.1.2 Peak Flow Factor (PFF)

Peak flow factor (PFF) is an important parameter for calibration. This parameter is shown as constant and it describes how in a specific time period vehicles concentrate on the roads or facilities. Table 3 shows the traffic volumes during 08:00–09:00 AM and the PFF of each approach is calculated as below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Traffic Volumes(veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td>08:00 ~ 08:30</td>
<td>15</td>
</tr>
<tr>
<td>08:30 ~ 09:00</td>
<td>16</td>
</tr>
</tbody>
</table>

- East: \[
\frac{(15 + 16)}{2} \div 16 = 97.0 \% 
\]
- West: \[
\frac{(130 + 294)}{2} \div 294 = 72.0 \% 
\]
- South: \[
\frac{(419 + 600)}{2} \div 600 = 85.0 \% 
\]
- North: \[
\frac{(238 + 385)}{2} \div 385 = 81.0 \% 
\]

5.1.3 Extra Bunching Value
This four-node roundabout is not a true roundabout which is formulated by four connected intersections. Thus, between the internal approaches, extra bunching values need to be considered. According to Akçelik (2009), the extra bunching parameter is normally defined as the parameter applied to find out how free vehicles in the stream are affected by upstream signals. Table 4 gives an explanation of the extra bunching values in accordance with the distance from upstream signals. Therefore, 25 percent of the extra bunching values are applied in the research except for the north approach because the distance of each internal approach is less than 100 meters.

Table 4. Extra bunching data

<table>
<thead>
<tr>
<th>Distance to upstream signals (m)</th>
<th>&lt;100</th>
<th>100-200</th>
<th>200-400</th>
<th>400-600</th>
<th>600-800</th>
<th>&gt;800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra bunching (%)</td>
<td>25</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: SIDRAINTERSECTION User-guide (2009)

5.2 Second Phase Calibration

At this phase, the above-discussed parameters may affect the roundabout’s analysis which can be manually adjusted slightly and Table 5 has documented the final values. An explanation for the values of the south approach (target approach) is that vehicles on the south approach need to wait 5.5 seconds before entering and so when the first vehicle enters the roundabout, the second vehicle should wait 2.6 seconds. In respect to PFF, although the one-hour traffic demand on the south approach is 1,019 veh/h, the first 30 minutes and the second 30 minutes are different. Thus, the busiest duration needs to be considered and 18.1 (100 − 81.9) percent more should be calculated compared to the average demand. In terms of extra bunching value, entering vehicles on the south approach are affected by circulation vehicles from the north and east approaches where traffic signals are installed. Therefore, 25 percent of extra bunching value needs to be applied.

Table 5. The adjusted parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Critical gap</th>
<th>Follow-up headway</th>
<th>PFF</th>
<th>Extra bunching</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAST</td>
<td>Dominant lane</td>
<td>4.2 s</td>
<td>2.7 s</td>
<td>97.0 %</td>
</tr>
<tr>
<td>WEST</td>
<td>Dominant lane</td>
<td>5.8 s</td>
<td>3.5 s</td>
<td>81.3 %</td>
</tr>
<tr>
<td></td>
<td>Sub-dominant lane</td>
<td>7.1 s</td>
<td>4.1 s</td>
<td>81.3 %</td>
</tr>
<tr>
<td>SOUTH</td>
<td>Dominant lane</td>
<td>5.5 s</td>
<td>2.6 s</td>
<td>81.9 %</td>
</tr>
<tr>
<td></td>
<td>Sub-dominant lane</td>
<td>5.5 s</td>
<td>2.6 s</td>
<td>81.9 %</td>
</tr>
<tr>
<td>NORTH</td>
<td>Dominant lane</td>
<td>5.0 s</td>
<td>2.5 s</td>
<td>81.0 %</td>
</tr>
<tr>
<td></td>
<td>Sub-dominant lane</td>
<td>5.0 s</td>
<td>2.5 s</td>
<td>81.0 %</td>
</tr>
</tbody>
</table>
6. RESULTS ANALYSIS

By conducting the above-mentioned calibration processes, the queue lengths of the connected intersections are closely matched to the observed data during 08:00–09:00 AM on March 4, 2009. Approximately 99 percent matching was achieved as shown in Table 6 except for with the east approach. However, due to low vehicle volumes on the east approach, the difference of three meters is less than half a vehicle's length.

Table 6. Queue length comparison

<table>
<thead>
<tr>
<th>Direction</th>
<th>Queue length (m)</th>
<th>Matching ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>West</td>
<td>294</td>
<td>289.3</td>
</tr>
<tr>
<td>South</td>
<td>147</td>
<td>146.1</td>
</tr>
<tr>
<td>North</td>
<td>798</td>
<td>803</td>
</tr>
</tbody>
</table>

6.1 Measure of Effectiveness

According to the Highway Capacity Manual (2010), the LOS is able to be decided by volume to capacity ratio and delay time. Thus, LOS and delay time can be the measure of effectiveness (MOE) for roundabout analysis. The results of the MOE are as below. Figure 11 shows that during 08:00–09:00 AM LOS of the north and west approaches are F whereas the south and east approaches are C and D respectively.

![Figure 11: The LOS of each approach](image)

The delay time is also similar to LOS because a roundabout’s LOS is determined by the average delay time (HCM 2010). According to Table 7, the average delay time of the south approach is shorter than the west and north approaches and, even during peak periods, vehicles need to wait 23.2 seconds before entering the roundabout.
Table 7. Average delay time

<table>
<thead>
<tr>
<th>Direction</th>
<th>Delay time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>43.2</td>
</tr>
<tr>
<td>West</td>
<td>246.2</td>
</tr>
<tr>
<td>South</td>
<td>23.2</td>
</tr>
<tr>
<td>North</td>
<td>429.8</td>
</tr>
</tbody>
</table>

6.2 Further Analysis

From the connected intersections, a variety of performance parameters can be analyzed, e.g. degree of saturation (ratio of demand volume to capacity), lane blockage probability (probability of blockage of upstream lanes), speed efficiency (ratio of average travel speed to desired speed for the approach) and queue storage ratio (ratio of the average back of queue to the available queue storage distance) and Figure 12 shows the results as images.

From Figure 12, it can be seen that, during 08:00–09:00 AM, the average delay time of each approach is east (43.2 s), west (246.2 s), south (23.2 s) and north (429.9 s), and the degree of saturation of each approach is determined as 0.13 (east), 1.22 (west), 0.87 (south) and 1.60 (north). In respect to lane blockage probability, only the north approach may block upstream lanes with the probability being larger than 30 percent while the other approaches do not affect the upstream lane.

Also, in respect to speed efficiency, the result shows that north and west approaches are less than 30 percent and the south approach falls into a range of 50–70 percent. In terms of queue storage ratio, only the north approach can reach the maximum capacity and the rest of the approaches reach less than 60 percent of their maximum capacity.
7. CONCLUSION AND FUTURE WORK

This paper has reported a development on the use of SIDRA INTERSECTION 6 for metering roundabout performance evaluations. SIDRA INTERSECTION 6 software is practicable for one traffic signal metering roundabouts only. This paper describes a new method of formulating a four-node intersection to extend the capacity and overcome the limitations of SIDRA INTERSECTION 6.

The results based on model output and field data comparisons demonstrate that the new method is capable of evaluating the LOS, delay time, degree of saturation, lane blockage probability, speed efficiency, and queue storage ratios.

Although this research suggests that the new modelling method can be applied for the analysis of double signals roundabouts, there are some critical steps to be followed. Firstly, parameters that may affect roundabout operations such as critical gaps and follow-up headways need to be collected from the site for a more rigorous analysis. Secondly, the variations in the geometry parameters, including entry angle and entry radius, need to be considered for a more decent analysis as well. Thus, the addition of micro-simulation modelling capabilities may be required.
Similar to SIDRA INTERSECTION 6, the micro-simulation model Aimsun is capable of modelling vehicle actuated signal operations and, as such, it can adjust the signal phase duration depending on the actual vehicle arrivals matching the real-life signal operation as controlled by the SCATS.

In order to model the double signalized roundabout in more detail and visualize individual vehicle movements in a 3D environment, the micro-simulation capabilities of Aimsun software can be utilized. This software can assess the effect of detector locations operated by the SCATS on entire roundabout performance. Furthermore, this study used SIDRA INTERSECTION 6 by forming four individual intersections to duplicate the function of a metering roundabout and evaluating its performance.

By deploying Aimsun in the investigation of the performance, the interactions between all approaches and individual vehicles could be measured continuously for the entire peak period rather than for only average and maximum values.

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REFERENCES