Feasibility Study

I-70/VAIL ROAD

August, 1994

Prepared for

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FEASIBILITY STUDY

I-70/VAIL ROAD

SUMMARY

Congestion at the diamond interchange of Interstate Highway 70 and Vail Road could be corrected by constructing a pair of modern roundabouts at the ramp and frontage road intersections. The project would reduce accidents and enhance the interchange's appearance. The Town would not need to acquire right of way or to widen the undercrossing.

The interchange would have ample capacity to operate at levels of service A and B even if existing flows increase by fifty percent. Accidents would decrease by about 19 percent following construction of the project.

ROUNDABOUTS AT MAIN VAIL

The diamond interchange of Interstate Highway 70 and Vail Road in Vail, Colorado, often called Main Vail, is subject to long delays. During peak traffic demand periods traffic wardens at the intersections north and south of the freeway direct traffic to relieve congestion. A proposal to install traffic signals was rejected by the Town of Vail. Yet the quality of life in the Town is threatened by worsening traffic congestion at this interchange and at the interchange of I-70 and Chamonix Road, known as West Vail.

The Town has commissioned this study of the feasibility of using modern roundabouts to solve the problem. Unlike nonconforming traffic circles, modern roundabouts conform to modern roundabouts guidelines. (See Appendix B for a one-page comparison of the two types of circular intersections.) Since 1990 modern roundabouts have been installed in about a dozen sites in the United States, including many locations in Florida, three in Nevada, two in California, and two in Maryland. All are success stories, reducing delay and accidents.

In the United Kingdom almost all freeway-to-street interchanges are based on the modern roundabout. Australia, Norway, Sweden, and France also have modern roundabout interchanges. Modern roundabout interchanges have been proposed in California. In Maryland one has been approved by the Federal Highway Administration.

PROJECT DESCRIPTION

At Main Vail two roundabouts would be built (see Appendix A). The north roundabout would have an inscribed circle diameter (outer diameter) of 120 feet. It would have a raindrop type of central island, which would prevent traffic from turning left onto the off ramp. It would provide high capacity continuous flow for traffic on Vail Road coming from under the bridge, since this traffic would not have to yield the right of way to circulating traffic.

All entries to the north roundabout would have two lanes, with 28 feet between curbs. The circulatory roadway would also be 28 feet wide from the outer curb to an inner nine-foot wide truck apron. The three-inch high concrete truck apron would discourage most vehicles from using it, deflecting and slowing entering vehicles, but the rear wheels of long trucks would easily mount it.

Both roundabouts are designed to accommodate a 65-foot long tractor and semitrailer. Long trucks would be able to make 60-foot radius U-turns from off ramps to frontage roads and from frontage roads to on ramps by beginning their turns in the left lane.

The connection from the north roundabout to Spraddle Creek Road is designed to accommodate a school bus, fire truck, or garbage truck. Right turns from the roundabout to Spraddle Creek Road would have a maximum turning radius of 50 feet. Turns by long vehicles would end next to the road's north curb.

The south roundabout would have a 200-foot inscribed circle diameter. Its central island would be 128 feet in diameter. The outer 39-foot wide margin of the central island would be kept clear of tall objects to provide adequate forward visibility, but a central area 50 feet in diameter could be used for landscaping or public art of any desired height.

To provide ample capacity, all but one entry to the south roundabout would have two lanes. The westbound South Frontage Road entry would have four lanes. The eastbound off ramp would have a right turn bypass lane in addition to its two-lane entry to the roundabout. The circulatory roadway would be 36 feet wide through most of the roundabout and 48 feet wide in front of the four-lane entry.

Splitter islands would be notched to allow pedestrian refuges 10 feet wide. Following modern guidelines, crosswalks would not be marked. Walkways would be designed where necessary as part of the landscape plan to align with the pedestrian refuges in the splitter islands.

TRAFFIC PERFORMANCE

A number of alternative road improvements were studied by Felsberg Holt & Ullevig and presented in the *Vail Transportation Master Plan* (see Appendix D). The preferred alternative is Alternative 8, given on their page number 78. This would remove the two east ramps at Vail Road and direct traffic needing this connection to ramps east of Vail Road in the Booth Falls area.

The study determined that the present volume/capacity ratio at the intersection of Vail Road and the westbound ramps is 1.16, level of service E. At Vail Road and the eastbound ramps and South Frontage Road the present volume/capacity ratio was determined to be 0.94, also level of service E, if traffic wardens or demand responsive traffic signals are used (see their page number 74).

The performance of modern roundabouts at the ramp and frontage road intersections with Vail Road was estimated using a computer application named Rodel. (See Appendix F for an explanation of Rodel.) Rodel estimates average delay in minutes per vehicle. By use of a little spreadsheet this was translated to average delay in seconds per vehicle and to the corresponding levels of service (see Appendix G). The *Highway Capacity Manual* relates levels of service to average delay for the whole intersection according to the table on the following page.

LEVEL OF SERVICE FROM AVERAGE STOPPED DELAY AT INTERSECTION
Taken from Table 9-1 of the
Highway Capacity Manual

STOPPED DELAY (SEC/VEH)	LEVEL OF SERVICE
d<=5	A
5<d<=15	B
15<d<=25	C
25<d<=40	D
40<d<=60	E
60<d	F

Both roundabouts would operate at level of service A with existing traffic. The roundabouts were designed to allow a traffic increase of at least fifty percent because it is thought that some longevity would be necessary to justify the substantial investment required for this project. Also, traffic surges of an unknown amount, perhaps fifty percent or more, presently occur at various times each year.

With a fifty percent increase in traffic, the north roundabout would continue to operate at level of service A, but the south roundabout would operate at level of service B. Levels of service are presented in the table below.

	AVERAGE DELAY (Seconds Per Vehicle)				**LEVEL OF SERVICE**			
	North R.		**South R.**		**North R.**		**South R.**	
TRAFFIC DEMAND	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
100% of Existing Traffic*	2.2	1.8	3.4	3.2	A	A	A	A
150% of Existing Traffic	3.0	2.8	11.8	11.5	A	A	B	B

*"Existing traffic" in this report refers to counts made on the twenty-fifth busiest ski day of the year (per Vail Associates), in March of 1990.

The design objective of allowing a fifty percent increase in existing flows will be exceeded. The following percent increases in existing traffic will be possible without exceeding average stopped delay of 30 seconds per vehicle on any leg (a measure of practical capacity), estimated at the 85th percentile.

ROUNDABOUT	A.M.	P.M.
Main Vail North	117%	65%
Main Vail South	52%	56%

SAFETY

In those countries that have adopted the modern roundabout as a standard type of intersection, the roundabout is generally regarded as the safest type of intersection on earth. Typically, accidents at roundabouts are around 55 percent less than at cross intersections of similar flows regulated by traffic signals. Serious injury and fatal accidents are reduced by more than property damage only accidents according to reports from all countries, typically by 80 to 90 percent when a signalized intersection is converted to a modern roundabout.

But all-way STOP sign regulated intersections, as at Vail's four-way, also have an excellent safety reputation, at least in general. Two-way STOP sign regulated intersections, like the two ramp intersections in this project, generally are not so safe as all-way stops. At Vail Road the reverse is true. The two-way STOP sign regulated intersections experience fewer accidents than the four-way intersection of Vail Road and South Frontage Road, perhaps because of the four-way's heavier flows.

The accident history of modern roundabouts in the United States has been similar to the success stories of roundabouts in foreign countries. Accidents have fallen 44 percent for the first eight months of operation of the Long Beach roundabout in California. This is in contrast to the same eight months of the previous three years, when the circular intersection operated as a nonconforming traffic circle. In Santa Barbara, California, the Five Points roundabout replaced a five-way STOP sign regulated intersection. Accidents previously averaged about four per year. During the first six months of roundabout operation, there were three reported accidents, all at night (the roundabout has poor street lighting). There have not been any accidents reported in the last 14 months. The first modern American roundabouts, built in Las Vegas in 1990, have very low flows. Nevertheless, it is comforting to note that no accidents have been reported at them. As far as this author knows, there has never been a bicycle or pedestrian accident at a modern American roundabout, but there have been two motorcycle accidents.

Roger D. Gilpin, of the Colorado Department of Transportation, prepared a report of all accidents at both the Main Vail and West Vail interchanges with Interstate Highway 70 over the three-year period of 1991-93. Appendix E contains the portion of his report that pertains to Main Vail.

Eighty-seven accidents were reported at this interchange over the three-year period. Of these, 62 were intersectional. The remaining 25 accidents would not be affected by the modern roundabouts proposed to replace the existing ramp and frontage road intersections.

At the intersection of the westbound ramps and Vail Road, which would be replaced by the north roundabout, 14 accidents were reported in the study period. At the two Vail Road intersections to be replaced by the south roundabout, the eastbound ramp and South Frontage Road intersections, 48 accidents were reported during the study period.

A large proportion of the 62 intersectional accidents, 27 accidents, were rear-end accidents, many of them involving vehicles sliding on ice into stopped vehicles. The roundabouts would not do anything to prevent icy conditions, but they would greatly reduce the number of vehicles stopped in queue. The potential for accidents between vehicles which are stopped and vehicles behind them which can not stop would be reduced as the roundabouts reduce queuing.

During the study period there were no pedestrian accidents, no motorcycle accidents, and two bicycle accidents. Modern roundabouts have an excellent reputation for reducing accidents involving most types of road users--trucks, cars, buses, and pedestrians--but not motorcycles and bicycles. Special bypass roads and lanes for bicycles have not been shown to reduce bicycle accidents at roundabouts. Based on British studies of similar roundabouts, it is estimated that the number of bicycle accidents would rise about 50 percent, perhaps by one accident in three years. It is estimated that all other types of accidents would decrease, to a total of around 50 accidents in three years, for a net reduction of about 12 accidents. This would be a 19 percent reduction in accidents following construction of the modern roundabout interchange.

SPECIAL ISSUES

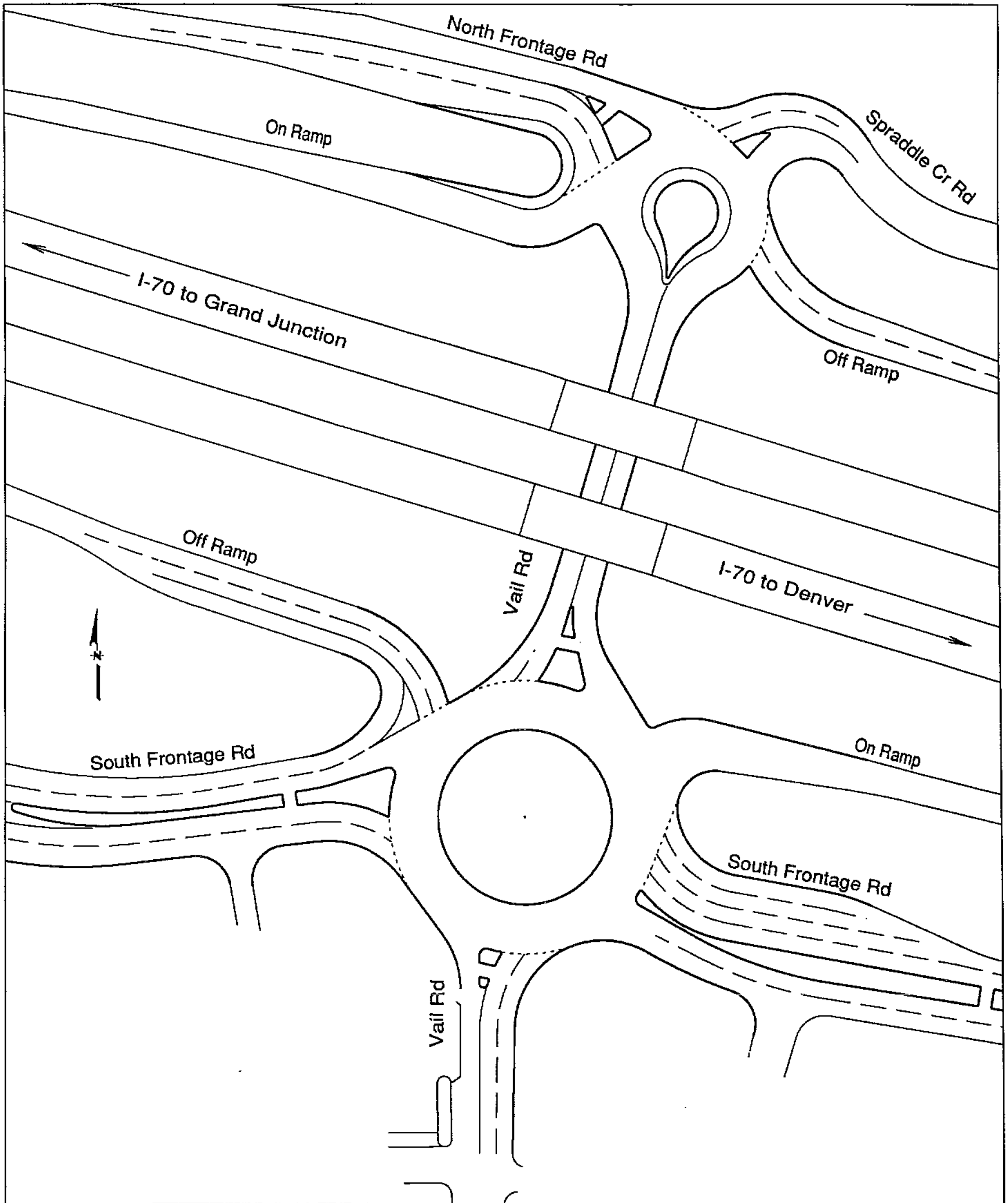
Special issues applicable to modern roundabouts in Vail are considered in Appendix C, "Vail's First Roundabouts." Among other issues discussed in this appendix are the following: snow and ice, tourists unfamiliar with roundabouts, lighting, signing, maintenance, trucks, buses, bicycles, pedestrians, flow fluctuations, potential traffic growth, landscaping, and emergency vehicles. The roundabouts will give good service with regard to all of these issues.

CONCLUSION

A modern roundabout interchange to replace the diamond interchange of Interstate Highway 70 and Vail Road is feasible. Unlike alternatives previously proposed, it would allow all present traffic movements to continue using the interchange. It would provide an excellent level of service, reduce accidents, and create a beautiful entry to Vail.

APPENDIX A

Proposed Interchange Layouts



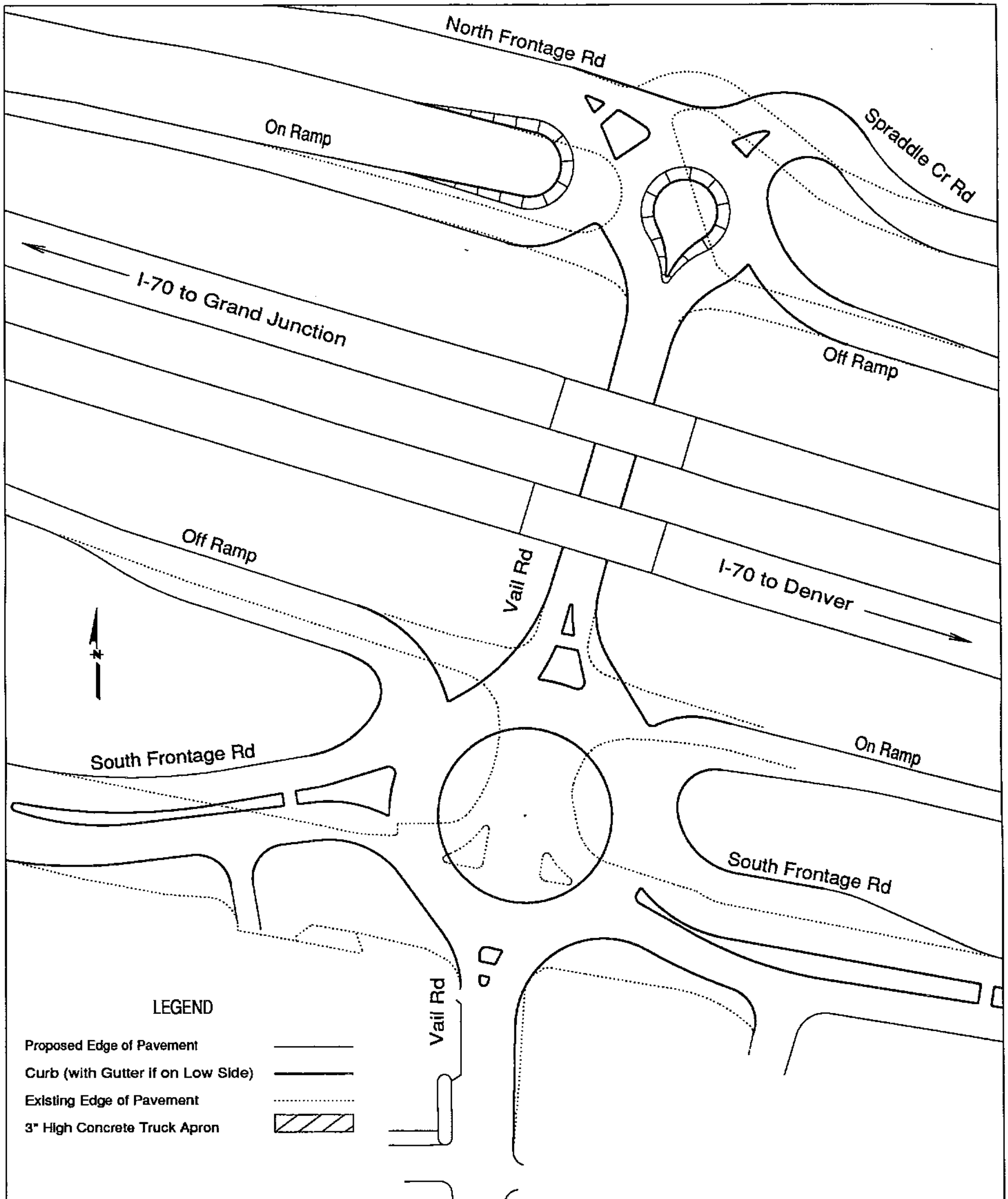
Leif Ourston & Associates

I-70/VAIL ROAD

Vail, Colorado

August 16, 1994

Scale: 1" = 100'



Leif Ourston & Associates

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Vail, Colorado

August 16, 1994

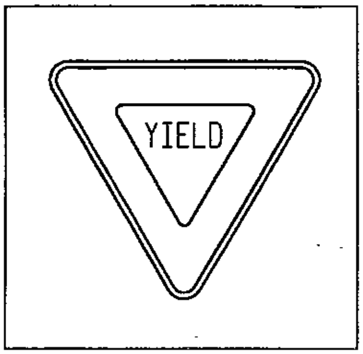
Scale: 1" = 100'

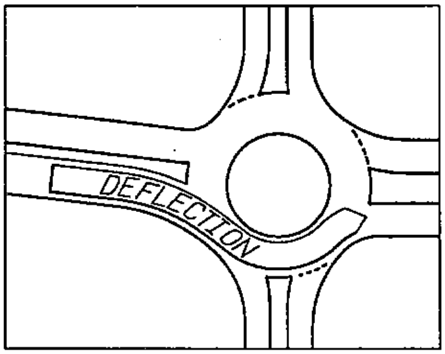
APPENDIX B

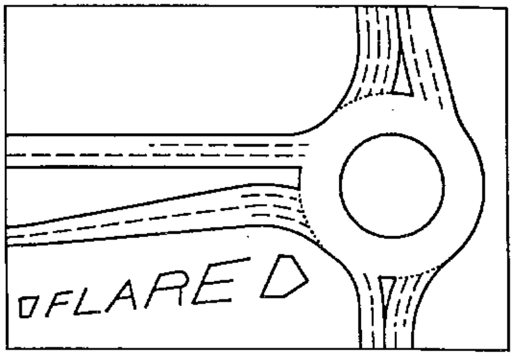
Modern Roundabout or Nonconforming Traffic Circle?

MODERN ROUNDABOUT OR NONCONFORMING TRAFFIC CIRCLE?

Unlike nonconforming traffic circles, modern roundabouts conform to modern roundabout guidelines. Among other important new features, modern roundabouts have yield at entry, deflection, and (often) flare, as illustrated below.







MODERN ROUNDABOUT

1. *Entering traffic yields to circulating traffic.*
- Circulating traffic always keeps moving.

- Works well with very heavy traffic.
- No weaving distance necessary. Roundabouts are compact.

2. *Entering traffic aims at the center of the central island and is deflected slowly around it.*
- Slows traffic on fast roads, reducing accidents.
- Deflection promotes the yielding process.

3. *Upstream roadway often flares at entry, adding lanes.*
- Provides high capacity in a compact space.
- Permits two-lane roads between roundabouts, saving pavement, land, and bridge area.

NONCONFORMING TRAFFIC CIRCLE

1. *Entering traffic cuts off circulating traffic.*
- Circulating traffic comes to a dead stop when the circle fills with entering traffic.
- Breaks down with heavy traffic.
- Long weaving distances for merging entries cause circles to be large.

2. *Entering traffic aims to the right of the central island and proceeds straight ahead at speed.*
- Causes serious accidents if used on fast roads.
- Fast entries defeat the yielding process.

3. *Lanes are not added at entry.*

- Provides low capacity even if circle is large.
- For high capacity, requires multilane roads between circles, wasting pavement, land, and bridge area.

APPENDIX C

Vail's First Roundabouts

VAIL'S FIRST ROUNDABOUTS

Prepared for Greg Hall, P.E.
Town Engineer
Town of Vail, Colorado

by Leif Ourston, P.E.
Leif Ourston & Associates
Santa Barbara, California

August 24, 1994

This report addresses thirteen concerns given in your letter of January 14, 1994. These important issues will be considered as you decide where and how to build the town's first modern roundabouts.

1. How do roundabouts work in extremely snowy climates, in which pavement markings are covered for stretches at a time, signs may be obstructed by wind packed snow, and grades may exceed roundabout standards and may be snow packed and icy?

We have heard from Professor Ragnvald Sagen, speaking to the Town of Vail by way of a videotape made in Norway two weeks before this year's winter Olympic games, standing in front of a roundabout after the deepest snow Norway has experienced in thirty years. He told us that snow impairs the performance of all types of intersections, but it seems to impair modern roundabouts less than others. Snow removal equipment can clear a roundabout in one forward circular movement. At cross intersections, it takes several back and forth movements to clear the middle.

The potential for a head-on or angle type of accident is much less at modern roundabouts than at cross intersections, in snow, ice, and other weather. The geometry of roundabouts requires slower speeds. Accidents tend to be of the less serious merging type.

In the iciest conditions, motorists can not completely stop at STOP signs. They slowly roll into the intersection. The YIELD signs of roundabouts accommodate this type of entry.

The four-way STOP sign regulated intersection of Vail Road and South Frontage Road experiences many tail-end icy weather accidents caused by motorists sliding into vehicles stopped at STOP signs. Since the modern roundabout proposed for this intersection will have very little queuing, there will be fewer rear-end accidents during icy conditions.

In your video, *Snow at Roundabouts*, we observed some snow packed YIELD signs at roundabouts, but the triangle-shaped YIELD signs were still easily recognized. We observed many roads on which the pavement markings, including yield lines, were completely covered by snow. Entering motorists understood where to yield the right of way to circulating traffic because of tracks in the snow and because the roadways were defined by plowed areas.

Grades should ordinarily not exceed 2% at roundabouts because truck drivers may set their circulating speeds based on comfort at a part of the roundabout where the crossfall if favorable, and they may shed their loads or roll their trucks where the crossfall changes abruptly to adverse superelevation. Grades at three of your four roundabouts will meet this 2% recommended maximum, which feels nearly flat on ice, snow, or wet or dry pavement. At the main Vail north roundabout, a raindrop-style central island will prevent trucks from circulating around the bottom of the roundabout, where the crossfall would be about 4.5%. Therefore grades at all of your roundabouts will meet modern roundabout standards.

Because of their success, modern roundabouts are proliferating in very snowy countries, including Norway, Switzerland, and Sweden. Two roundabouts in the United States, in Maryland, have done very well through recent heavy snow storms, even though the roundabouts are new to the drivers of their state.To check on this, you may call the traffic engineers in charge of the roundabouts in Gaithersberg and Lisbon, Maryland. They are:

Ollie Mumpower, P.E.
Traffic Engineer
Department of Public Works
City of Gaithersburg
800 Rabbitt Road
Gaithersburg, Maryland 20878
301 258-6370

and

Gene R. Straub
Assistant District Engineer--Traffic
Maryland State Highway Administration
Traffic Engineering Division
P.O. Box 308
Frederick, Maryland 21701
301 694-2595.

2. Can a motoring public, the majority being on vacation, whose alertness is altered by the fact that they are vacationing and are unfamiliar with where they need to go anyway, be able to comprehend and properly use a non-traditional traffic control system such as roundabouts?

Yes. Your roundabouts will be designed for first-time users, because even years from now many of the visitors to Vail will never have driven a modern roundabout and will not be expecting one at the end of an off ramp.

There will be several visual cues of the roundabout ahead, the yielding process, and the one-way circulation around the central island. The circular patterns of the roundabouts will be seen far in advance at the bottoms of the off ramps. YIELD AT ROUNDABOUT warning signs will announce the roundabouts ahead and the need to yield the right of way at them. Below the standard YIELD signs the international standard round plate, called a roundel, with a dark blue field and three white arc arrows, will indicate that one must yield the right of way to a stream of traffic circulating to the right.

On the pavement a broken white yield line of three-foot marks and three-foot gaps will delimit the interface between entering and circulating streams of traffic. Lines separating entering lanes of traffic will end at the yield line, as they do at stop bars next to STOP signs and at limit lines at traffic signals, conveying to the motorist that he is entering a crossing stream of traffic. In each lane of traffic a YIELD legend will be painted. In the central island one-way signs will be erected below the international standard internally illuminated one-way sign, a round sign having a blue background and a white arrow pointing to the right.

Directional signs will guide motorists to their destination much better than is done by the present signing system. Map-type diagrammatic signs in advance of the roundabouts on each approach will give the sequence of route names where the motorist may exit as he circulates around the roundabout. At each exit from the roundabout these names will be repeated on a roundabout exit sign. These exit signs will also give destinations. In some cases further directional information will be given on directional signs downstream from the roundabout.

We have observed first-time drivers at two recently opened modern roundabouts in California. The Five Points roundabout replaced a five-way STOP sign regulated intersection in Santa Barbara in November of 1992. The roundabout was the first that most drivers had ever seen. For the most part they drove it skillfully and correctly the first time through, but if one watched carefully, he could see some mistakes, and even today there are a few first-time drivers who make mistakes.

The mistakes have not led to increased accidents. They tended to involve too much courtesy and hesitation, not too much aggression as had been predicted. Circulating drivers sometimes stopped to wave entering drivers into the roundabout in front of them, thus stopping the circulating stream, which should never be interrupted. Entering drivers sometimes paused too long at the yield line even when there was no traffic to pause for. Slow learners benefited from the majority of drivers who showed the correct way to drive a roundabout. Occasionally there was even a wrong way movement, but at a circulating speed of twelve miles per hour, it was easy for motorists to adjust to the mistakes of others.

The prediction before opening the roundabout was that there would be an initial blood bath until motorists got the hang of it, but eventually things might settle down. The previous situation had about four accidents per year. During its first six months of operation the Five Points roundabout had three reported accidents, all of them at night. It has very bad street lighting, not up to modern roundabout standards. This situation, and perhaps the nighttime accidents, will be corrected when the roundabout, which is made of temporary materials, is replaced with permanent materials. On the other hand, the problem may have already been corrected, as the there have not been any accidents, day or night, after the first six months of operation. The modern roundabout has either eliminated daytime accidents or greatly reduced their frequency.

The Long Beach roundabout was completed June 30, 1993. Processing 4,700 vehicles during the peak hour, this high volume circular intersection used to average about 40 accidents per year. The project added YIELD signs to the two previously uncontrolled Pacific Coast Highway entries. It also widened all entries to three or four lanes and removed lanelines from the circulatory roadway.

The prediction from opponents to the project was that motorists who had never yielded the right of way during the circle's 55 years of existence would not be able to change their ways. Especially feared was the southbound Pacific Coast Highway approach, which entered the circle on a seven percent down grade. The prediction from Caltrans, who built the roundabout, was that it would reduce the amount of white knuckle driving and clear up some queuing, but that accidents would remain about the same. The prediction by the consultant was that accidents would be reduced by about 40 percent. As a matter of fact, during the first eight months of operation accidents have dropped 44 percent compared to the same eight months of the previous three years.

Apart from signs warning that entering traffic would have to yield the right of way at a future date, there was no driver education for the project--no newspaper spots or television announcements. On the changeover day some drivers were observed to run the YIELD signs before the yield lines and legends had been painted. After the yield lines and legends were painted, no one was observed to run the yield signs on the changeover day, although occasionally this has happened on days since.

(This experience leads me to believe that the yield lines and legends are essential visual cues. It will be up to the Town of Vail to keep their pavement markings up, even though snow plows tend to obliterate them, if the Town wants its roundabouts to operate safely for years to come, through all seasons.)

The project has been a tremendous success. With less than five seconds average stopped delay per vehicle, the roundabout operates at level of service A all day long. Queuing has been eliminated from within the circle, and short peak hour queues on the approaches quickly dissipate. The Long Beach roundabout appears to be the most efficient intersection on Pacific Coast Highway, where queuing exists at all other major intersections all day long. Video taken on changeover day shows smooth, skillful operation with few mistakes.

What we have observed with both projects is that there are some mistakes from first-time users, but these mistakes do not lead to increased accidents. The slow, one-way nature of traffic circulation at modern roundabouts causes them to be very resilient to mistakes. Modern roundabouts in this country reduce accidents just as they have done in every country to which modern roundabouts have been introduced in recent years. In all of these countries, all users were first-time users initially, yet accident reduction prevailed over mistakes, even during the first months of operation .

3. How will those motorists who are very familiar with using the roundabouts once installed, and who drive very aggressively, interact with the much more timid first-time user?

Skillful drivers will honk their horn, but they will not ram timid, less skilled users. At Long Beach and in Santa Barbara we have observed on-the-road driver training of first-time drivers by more skilled drivers. The more skilled drivers honk at those who make mistakes. From this self-adjusting process skillful drivers are produced.

Since queues and delay are very short on the approaches to modern roundabouts, there is no need for entering aggressive motorists to cut off circulating timid motorists. It is easy and convenient to simply wait one's turn.

4. How can overhead lighting and proper signing be accomplished in an aesthetically pleasing way, yet still meet proper standards and be effective?

Good lighting is critical to the roundabouts' success. It is essential that overhead lighting alert the approaching motorist in advance that he is entering a roundabout, as he may miss advance warning signs. Good overhead lighting is also essential to protect cyclists, motorcyclists, and pedestrians.

Street lights ringing the roundabouts will be equally spaced from each other and from the center. The exits will be lighted at least 200 feet from the roundabouts. Horizontal illuminance will be at least 0.9 footcandle, a somewhat bright standard compared to the illuminance of conventional intersections. Roughly thirty streetlights will be provided to light the whole interchange. The lights on Christmas trees at the four-way STOP sign regulated intersection at Main Vail will be dimmed or raised or eliminated so that they to not cause the motorist to look into a wall of light at eye level.

Good signing is also important, both to prevent accidents and to make the first-time user's experience of the roundabout and of the Town of Vail a pleasant one. Good signing, as described under question 2, above, will prepare the motorist for the roundabout, guide him through the roundabout, and guide him to his desired destination within Vail. A signing expert, Fred Hanscom of the Transportation Research Corporation of Haymarket, Virginia, will help develop a sign plan that provides essential user information when it is needed while avoiding information overload.

Signing and lighting designs will be brought to the Town of Vail before implementation to be sure that signs and lights will be both effective and aesthetically pleasing. Adjustments in the designs will be made to meet Vail's requirements.

5. How will maintenance efforts be altered with regard to pavement markings, which are worn very easily by sanding abrasives.

It is essential to keep pavement markings at roundabouts and on their approaches and exits bright and clear right through the winter and all year long. Snow removal and the use of sand and salt on the roads will not be altered on behalf of roundabouts.

What will be altered is the type of markings and the frequency of their maintenance. Long lasting materials, such as thermoplastic, cold plastic, and embedded plastic, will be used where necessary in lieu of paint. The scheduled maintenance cycle may be shortened from one year to half a year. Earlier unscheduled maintenance will be done as necessary when stripes show unexpected wear.

The use of high-priced pavement markings and more frequent maintenance of them are necessary expenses of successful modern roundabouts. There are offsetting cost savings compared to other types of interchanges and traffic control. For example, high capacity will be achieved by the roundabouts without widening the undercrossings, a multimillion dollar cost.

6. How easily can truck traffic and bus traffic function through all of the turning movements?

The roundabouts will be designed to cater to large trucks and buses. At the north roundabout of Main Vail, around the central island and along the right side of North Frontage Road and the on ramp, three-inch high concrete mountable aprons will be constructed. The rear wheels of truck trailers can safely roll over mountable aprons, but motorists are discouraged from driving on them. The aprons will be designed to accommodate snow removal operations.

U-turns between frontage roads and ramps will be facilitated by bypass lanes in west Vail. The distance between ramps and frontage roads is too short for some of the largest trucks to make these turns now. The roundabouts will offer truckers an alternative to present tight U-turns. They may simply drive all the way around the roundabout, from which they can easily exit to the frontage road or ramp using a longer turning radius.

7. How will bicycles and pedestrians be safely transported through the intersections?

Bicycles will enter the roundabouts and circulate through them, mingling with other traffic. Painted bike lanes have been tried in some European countries, without success. In Netherlands, in which modern roundabouts are reported to have reduced bicycle and pedestrian accidents as well as accidents to all other road users, the only fatalities suffered at roundabouts according to a 1992 report all involved trucks exiting the roundabouts and driving over cyclists who wished to continue ahead by circling the roundabout in marked bike lanes. The marked bike lanes may have given cyclists a false sense of security.

Peripheral bike roads have been used at roundabouts, but there is no information as to whether they improve or worsen cyclist safety. Vail's roundabouts will have up to six legs each, with little space between them, so that a peripheral bike road would carry the cyclist only a very short distance before being interrupted by another spoke road. Therefore no special bicycle facility will be provided at Vail's roundabouts. At Main Vail bike lanes will be painted between roundabouts along Vail Road under the freeway.

Reports on bicycle safety at roundabouts are mixed. A 1986 British study found cyclists to be at greater risk at circular intersections, but the study did not differentiate nonconforming traffic circles (circular intersections that do not conform to modern standards) from modern roundabouts (which do follow modern design standards). The study found concentrations of bicycle accidents at entries that did not have adequate deflection. Good deflection is the principle safety requirement of modern roundabout design. A more recent study of miniroundabouts in Britain found that bicycle safety at miniroundabouts is about equal to bicycle safety at signalized intersections. A recent Dutch study found that bicycle and pedestrian accidents both declined when conventional intersections were replaced by small, one-lane Dutch-style roundabouts.

Pedestrians will cross the entries to the roundabouts in two stages, pausing at a median splitter island before completing the second stage of crossing. In this way the pedestrian gives all of his attention to traffic flowing from only one direction at a time, and his crossing distance is divided into two halves, making gaps in traffic easier to find. All research suggests that the modern roundabout is the safest type of intersection for pedestrians.

8. How well do roundabouts designed and constructed for handling our future peak demands operate when the seasonality of demand fluctuates to very low volumes?

You have very large infrequent peak traffic demands in Vail, when it takes more than an hour to enter the freeway. Your roundabouts will be designed to reduce the number of these times per year when capacity is exceeded. We will seek to eliminate these frustrating times altogether. Therefore the capacity of your roundabouts will be high for normal daily traffic, and their capacities will far exceed your needs during low traffic periods.

Operationally, you will be very proud of how your roundabouts operate during normal peak periods and during periods of very low traffic demand. The lighter the traffic demand, the easier the roundabouts will be to negotiate. The roundabouts' easy low volume operation is similar to the ease of operation of other high capacity intersections during periods of very low traffic demand.

9. Can the roundabouts be constructed as low cost, temporary facilities to show they can handle the traffic effectively, yet be removed or made permanent in the same season?

Yes. But I do not recommend temporary roundabouts, for a number of reasons. If you skimped on cost, you might also skimp on safety, omitting street lighting and backlit signing, for example. You would almost certainly skimp on landscaping if you used temporary materials initially, and your trial roundabout might look like a mess.

Temporary roundabouts would also give the impression that we do not know what we are doing, and this would be a false impression. We do know what we are doing, and the roundabouts will be hugely successful, to the credit of everyone associated with them. Temporary roundabouts could be resisted with the fear that we would be experimenting with people's lives. The Vail roundabouts will not be experiments or demonstrations. They will be permanent integral parts of your road system, a source of pride for years to come.

10. Can a low cost temporary solution be tested through a winter season?

Yes. But I do not wish to be associated with temporary roundabouts, for the reasons given under question 9, above.

11. If future traffic projections are inaccurate and Vail's traffic volumes continue to grow at alarming rates, at what level do the improvements fail to satisfactorily function?

It was felt that the large investment required by this project demanded that the improved interchange have substantial longevity. The remodelled interchange should also be able to accommodate the infrequent, irregular bursts in traffic demand that sometimes cause great delay here. Our design objective was therefore to design the interchange so that both peak hour flows on both roundabouts could increase proportionally by at least 50 percent. With the present design, we will meet that objective.

According to the roundabout analysis program Rodel, the following percent increases in existing (March of 1990) traffic will be possible without exceeding average stopped delay of 30 seconds per vehicle on any leg (a measure of practical capacity), estimated at the 85th percentile.

ROUNDABOUT	A.M.	P.M.
Main Vail North	117%	65%
Main Vail South	52%	56%

The British research on which Rodel is based was found to closely predict delay at the Long Beach roundabout in California, where observed average stopped delay per vehicle was within one second of predicted delay. Therefore the above estimates are probably close.

12. Show how any proposed landscape features do not obstruct traffic and maintenance functions.

Plants must be kept low in areas where drivers' visibility is required. In these same areas some signs are allowed, but their panels must be kept high enough for drivers to see under them. The exact clear areas, together with maximum height of plants and minimum height of sign panels, will be marked on drawings that I submit.

Small central islands must not have any trees or other tall plants. In Vail, only the main Vail south roundabout will have a central island large enough for trees or sculpture. The cylinder on the central island within which tall things may grow or be erected is fifty feet in diameter.

13. Finally, the biggest issue, convince skeptics on how well roundabouts will work in handling Vail's current and future traffic volumes and the characteristics of this volume in all types of circumstances, without building one before hand.

The narrator of your video, "Snow at Roundabouts," is Professor Ragnvald Sagen. He told me that in the early eighties, with the help of Frank Blackmore of Britain's Transport and Road Research Laboratory, he brought the concept of the modern roundabout to Norway. They began in Bergen in west Norway. When they got to east Norway, the skeptics there told them, "Well of course it works in west Norway, but it would never work in east Norway." Nevertheless, one was built in east Norway, and it worked well, and now hundreds of them are working all over Norway.

We have similar reports of early resistance from very high-level, intelligent decision makers, from Australia and Netherlands. Upon opening of the road system's first roundabout, after accidents fall, skepticism gives way to unbridled enthusiasm, and roundabouts spread. This pattern is seen in all of the countries where the modern roundabout revolution is under way. The same pattern is beginning here in California, and I am sure Colorado's initial skepticism will change to enthusiastic support.

When I first became very active in promoting modern roundabouts, in 1983, France had ignored the phenomenal roundabout success story going on across the English Channel. Now France is the world's biggest builder of modern roundabouts, building more than 1,000 per year. I expect to see the time in the not too distant future when the United States, with three times the population of France, builds 3,000 modern roundabouts a year. The modern roundabout interchange is now the standard type of interchange in France and Britain. I expect it to become the standard type of interchange here.

A picture is worth a thousand words. A video is worth a thousand pictures. But a modern roundabout on your own road system is worth a thousand videos. Multiplying these thousands together and by the two roundabouts you will build in Vail, I estimate that you will have a testament to modern roundabouts worth two billion words. There is nothing I can say to equal that.

14. Do fire trucks and other emergency vehicles have a problem getting through roundabouts?

I suggest that anyone concerned with this problem call a fire station in Britain and ask a fireman that question. I called the fire department in Swindon at 011 44 21 359-5161 and talked to Fire Fighter Burns. I questioned him over and over in different ways, and took the following notes as he spoke.

"No problem."
"They never block it."
"There shouldn't be any problems."
"Not everyone gets out of the way, but the majority do."
"Hardly ever have a problem."

APPENDIX D

Vail Transportation Master Plan

MAIN VAIL INTERCHANGE ALTERNATIVES

The range of alternatives for the Main Vail interchange is summarized in Table 11. Shown are alternatives that have been previously considered for Vail as well as new and modified alternatives and supplemental improvements. Table 12 shows the Main Vail interchange alternatives diagrammatically.

An initial screening of the Main Vail interchange alternatives yield several that should be omitted from detail analysis. The following illustrates which alternatives are no longer considered and the reasoning for omitting it.

o *Alternative 1 - Close Vail Road at 4-Way Stop*

This alternative would force Vail Road traffic to reroute along East Meadow Drive to Village Center Road in order to reach the Frontage Road. Traffic would be detoured through a pedestrian area. "De-pedestrianizing" East Meadow Drive has been considered unacceptable and is sufficient reason to drop this alternative from detailed analysis.

o *Alternative 2 - Single Point Diamond (Urban)*

This alternative would alleviate some of the intersection spacing concerns, but it would have little affect on operations at the 4-way stop intersection. Therefore, any benefits that would be gained by this alternative would not be justified by its excessive cost.

o *Alternative 4 - Relocate Eastbound Entry Ramp*

This alternative will simplify some of the traffic operations that are occurring under the interchange, but basic travel patterns will not differ significantly and the 4-way stop intersection will remain congested.

o *Alternative 5 - High Capacity Diamond*

This alternative provides minimal operational benefits but it will not improve turning movements off the ramps nor will it have any affect on operations at the 4-way stop intersection since its travel patterns would not change. Therefore, this alternative is dropped from further evaluation.

o *Alternative 6 - Relocate Eastbound and Westbound Entry Ramps*

This alternative has the same impact as Alternative 4 along the south side of the interchange and would further enhance north ramp intersection operations. However, basic travel patterns will not be altered significantly and the 4-way stop intersection will still be congested during peak periods.

The remaining alternatives (3, 7 and 8) have been evaluated as to their impact on interchange operations. Table 13 shows the volume-to-capacity ratios at key intersections for each alternative. In addition to the 4-way stop and ramp intersections, other intersections are presented whose operations are an important consideration in evaluating each alternative.

Table 11
Main Vail Interchange Design Alternatives

Alternative		Comments
	Previously Considered Alternatives (*)	
0.	No Action	Used as base case for comparative analysis.
1.	Close Vail Road at 4-Way Stop	To be re-evaluated in terms of the entire I-70 access system for the long-range transportation plan
2.	Single Point Diamond (Urban)	
3.	Remove/Modify EB Exit Ramp; Provide New Ramp(s) at VA Shops	
4.	Relocate EB Entry Ramp	
5.	High Capacity Diamond	
(*)	Traffic signals were proposed to be included in all of the alternatives previously considered.	
	New or Modified Alternatives	
6.	Relocate EB and WB Entry Ramps	
7.	Extend North Frontage Road East	
8.	Relocate East Ramps to Existing Underpass East of Golf Course (Modified Split Diamond)	
	Supplemental Actions Previously Considered	
9.	Frontage Road Modifications (One-Way, Widen, Relocate)	While not recommended as isolated alternatives, these actions are an integral part (in varying degrees) of any future improvement option.
10.	Additional I-70 Crossings	
11.	Signing Modifications	
12.	Expanded Peripheral Parking	
13.	Expanded Bus Services	
14.	Manual Traffic Control	

Table 12
Main Vail Interchange Design Alternatives

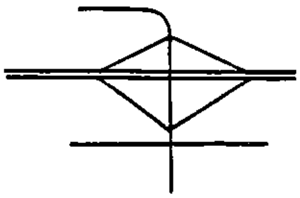
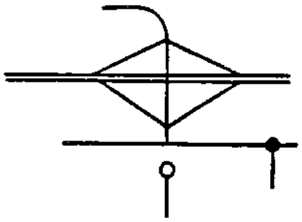
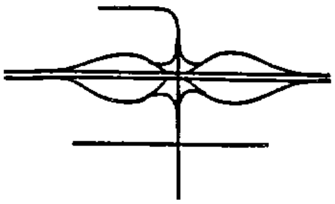
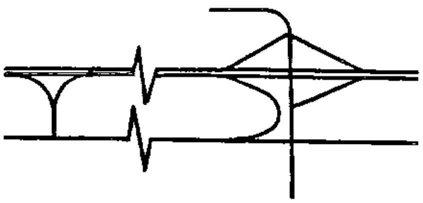
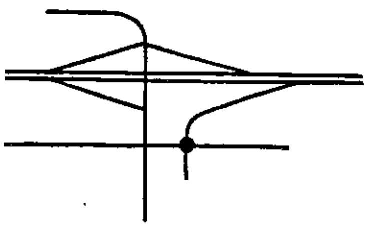
Alternative		Characteristics
0.		Existing situation for comparison.
1.		Converts 4-way stop to 3-way stop. Diverts traffic to Village Center Road. Impacts Meadow Drive pedestrian zone.
2.		Combines ramp terminals into one intersection. Reduces turning movement conflicts. Increases intersection spacing.
3.		New exit/entry ramps at VA shops. Right turns only at EB exit to Vail Road. Operational analysis to be done without signals. Federal access approval to I-70 exists.
4.		Relocates EB entry to South Frontage Road. Simplifies operations at EB exit ramp. Complicates directional signing to I-70 east.

Table 12 (con't)
Main Vail Interchange Design Alternatives

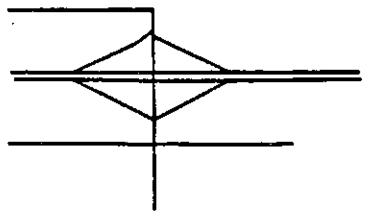
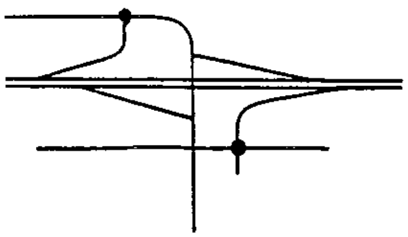
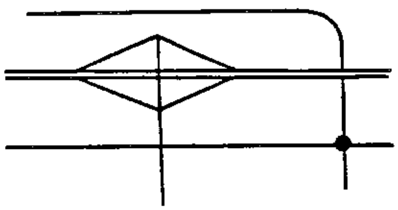
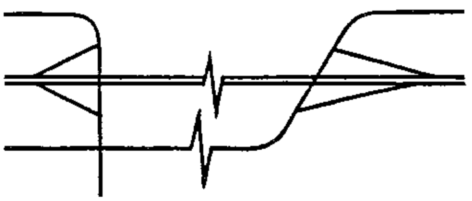
Alternative		Characteristics
5.		Increases laneage at existing interchange. Retains all existing traffic patterns.
6.		Relocates EB and WB entries to Frontage Roads. Simplifies individual intersection operations. Complicates directional signing to I-70.
7.		Provides new I-70 crossing east of Main Vail interchange. Reduces traffic through interchange area.
8.		Relocates east ramps to existing underpass east of golf course. Reduces traffic through interchange and 4-way stop.

Table 13
Main Vail Volume-to-Capacity Ratio Summary

Intersection	Existing Demand/ Existing Network	Future Demand/ Existing Network	Future Demand on Existing Network w/ New I-70 Crossing (Simba Run) Only	Future Demand/ VA Shops Ramps (Alt. 3)	Future Demand Vail Valley Connection/ Underpass (Alt. 7)	Future Demand/ Booth Falls Split Diamond (Alt. 8)
Vail Road/North Ramps (Left Turns)	1.16	1.33	1.21	1.21	0.96	0.77 (1)
Vail Road/South Frontage Road/ South Ramps	0.94 (2)	1.11 (2)	1.09 (2)	0.90 (2)	1.02 (2)	0.92 (2)
South Frontage Road/VA Shops Area	-	-	-	0.89 (2)	-	-
South Frontage Road/Vail Valley Drive	1.14	1.26	1.26	0.74 (2) (3)	0.76 (2) (3)	0.85 (2) (3)

(1) All way stop control along East Frontage Road/westbound off-ramp intersection near Booth Falls.

(2) Demand responsive traffic control required (manual control or traffic signal).

(3) Intersection modification required (lower South Frontage Road).

It can be seen from Table 13 that Alternative 8, relocating the east ramps to the Booth Falls underpass, would yield the best intersection operations given the appropriate traffic control and intersection improvements. Alternative 3 is significantly over capacity at Vail Road/north ramps intersection without demand responsive control. In addition demand response control is required at a total of three other intersections while Alternative 7 and 8 require demand responsive control at only two intersections. While Alternative 7 results in significant overall improvements to traffic operations, it is the least effective in eliminating congestion at the 4-way stop even under demand responsive control.

In addition to traffic operations, right-of-way considerations, approvals required, physical and visual impacts, and construction costs are also important. These aspects are summarized for each alternative in Table 14. In addition, each aspect has been subjectively rank ordered by alternative, and rankings have been summed for an overall ranking of each alternative for comparative planning purposes. Table 15 illustrates the results.

MAIN VAIL INTERCHANGE RECOMMENDATIONS/PRIORITIES

The following are recommendations regarding the Main Vail interchange to relieve traffic congestion prioritized by short-term and long term actions.

<u>Short-Term</u>

- o As a first priority, construct an I-70 underpass in the vicinity of Simba Run connecting the North and South Frontage Roads.

- o Conduct a controlled test in which the east Main Vail ramps would be closed and sign easterly oriented traffic to use the East Vail interchange. Results of this will indicate how well the Long-range solution will work.

- o Continue to manually control (Vail's preferred traffic control method) the 4-way stop intersection during peak periods.

<u>Long-Term</u>

- o Relocate the east ramps to the Booth Falls underpass as shown in Figure 16. The westbound off-ramp/East Frontage Road intersection will require stop sign traffic control in all directions. Keeping the east ramps at the Main Vail interchange open during non-peak months may also be a possibility.

- o Improve the frontage road between Main Vail and Booth Falls as necessary to accommodate increase volumes and improve safety.

- o Depress and modify the South Frontage Road in the vicinity of Vail Valley Drive and manually control the intersection during peak hours. This is required because the existing grades on Vail Valley Drive necessitate that the minor roadway have the right-of-way. This greatly impacts the capacity of the major roadway and will only worsen in the future.

Table 14
Implications and Consequences of Main Vail Interchange Alternatives

Alternative/Phase	R/W Implications	Approvals Required	Physical Implications	Planning Level Cost (1)
Booth Falls Split Diamond	Minimal or no R/W required at Booth Falls.	I-70 access approval required for Booth Falls. Currently FHWA policy prohibits half diamonds.	Minor relocations of EFR north of I-70 and local street access may be needed at Booth Falls. A facility of the Upper Eagle Valley Water and Sanitation District will have to be maintained on the south side of the interchange. Visual and noise impacts on adjacent neighborhoods. Lowering of Vail Valley Drive/SFR intersection.	$0.5M
Vail Valley Connection/ Underpass	R/W required along with slope easements north of I-70.	No I-70 access approval required for NFR extension. Standard review of I-70 bridge construction is required.	Retaining walls required for cut area on portions of NFR extension of I-70. Walls would be approximately 40-feet in height with approximately 20-feet above the grade of I-70. Lowering of Vail Valley Drive/ SFR intersection.	$2.0M
Holy Cross/ VA Shops Ramps	R/W required in the VA shops area (Holly Cross site).	I-70 access approval is required, has been previously granted, and is still valid. Approval may be conditioned on the installation of traffic signal equipment.	New intersection on SFR at VA shops with restricted movements at Vail Road and EB exit ramp. Modifications at Main Vail interchange. Removal of large evergreen trees.	$1.2M

(1) Costs are in 1990 dollars and do not include land acquistion nor improvements to the frontage roads beyond the interchange area.

Table 15
Main Vail Interchange Alternative Ranking

Interchange Alternative	Traffic Operations	Right-of-Way Impact	Institutional Considerations	Physical Impact	Visual Impact	Cost	Rank Sum
Alternative 3 VA Shops Ramps	3	3	1	1.5	2	2	12.5
Alternative 7 NFR Vail Valley Connection	2	1.5	1.5	3	3	3	14.0
Alternative 8 Booth Falls Split Diamond	1	1.5	3	1.5	2	1	10.0

Note: 1 = Good, 2 = Moderate, 3 = Poor

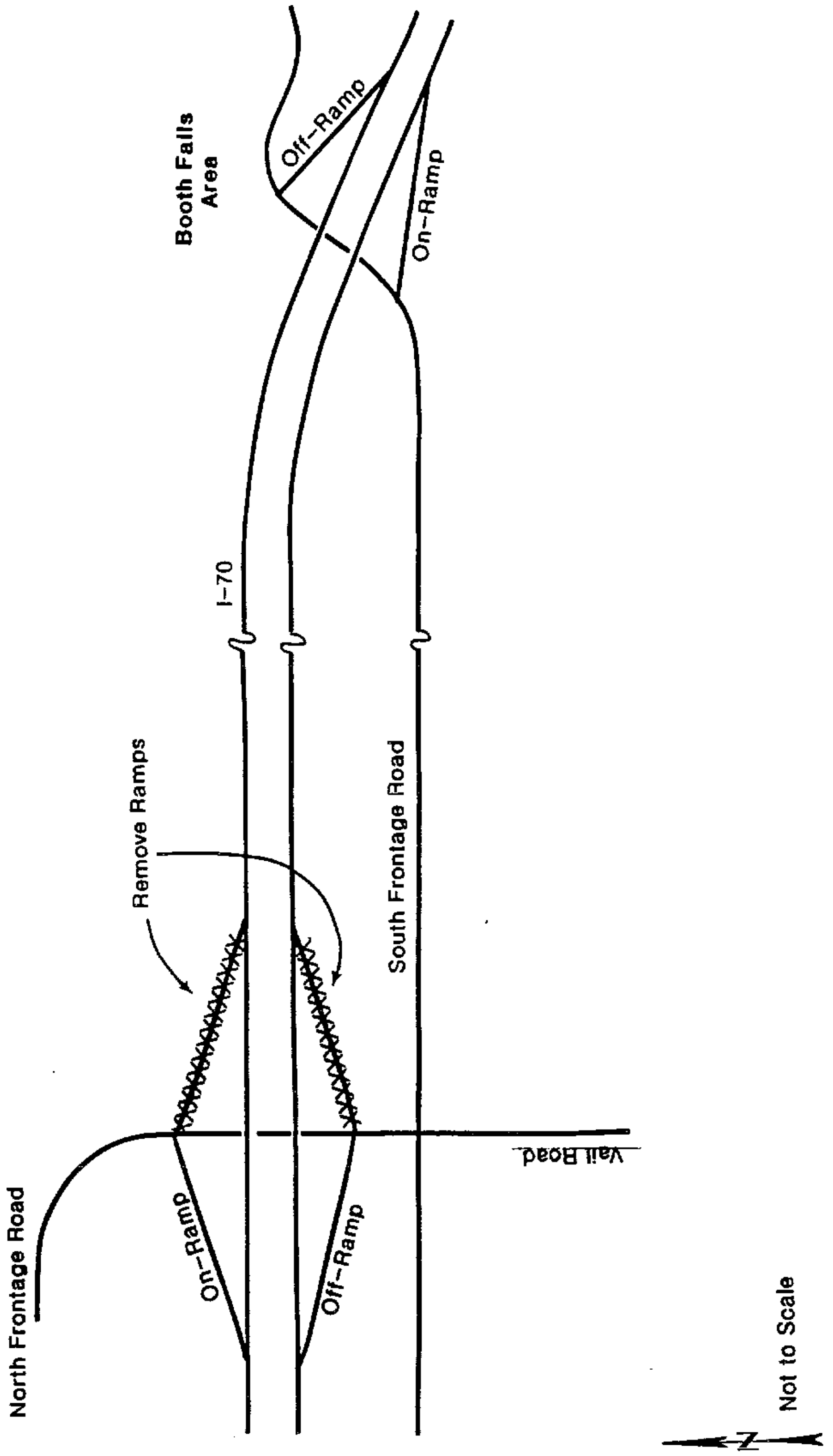


Figure 16
Recommended Main Vail Interchange Improvements

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/NORTH RAMPS

Existing

Critical movement at this intersection is the left turn off of the ramp. Both A.M. and P.M. volumes were evaluated and it was found that the A.M. peak hour was more critical. Unsignalized analysis (next page) yield a LOS F with reserve capacity at 156. LOS thresholds are as follows:

> - 400	LOS A →	<0.60
300 - 400	LOS B →	0.60 to 0.70
200 - 300	LOS C →	0.70 to 0.80
100 - 200	LOS D →	0.80 to 0.90
0 - 100	LOS E →	0.90 to 1.00
< 0	LOS F →	1.00
		Assign V/C Ratio to Thresholds

1 vehicle of reserve capacity would be equivalent to 0.001 of V/C. So, 156 is 1.156 or 1.16 for left turn in A.M. peak hour.

Future - No Improvements

Volumes were increased 18% and analysis was redone

Reserve Capacity is 325
From Above, V/C = 1.325, say 1.33 A.M. Peak

Future - With Simba Run Underpass

Volumes were adjusted to reflect UP (page 4 for analysis)

Reserve Capacity is 209
From Above, V/C = 1.209, say 1.21 A.M. Peak

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/NORTH RAMPS

Future - Alternative 3 (Red Sandstone Partial Interchange) and Underpass

This interchange alternative does not affect operations along the north side of the interchange.

the V/C is identical to the previous calculations

1.21 A.M. Peak

Future - Alternative 7 (Vail Valley Connection) and Underpass

This interchange alternative simplifies the north ramps intersection; only two movements would be occurring - the left turn onto the WB on-ramp and the left turn off of the WB off-ramp. An unsignalized LOS analysis was run (p.56) with a resulting reserve capacity of 45 vehicles for the left turn off. From page 1,

V/C = 0.955 or 0.96 A.M. peak

Future - Alternative 8 (Booth Falls Ramps) and Underpass

North ramp operations would be divided in this alternative. The left turns onto WB on-ramp would remain at the Main Vail interchange, but they would be the only movement along the north side of the interchange and would be free flow. Hence, there is no longer an intersection at that location and therefore no intersection LOS problems.

The left turns off of WB off-ramp would now take place near Booth Falls. An unsignalized LOS analysis of A.M. peak volumes there yielded a LOS F for left turns off of the off-ramp. Therefore, an all-way STOP analysis was done as follows:

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/NORTH RAMPS

Revise Volumes at Booth Falls Off-Ramp Intersection (Existing A.M. Peak)

NB and SB Approach Volumes	-	553
EB and SB Approach Volumes	-	345 + 75 = 420

LOS C is 1,118 (assume V/C = 0.75)

Total Approach Volumes = 973

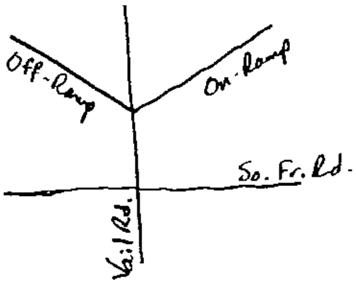
Multiply by 1.18 for Growth → 1,148

1,148/(1,118/0.75) = 0.77

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/SOUTH FRONTAGE ROAD (4-WAY STOP INTERSECTION)

This intersection is extremely close to the south ramps intersection and could be analyzed as a multi-legged intersection as was done for the West Vail interchange. However, patterns at the south ramps intersection are such that the largest movements are the thru movements along Vail Road and the right turns off of and onto the ramps. Left turns onto and off of the ramps are relatively light, and operations at this intersection will largely depend on operations at the 4-way. Therefore, the 4-way STOP intersection is analyzed separately and is considered to be indicative of the entire area south of the interchange.

Existing



Existing P.M. Peak Traffic (P.M. Peak Hour is Critical)

The intersection is STOP sign controlled but is controlled manually during peak periods which is essentially the same as signal control. Therefore, since a peak hour is being evaluated, this intersection will be analyzed as traffic signal controlled.

Sum Critical Movements (4-Phase Signal)

Total = 1,290

LOS E/F for 4-Phase is 1,375
1,290/1,375 = 0.94 P.M. Peak DRC

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/SOUTH FRONTAGE ROAD (4-WAY STOP INTERSECTION)

Future - No Improvements

Volumes will increase 18% and so will V/C ratio in this case.

V/C = 1.18 x 0.94 - 1.11 P.M. Peak DRC

Future - with Simba Run Underpass

Revised Volumes to Reflect Underpass (Existing P.M. Peak)

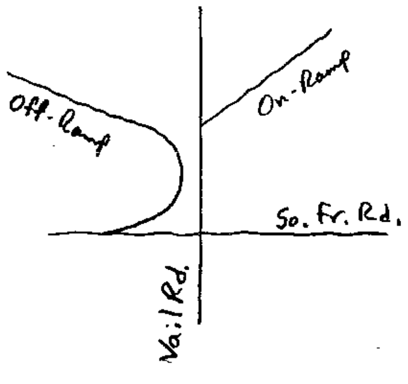
Sum critical movements similar to that done on page.8 (4-phase)

Multiply by 1.18 for growth → 1,494

LOS E/F Threshold for 4-phase Signal is 1,375

1,494/1,375 = 1.09

Future - Alternative 3 (Red Sandstone Partial Interchange) with Underpass



Revise Volumes (Existing P.M. Peak)

SUM CRITICAL MOVEMENTS

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/SOUTH FRONTAGE ROAD (4-WAY STOP INTERSECTION)

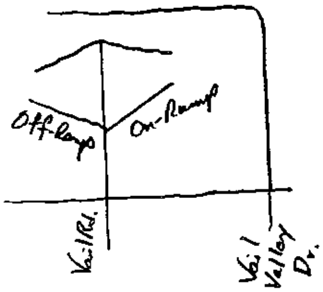
= 1,045

Multiply by 1.18 for Growth → 1,233

LOS E/F Threshold for 4-Phase Signal is 1,375

1,233/1,375 = 0.90

Future - Alternative 7 (Vail Valley Connection) with Underpass



Revised Volumes (Existing P.M. Peak)

SUM CRITICAL MOVEMENTS

Multiply by 1.18 for Growth → 1,396

LOS E/F Threshold for 4 Phase is 1,375

1,396/1,375 = 1.02

Future - Alternative 8 (Booth Falls Ramps) and Underpass

Revised Volumes (Existing P.M. Peak)

SUM CRITICAL MOVEMENTS

MAIN VAIL INTERCHANGE LOS ANALYSIS - VAIL ROAD/SOUTH FRONTAGE ROAD (4-WAY STOP INTERSECTION) SOUTH FRONTAGE ROAD/RED SANDSTONE RAMPS

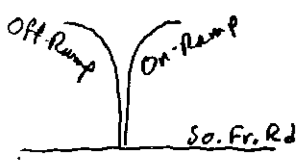
= 1,077

Multiply by 1.18 for Growth → 1,271

LOS E/F Threshold for 4-Phase is 1,375

1,271/1,375 = 0.92

Future - Alternative 3 (Red Sandstone Partial Interchange) with Underpass



Analyze South Frontage Road/Ramps Intersection (Existing P.M. Peak Volumes)

All way STOP control was originally evaluated resulting in LOS F. Therefore, DRC is evaluated (3-phase)

SUM CRITICAL MOVEMENTS

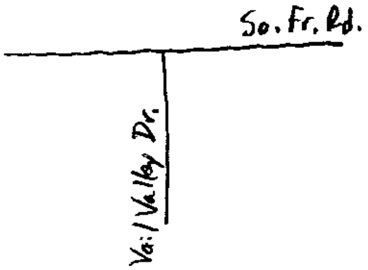
= 1,069

Multiply by 1.18 for growth → 1,261
LOS E/F Threshold for 3-Phase is 1,425
1,261/1,425 = 0.89

MAIN VAIL INTERCHANGE LOS ANALYSIS - SOUTH FRONTAGE ROAD/VAIL VALLEY DRIVE INTERSECTION

Several interchange alternatives have a direct impact on this intersection and it is therefore included in the analysis.

<u>Existing</u>



Existing P.M. Peak Volumes

South frontage road approaches must stop, so conduct an unsignalized LOS analysis (p. 13).

Lowest reserve capacity is 53 (WB approach) and using information derived on p.1, this corresponds to
V/C = 1,053 say 1.05

<u>Future</u>

Volumes are increased 18% and unsignalized analysis is rerun (p.14). Lowest reserve capacity is 239 (WB approach) and using information on p.1, V/C = 1,289 say 1.24

<u>Future with Underpass at Simba Run</u>

This underpass would not affect the Vail Valley Drive intersection. → still 1.24

SUM CRITICAL MOVEMENTS

Multiply by 1.18 for Growth → 1,134
LOS E/F Threshold for 3-Phase is 1,425
1,134/1,425 = 0.80

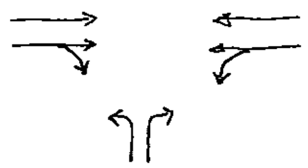
MAIN VAIL INTERCHANGE LOS ANALYSIS - SOUTH FRONTAGE ROAD/VAIL VALLEY DRIVE INTERSECTION

Future - Alternative 3 (Red Sandstone Ramps) with Underpass

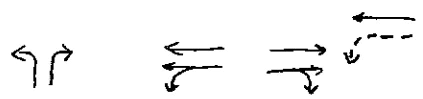
The Red Sandstone ramps and UP do not affect this intersection. However, part of this interchange alternative would include improving this intersection; i.e. lowering and/or lane additions. Volumes shown on p.12 still apply.

All way STOP analysis resulted in a LOS F still, so try DRC with increased lane geometry.

Lane Geometry



Phasing



SUM CRITICAL MOVEMENTS

= 810

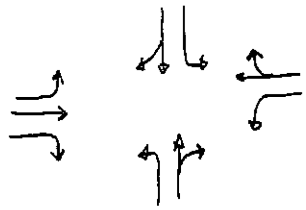
Multiply by 1.18 for growth → 956
LOS E/F Threshold is 1,425 of 3-Phase
9,560/1,425 = 0.67

MAIN VAIL INTERCHANGE LOS ANALYSIS SOUTH FRONTAGE ROAD/VAIL VALLEY DRIVE INTERSECTION

Future - Alternative 7 (Vail Valley Connection) with Underpass

We now have a 4-legged intersection. All way STOP resulted in LOS F.

Existing P.M. Peak
Revised Volumes



Assumed
Geometry

SUM CRITICAL MOVEMENTS (4-PHASE SIGNAL)

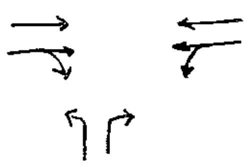
= 811

Multiply x 1.18 for growth → 957
LOS E/F Threshold is 1,375 for 4 Phases
957/1,375 = 0.70

Future - Alternative 8 (Booth Falls Ramps) with Underpass

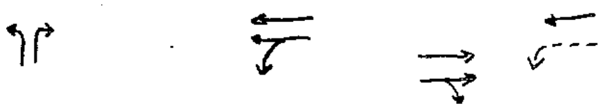
All way STOP resulted in LOS F try DRC

Existing P.M. Peak
Revised



Assumed
Geometry

Phasing



APPENDIX E

Main Vail Accident History

MEMORANDUM

DEPARTMENT OF TRANSPORTATION

4201 East Arkansas Avenue
Denver, Colorado 80222
(303) 757-9011
303 757-9345

File No. 880.070.02

TRAFFIC
(Accidents)

DATE: July 19, 1994

TO: R. P. Moston

FROM: Roger D. Gilpin

SUBJECT: Accident Experience - Two Locations in Region III

In response to Mr. Nall's request of June 16, 1994, we have completed accident experience for the three-year period January 1, 1991 to January 1, 1994.

1. SH 70 (I 70) at the West Vail (Chamonix Rd.) Interchange

2. SH 70 (I 70) at the Main Vail (Vail Rd.) Interchange

Location diagrams and accident summary sheets are being sent to Mr. Nall.

RDG:jw

cc: J. Nall w/encl.
File

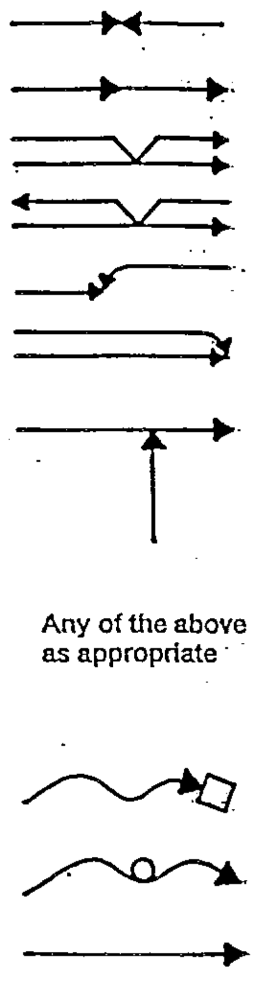
STAFF TRAFFIC AND SAFETY PROJECTS BRANCH

TYPICAL COLLISION DIAGRAM LEGEND FOR MOTOR VEHICLE TRAFFIC ACCIDENTS

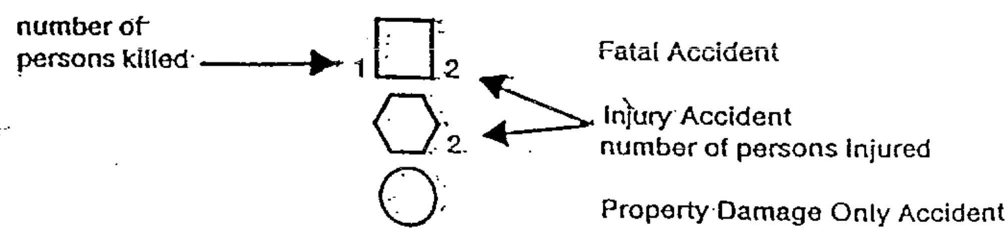
ACCIDENT LOCATION

On-roadway   Off-roadway (right)   Off-roadway (left)

ACCIDENT TYPES	SYMBOL
HO - Head-on	HO
RE - Rear-end	RE
SS - Sidewsipe-same direction	SS
SO - Sideswipe-opposite direction	SO
AT - Approach turn	AT
OT - Overtaking turn	OT
BS - Broadside	BS T or AN (type indicated)
T - Train	
AN - Animal	
PC - Parked car	PC, P or B — Any of the above as appropriate
P - Pedestrian	
B - Bicycle, Motorized bicycle	
FO - Fixed object	FO or O (type indicated)
O - Other object	
OTR - Overturning	OTR
ONC - Other non-collision	ONC (type indicated)



ACCIDENT SEVERITY



COLORADO DEPARTMENT OF TRANSPORTATION
SUMMARY OF MOTOR VEHICLE TRAFFIC ACCIDENTS

File # 880.070.02

Date July 12, 1994

Sheet 1 of 5

Description: SH 70 (I 70) at the Main Vail (Vail Rd.) Interchange

Milepoint: 176.03 to:

Period: January 1, 1991 to: January 1, 1994

I. NUMBER OF ACCIDENTS REPORTED

One-car accidents	25
Two-car accidents	58
Three or more cars	4
Total	87

II. SEVERITY

Fatal accidents	0
Injury accidents	15
Property damage only	72
Total	87
Persons killed	0
Persons injured	19

III. LIGHT

Daylight	63
Dark, roadway not lighted	
Dark, roadway lighted	24

IV. ADVERSE CONDITIONS

Weather	
Raining	
Snowing	30
Road	
Wet	4
Snowy	6
Icy	44

V. LOCATION

On-roadway accidents	66
Off-roadway accidents	21
Total	87

VI. TYPES OF ACCIDENTS

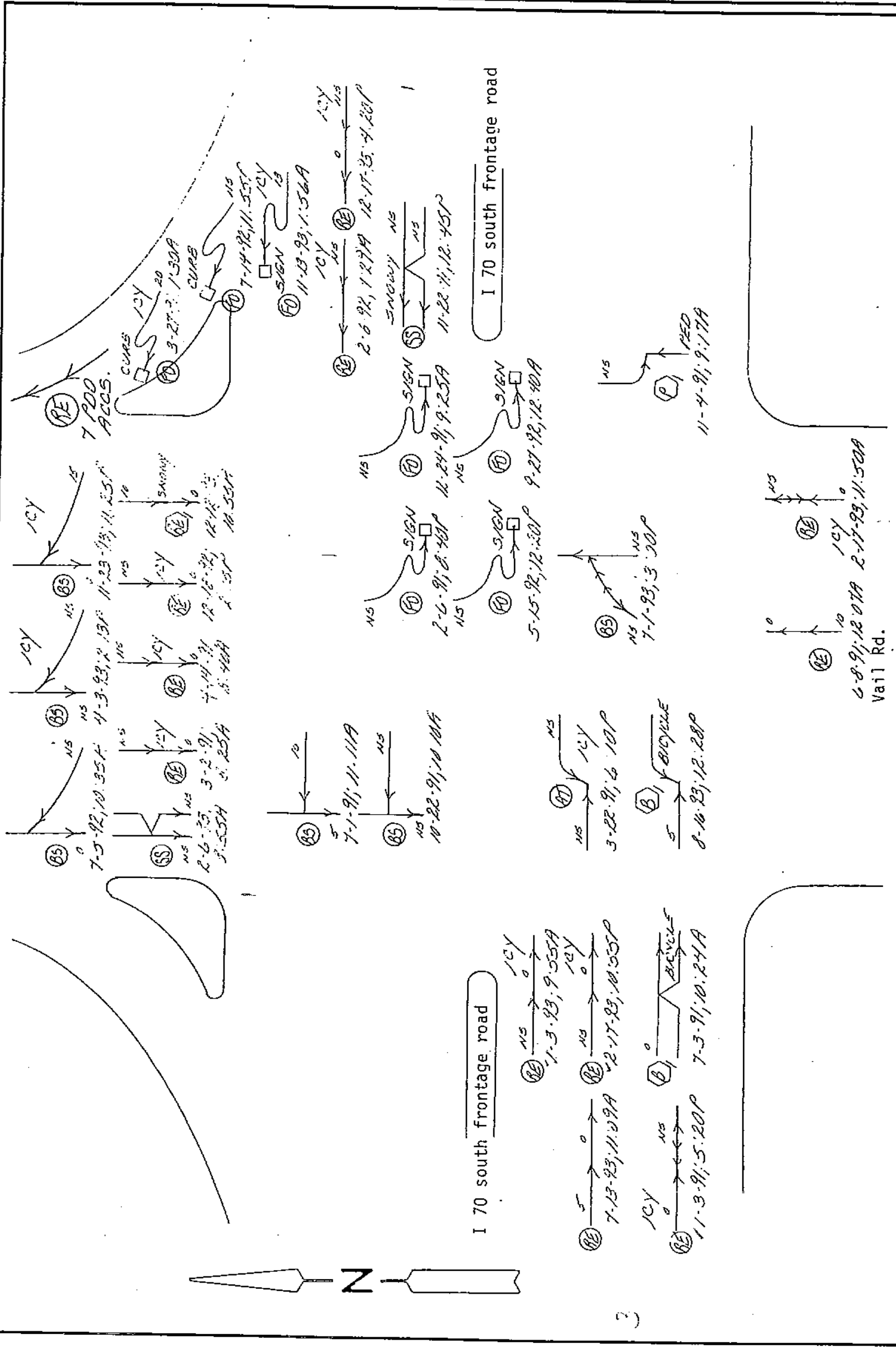
Non-collision accidents	
Overturning	2
Other non-collision	1
Collision accidents	
Pedestrian	1
Broadside	11
Head-on	1
Rear-end	34
Sideswipe S.D.	9
Sideswipe O.D.	3
Approach turn	2
Overtaking turn	
Parked car	
Train	
Bicycle	2
Motorized Bicycle	
Domestic animal	
Wild animal	
Fixed object	18
Other object	2
Total	87

COMMENTS:

One accident was not plotted due to inconsistent information.

COLORADO DEPARTMENT OF TRANSPORTATION
TRAFFIC ACCIDENT LOCATIONS

File NO.	880.070.02
Date	July 12, 1994
S.H. NO.	70
District	III
Period	January 1, 1991 to January 1, 1994
Sheet	5 of 5
Description	SH 70 (I 70) south frontage road at the Intersection with Vail Rd.
Milepoint	176.03 to



NOTE: Date, time, speed of vehicles, fixed objects struck and adverse driver and ...

CDOT Form #406 6/92

COLORADO DEPARTMENT OF TRANSPORTATION

TRAFFIC ACCIDENT LOCATIONS

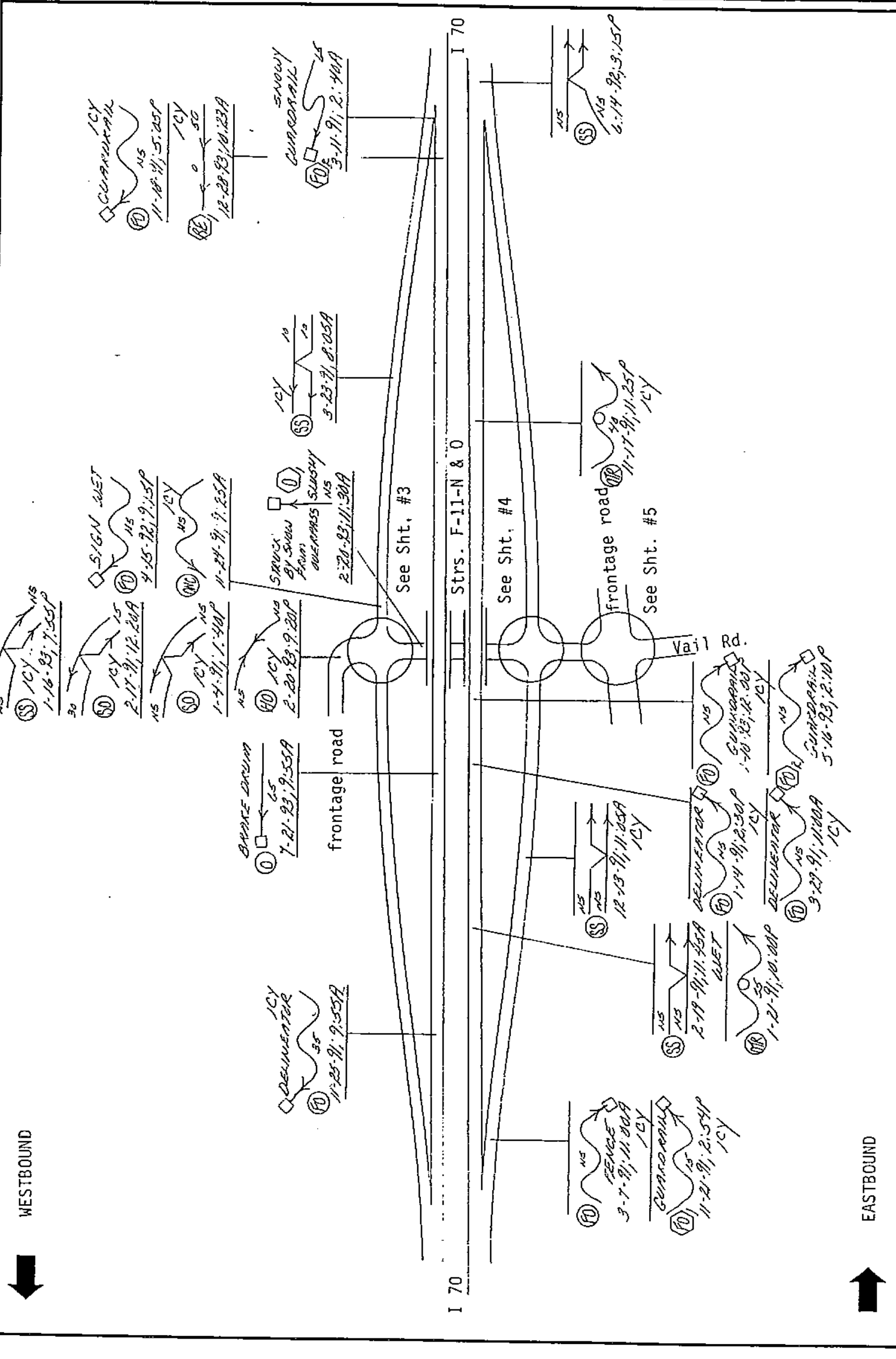
File NO. 880.070.02

Date July 12, 1994

S.H. NO.	District	Period		Sheet
70	III	January 1, 1991	to January 1, 1994	2 of 5

Description: SH 70 (I 70) at the Main Vail (Vail Rd.) Interchange

Milepoint 176.03 to

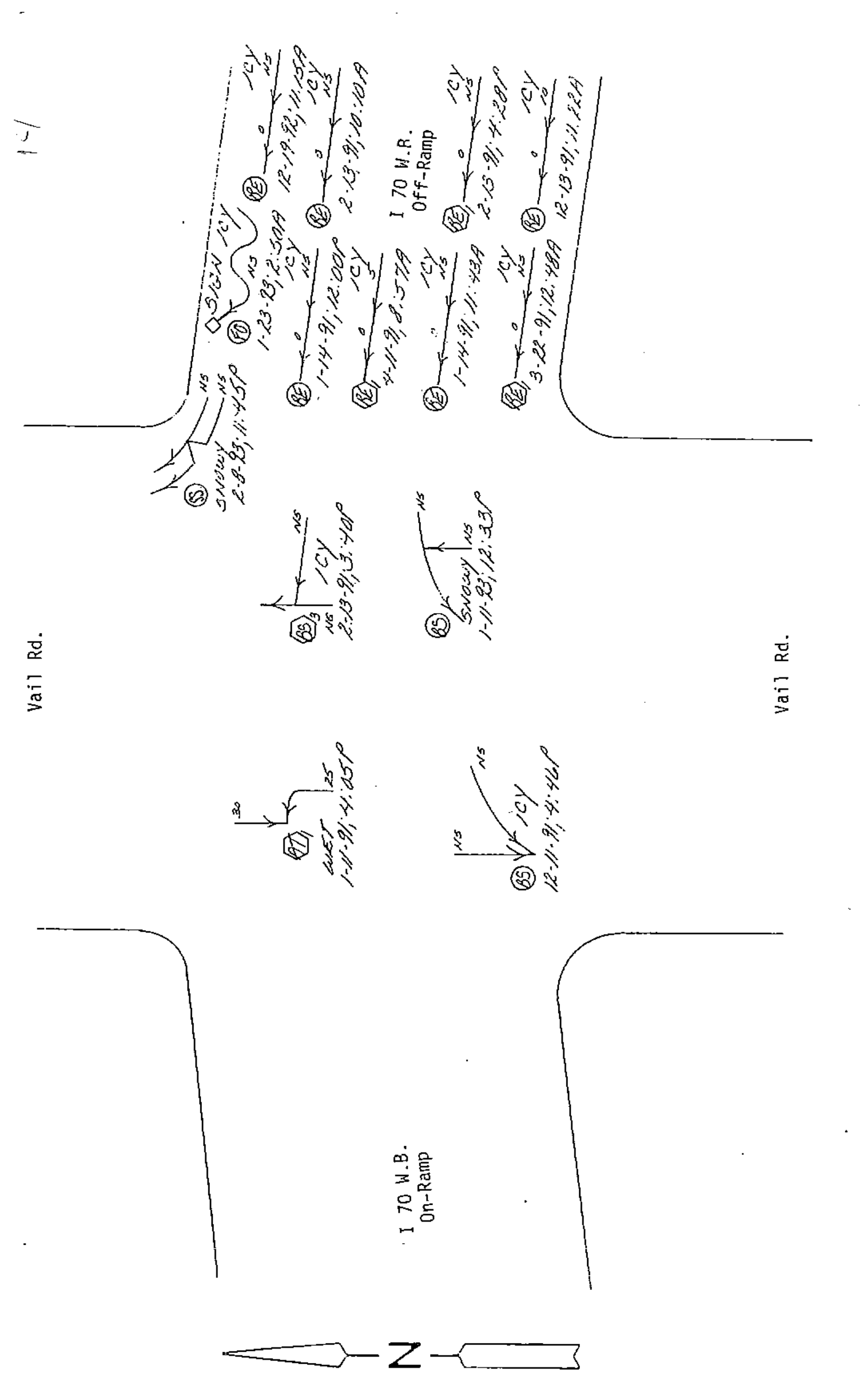


NOTE: Date, time, speed of vehicles, fixed objects struck, and adverse driver and road surface conditions shown for each accident.

COLORADO DEPARTMENT OF TRANSPORTATION

TRAFFIC ACCIDENT LOCATIONS

File NO. 880.070.02					
Date July 12, 1994					
S.H. NO. 70	District III	Period January 1, 1991 to January 1, 1994		Sheet 3 of 5	
Description SH 70 (I 70) Westbound Ramps at the Intersection with Vail Rd.					
Milepoint 176.03 to					



NOTE: Date, time, speed of vehicles, fixed objects struck, and advisory ...

COLORADO DEPARTMENT OF TRANSPORTATION
TRAFFIC ACCIDENT LOCATIONS

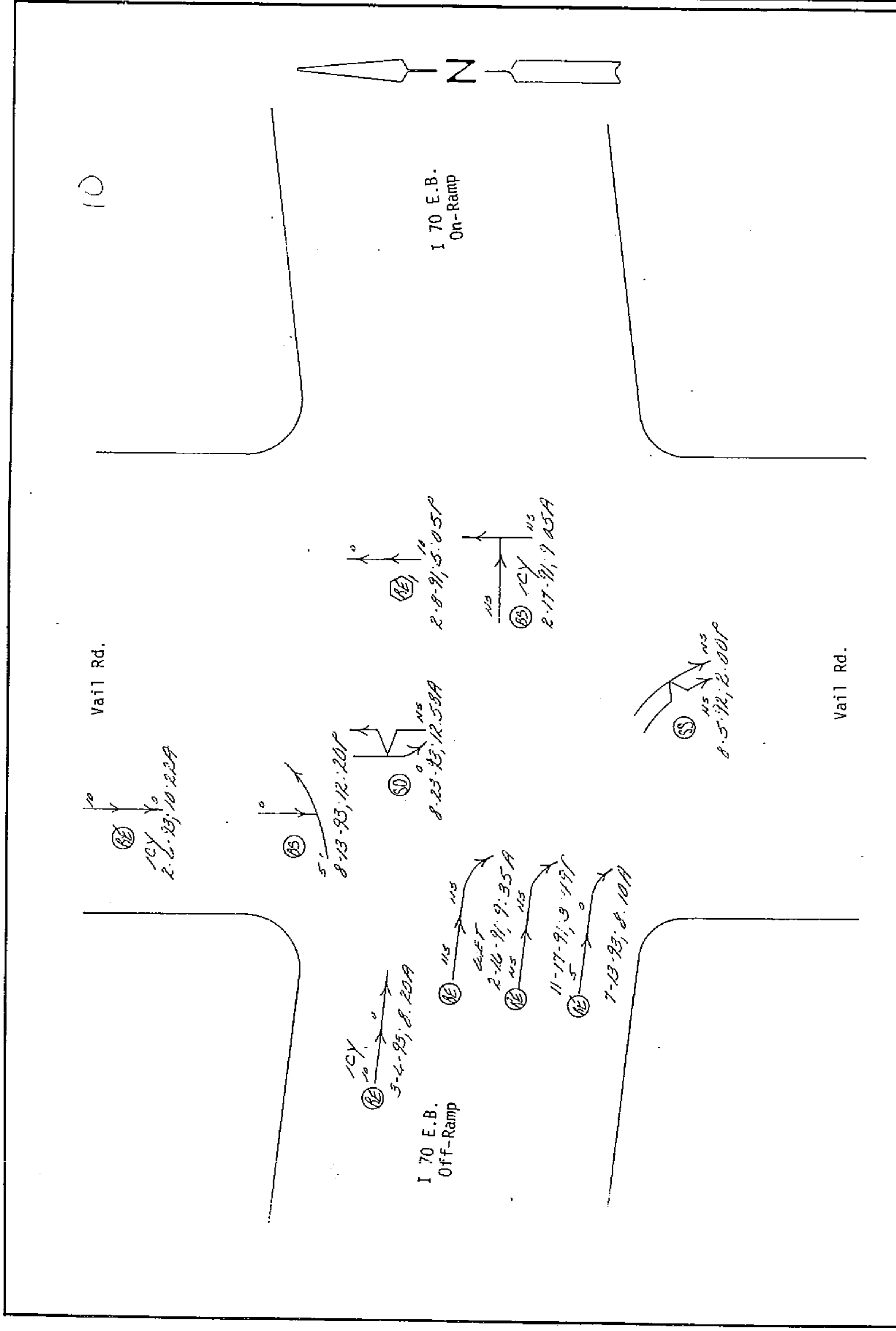
File NO. 880.070.02

Date July 12, 1994

S.H. NO.	District	Period	to	Sheet
70	III	January 1, 1991	January 1, 1994	4 of 5

Description SH 70 (I 70) Eastbound Ramps at the Intersection with Vail Rd.

Milepoint 176.03 to



NOTE: Date, time, speed of vehicles, fixed objects struck, and ...

APPENDIX F

Understanding Rodel

UNDERSTANDING RODEL

Prepared for Greg Hall, P.E.
Town Engineer
Town of Vail, Colorado

by Leif Ourston, P.E.
Leif Ourston & Associates
Santa Barbara, California

August 25, 1994

ABSTRACT

This report explains Rodel, a computer application that predicts the traffic performance of modern roundabouts. Rodel estimates delay, queue length, and capacity as functions of roundabout geometry and flows. It was used to design Vail's proposed modern roundabout interchanges.

PHILOSOPHY BEHIND RODEL

Rodel was developed by Barry Crown of the Staffordshire County Council in England. It applies research by the United Kingdom's Transport Research Laboratory, which licenses its use. Rodel is faster and easier to use than a widely used program by the British Transport Research Laboratory, ARCADY. Insofar as the two programs overlap, their output is identical.

Rodel works like a spreadsheet in which the designer answers what-if questions by changing one of the input parameters and running the program again. Because Rodel is fast and easy to use, the designer is likely to continue altering his design until a nearly optimal design is achieved.

Rodel permits the designer to select the confidence level of his estimates of traffic performance. A confidence level of 50 percent is implicit in other traffic performance programs, like ARCADY or TRANSYT. Rodel's author recommends using a confidence level of 85 to 95 percent. This allows for inaccuracies in both the input design flows and the output capacity estimate. Often a small increase in roundabout entry width or flare length will greatly increase the probability that the roundabout will perform well at a high confidence level.

The Long Beach roundabout in California was designed using ARCADY before Rodel became available. ARCADY's delay predictions are equal to those of Rodel when Rodel is set to the 50-percent confidence level. Delay predictions at the Long Beach roundabout (the busiest modern American roundabout) compare with actual observed delays as follows:

	AVERAGE STOPPED DELAY (SECONDS PER VEHICLE)	
	PREDICTED	OBSERVED
A.M. Peak Hour	2.2	2.7
P.M. Peak Hour	2.4	3.4

The difference between estimated and observed delay was 0.5 second per vehicle in the morning peak hour and 1.0 second per vehicle in the afternoon peak hour. Because of the close correlation, it is believed that Rodel's estimates of delay may be close to the actual delay that will be observed at modern roundabouts in Vail.

RESEARCH STUDIES

Capacity estimates of Rodel are based on research reported in Kimber, R.M, *The Traffic Capacity of Roundabouts, TRRL Laboratory Report 942*, 1980. Regression equations were developed from data taken at 86 roundabouts on public roads and 35 geometric variations on the TRRL study track. The capacity of each entry to a roundabout (Q_e) was found to be a function of one flow variable, circulating flow, and six geometric parameters. The definitions of symbols are given below.

PARAMETER	SYMBOL
Capacity = maximum entering flow, pcu/h	Q_e
Circulating flow, pcu/h	Q_c
Entry width, m	e
Approach half-width, m	v
Length of flare, m	l'
Inscribed circle diameter, m	D
Entry angle, degrees	ϕ
Entry radius, m	r

Capacity is estimated using the following six regression equations.

PARAMETER	EQUATION
Sharpness of flare	$S = 1.6(e-v)/l'$
Entry width parameter	$x_2 = v+(e-v)/(1+2S)$
Function of D	$t_D = 1+0.5/(1+\exp((D-60)/10))$
Adjustment factor, cap. curve	$k = 1-0.00347(\phi-30)-0.978((1/r)-0.5)$
Slope of capacity curve	$f_c = 0.210t_D(1+0.2x_2)$
Y-intercept, pcu/min	$F = 303x_2$

The best predictive equations of capacity were:

$Q_e = k(F-f_cQ_c)$ when $f_cQ_c <= F$, and
$Q_e = 0$ when $f_cQ_c > F$.

Queues and delays are estimated by use of time-dependent queuing theory. This is reported in Kimber, R.M. and Erica M. Hollis, *Traffic Queues and Delays at Road Junctions, TRRL Laboratory Report 909*, 1979. Queue lengths are estimated in a series of small consecutive time intervals. Traffic demand and capacity are assumed to vary from interval to interval.

INTERPRETING RODEL'S PRINTOUTS

Rodel prints out traffic performance given on a main screen, which has the following twelve fields.

1. TITLE

In the title section of the main screen are the date, written the British way, day:month:year, the name of the roundabout, and the number of the computer run. This last number corresponds to the number given in subsequent statistics screens.

2. GEOMETRY

The user inputs seven geometric parameters. Distances are in meters.

E	Entry width.
L'	Length of flare between V and E.
V	Upstream roadway width before flaring begins.
RAD	Curb return radius.
PHI	Angle between entering traffic and circulating traffic.
DIA	Inscribed circle diameter of the roundabout.
GRAD SEP	Grade separated, 0 or 1? The user inputs a one in this field if the roundabout is very large, as at huge two-bridge British grade separated roundabouts that run over or under the freeway at some interchanges.

3. TIME

The user inputs the following seven parameters which set the periods over which traffic performance estimates are made. Times are in minutes.

TIME PERIOD	The total period to be modeled.
TIME SLICE	Equal pieces of the time period during which capacity and demand flow remain constant. Capacity and flow may change from slice to slice but not within each slice.
RESULTS PERIOD	The period over which results are computed. If the time period is 90 minutes and the results period is from minute 15 to minute 75, then results for the middle 60 minutes are given.
TIME COST	The value of driver's time in British pence per minute.
FLOW PERIOD	The period over which the user inputs turning flows in field 5, explained below. If a 15 and 75 are given, the user inputs flows for the middle 60 minutes.
FLOW TYPE	Flows of field 5 may be entered in passenger car units (pcu's) or vehicles. A truck equals one vehicle or two pcu's.
FLOW PEAK	The peak hour being analyzed: a.m., off peak, or p.m.

4. LEG NAME

The user inputs an abbreviation of the name of each leg of the roundabout. The leg names are in the order of the direction that traffic flows around the roundabout.

5. PCU FACTOR

This is the number of vehicles having more than four wheels divided by the total number of vehicles.

6. TURNING FLOWS
For each leg, the user enters the number of vehicles exiting at the first exit, the second exit, and so on up to the final flow, which is the number of U-turns exiting at the entry leg.

7. FLOW FACTOR (FLOF)
The input flows are multiplied by this factor. With this factor the user can perform a sensitivity analysis to see what would happen if flows were to increase.

8. CONFIDENCE LEVEL (CL)
Queues and delays are predicted at the input confidence level. If 85 is entered, we are 85 percent confident that the queues and delays will not be greater than predicted.

9. FLOW RATIOS
To allow for peaking of traffic within the peak period, the turning flows are shaped into a flow profile. If the time period is 90 minutes and flow times are set at minute numbers 15 and 75, then Rodel shapes the flow profile into three rectangular steps: a beginning 15 minute step, a middle 60 minute step, and a final 15 minute step, the flow being constant within each step. If the user inputs flow ratios of 0.75, 1.125, and 0.75, then Rodel models the flow profile so that flows of the first and third step are 0.75 times the average input flows, and flows of the middle step are 1.125 times the average input flows.

10. FLOW TIMES
The user inputs the flow times that are used with the flow ratios to produce the flow profile from the turning flows.

11. TRAFFIC PERFORMANCE
Rodel outputs the traffic performance of each leg in this field, as follows.

FLOW	Entry flow, vehicles per results period.
CAPACITY	Capacity, vehicles per results period.
AVE DELAY	Average delay, minutes per vehicle over results period.
MAX DELAY	Maximum delay, minutes per vehicle over results period.
AVE QUEUE	Average vehicles in queue over results period.
MAX QUEUE	Maximum vehicles in queue over results period.

12. TOTAL DELAYS AND COSTS
Rodel outputs the total vehicle delay in hours over the results period. It gives the cost of this delay in British pounds stirling.

APPENDIX G

Roundabout Levels of Service

ROUNDABOUT LEVELS OF SERVICE

08-24-94

Leif Ourston & Associates

Main Vail North
100% of Existing Flows

A.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	307		418	564	16		1,305
AVE DELAY	min/veh	0.05		0.02	0.04	0.06		
OUTPUT								
AVE DELAY	sec/veh	3.0		1.2	2.4	3.6		
DELAY	sec/hr	921		502	1354	58		2,834

AVE DELAY, sec/veh	2.2
LEVEL OF SERVICE	A

P.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	231		1078	313	17		1,639
AVE DELAY	min/veh	0.04		0.02	0.05	0.08		
OUTPUT								
AVE DELAY	sec/veh	2.4		1.2	3.0	4.8		
DELAY	sec/hr	554		1294	939	82		2,869

AVE DELAY, sec/veh	1.8
LEVEL OF SERVICE	A

```
***************************************************************************
*                                                                         *
*   5:8:94              MAIN VAIL NORTH, 120' ROUNDABOUT             60  *
*                                                                         *
***************************************************************************
*                                                  *                      *
* E    (m)   9.35  15.00  15.00   8.53   7.80     * TIME PERIOD    min    90  *
* L'   (m)  74.09   0.00   0.00  39.19  23.82     * TIME SLICE     min    15  *
* V    (m)   6.38  15.00  15.00   6.93   3.66     * RESULTS PERIOD min  15 75  *
* RAD  (m)   9.95  15.00  15.00  28.96  19.81     * TIME COST    p/min  7.79  *
* PHI  (d)  40.00   0.00   0.00  18.00  29.00     * FLOW PERIOD    min  15 75  *
* DIA  (m)  36.58  36.58  36.58  36.58  36.58     * FLOW TYPE  pcu/veh   VEH  *
* GRAD SEP      0      0      0      0      0     * FLOW PEAK am/op/pm    AM  *
*                                                  *                      *
***************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                            *    *  *               *         *
*N FR RD EB*1.03*  16  259    0    0  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP WB*1.03*   0    0    0    0  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*   0    1  124  249  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP WB*1.03*   2   25    0  478  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*SP C RD SB*1.03*   2    4    8    0  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *               *         *
*          *    *                            *    *  *               *         *
***************************************************************************
*                                                          *               *
* FLOW        veh      307      0     418    564     16    *  TOTAL DELAYS  *
* CAPACITY    veh     1572   3261    4239   1973   1047    *               *
* AVE DELAY  mins     0.05   0.00    0.02   0.04   0.06    *        1 hrs  *
* MAX DELAY  mins     0.06   0.00    0.02   0.06   0.08    *               *
* AVE QUEUE   veh        0      0       0      0      0    *       4 pounds *
* MAX QUEUE   veh        0      0       0      0      0    *               *
*                                                          *               *
***************************************************************************
```

```
*****************************************************************************
*                                                                           *
*   5:8:94            MAIN VAIL NORTH, 120' ROUNDABOUT                 61   *
*                                                                           *
*****************************************************************************
*                                                 *                         *
* E    (m)   9.35  15.00  15.00   8.53   7.80     * TIME PERIOD    min    90 *
* L'   (m)  74.09   0.00   0.00  39.19  23.82     * TIME SLICE     min    15 *
* V    (m)   6.38  15.00  15.00   6.93   3.66     * RESULTS PERIOD min 15 75 *
* RAD  (m)   9.95  15.00  15.00  28.96  19.81     * TIME COST    p/min  7.79 *
* PHI  (d)  40.00   0.00   0.00  18.00  29.00     * FLOW PERIOD    min 15 75 *
* DIA  (m)  36.58  36.58  36.58  36.58  36.58     * FLOW TYPE  pcu/veh   VEH *
* GRAD SEP      0      0      0      0      0     * FLOW PEAK am/op/pm    PM *
*                                                 *                         *
*****************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                            *    *  *               *         *
*N FR RD EB*1.03*   5  201    0    1  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP WB*1.03*   0    0    0    0  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*   0    4  423  538  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP WB*1.03*   1   64    0  215  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*SP C RD SB*1.03*   5    5    5    0  0      *1.00*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *               *         *
*          *    *                            *    *  *               *         *
*****************************************************************************
*                                                        *                  *
* FLOW        veh     231      0   1078    313     17    *  TOTAL DELAYS    *
* CAPACITY    veh    1554   3685   4237   1469    798    *                  *
* AVE DELAY  mins    0.04   0.00   0.02   0.05   0.08    *        1 hrs     *
* MAX DELAY  mins    0.06   0.00   0.02   0.07   0.11    *                  *
* AVE QUEUE   veh       0      0      0      0      0    *        4 pounds  *
* MAX QUEUE   veh       0      0      0      0      0    *                  *
*                                                        *                  *
*****************************************************************************
```

ROUNDABOUT LEVELS OF SERVICE

08-24-94

Leif Ourston & Associates

Main Vail South
100% of Existing Flows

A.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	823	284	603	321	630		2,661
AVE DELAY	min/veh	0.08	0.07	0.05	0.05	0.03		
OUTPUT								
AVE DELAY	sec/veh	4.8	4.2	3.0	3.0	1.8		
DELAY	sec/hr	3950	1193	1809	963	1,134		9,049

AVE DELAY, sec/veh	3.4
LEVEL OF SERVICE	A

P.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	465	216	919	484	1,247		3,331
AVE DELAY	min/veh	0.06	0.06	0.06	0.06	0.04		
OUTPUT								
AVE DELAY	sec/veh	3.6	3.6	3.6	3.6	2.4		
DELAY	sec/hr	1674	778	3308	1742	2,993		10,495

AVE DELAY, sec/veh	3.2
LEVEL OF SERVICE	A

```
******************************************************************************
*                                                                            *
*  24:8:94             MAIN VAIL SOUTH, 200' ROUNDABOUT                120   *
*                                                                            *
******************************************************************************
*                                                   *                        *
* E     (m)   8.01  7.21  8.67  8.50 14.63 15.00    * TIME PERIOD    min   90 *
* L'    (m)   7.81 85.23  9.23  6.39 64.78  0.00    * TIME SLICE     min   15 *
* V     (m)   5.27  6.32  7.92  7.37  6.40 15.00    * RESULTS PERIOD min 15 75 *
* RAD   (m)  42.67 23.32 21.34 19.81 15.85 15.00    * TIME COST    p/min  7.79 *
* PHI   (d)  14.0  39.0  14.5  22.0  17.0   0.0     * FLOW PERIOD    min 15 75 *
* DIA   (m)  60.96 60.96 60.96 60.96 68.28 60.96    * FLOW TYPE  pcu/veh   VEH *
* GRAD SEP     0     0     0     0     0     0    * FLOW PEAK am/op/pm    AM *
*                                                   *                        *
******************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                             *    *  *              *         *
*VAIL RD SB*1.03*   0  232  140  339   26   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP EB*1.03*   0   48  204    0    2   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*S FR RD EB*1.03* 156  263   67   54    0   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*  53   35  100    0   99   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*S FR RD WB*1.03*  42  217    0  178  127   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP EB*1.03*   0    0    0    0    0   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*          *    *                             *    *  *              *         *
******************************************************************************
*                                                            *                *
* FLOW        veh     823    284    603    321    630      0 *  TOTAL DELAYS  *
* CAPACITY    veh    1584   1125   1689   1501   2960   3372 *                *
* AVE DELAY  mins    0.08   0.07   0.05   0.05   0.03   0.00 *      3 hrs     *
* MAX DELAY  mins    0.11   0.10   0.08   0.07   0.03   0.00 *                *
* AVE QUEUE   veh       1      0      1      0      0      0 *     12 pounds  *
* MAX QUEUE   veh       1      0      1      0      0      0 *                *
*                                                            *                *
******************************************************************************
```

```
*****************************************************************************
*                                                                           *
*  24:8:94             MAIN VAIL SOUTH, 200' ROUNDABOUT              122    *
*                                                                           *
*****************************************************************************
*                                                *                          *
* E    (m)   8.01  7.21  8.67  8.50 14.63 15.00  * TIME PERIOD    min    90  *
* L'   (m)   7.81 85.23  9.23  6.39 64.78  0.00  * TIME SLICE     min    15  *
* V    (m)   5.27  6.32  7.92  7.37  6.40 15.00  * RESULTS PERIOD min  15 75  *
* RAD  (m)  42.67 23.32 21.34 19.81 15.85 15.00  * TIME COST    p/min  7.79  *
* PHI  (d)  14.0  39.0  14.5  22.0  17.0   0.0   * FLOW PERIOD    min  15 75  *
* DIA  (m)  60.96 60.96 60.96 60.96 68.28 60.96  * FLOW TYPE  pcu/veh   VEH  *
* GRAD SEP     0     0     0     0     0     0   * FLOW PEAK am/op/pm    PM  *
*                                                *                          *
*****************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                            *    *  *               *         *
*VAIL RD SB*1.03*   0  128   75  189  24   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP EB*1.03*   0   34  154    0   5   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*S FR RD EB*1.03* 127  372  179  145   0   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*  55   73  206    0  99   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*S FR RD WB*1.03* 117  605    0  289 105   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP EB*1.03*   0    0    0    0   0   0 *1.00*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *               *         *
*****************************************************************************
*                                                          *                *
* FLOW        veh     465    216    919    484   1247     0 *  TOTAL DELAYS  *
* CAPACITY    veh    1527   1266   1909   1423   2664  2617 *                *
* AVE DELAY  mins    0.06   0.06   0.06   0.06   0.04  0.00 *      3 hrs     *
* MAX DELAY  mins    0.07   0.08   0.09   0.09   0.06  0.00 *                *
* AVE QUEUE   veh       0      0      1      1      1     0 *     14 pounds  *
* MAX QUEUE   veh       1      0      1      1      1     0 *                *
*                                                           *                *
*****************************************************************************
```

ROUNDABOUT LEVELS OF SERVICE

08-24-94

Leif Ourston & Associates

Main Vail North
150% of Existing Flows

A.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	461		627	846	23		1,957
AVE DELAY	min/veh	0.07		0.02	0.06	0.08		
OUTPUT								
AVE DELAY	sec/veh	4.2		1.2	3.6	4.8		
DELAY	sec/hr	1936		752	3046	110		5,845

AVE DELAY, sec/veh 3.0
LEVEL OF SERVICE A

P.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	347		1617	469	25		2,458
AVE DELAY	min/veh	0.07		0.02	0.11	0.20		
OUTPUT								
AVE DELAY	sec/veh	4.2		1.2	6.6	12.0		
DELAY	sec/hr	1457		1940	3095	300		6,793

AVE DELAY, sec/veh 2.8
LEVEL OF SERVICE A

```
****************************************************************************
*                                                                          *
*  24:8:94            MAIN VAIL NORTH, 120' ROUNDABOUT                 66  *
*                                                                          *
****************************************************************************
*                                                *                         *
* E     (m)   9.35  15.00  15.00   8.53   7.80   * TIME PERIOD     min   90  *
* L'    (m)  74.09   0.00   0.00  39.19  23.82   * TIME SLICE      min   15  *
* V     (m)   6.38  15.00  15.00   6.93   3.66   * RESULTS PERIOD min  15 75 *
* RAD   (m)   9.95  15.00  15.00  28.96  19.81   * TIME COST    p/min  7.79  *
* PHI   (d)  40.00   0.00   0.00  18.00  29.00   * FLOW PERIOD     min 15 75 *
* DIA   (m)  36.58  36.58  36.58  36.58  36.58   * FLOW TYPE  pcu/veh   VEH  *
* GRAD SEP       0      0      0      0      0   * FLOW PEAK am/op/pm    AM  *
*                                                *                         *
****************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO  *FLOW TIME*
*          *    *                            *    *  *              *         *
*N FR RD EB*1.03*  16  259    0    0  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP WB*1.03*   0    0    0    0  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*   0    1  124  249  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP WB*1.03*   2   25    0  478  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*SP C RD SB*1.03*   2    4    8    0  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *              *         *
*          *    *                            *    *  *              *         *
****************************************************************************
*                                                         *                *
* FLOW          veh      461      0    627    846    23   *  TOTAL DELAYS  *
* CAPACITY      veh     1286   2772   4239   1814   747   *                *
* AVE DELAY    mins     0.07   0.00   0.02   0.06  0.08   *       2 hrs    *
* MAX DELAY    mins     0.11   0.00   0.02   0.09  0.12   *                *
* AVE QUEUE     veh        1      0      0      1     0   *       8 pounds *
* MAX QUEUE     veh        1      0      0      1     0   *                *
*                                                         *                *
****************************************************************************
```

```
****************************************************************************
*                                                                          *
*  24:8:94            MAIN VAIL NORTH, 120' ROUNDABOUT               67  *
*                                                                          *
****************************************************************************
*                                              *                           *
* E     (m)   9.35  15.00  15.00   8.53   7.80    * TIME PERIOD     min     90  *
* L'    (m)  74.09   0.00   0.00  39.19  23.82    * TIME SLICE      min     15  *
* V     (m)   6.38  15.00  15.00   6.93   3.66    * RESULTS PERIOD min   15 75  *
* RAD   (m)   9.95  15.00  15.00  28.96  19.81    * TIME COST     p/min   7.79  *
* PHI   (d)  40.00   0.00   0.00  18.00  29.00    * FLOW PERIOD     min  15 75  *
* DIA   (m)  36.58  36.58  36.58  36.58  36.58    * FLOW TYPE  pcu/veh     VEH  *
* GRAD SEP       0      0      0      0      0    * FLOW PEAK am/op/pm      PM  *
*                                              *                           *
****************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                            *    *  *               *         *
*N FR RD EB*1.03*   5  201    0    1  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP WB*1.03*   0    0    0    0  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*   0    4  423  538  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP WB*1.03*   1   64    0  215  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*SP C RD SB*1.03*   5    5    5    0  0      *1.50*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *               *         *
*          *    *                            *    *  *               *         *
****************************************************************************
*                                                        *                 *
* FLOW         veh     347      0   1617    469     25     *  TOTAL DELAYS   *
* CAPACITY     veh    1258   3408   4237   1058    373     *                 *
* AVE DELAY   mins    0.07   0.00   0.02   0.11   0.20     *         2 hrs   *
* MAX DELAY   mins    0.09   0.00   0.03   0.17   0.33     *                 *
* AVE QUEUE    veh       0      0      1      1      0     *       9 pounds  *
* MAX QUEUE    veh       0      0      1      1      0     *                 *
*                                                        *                 *
****************************************************************************
```

ROUNDABOUT LEVELS OF SERVICE

08-24-94

Leif Ourston & Associates

Main Vail South
150% of Existing Flows

A.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	1235	426	905	481	945		3,992
AVE DELAY	min/veh	0.40	0.19	0.15	0.09	0.03		
OUTPUT								
AVE DELAY	sec/veh	24.0	11.4	9.0	5.4	1.8		
DELAY	sec/hr	29640	4856	8145	2597	1,701		46,940
					AVE DELAY, sec/veh			11.8
					LEVEL OF SERVICE			B

P.M. PEAK HOUR

		LEG 1	LEG 2	LEG 3	LEG 4	LEG 5	LEG 6	WHOLE ROUNDABOUT
INPUT FROM RODEL OR ARCADY								
FLOW	veh/hr	697	323	1379	725	1,870		4,994
AVE DELAY	min/veh	0.09	0.09	0.27	0.24	0.17		
OUTPUT								
AVE DELAY	sec/veh	5.4	5.4	16.2	14.4	10.2		
DELAY	sec/hr	3764	1744	22340	10440	19,074		57,362
					AVE DELAY, sec/veh			11.5
					LEVEL OF SERVICE			B

```
****************************************************************************
*                                                                          *
*  24:8:94             MAIN VAIL SOUTH, 200' ROUNDABOUT              121  *
*                                                                          *
****************************************************************************
*                                               *                          *
* E     (m)   8.01  7.21  8.67  8.50 14.63 15.00   * TIME PERIOD     min      90  *
* L'    (m)   7.81 85.23  9.23  6.39 64.78  0.00   * TIME SLICE      min      15  *
* V     (m)   5.27  6.32  7.92  7.37  6.40 15.00   * RESULTS PERIOD min  15 75  *
* RAD   (m)  42.67 23.32 21.34 19.81 15.85 15.00   * TIME COST     p/min    7.79  *
* PHI   (d)  14.0  39.0  14.5  22.0  17.0   0.0    * FLOW PERIOD     min  15 75  *
* DIA   (m)  60.96 60.96 60.96 60.96 68.28 60.96   * FLOW TYPE  pcu/veh     VEH  *
* GRAD SEP     0     0     0     0     0     0     * FLOW PEAK am/op/pm      AM  *
*                                               *                          *
****************************************************************************
* LEG NAME *PCU *FLOWS (1st exit 2nd etc...U)*FLOF*CL*  FLOW RATIO   *FLOW TIME*
*          *    *                            *    *  *               *         *
*VAIL RD SB*1.03*   0  232  140  339   26   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*OFFRAMP EB*1.03*   0   48  204    0    2   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*S FR RD EB*1.03* 156  263   67   54    0   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*VAIL RD NB*1.03*  53   35  100    0   99   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*S FR RD WB*1.03*  42  217    0  178  127   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*ON RAMP EB*1.03*   0    0    0    0    0   0 *1.50*85*0.75 1.125 0.75*15 45 75 *
*          *    *                            *    *  *               *         *
****************************************************************************
*                                                           *              *
* FLOW        veh     1235     426     905     481     945       0 *  TOTAL DELAYS  *
* CAPACITY    veh     1455     778    1365    1172    2797    2939 *                *
* AVE DELAY  mins     0.40    0.19    0.15    0.09    0.03    0.00 *      13 hrs    *
* MAX DELAY  mins     0.80    0.33    0.25    0.13    0.04    0.00 *                *
* AVE QUEUE   veh        8       1       2       1       1       0 *     61 pounds  *
* MAX QUEUE   veh       15       2       3       1       1       0 *                *
*                                                           *              *
****************************************************************************
```

24:8:94 MAIN VAIL SOUTH, 200' ROUNDABOUT 123

E	(m)	8.01	7.21	8.67	8.50	14.63	15.00	TIME PERIOD	min	90
L'	(m)	7.81	85.23	9.23	6.39	64.78	0.00	TIME SLICE	min	15
V	(m)	5.27	6.32	7.92	7.37	6.40	15.00	RESULTS PERIOD	min	15 75
RAD	(m)	42.67	23.32	21.34	19.81	15.85	15.00	TIME COST	p/min	7.79
PHI	(d)	14.0	39.0	14.5	22.0	17.0	0.0	FLOW PERIOD	min	15 75
DIA	(m)	60.96	60.96	60.96	60.96	68.28	60.96	FLOW TYPE	pcu/veh	VEH
GRAD SEP		0	0	0	0	0	0	FLOW PEAK	am/op/pm	PM

LEG NAME	PCU	FLOWS (1st exit 2nd etc...U)						FLOF	CL	FLOW RATIO			FLOW TIME		
VAIL RD SB	1.03	0	128	75	189	24	0	1.50	85	0.75	1.125	0.75	15	45	75
OFFRAMP EB	1.03	0	34	154	0	5	0	1.50	85	0.75	1.125	0.75	15	45	75
S FR RD EB	1.03	127	372	179	145	0	0	1.50	85	0.75	1.125	0.75	15	45	75
VAIL RD NB	1.03	55	73	206	0	99	0	1.50	85	0.75	1.125	0.75	15	45	75
S FR RD WB	1.03	117	605	0	289	105	0	1.50	85	0.75	1.125	0.75	15	45	75
ON RAMP EB	1.03	0	0	0	0	0	0	1.50	85	0.75	1.125	0.75	15	45	75

FLOW	veh	697	323	1379	725	1870	0	TOTAL DELAYS
CAPACITY	veh	1369	990	1694	1055	2354	1807	
AVE DELAY	mins	0.09	0.09	0.27	0.24	0.17	0.00	16 hrs
MAX DELAY	mins	0.13	0.13	0.53	0.44	0.32	0.00	
AVE QUEUE	veh	1	1	6	3	5	0	75 pounds
MAX QUEUE	veh	1	1	11	5	9	0	