U.S. Department
of Transportation
**Urban Mass
Transportation
Administration**

DOT-TSC-1752

Articulated Buses

A Planning Handbook
November 1984

UMTA Technical Assistance Program
Office of Service and Management Demonstration

Contents

Page

I. Basic Facts About Articulated Buses . . . 1

I-A. Introduction . . . 1
I-B. Examples of How Artics Are Used . . . 2
I-C. Specifications . . . 6
I-D. Manufacturers . . . 9

II. Are Artics Right for my Agency? . . . 11

II-A. Capital Costs . . . 11
II-B. Operating Costs . . . 13
II-C. Ridership Benefits of Articulated Buses . . . 16
II-D. Alternative Methods for Increasing Vehicle Capacity . . . 20
II-E. Conclusions . . . 21

III. Identifying Potential Routes for Artic Deployment . . . 23

III-A. Identifying Routes Which Are Not Amenable to Artics . . . 23
III-B. Identifying Clear Opportunities . . . 25
III-C. Maintenance Bases and Route Choice . . . 26

IV. Maintenance of Articulated Buses . . . 27

IV-A. Startup Issues . . . 27
IV-B. On-going Maintenance . . . 32

V. Other Startup Issues . . . 35

VI. Operating Issues . . . 37

VI-A. Turns . . . 37
VI-B. Acceleration and Hill Climbing . . . 39
VI-C. Handling . . . 39
VI-D. Turntable Damage . . . 40
VI-E. Fare Collection . . . 40

VII. Scheduling of Articulated Buses . . . 43

VII-A. Running Times . . . 43
VII-B. Mixing Artics With Standard Buses . . . 44
VII-C. Alternative Service Types . . . 46
VII-D. Peak-Only versus All-Day Service . . . 46

VIII. Economic Analysis Worksheets . . . 49

VIII-A. Introduction to Worksheets . . . 49
VIII-B. Example Run . . . 55
VIII-C. Using a Simplified Cost Model to Screen Potential Artic Routes . . . 83
VIII-D. Worksheets and Supporting Data . . . 91

List of Tables

		Page
I-1	Articulated Bus Fleets in the United States	5
I-2	Articulated Bus Options Ordered	7
II-1	Articulated Bus Price History	13
VIII-1	UMTA Section 15 Year 4 Unit Labor Operating Cost Data	52
VIII-2	Some Actual Agency Values for Unit Cost Parameters	53
VIII-3	UMTA Section 15 Year 4 per Mile Operating Cost Data	54

List of Figures

		Page
I-1	Comparative Size and Seating Arrangement of Articulated Buses and GM New-Look Buses	8
V-1	Articulated Bus Stop Lengths	35
VI-1	Swing-out Accident Caused by Turning Trailer Wheels	37
VII-1	Scheduling a Mixture of Articulated and Standard Buses on a Route	45
VIII-1	Flow Chart of Artic Substitution Worksheet Process	50

Foreword

The Urban Mass Transportation Administration's (UMTA) Service and Methods Demonstration (SMD) Program was established in 1974 to promote the development and widespread adoption of innovative transit services and transportation management techniques throughout the United States. The program focuses on concepts that use existing technology to create improvements which require relatively low levels of capital investment and which can be implemented within a short time frame. Through the SMD Program, these concepts are demonstrated and evaluated to determine their costs, impacts, and implementation characteristics. Evaluation findings are then disseminated through various media to transportation planners, policymakers, and transit operators in the United States and abroad.

This handbook is the second in a series of documents which synthesize past SMD evaluation findings and current experience to provide practical guidance to state and local areas for planning and implementing public transportation improvements. (A handbook on user-side subsidies was the first document in the series.) This Articulated Bus Handbook provides guidance for evaluating, purchasing, and deploying articulated buses; relates the experience which US transit agencies have had with this equipment; and suggests methods for analyzing the economic implications of various articulated bus service strategies. Separate publications are available through UMTA on related topics such as applying for federal assistance and writing detailed articulated bus specifications for procurements. All of the manufacturers also offer literature and assistance to potential customers. Two other available reports may be of particular interest to transit operators:

- **Articulated Bus Report;** U.S. Department of Transportation, Transportation Systems Center, and Cambridge Systematics, Inc.; UMTA/TSC Project Evaluation Series; UMTA-MA-06-0049-82-1; June, 1982.

- **Technology of Articulated Transit Buses;** Gundersen, Richard G.; U.S. Department of Transportation, Transportation Systems Center; DOT-TSC-UM262-PM-82-14; March, 1982.

The first of these reports describes the initial experience of U.S. transit operators with articulated buses, including an extensive description of how artics were being deployed in each of the agencies, some early problems, and some preliminary data. The second of these reports contains technical specifications and performance information from a wide variety of artic manufacturers.

Literally dozens of people contributed to the development of this handbook. Paul Thompson and Bill Jessiman of Cambridge Systematics, Inc. were the principal authors, though major sections were written by Richard Lung and Barry Faulkner of Cambridge Systematics, and Richard Bertz, former Maintenance Manager at AC Transit in Oakland. Richard Barber, former Superintendent of Plans and Schedules at Boston's MBTA, contributed some of his thoughts from a scheduler's perspective. Jim Wojno, Shelli Sandrew, and Cathy DeMaggio of Cambridge Systematics were responsible for graphics, production and typing. Bruce Spear of the Transportation Systems Center was the project manager, and Joseph Goodman monitored the project for UMTA. Others at TSC who contributed their data or their time in the review of this material include Robert Waksman, Richard Gundersen, Michael Jacobs, Neil Patt, and Tom Comparato.

Numerous representatives of US transit properties contributed data, anecdotes and insights. These include:

Seattle METRO (James Munson, Emmett Heath, Paul Donnelly, Bill Branch, Terry Compton, John Daniels, Brian O'Leary, Dave Wyrick, Karol Olsen)
Minneapolis/St. Paul MTC (Aaron Isaacs)
Chicago CTA (Bernard Ford)

Los Angeles SCRTD (Susan Phifer, Peter DeHaan, Kim Massey-Eberle, Harold Orr, Richard Morton, Ray Turpin, Josie Nicasio)

Denver RTD (Bill Byrne, Joe Racosky, Bill Hoople)

San Francisco MUNI (Anthony Bruzzone, Angelo Figone, Buford Johnson, Dan Wong)

Pittsburgh PAT (Hank Cusack, Ralph Burrelli, Joe Mundo, Tom Rochon, Fred Maffi)

Portland Tri-Met (Tom Newhouse, Phil Selinger, Ken Stanley)

San Rafael GGBHTD (Donald White)

Oakland AC Transit (David Yazhari)

Louisville TARC (John Woodford)

Atlanta MARTA (Ann Johnson)

Phoenix Transit (J. S. Loe)

Indianapolis PTC (William Peterson)

San Mateo SAMTRANS (Larry Stueck, Gregory Kipp, Michael Hubbell)

Santa Clara SCCTD (Robert Scott, Art Douwes)

Detroit SEMTA (Marty Steinmetz)

Additional information was contributed by representatives of all four active manufacturers of articulated buses in the United States: M.A.N., Crown, Neoplan, and Volvo.

Basic Facts About Articulated Buses

Page

I-A. Introduction 1
I-B. Examples of How Artics Are Used 2
I-C. Specifications 8
I-D. Manufacturers 9

I. Basic Facts About Articulated Buses

I-A. Introduction

Articulated buses (commonly called "artics") are high-capacity buses, capable of carrying approximately 50 percent more passengers than standard buses. Because of their great length, artics consist of two rigid sections connected by a bending middle. A typical 60-foot artic can provide this 50 percent greater capacity while still using only one driver. Since driver costs are a large percentage (a half or more) of total bus operating costs, this suggests an opportunity to reduce operating costs by substituting artics for standards. However, this can only be done cost-effectively under certain circumstances, and the way to determine those situations is the subject of this Handbook. By mixing standard and articulated buses in a fleet, and deploying them sensibly, a transit agency can match or improve its service while reducing its costs.

Since the first U.S. articulated bus orders were placed in 1976 (they have been in use in Europe for a much longer time), 29 U.S. transit agencies have purchased a total of 1574 such vehicles, at a total cost of over $350 million. Artics have been used in a wide range of routes, schedules, and climatic and geographic conditions. For any particular route, there are two primary purposes for deploying artics, both of which increase productivity:

- **To carry the same number of passengers at a lower cost; and**
- **To increase route capacity, thereby increasing service quality and ridership.**

In order to achieve these goals, the transit operator must carefully deploy the extra-large buses on routes and trips where the extra capacity is needed. In addition, certain changes in scheduling, maintenance, and operating procedures may be necessary. This Handbook introduces these issues in a way which will help potential artic purchasers to decide whether to buy the equipment; where to deploy it; and how to make it a successful addition to the fleet.

This Handbook freely mentions articulated bus manufacturers by name. However, nothing in this document should be interpreted as an endorsement of any one of them or even any comparison among them.

How to use this Handbook. The Articulated Bus Handbook is organized with the most general material toward the front and more detailed information toward the rear:

Chapter I introduces this Handbook, describes the uses to which artics are being put, and discusses in general terms the equipment options available and the manufacturers.

Chapter II asks the central question, "Are artics right for my agency?" and offers guidance on how the transit agency can answer this for itself.

Chapter III gives practical tips on how to identify routes which are good artic opportunities.

Chapter IV introduces articulated bus maintenance considerations and the preparations which must be made in order to keep the equipment in good working order.

Chapter V covers other startup issues which must be settled before artics can be put into operation.

Chapter VI discusses how the operation of artics is different from standard transit coaches and what to expect given the experiences of current artic operators.

Chapter VII covers the performance of artics in keeping to schedules, and offers suggestions on how artics can be scheduled so that they are used most effectively.

Finally, **Chapter VIII** shows, through worksheets, unit cost tables, and detailed instructions, how a transit planner can conduct his or her own analysis of the economic pros and cons of deploying articulated buses on particular routes.

1-B. Examples of How Artics Are Used

Most U.S. transit systems which have deployed articulated buses have found specific, unique routes or service types for which the vehicles appear to be best suited. These operating conditions vary widely from city to city. Many transit agencies have experimented with different types of routes until finding those where the extra-long buses work especially well. Others, including most recent, large procurements, have had specific objectives in mind before the purchase.

Seattle's METRO, for instance, uses articulated buses as part of a successful overall program, which includes part-time drivers and other labor practices, to improve productivity on its highly-peaked bus system. (Seattle's peak-to-base ratio, the ratio of peak vehicles required to base vehicles required to meet the schedule, is 2.7). With 353 M.A.N. 60-foot buses, approximately 33 percent of its total bus fleet, METRO is the nation's largest artic operator.

Most of Seattle's artic fleet is used in peak-period service only, especially on express routes and freeway routes serving suburban park-and-ride lots. A smaller number of vehicles are used on heavily-patronized local routes, again mostly during peak periods. A few all-day runs are operated in cases where this is less expensive than deadheading artics back to the garage. In some local route cases, artics and standard buses operate in mixed service on the same routes. Seattle is very pleased with the cost-effectiveness of artics, especially in express service from park-and-ride facilities.

Because of its heavy commitment to the articulated bus, Seattle has been able to justify a large investment in maintenance facilities designed especially for the vehicle. Two new bus garages were designed and equipped specifically with the articulated bus in mind. Two other divisions out of METRO's six also use artics. All drivers and mechanics on the system are trained for articulated buses.

Seattle's employees and passengers alike have reacted very favorably to articulated bus operation. While a few equipment problems have arisen, none of these have been particularly unusual for a new bus design. In fact, METRO has been so happy with the concept of larger bus capacity, that it has recently ordered 46 articulated electric trolley buses, becoming the first North American transit system to do so.

Tri-Met in **Portland, Oregon,** has also deployed articulated coaches with a particular objective in mind. In 1981, Tri-Met completely restructured bus routes on the city's Eastside, forming a grid-type structure. Several north-south crosstown routes carry passengers to east-west radial routes leading to downtown. Six of these radial trunk routes carry particularly high passenger volumes with mixed artic and standard bus service.

Articulated buses were chosen for these six trunk routes because of high transfer rates from intersecting routes. The added capacity and comfort offered by artics makes these transfers more attractive to passengers than they otherwise would be.

In order to begin articulated bus service, it was necessary for Tri-Met to relocate or lengthen most of the bus stop zones along the six routes. It was also necessary to make many changes to the existing maintenance facilities, and to train all its drivers and mechanics.

Tri-Met has been hit particularly hard by the problems which plague any new bus design. US-made parts, which were substituted for European parts so that the artics could be sold in the US, have not performed well in the European-designed bus. Tri-Met has had to rebuild the Detroit-Diesel transmissions and Rockwell differentials on all 87 of its artics, and has had extensive trouble with malfunctioning wiper systems and cracked frames. Crown Coach Corporation and the manufacturers of the individual components have worked very hard to rectify the problems. But in the meantime, Tri-Met has been experiencing three times the per-mile operating cost and one-third the road call mileage of its standard bus fleet.

Southern California Rapid Transit District in Los Angeles, the Regional Transportation District in Denver, and San Francisco's MUNI all use artics in all-day service along heavily patronized local routes. SCRTD initially used its 30 (now 40) artics mixed with standard buses on a few heavy local routes; in April of 1984 they consolidated their artics onto one all-artic (except night service) route, Line 1.-Hollywood Boulevard. In general, when artics were operated in mixed service with standard buses, no schedule adjustments were made, despite the fact that artics can take 7 to 10 percent longer to make the trip.

SCRTD's bus operators, driving the buses through heavy traffic on narrow streets, have given mixed reactions to the vehicles. Passenger reaction, however, has been very positive. Surveys conducted by SCRTD in 1979 and again in 1980 showed that 67 percent of its passengers prefer articulated buses over regular buses; 63 percent said that artics are more comfortable, as opposed to only 11 percent who said that they are less comfortable. An AC Transit (Oakland) survey corroborated the comfort preferences. SCRTD management has been less enthralled with artics because of a much higher accident rate (three times the accidents per bus-mile as standard buses), resulting in higher than anticipated maintenance and liability costs.

Denver's RTD is mixing artics with standard buses in a particularly interesting way. Although both vehicle types traverse the same, high-density local route, the standards serve every stop whereas the artics serve only the major stops, say every fifth stop.

on average.

The Metropolitan Transit Commission in Minneapolis/St. Paul, Minnesota has been using its 82 articulated buses primarily for peak-only service on its most over-crowded routes. Artics have been placed into service on trips which experienced over 140 percent load factors, as an alternative to adding a second standard bus. MTC has also experimented with all-day service on a heavy intercity route, but discontinued this service when it was discovered that vandalism by midday riders was excessive.

Table 1-1 shows a complete list of the 29 U.S. transit systems which own articulated buses.

Table I-1
Articulated Bus Fleets in the United States
(as of May, 1984)

City	Qty	Date in Service	Date of Award	Months Delay	Manufacturer
Delivered:					
Albany, NY	8	3-84	9-82	18	Crown-Ikarus
Atlanta, GA	10	1-79	9-76	28	M.A.N.
Atlanta, GA	46	12-82	4-82	8	Neoplan
Chicago, IL	20	12-78	2-77	22	M.A.N.
Chicago, IL	125	12-82	10-80	26	M.A.N.
Denver, CO	89	11-83	7-81	28	M.A.N.
Indianapolis, IN	21	1-84	8-82	17	M.A.N.
Jacksonville, FL	10	3-84	9-82	18	Crown-Ikarus
Los Angeles, CA	30	4-78	8-76	20	M.A.N.
Los Angeles, CA*	10	10-78	9-76	25	M.A.N.
Louisville, KY	15	5-81	11-79	18	Crown-Ikarus
Memphis, TN	10	9-83	7-81	26	M.A.N.
Nashville, TN	15	8-83	7-81	25	M.A.N.
Oakland, CA	30	5-78	9-76	20	M.A.N.
Phoenix, AZ	20	2-79	10-76	28	M.A.N.
Phoenix, AZ	15	4-84	11-82	17	M.A.N.
Pittsburgh, PA	20	1-79	2-77	23	M.A.N.
Pittsburgh, PA	30	2-83	7-81	19	M.A.N.
Portland, OR	87	10-81	4-80	18	Crown-Ikarus
Rochester, NY	17	5-84	8-83	9	M.A.N.
San Diego, CA	45	7-78	8-76	23	M.A.N.
San Jose, CA	15	8-83	7-81	25	M.A.N.
San Jose, CA	15	3-84	10-81	29	Crown-Ikarus
San Juan, PR	12	4-84	7-83	9	M.A.N.
San Mateo, CA	10	7-81	4-80	15	Crown-Ikarus
Seattle, WA	151	5-78	8-76	21	M.A.N.
Seattle, WA	202	2-82	5-80	21	M.A.N.
St. Paul, MN	20	10-78	8-76	26	M.A.N.
St. Paul, MN	62	5-83	7-81	22	M.A.N.
Washington, DC	43	1-79	9-76	28	M.A.N.
Washington, DC	33	6-83	7-81	23	M.A.N.
White Plains, NY	61	9-83	7-81	26	M.A.N.
On Order:					
Honolulu, HI	8		11-83		Crown-Ikarus
Houston, TX	50	9-84	11-83	10	Crown-Ikarus
Indianapolis, IN	9	9-84	8-82	25	M.A.N.
Milwaukee, WI	40		8-82		Crown-Ikarus
Philadelphia, PA	50	9-84	10-83	11	Volvo
Providence, RI	5	8-84	2-84	6	Neoplan
San Francisco, CA	100	6-84	6-83	12	M.A.N.
San Mateo, CA	15	12-84	2-84	10	Volvo

* originally purchased by Golden Gate Transit of San Rafael, CA

I-C. Specifications

While all articulated buses are generally similar in appearance, prospective purchasers have a number of options available. Table I-2 shows the 40 U.S. artic orders to date, grouped by types of options chosen. The most important variables are:

Size—60 feet or 55 feet long, 96 or 102 inches wide. Smaller artics have better turning characteristics and higher power-to-weight ratios, but fewer seats. They cost about the same as the larger ones. Of the 40 U.S. orders placed to date, 33 have been for the 60-foot by 102-inch version.

Doors—2 or 3, usually double-width. The three-door version, used on systems where fare collection procedures allow boarding through all doors (such as Portland's now-defunct self-service system or cities with downtown fare-free zones), generally have 4 to 8 fewer seats.

Seating arrangement—The number of seats on an articulated bus ranges from 57 to 76, with an average of 68. Every manufacturer offers a variety of seating configurations. Figure I-1 shows a comparison of typical seating arrangements for two artic models and a conventional bus model.

Equipment—Artics may be ordered with many different kinds of optional equipment, but two of the most visible options are air conditioning and wheelchair lifts. Thirty-three of the forty U.S. artic fleets are air conditioned, adding an average of $33,000 to the vehicles' unit purchase price. Wheelchair lifts are no longer required for federal assistance to purchase artics, but still one-quarter of the U.S. fleets have them, adding an average of $7000 (for one lift per vehicle) to the unit purchase price.

Rear axle—On most articulated buses, other than pushers, the rear axle is linked to the hinge between the front and rear sections in such a way that the back end of the bus tracks toward the outside of turns. This steerable rear axle gives a better turning radius but makes the outer rear corner of the bus vulnerable to swing-out collisions, especially for artic-inexperienced drivers. This danger has been reduced in more recent artic deliveries by tapering the back end of the bus. Also, it might be noted that collisions of this type have decreased greatly over time on systems which have operated artics for several years, reflecting increasing driver experience.

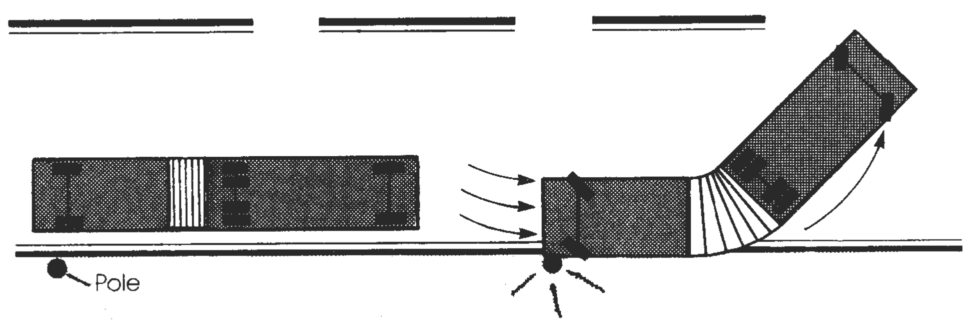


Table I-2
Articulated Bus Options Ordered

For the 40 US articulated bus orders as of May, 1984.
Fleets with similar characteristics are grouped together.

City	Length	Width	Doors	Air Cond	W/C Lift	Mfr	Horse-power	Date of Award	Qty	Seats
Louisville, KY	60	102	2	Y	Y	Crown	290	11-79	15	73
San Jose, CA	60	102	2	Y	Y	Crown	290	10-81	15	73
Los Angeles, CA	60	102	2	Y	Y*	M.A.N.	280	9-76	10	69
San Jose, CA	60	102	2	Y	Y	M.A.N.	310	7-81	15	72
San Juan, PR	60	102	2	Y	Y	M.A.N.	310	7-83	12	70
San Mateo, CA	60	102	2	Y	Y	Volvo	242	2-84	15	64
Albany, NY	60	102	2	Y	N	Crown	290	9-82	8	74
Jacksonville, FL	60	102	2	Y	N	Crown	290	9-82	10	71
Honolulu, HI	60	102	2	Y	N	Crown	290	11-83	8	66
Houston, TX	60	102	2	Y	N	Crown	290	11-83	50	70
San Diego, CA	60	102	2	Y	N	M.A.N.	280	8-76	45	69
St. Paul, MN	60	102	2	Y	N	M.A.N.	280	8-76	20	67
Oakland, CA	60	102	2	Y	N	M.A.N.	280	9-76	30	69
Phoenix, AZ	60	102	2	Y	N	M.A.N.	280	10-76	20	69
Memphis, TN	60	102	2	Y	N	M.A.N.	310	7-81	10	72
Washington, DC	60	102	2	Y	N	M.A.N.	310	7-81	33	72
Nashville, TN	60	102	2	Y	N	M.A.N.	310	7-81	15	72
St. Paul, MN	60	102	2	Y	N	M.A.N.	310	7-81	62	67
White Plains, NY	60	102	2	Y	N	M.A.N.	310	7-81	61	72
Indianapolis, IN	60	102	2	Y	N	M.A.N.	310	8-82	9	72
Indianapolis, IN	60	102	2	Y	N	M.A.N.	310	8-82	21	72
Phoenix, AZ	60	102	2	Y	N	M.A.N.	310	11-82	15	69
Rochester, NY	60	102	2	Y	N	M.A.N.	310	8-83	17	67
Atlanta, GA	60	102	2	Y	N	Neoplan	330	4-82	46	67
San Mateo, CA	60	102	2	N	Y	Crown	350	4-80	10	69
Seattle, WA	60	102	2	N	Y	M.A.N.	310	5-80	202	70
Denver, CO	60	102	2	N	Y	M.A.N.	310	7-81	89	70
Milwaukee, WI	60	102	2	N	N	Crown	350	8-82	40	76
Seattle, WA	60	102	2	N	N	M.A.N.	280	8-76	151	72
Providence, RI	60	102	3	Y	N	Neoplan	330	2-84	5	60
Los Angeles, CA	60	102	3	Y	N	M.A.N.	280	8-76	30	65
Portland, OR	60	102	3	N	Y	Crown	290	4-80	87	66
San Francisco, CA	60	102	3	N	Y	M.A.N.	310	6-83	100	57
Philadelphia, PA	60	96	2	Y	N	Volvo	242	10-83	50	64
Washington, DC	55	102	2	Y	N	M.A.N.	280	9-76	43	61
Atlanta, GA	55	102	2	Y	N	M.A.N.	280	9-76	10	65
Pittsburgh, PA	55	102	2	Y	N	M.A.N.	280	2-77	20	61
Chicago, IL	55	102	2	Y	N	M.A.N.	280	2-77	20	64
Chicago, IL	55	102	2	Y	N	M.A.N.	310	10-80	125	66
Pittsburgh, PA	55	102	2	Y	N	M.A.N.	310	7-81	30	61

*wheelchair lifts were retrofitted in 1982 when these 10 artics were operated by Golden Gate Transit

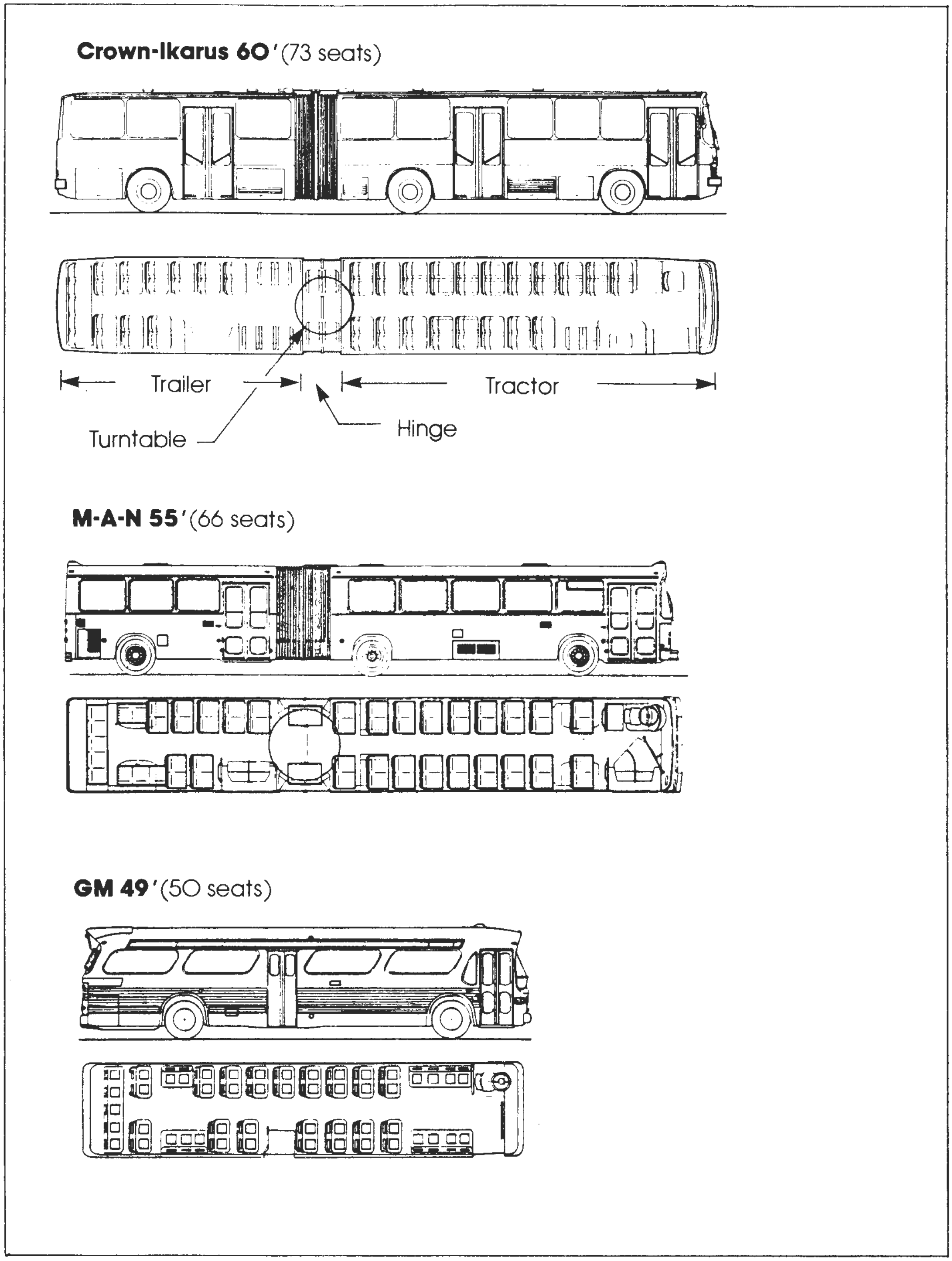


Figure I-1. Comparative Size and Seating Arrangement of Articulated Buses and GM New-Look Bus
(Crown-Ikarus seating shown for two-door version)

Engine—The standard engine on most artics gives a lower power-to-weight ratio than most standard coaches. Most manufacturers offer optional larger engines or lower final-drive ratios to give adequate acceleration and speed on hilly routes. Seattle, whose initial purchase was 280 HP vehicles, opted for 310 HP artics on their second order to cope with concerns that the initial artics were underpowered.

Drive train—Most artics have their engines mounted in the front section, driving the middle wheels. However, another option commonly used in Europe is an engine in the rear section driving the rear wheels. This configuration is called a "pusher".

I-D. Manufacturers

A large number of bus builders around the world manufacture articulated buses, but only four of these have been successful in winning orders from U.S. properties. Many of these firms use designs and technology imported from Europe.

Because of "buy America" provisions in all UMTA grant awards, all articulated buses in the United States contain at least 50 percent U.S. components, with final assembly in the U.S. In general, American-made parts are less expensive to replace than foreign parts, are more readily available, and require fewer special tools. Because of this, and because of increasing U.S. orders, artic manufacturers are increasingly using U.S.-made parts. The four current suppliers of U.S. articulated buses are:

- **M.A.N.** Truck and Bus Corporation, a North Carolina-based firm which is a subsidiary of Maschinenfabriken-Augsburg-Nurnberg of West Germany. M.A.N. has extensive experience with artics in Europe, and has dominated the U.S. artic market as well, having made 27 of the 40 U.S. orders. M.A.N. delivered its first artics to a consortium of transit systems in 1978. It was associated with AM General, then a U.S. bus manufacturer, until 1980, when AM General dropped out of the bus business, and M.A.N. created the U.S. subsidiary. Except for the engine, axles, and certain other parts, M.A.N. artics are now manufactured and assembled chiefly in the United States, at its Cleveland, North Carolina plant. The six-cylinder M.A.N. engine is mounted in the front section, driving the middle wheels. The rear axle is steerable.

- **Crown** Coach Corporation, a Los Angeles company which makes Crown-Ikarus articulated buses. Crown delivered its first artic to Louisville in 1981, and has subsequently delivered, or taken orders for, a total of 243 buses for 9 U.S. transit systems. The Crown-Ikarus chassis and empty body shell are made in Hungary by Ikarus Body and Coach Works. The final product is then assembled in Los Angeles, where American-made engines, transmissions, and other parts are added. Crown-Ikarus artics have engines mounted in the front section driving the middle axle, with a steerable rear axle.

- **Neoplan** USA, owned by Gottlob Auwarter GmbH of West Germany. It manufactures conventional buses and artics at a plant in Lamar, Colorado. Neoplan delivered its first articulated bus to Atlanta in 1982. The engine, chassis, body, and most other major parts are manufactured and assembled in the

United States. Neoplan artics use a pusher design, with the rear engine driving the rear axle.

- **Volvo** of America, a subsidiary of AB Volvo of Sweden. Volvo is the newest entry in the U.S. artic market, planning to deliver its first articulated bus order to Philadelphia in September, 1984. Based in New Jersey, Volvo assembles its artics at its plant in Chesapeake, Virginia. The body, seats, electrical system, and air conditioning are American-made, while the chassis is manufactured in Sweden. Volvo artics have their engines in the middle of the bus, driving the middle axle.

A number of other manufacturers, including Mack Trucks (with Renault), Magirus-Deutsch, MCR Technology (with Coach and Equipment Manufacturing Co.), and Saab-Scania, have expressed an interest in the U.S. articulated bus market. Several have produced prototype buses to meet U.S. specifications, and/or have plans to demonstrate artics at U.S. transit agencies.

The previously-cited report, **Technology of Articulated Transit Buses,** contains further technical specification information for a wide variety of manufacturers.

II

Are Artics Right for my Agency?

Page

II-A. Capital Costs 11
II-B. Operating Costs 13
II-C. Ridership Benefits of Articulated Buses 16
II-D. Alternative Methods for Increasing Vehicle Capacity 20
II-E. Conclusions 21

II.

Are Artics Right For My Agency?

Articulated buses have been successfully deployed on a wide variety of transit routes across the United States. However, not all systems will necessarily find artics to their advantage; a number of important tradeoffs must be considered. Among the questions which a potential artic operator must ask are:

- **Will expected operating cost savings outweigh the higher capital cost?**

- **Can artics be used as part of a strategy to increase ridership or fulfill other goals of the organization?**

- **Are there more effective ways of achieving improved service and reduced cost goals?**

- **Are there specific existing or planned bus routes for which articulated buses can be cost effective? What kind of routes should I be looking for?**

- **Can the organization successfully adapt to the new equipment in its maintenance, scheduling, marketing, and other operating procedures?**

General considerations as to whether articulated buses are appropriate for a transit agency are discussed in this chapter. Operating costs and ridership must be analyzed at the route level; Chapter VIII shows how the cost of operating a route with articulated buses can be compared with standard buses. The effect of artics on ridership is not easy to analyze, but some of the basics are discussed in this chapter. The final two of the above questions are the subject of the following five chapters.

II-A. Capital Costs

A 60-foot articulated bus normally costs 1.6 to 1.9 times as much as a standard 40-foot transit bus. The average cost for artic contracts awarded in 1983-84 has been about $220,000 per bus, but has been dropping markedly in the past two years:

For awards in:	Average unit price was:
1976-77	$170,787
1979-80	243,681
1981-82	268,591
1983-84	219,779

Much of the recent price decrease can be attributed to decreases in materials costs, increased competition among manufacturers, and increased availability of domestic parts. If the present trend continues, the average price could drop to the $200,000 neighborhood by 1985.

Taking a closer look at artic capital costs, the approximate cost of air conditioning ($33,000 per bus) and wheelchair lifts ($7,000 per bus) add some statistical "noise" to the computation of average costs. For the 1983-1984 awards, if this average cost for air conditioning and wheelchair lifts is taken out of the unit price where appropriate, the average artic unit price becomes about $188,000. This might be expected to drop to about $170,000 per artic by 1985. If air conditioning is desired, the $170,000 expected unit price becomes $200,000. If wheelchair lifts are also desired, a $205,000-$210,000 average price might be expected.

Transit properties with large artic orders have enjoyed substantial quantity discounts on their unit prices. A statistical analysis of award prices shows that, on average, the price has decreased by $2000 for each additional 10 buses purchased above the 39-bus average order. Table II-1 shows the 40 US artic orders chronologically, with the number of units purchased and their contract unit prices. (The actual price is usually somewhat different because of international currency fluctuations and contract change orders.)

Since artics normally have 1.5 times the seating capacity of conventional buses, their per-seat capital cost is somewhat higher than 40-foot buses, by 10 to 30 percent. This difference is even larger for 55-foot artics, which have 8 to 16 percent fewer seats than 60-foot buses but cost about the same.

The additional capital cost of an articulated bus may be mitigated somewhat by its longer life. While artics have not been in service in the U.S. long enough to provide conclusive evidence, a number of maintenance officials of US transit systems owning artics have commented that the buses are more solidly built than conventional coaches and should therefore give more years of service. If an articulated bus fleet lasts 15 years instead of the standard 12, the capital cost per seat per year may be very close to, or somewhat less than, the cost for standard buses.

It might also be borne in mind that artics' competitive advantage is primarily in the peak hours, so artics tend to be used for fewer miles per year than standard buses.

Seattle, which uses more artics than any other transit system, gets about 90% of the mileage per year from its average artic that it does from its average standard bus (33,600 miles per year vs. 37,200 miles per year for standard buses over the last three years). However, Seattle has a very peak-oriented operation which favors artic utilization. Chicago and Portland are similar to Seattle in that they realize about 90% of the mileage per year with artics that they do with standard buses. Other systems such as Oakland, Los Angeles, and Louisville, have annual mileages per artic of only about 50% of their standard buses.

II-B. Operating Costs

In exchange for possible higher capital costs, articulated buses offer the potential for operating cost savings. The obvious opportunity for savings is in driver labor costs where, if the capacity of the artic is fully utilized, the cost per passenger can be reduced by one-third. Other operating cost effects of the new equipment are:

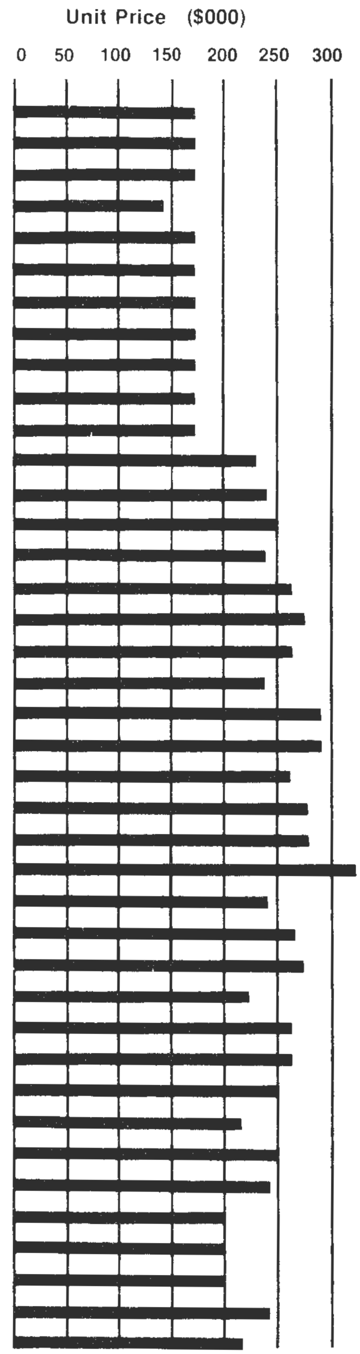
- **Maintenance costs, which are typically one third to one-half higher per bus-mile for an artic than for a standard bus. (Seattle is an exception; they show maintenance costs per artic-mile to be the same or slightly less than for standard buses.)**

- **Fuel costs, which tend to be about 10 percent greater per bus-mile for artics than for standard buses.**

Table II-1
Articulated Bus Price History

For the 40 US articulated bus orders as of May, 1984

Date of Award	City	Manu-facturer	Qty	Air Cond	W/C Lift	Unit Price
8-76	San Diego, CA	M.A.N.	45	Y	N	$ 174,286
8-76	St. Paul, MN	M.A.N.	20	Y	N	174,286
8-76	Los Angeles, CA	M.A.N.	30	Y	N	174,286
8-76	Seattle, WA	M.A.N.	151	N	N	142,246
9-76	Washington, DC	M.A.N.	43	Y	N	172,673
9-76	Los Angeles, CA	M.A.N.	10	Y	N	174,286
9-76	Atlanta, GA	M.A.N.	10	Y	N	172,673
9-76	Oakland, CA	M.A.N.	30	Y	N	174,286
10-76	Phoenix, AZ	M.A.N.	20	Y	N	174,286
2-77	Chicago, IL	M.A.N.	20	Y	N	172,673
2-77	Pittsburgh, PA	M.A.N.	20	Y	N	172,673
11-79	Louisville, KY	Crown	15	Y	Y	228,000
4-80	Portland, OR	Crown	87	N	Y	236,538
4-80	San Mateo, CA	Crown	10	N	Y	247,467
5-80	Seattle, WA	M.A.N.	202	N	Y	236,400
10-80	Chicago, IL	M.A.N.	125	Y	N	270,000
7-81	Memphis, TN	M.A.N.	10	Y	N	284,683
7-81	White Plains, NY	M.A.N.	61	Y	N	274,467
7-81	Denver, CO	M.A.N.	89	N	Y	240,144
7-81	Washington, DC	M.A.N.	33	Y	N	286,699
7-81	San Jose, CA	M.A.N.	15	Y	Y	290,993
7-81	Nashville, TN	M.A.N.	15	Y	N	264,816
7-81	Pittsburgh, PA	M.A.N.	30	Y	N	275,679
7-81	St. Paul, MN	M.A.N.	62	Y	N	278,745
10-81	San Jose, CA	Crown	15	Y	Y	317,545
4-82	Atlanta, GA	Neoplan	46	Y	N	244,389
8-82	Indianapolis, IN	M.A.N.	9	Y	N	265,382
8-82	Indianapolis, IN	M.A.N.	21	Y	N	275,116
8-82	Milwaukee, WI	Crown	40	N	N	224,000
9-82	Jacksonville, FL	Crown	10	Y	N	256,465
9-82	Albany, NY	Crown	8	Y	N	263,585
11-82	Phoenix, AZ	M.A.N.	15	Y	N	254,754
6-83	San Francisco, CA	M.A.N.	100	N	Y	211,911
7-83	San Juan, PR	M.A.N.	12	Y	Y	252,809
8-83	Rochester, NY	M.A.N.	17	Y	N	239,285
10-83	Philadelphia, PA	Volvo	50	Y	N	200,000
11-83	Houston, TX	Crown	50	Y	N	198,600
11-83	Honolulu, HI	Crown	8	Y	N	201,850
2-84	Providence, RI	Neoplan	5	Y	N	243,777
2-84	San Mateo, CA	Volvo	15	Y	Y	210,000



■ **Servicing costs, which are about 20 percent higher per bus-mile for artics than for standard coaches.**

■ **Tire costs, which are 60 percent higher per bus-mile for artics.**

Overall, per bus-mile costs (excluding driver's wages) are about 25 percent higher for artics than standards. However, on a per seat-mile basis, artics become about 17 percent less expensive than standards. If one were to factor in driver labor costs using the assumption that labor is about half the total operating cost for standard buses, then artics become about 25% percent less expensive per seat-mile. Obviously, the key to the articulated bus' cost effectiveness is finding situations where its capacity can be fully utilized.

More specific information on unit costs from various systems can be found in Chapter VIII.

Driver wage costs. For most transit systems operating articulated buses, the hourly cost for bus driver wages and fringes is the same for standard and articulated buses.

Two notable exceptions are **Seattle** and **Portland,** where drivers are paid a premium of 50 cents per hour to drive artics. The drivers justify this differential by the added responsibility of having to deal with 50 percent more passengers. In no other agency was there any particular pattern of pay or seniority status differentials observed for artic drivers.

With wage rates being relatively unchanged with the introduction of artics, great cost savings can be realized by reducing the number of runs, and therefore drivers, needed to carry a given number of passengers on a particular route. Most transit agencies, however, have difficulty taking full advantage of this potential on a systemwide basis. This is because organized labor would strongly resist such a move. In most cases, therefore, artics are used to improve service levels with a given number of drivers. This approach will save driver costs in the long-run only when normal attrition reduces the total number of drivers or, in an expanding transit system, where the number of runs is otherwise increasing.

One other observation on labor costs which is pertinent to the question of whether artics are right for a particular system: in agencies where labor rules limit the use of part-time drivers, the overtime and spread time premiums paid drivers (because of the need to cover peak period trips) can lead to the average driver cost during the peak hours being as much as 20 percent higher than the normal hourly rate.[1] The more peaked the operation is, the more significant this effect becomes. Accordingly, the articulated bus' potential for labor cost savings is going to be greater in systems with limitations on part-time drivers and/or heavily peaked

[1]Herzenberg, Anne; **A Method for Estimating the Costs of Driver's Wages for Bus Services.** This paper calculated the average peak hour wage rate for the MBTA in Boston to be 20-25% higher than the basic wage rate before the MBTA made use of part-time drivers. Similar analysis performed on Denver RTD run cuts showed peak wage rates to be 7-9 percent greater than off-peak, and San Francisco (MUNI) 4 percent higher.

operations. Furthermore, heavily peaked operations where part-time drivers can be used, like Seattle, are very conducive to the deployment of artics, too, because the part-timers can drive the trippers during the peaks, using the artics, then take the artics back to the garage during the base period when they are not needed.

Maintenance labor costs. While the maintenance experience of U.S. transit agencies with articulated buses is still very sketchy, a good rule of thumb is for artic maintenance costs per bus mile to be about a third more than for standard coaches. Several transit agencies owning artics have compiled separate maintenance cost factors for artics and standard buses, but none have compared buses of the same age with each other. Thus, although Seattle found 1983 artic maintenance cost per mile to be 26 percent **lower** than that of standard buses, this to some extent reflects the artics' relative newness compared to the fleet as a whole, rather than any intrinsic economies.

Preventive maintenance inspections for artics are reported to require 50 to 100 percent more time than for standard coaches. This is partly because there is simply more bus to inspect and perhaps partly because maintenance staff are still less familiar with the new artics than with standard buses. If the artic has air conditioning, then the presence of a second engine makes it almost certain that inspections will take twice as long. This ratio of 100 percent extra time appears to be a good rule of thumb.

Chapter IV discusses artic maintenance considerations in more detail. A few portions of the articulated bus, particularly the air conditioning system, have been notoriously unreliable, while other parts, such as the brakes, have performed especially well. Since articulated buses are relatively new to the American transit industry, it is likely that maintenance experience will improve as initial "bugs" are worked out of the equipment. This improvement is already noticeable. It is too soon, however, to tell how gracefully the new U.S. artic fleet will age. If the vehicles are built as solidly as many U.S. maintenance officials have observed, it is likely that maintenance costs will increase more slowly with vehicle age than they do for standard buses.

Fuel costs. Fuel economy of articulated buses, on a miles-per-gallon basis, runs about 92 percent of that of standard coaches, assuming the same status regarding the presence of air conditioning. Since both use the same fuel, this means that artic fuel cost per mile is likely to be 9 percent greater than the fuel cost for standard coaches.

Based on information from eight cities for the period from 1980 to 1983, average articulated bus fuel economy is 3.1 miles per gallon for buses with air conditioning[1] and 3.65 mpg for buses without air conditioning. Comparative standard bus figures from the same cities are 3.4

[1]It is actually about 3.1 mpg during the air-conditioning season. Assuming air conditioning is in effect only about 30-40% of the year on average, as in areas like Chicago, the Twin Cities, and Pittsburgh, the annual average fuel economy increases to about 3.35 mpg.

and 3.9 respectively. It might be noted that the standard bus fleet is, on average, older than the artic fleet, and consequently these standard bus fuel economy figures may reflect the age of the fleet. Reported fuel economy of some of the new standard size coaches is in the 4.5-5.5 mpg range.

The transit agency reporting the highest artic fuel economy is **Seattle,** with 4.01 mpg for its 280 horsepower artics without air conditioning. Seattle's temperate climate and large number of express routes probably contributed to this high mileage.

The property reporting the lowest fuel economy is **SCRTD in Los Angeles,** where its air-conditioned artics, used exclusively on local routes in heavy traffic, achieved only 1.97 mpg.

In 1982, **Seattle** augmented its fleet of 151 M.A.N. 280-horsepower artics with 202 of the new 310-horsepower version. Since then, METRO has noted that the newer, more powerful vehicles have achieved only about 91 percent of the fuel economy of the 280-horsepower artics.

Spare parts. The early experience of U.S. artic operators has been that spare parts of European (particularly West German) origin are much more expensive, often by a factor of 2 to 4, than comparable U.S. parts. Fortunately, the number of artics in the U.S., and therefore the quantity of spare parts available, is increasing; and current artics usually have many U.S.-made major components (typically engine, axles, transmissions, air conditioners, etc.)

MTC in the Twin Cities reports that in 1982 its spare parts cost 30 cents per mile for artics as opposed to only 17 cents per mile for standard buses, about 76 percent more.

SCRTD, in 1981, compared the prices of a sample of artic parts and comparable GMC parts, and found the artic parts to cost about 38 percent more.

Tires. Since articulated buses have three axles, it is not surprising that tire costs are higher than for standard buses. Also, transit systems owning artics have reported particularly high tire wear on the middle or driving axle. Based on the experience of Seattle, Minneapolis-St. Paul, and Los Angeles, since 1981, tire costs can be expected to average 5.5 cents per mile, which is 60 percent higher than the average for standard buses.

II-C. Ridership Benefits of Articulated Buses

Because of their higher capacity, comfort, new technology image, and novelty, artics have potential for increasing ridership. Most transit agencies have used artics to pursue this objective rather than to achieve operating cost savings. One-for-one substitution of artics for standard buses is common, particularly on express routes, where the added capacity and associated increase in comfort (more seats) has resulted in 10 percent to 20 percent ridership increases, but, of course at increased operating cost.

The Twin Cities reported noticeable ridership improvement particularly on express routes; they indicated that passengers perceived artics to be more comfortable, and they liked the "novelty".

Indianapolis likewise reported increases in ridership on express routes when artics were substituted for standard buses; their best judgment was that the increases were in the 10 to 20 percent range.

Articulated buses are also often placed into service as an integral part of special promotions or major service changes.

In **Chicago,** for instance, the initial shipment of 20 artics was rotated through most of the routes in the CTA system, to introduce the articulated bus to as many of CTA's patrons as possible. Then, on Sundays and holidays, the vehicles became "culture buses" serving three lines accessing museums and other cultural attractions. The buses were also used for special events such as baseball games, Chicago Fest, and events on the Navy pier, in addition to their normal use on overcrowded or low-headway routes.

In **San Francisco,** MUNI is using its artics and the resulting higher capacity to build up ridership on three routes which it is contemplating converting to light rail.

In **Portland,** Tri-Met uses its artics on six heavy trunk lines to increase passenger acceptance of its new Eastside grid route system.

Other agencies, more conscious of operating costs, have accompanied the introduction of artics with a reduction in the overall number of trips. Since this strategy increases headways, it could conceivably reduce ridership.

In **Pittsburgh,** for example, on a local route (91A, Butler Street), PAT is using 8 artics on a 10-minute AM peak headway to replace 11 standard buses on an 8-minute headway. Operating cost savings (productivity increases) were achieved without any discernible change in ridership.

Unfortunately, in no case did we find that actual changes in ridership were accurately measured when articulated coaches were substituted for standard coaches; reports of "no change in ridership", "noticeable improvement in ridership on express routes", or "10 percent to 20 percent increases in ridership" are based on qualitative judgments rather than actual counts. Nevertheless, a theoretical feeling for likely ridership impacts can be aided by considering five major characteristics of bus service which may affect ridership:

Travel Time
Headway
Crowding
Comfort
Image

Travel time. As will be shown in Chapter VII, for two good reasons, artics have more trouble than standard buses in keeping to a schedule:

1. Total dwell time is increased, partly because of slower door-opening time and partly because the increased passenger load leads to increases in numbers of passengers boarding and alighting over the course of a route. This can amount to a total of two or three minutes over a 40-stop local run. It is imperceptible on express routes with a limited number of stops.

2. Acceleration is slower, especially with full loads. Seattle has not found this to be a significant problem, but has reported that its new 310 horsepower artics perform noticeably better in this regard than the 280 horsepower artics.

Most transit properties using artics have found that the impact of longer running times is not large enough to warrant increasing the scheduled running time for most routes. However, in some local route cases, it has been necessary to add 7 to 10 percent more time to the schedule. If this adds noticeably to the average passenger's trip time, it may reduce overall ridership. Ridership response to increases in travel time varies dramatically depending on time of day, trip purpose, socioeconomic characteristics, availability of alternative modes, length of trip, captive versus choice, etc. There are several sources of information on short-run travel time elasticities (an elasticity is the percentage change in ridership attributable to a one percent change in service variable–in this case, bus travel time).[1] However, the figures vary so dramatically from one situation to another that it is difficult to suggest a figure to be used in analyzing articulated bus cost-effectiveness. A travel time elasticity of -0.3 would be an average value for peak periods. Off-peak elasticities are generally higher, with -0.8 being an average value. This implies that, on a route where the average passenger trip time increases by 7 percent, a ridership loss of 2.1% might be expected in the peak hour, and a 5.6% loss might be expected in the off-peak.

Stated in an easier to apply manner: As a general rule of thumb for an average (20 minute average trip length) bus route, peak hour ridership will drop by 1.5 percent for each additional minute of average passenger trip time.

Headway. If a route's headway is increased to take advantage of the artic's higher capacity, this is likely to reduce ridership. However, this effect is likely to be perceived only for headways greater than 5 minutes or so, where passengers really begin to notice the waiting time at bus stops. Headway elasticity data vary extensively from situation to situation, making it difficult to provide a sound figure for use in artic substitution economic analysis. From a composite of various sources, the following headway elasticities are suggested:

Original Headway	Peak Hour	Off-Peak
0-10 minutes	−.33	−.2
10-30 minutes	−.50	−.5
Greater than 30 minutes	−.50	−.8

This means, for example, that if artic substitution during the peak increases headway from 8 minutes to 10 minutes (25 percent increase), one might expect a ridership drop of about 8.3 percent. It is our opinion that the above table represents **maximum** elasticity figures; in fact, passengers are not likely to perceive small changes in headway

[1]One good source of transit elasticities is Lago, Armando M. et al., "Transit Service Elasticities: Evidence from Demonstrations and Demand Models", Transportation Research Board, 1981.

and, for long headways (say 30-minutes going to 40-minutes), passengers will be arriving by the schedule, not at random. While such headway increases might affect their travel flexibility, they probably would not increase average waiting time appreciably, so it is doubtful that such a service change would really produce a ridership loss anywhere near 16 percent as the table would suggest. A simplified rule of thumb is that ridership can be expected to drop by half a percentage point for each one-percent increase in headway (i.e. -0.5 elasticity), as long as the change is not very large.

Crowding. If the schedule is not changed, the increased availability of seating is likely to be the most visible effect of introducing artics on a route. Although few would question that this makes the route more attractive to passengers, no conclusive studies have been done to show just how large an effect this has on total ridership.

Comfort. Most of the transit properties owning artics have reported that riders find the buses to be more comfortable than their existing standard buses. In Los Angeles, an SCRTD passenger survey found that 63 percent of its riders thought artics to be more comfortable than standard buses, as opposed to 11 percent who found them less comfortable. An AC Transit (Oakland) survey saw similar results, with 67 percent of passengers finding artics to be more comfortable and 11 percent feeling that standard buses were more comfortable.

Both the Los Angeles and Oakland surveys further agreed on the assessment of comfort among age groups. Younger passengers, say less than 30 years old, found the artic substantially more comfortable:

	Age Group			
	0-30	31-59	60 +	Total
Oakland:				
Artic more comfortable	71%	63%	56%	67%
Standard more comfortable	8	15	18	11
Indifferent	21	22	26	22
Total	100%	100%	100%	100%

	0-29	30-49	50 +	Total
Los Angeles:				
Artic more comfortable	72%	65%	44%	63%
Standard more comfortable	6	10	23	11
Indifferent	22	25	33	26
Total	100%	100%	100%	100%

These survey results aside, it is not clear that there is anything intrinsic about an articulated bus that would make it any more comfortable than any other new, well-furnished bus. The positive results in these surveys could well be because of the newness of the vehicles and the lower load factors that come with direct, one-for-one substitution for standard buses.

The same two surveys (Los Angeles and Oakland) produced the following additional passenger perceptions about artics:

Artics are equally noisy, more so in the rear section:

Are Artics Noisier?

	More	Same	Less
Oakland	26%	43%	31%
Los Angeles	26%	47%	28%

The front doors of the artic were overwhelmingly felt to be easier to enter than the standard bus front doors; the rear doors were also felt to be easier to use on artics than standards, but not so overwhelmingly:

Are Artics Easier to Enter?

	More	Same	Less
Oakland	70%	24%	6%
Los Angeles	69%	22%	9%

Are Artics Easier to Exit?

	More	Same	Less
Oakland	47%	28%	25%
Los Angeles	51%	28%	21%

Image. The introduction of artics provides the transit agency with a great opportunity to bolster its image. The novelty of the vehicle attracts attention to the agency's new modern fleet. If this novelty is to be exploited, it should be done in the first two or three years, before the artic's newness wears off. Artics can be made the subject of advertisements and promotions, aiding the general effort to make the transit service more attractive to the general public. More than one transit agency has adopted the slogan, "Going to great lengths to serve you!"

In total, it is virtually impossible to predict overall ridership response to artic substitution for standard buses without actual ridership count and level of service measurements. How do all these ridership factors or effects balance out? There are no quantitative answers available, but all of the artic properties surveyed (and, of course there may be some pro-artic bias inherent in their statements) reported either no noticeable change in ridership on the route or a slight increase in ridership when artics were deployed.

II-D. Alternative Methods for Increasing Vehicle Capacity

Aside from articulated buses, a number of other technologies are available for improving vehicle capacity. Rail systems, for instance, can increase capacity per driver at the expense of higher capital costs and reduced routing flexibility. A great deal of literature already exists on rail versus bus alternatives analysis, so that will not be pursued here.

Another alternative is the double-decker bus. Although double-deckers were demonstrated in New York and Los Angeles under UMTA's Service and Methods Demonstration Program, they are not commonly used in the United States. However, there is extensive experience with them in Europe, and the potential exists for federally-assisted procurements in the United States. The advantages of this type of equipment are: its seating capacity, typically 25 percent greater than the capacity of an articulated bus; and its novel appearance, which can be a potential marketing tool. Its disadvantages are: its 14.5 foot height, which would cause vertical clearance problems in many American cities, and would require extensive modification of existing maintenance facilities; the internal stairway, which would be a major impediment to efficient loading and unloading; and the inability of drivers to adequately monitor the upper deck to prevent vandalism and crime.

Because of these limitations, the most common use of double-deckers in the U.S. is for special events and tourist-oriented transportation.

II-E. Conclusions

In general, a transit agency can benefit from the deployment of articulated buses **if** it has routes which are over-crowded and already operating at low headways; **if** it has a specific marketing or operations strategy in mind in which artics can help to reduce operating costs or increase ridership; and **if** the capital and start-up costs are not so high that they become prohibitive. This chapter has listed many of the factors which would weigh for or against a decision to deploy artics in a transit agency as a whole. However, whether articulated buses are more cost-effective than standard buses is a very complex, circumstance-specific situation, requiring analysis of each candidate route individually. Such a route-level analysis is demonstrated in the next chapter.

III

Identifying Potential Routes for Artic Deployment

Page

III-A. Identifying Routes Which Are Not Amenable to Artics 23
III-B. Identifying Clear Opportunities 25
III-C. Maintenance Bases and Route Choice 26

III.

Identifying Potential Routes for Artic Deployment

Since the most important difference between articulated buses and standard buses is the artic's greater passenger capacity, routes should be chosen for artic deployment based on how well the extra capacity can contribute to cost savings, increased ridership, or other organizational objectives.

In general, higher density routes with already short headways, overcrowded trips, high-cost trips, and/or the potential for ridership growth are prime candidates for artic service. If a ridership gain is an objective, then it is helpful to choose routes which can fit into a well-defined marketing strategy. Another type of route which has proven to be an attractive candidate for articulated buses is the peak period, heavy-volume express route, typically from suburban park/ride lots. Generally these are not low headway routes, and passengers tend to ride them according to a schedule rather than by random arrival at the bus stop. Thus any lengthening of headways due to the substitution of artics is not perceived as especially onerous; if a higher seat per passenger ratio ensues from artic substitution, it is viewed positively; and the artic's running time will not be significantly different from a standard bus if there are relatively few stops involved.

For most medium and large transit systems, there will be some routes which are obvious artic candidates based on current ridership and service levels, and some which are obviously out of the running. Routes which are marginal candidates based on detailed analysis can be chosen or rejected by considerations of marketing strategy or the need for a "critical mass" of artics at each maintenance base.

A number of scheduling strategies are available for artics on any particular route. They can be used all day or just during peak periods; they can be used on trippers only; they can cover an entire route or be short-lined, or be used exclusively for limited stop or express runs. Normally, then, the decision of whether to deploy artics on a particular route should be partly based on the scheduling opportunities available on that route. Scheduling considerations are covered more fully in Chapter VII.

III-A. Identifying Routes Which Are Not Amenable to Artics

In order to see which routes are most suited to artic use, it is useful to first determine which routes are **not** good artic candidates. If a route does not suffer from crowding,* and if headways are already long, then chances are that that route will not benefit from articulated buses. In fact, placing artics into service on such a route can even be counter-productive: if headways are not changed, the extra capacity will not be put to good use, and operating costs will rise (because of artics' higher operating costs per bus-mile); but if headways are lengthened, especially if they are already longer than 5 or 10 minutes, the quality of

*The definition of "crowding" will vary with the type of service. In high-speed express service, crowding could be anytime any passengers have to stand.

service will perceptibly go down, and so, presumably, will ridership. Routes like this do not need artics.

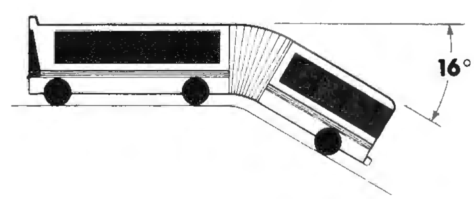
In 1978, the **Golden Gate Bridge, Highway, and Transportation District in Marin County, California,** took delivery on 10 articulated buses to be used to feed a ferry service from Sausalito to San Francisco, where heavy passenger loads were expected. When the ferry's demand did not live up to expectations, the artics were moved to local service on 30-minute headways. However, even on these routes, the extra capacity was not really needed. The artic was considered for commuter service into San Francisco via the Golden Gate Bridge, but could not maintain speed going up the long, steep grade to the Bridge from the north. Seeing this uneconomical use of artics, Golden Gate officials finally decided to sell the artics to Los Angeles.

Even if a route is over-crowded, there may be barriers to deployment or reasons why artics cannot be operated on it. If a route has narrow streets with heavy traffic and tricky turns, drivers may find it unreasonably difficult. Regardless of whether it is physically possible to operate on such a route, the exposure to accident risk and the added stress on bus operators may make it undesirable.

AC Transit removed their artics from a high-volume local route between Oakland and Berkeley because of heavy traffic and parking congestion; if cars were illegally parked in a bus stop zone, the longer artic could not pull all the way in, blocking traffic. Once in a bus stop, the heavy traffic made it difficult for the artic to re-enter the travel lane.

MTC (Twin Cities) declined to deploy artics on two routes, which otherwise were good candidates, because of the presence of bus wyes to turn the buses around. They felt that backing artics was tricky, could lead to damaging the turntable, and should be avoided if possible.

While the artic actually has a shorter turning radius than standard buses, the turntable can present some problems in the vertical dimension. In certain steep hill situations, such as found in San Francisco and Seattle, where a steep grade levels out at a crossing intersection, then returns to a steep grade, the turntable can be damaged if asked to bend too much vertically in traversing the intersection. Sixteen degrees is a typical maximum vertical bend, though this varies between manufacturers.



Long, steep grades may also make artic operation more inefficient, as was the case previously mentioned for Golden Gate. Bridge weight restrictions could prohibit articulated buses entirely. MTC (Twin Cities), for example, is prevented by weight restrictions from using artics on routes over the Lake Street bridge. In some cases, use of 55-foot artics can ameliorate these problems. An ordinance in at least one city, Pittsburgh, prohibits any buses longer than 55 feet.

Weather conditions may contribute to the exclusion of artics from certain routes.

Pittsburgh took artics off a particular route with steep hills when the artic had trouble climbing the hills in snowy or icy weather.

Denver and the **Twin Cities** mentioned traction problems with the artics in snow, especially when lightly loaded.

Other reasons for ruling out artics may include the cost of lengthening bus stop zones or the presence of neighborhood objections.

III-B. Identifying Clear Opportunities

On the other hand, many routes may be obvious candidates for articulated bus service. These routes include:

Peak-period trippers—These runs are often the most expensive to operate, since operators must be paid a guaranteed minimum number of hours and/or a spread premium. By substituting artics for conventional buses, the number of these expensive runs can be reduced.

Many transit agencies have labor agreement restrictions on the number of trippers which can be assigned to regular drivers (usually expressed as a minimum percentage of runs which must be straight 8-hour runs). The use of artics on tripper assignments allows the scheduler to provide needed peak-hour capacity without having to provide excess base period capacity to satisfy minimum straight run requirements.

Heavily-patronized trunk routes—These routes are characterized by frequent service and high ridership levels throughout the day, and generally require a substantial number of buses to meet the schedule.

The use of articulated buses on such routes allows the scheduler to better meet loading standards and/or adjust schedules to save costs. Artics can also serve to draw attention to the trunk routes as transfer opportunities, making these vehicles an important marketing asset.

Replacing double-headers—On some routes, especially those which operate on clock headways, it is sometimes necessary to run two standard buses on exactly the same schedule in order to ensure sufficient capacity. Often the second bus is an expensive tripper, since the added capacity is only needed for that one trip.

An articulated bus can replace this "double-header" and cut peak-period operating costs in half.

Since over-crowding of buses normally happens only during peak hours, and off-peak headways are usually determined by a maximum headway service policy, not by full loads, it is usually peak hour demand which makes articulated buses desirable on any particular route. However, there may be good reasons for operating artics in all-day service on these routes. One reason might be high deadheading costs. If an artic must be deadheaded to its garage after the A.M. peak to be replaced by a standard bus, which is deadheaded to the route, and if this process must be reversed before the PM peak, it may well be more economical to leave the artic in service all day, even though its capacity is only needed during peak hours. This must be costed out on a case-specific basis.

III-C. Maintenance Bases and Route Choice

Because of the need for special maintenance facilities, spare parts inventories, and specialized mechanic training, it is normally advisable to concentrate articulated buses in just one or two garages. Seattle METRO, for instance, operates artics out of only four of its six bases. However, this basing constraint can greatly reduce a transit property's flexibility in choosing articulated bus routes, since some routes would suffer very high deadheading costs.

Once a set of candidate routes has been chosen, therefore, it should be narrowed down by selecting one or two appropriate garages (preferably garages which can be easily adapted to the larger buses without incurring high capital costs) and eliminating those routes which cannot easily be operated out of them. It may be necessary to shift routes between different bases in order to concentrate the artic routes without adversely affecting the distribution of work load among facilities.

IV

Maintenance of Articulated Buses

Page

IV-A. Startup Issues 27
IV-B. On-going Maintenance 32

IV. Maintenance of Articulated Buses

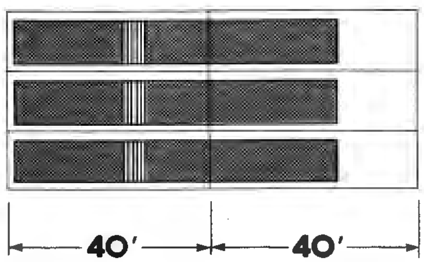
(Note: This chapter was prepared, in large part, by Richard Bertz, former Maintenance Manager at AC Transit in Oakland.)

Articulated buses, overall, have proven to be solidly built and reliable. A few maintenance problems have arisen, but nothing unusual for a new technology. When troubles have surfaced, the manufacturers have been very helpful in almost all cases. However, maintenance of artics is in many ways different from standard buses, because of their European design, their extra length, and the presence of certain systems, such as the turntable, which are not present on other buses. In general, because of low labor costs in Europe (relative to materials costs), maintenance of European-design buses is more labor-intensive than American vehicles.

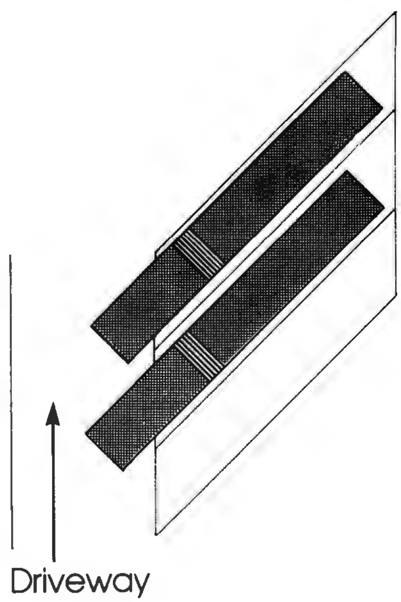
IV-A. Startup Issues

One issue which can make artics look far more attractive to some properties than to others is the degree to which existing maintenance facilities can be adapted to articulated buses. If it is necessary to construct an entirely new garage to house the extra-large buses, this can make the deployment of artics quite infeasible. Other considerations which affect the feasibility of articulated buses include the need for special tools and towing equipment, separate spare parts inventories, and extra training of mechanics. In general, it is important for the transit property as a whole, as well as each specific garage housing artics, to have a "critical mass" of vehicles in order to justify the high capital and startup costs and to properly motivate maintenance personnel to specialize in artic maintenance.

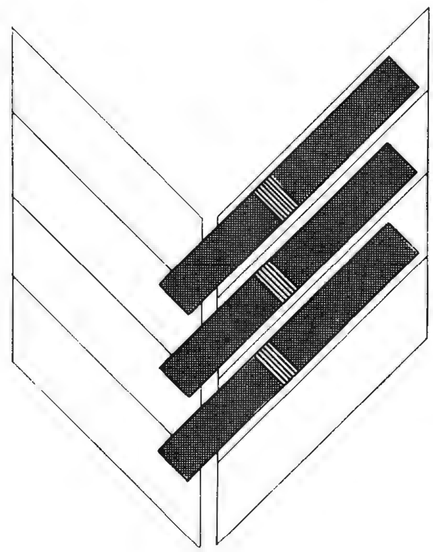
Yard parking and servicing. In a typical bus parking yard, an articulated bus will take up at least twice as much space as a standard bus. If buses are parked one behind the other, an artic will need two stalls:



If buses are parked in a herringbone pattern, an artic will block one driving lane:



If buses are parked in a chevron style, two or more stalls may be lost:



In general, articulated buses can be maneuvered anywhere in the yard that a 40-foot bus can. Traffic flow should be designed with left-turns, however, to compensate for driver blind spots on the right side of the bus. In addition, the fuel island and wash racks must be compatible with artics; there must be sufficient distance between the wash rack and the fuel island to make it possible to maneuver the artic from one to the other.

Shop area. The physical facilities for maintaining and storing artics should be considered carefully. Many parts and repairs involve access to the underside of the bus. There are several ways to accomplish this:

- **floor area of 65 level feet plus room on the side for wheel hoists;**
- **three-post hoists with lifting points at the six wheels or the three axle areas;**
- **pits which are 65 feet long;**
- **six portable wheel/body hoists;**
- **drop pit hoist (used mostly for paint shops).**

Many systems have selected portable hoists, since they are useful for any vehicle. They cost about $50,000 for the six lifts and the control unit needed for one bus. Three-post hoists and 65-foot pits are more expensive, typically costing $80,000 and $75,000, respectively.

Garages in which artics are to be hoisted must have ample clearance for the entire 60-foot length of the vehicle. A ceiling height of 17 feet is recommended, so that the bus can be raised 5 feet off the floor.

If pits are used, it is useful to have a work area or drop section around the engine/transmission area. A transmission can be pulled out using a pit and pit hoist, but it is easier and safer to use a hoist which raises the entire bus. Some shops have

connecting pits which enable pits for 35 and 40 foot buses to be combined and used for maintenance of artics. In this case, a grease hose would be needed in both pit areas, and the oil drain piping may have to be moved to meet the artic under the engine.

Shops without a hoist or 65-foot pit will have a problem servicing articulated buses. The only way it can be done is to back the bus over the pit to service the trailer section and then turn it around to do the front section. This is awkward and time-consuming.

> **Portland** discovered this problem in one of its garages where the pits were too short. It was so awkward to move the back end of the bus over the pit that mechanics were found to be neglecting the trailer end in inspections. More careful supervision was needed to eliminate this practice.

Regardless of the type of hoist or pit used, bays should be long enough that the garage doors can be closed. Outside, there should be at least 60 feet of unobstructed space for maneuvering buses into and out of the garage.

Spare parts. As much as is practical, it is best to maintain all artics out of one shop so that they can share the same parts supply. The stock of parts required is almost the same for any number of buses up to ten, so it is recommended that at least ten buses be maintained at each site. As the number of buses increases, the supply of parts will have to be adjusted as well.

> **AC Transit in Oakland** learned from its own experience the importance of operating all artics out of the same maintenance base. They had 3 artics at one division, 5 at another, and 22 at a third. At the first two, particularly the first, maintenance personnel were always looking to the other division for parts, causing many morning runs to be missed.

Spare parts have proven to be a source of major problems, particularly for parts which come from Europe. These problems include cost, availability, delays in delivery, and adequacy of parts descriptions and price lists. Availability and delay problems are being alleviated as manufacturers expand their U.S. operations, and the entry of independent parts suppliers may improve the situation even more. For now, though, it may be advisable to specify a large spare parts inventory with the initial vehicle procurement. On average, the cost of spare parts per vehicle has typically been half again as much as for standard buses, though this difference drops considerably for systems with large artic fleets.

> Most artic systems report that they do not customarily keep a larger parts inventory for artics than for standard buses, though at least one, **SCRTD**, keeps an extra supply of about ten specific components for which usage is especially high, including relays, bearings, and radiator caps.
>
> **Seattle METRO** has found that spare parts prices have dropped dramatically in the past several years as US manufacturers begin to produce more parts for its M.A.N. artics. This has often forced M.A.N. to reduce its own prices accordingly. Although parts were initially difficult to obtain, most

can now be ordered with a two-week lead time. METRO placed a large parts order with its initial purchase of artics, correctly anticipating delivery problems. However, in its second order, four years later, Seattle ordered only minimal quantities of parts. Now, Seattle's artic spare parts stocking levels are not much different from those for its standard buses.

Tri-Met has found spare parts for its buses to be exceedingly hard-to-get and expensive, though the situation is improving. At times, buses have been out of service for literally months waiting for parts.

San Mateo (SamTrans) reports that as many as five out of their ten artics are out of service because of unavailability of parts.

Special tools. Because of the high foreign parts content of most articulated buses, it is normally necessary to acquire sets of metric tools. Certain special tools are usually provided with the vehicles in the initial procurement. Examples are: transmission jacks, with adapters for alternators, suspensions, and other components; electric test equipment; engine tune-up, repair, and diagnostic equipment; and transmission diagnostic, repair, and assembly/disassembly tools. For some artics, special towing equipment may also be required.

Training. All mechanics who work on artics should receive special training. In most transit systems with significant articulated bus fleets, all mechanics in the garages where artics are housed are trained. Usually, the manufacturer stations one or more of its own technicians on the transit property for periods of up to a year. Training methods range from informal "apprenticeships" for interested mechanics, up to formal classroom-type training for everyone. Articulated bus training normally takes longer than conventional bus training, because most mechanics are unfamiliar with foreign bus designs and the metric system.

SCRTD's aim is to give each of its mechanics 200 hours of training under direct supervision before allowing him to work unsupervised, followed by 800 hours of additional experience needed before an apprentice mechanic is considered fully qualified.

MTC in the Twin Cities gives its mechanics 80 hours of special artic training.

Seattle maintenance officials estimate that 40-120 hours of classroom and/or on-the-job training is required for a journeyman mechanic to familiarize himself with artics and be able to work on his own.

It is very important that a portion of the maintenance personnel in each garage become artic specialists. These people will, either formally or informally, become familiar with the fine points of articulated bus maintenance, and will be responsible for the training of new mechanics after the manufacturer's representative has gone. Most artic systems have found that no special incentives are needed to encourage specialization, since there are usually plenty of mechanics who will become interested on their own. It is important that enough artics be concentrated in each garage so that a significant portion of the mechanics' time is spent on this equipment.

IV-B. On-going Maintenance

Preventive maintenance inspections. It is more time-consuming to inspect an artic than it is to inspect a standard bus because there are more areas to check and service. Areas of particular concern are:

Turntables—These must be inspected for jacknife switch adjustment, and greasing.

Air-conditioning—Artic systems are larger than those used on standard buses. Many agencies have reported problems with equipment reliability and coolant leaks. The air conditioner on artics usually has a separate engine, and this can easily double the amount of time needed for inspections.

Oil and filter changes, and lubrication—In most cases, European buses require more oil changes than U.S. buses.

Third axle steering—The linkage between the steered rear axle and the turntable must occasionally be inspected and lubricated.

Belts—These must be serviced almost daily. Artics use more belts than standard buses.

Brakes—While most maintenance activities are more expensive on artics than on standard buses, brake life has been reported by several agencies to be better than conventional buses.

In all, it is common practice to allow 50 to 100 percent more time for an artic preventive maintenance inspection than for a comparable standard bus inspection. Most transit agencies inspect artics on the same schedule as standard buses, usually every 6000 miles.

Common complaints. While most mechanics are very satisfied with the articulated bus, certain complaints are so common that they deserve special mention:

Air-conditioning—The air-conditioning system has been a continuing problem for many transit operators. Most often, the problem involves deterioration and leakage of coolant tubes, or breakdown of the air-conditioning system's separate engine. In cities with hot climates, the air-conditioning system can be the number one cause of road calls. The problem with air-conditioning systems on early artics was exacerbated by the location of the engine exhaust, which caught hot air underneath the bus when it was stopped and overloaded the air-conditioning system. This has since been addressed.

Cooling system—Since the cooling system on most artics is located underneath the bus, articulated buses operated in heavy traffic on hot days are similarly prone to overheating.

Electrical system—Several transit agencies have commented that the electrical system on artics is unusually complicated. This makes it harder to trace electrical problems and adds to the time necessary to train mechanics. Seattle, however, has found its artic electrical systems to be more reliable than those on its standard buses.

Engine seals—On early M.A.N. buses, certain transit agencies have experienced premature engine failure due to deterioration of engine seals after as little as 100,000-150,000 miles. This problem appears to have been corrected on more recent vehicles.

Engine location—On all but Neoplan buses, the engine is mounted under the floor of the bus in the front section, making it particularly difficult to access.

On the positive side, artic maintenance officials have almost universally praised the effectiveness and reliability of the automatic brake adjusters, which are credited with the artic's long brake life.

Portland has experienced unusually severe maintenance problems, including malfunctioning transmissions, differentials, and wiper systems; cracked frames; and poor documentation, especially wiring diagrams and parts lists. These have led to per-mile operating costs thrice the standard-bus level, and road call mileage only a third of what is achieved with conventional buses. Many of the poorly-functioning parts are American-made components appearing for the first time in a European articulated bus design. The manufacturers of Tri-Met's artics and artic components have been working in campaigns to replace or rebuild many of the defective parts. Since Portland has the first large fleet of Crown-Ikarus coaches ever manufactured for a US transit agency, it is likely that more recent orders will have fewer of these initial problems.

Road calls. On average, after an initial get-acquainted period, artics have a better road call record than conventional buses. This is partly because the U.S. artic fleet is much newer than the standard bus fleet. Part of the reason may also be the intrinsic reliability of many of the artic's systems, though there is not enough experience in the U.S. to prove this. Here is a breakdown of the road call experience in recent years at selected U.S. properties:

		Miles between road calls		
		Artic	**Standard**	**Ratio**
Twin Cities	(1979)	18,958	2,651	7.15
	(1980)	12,475	2,632	4.74
	(1981)	16,333	3,123	5.23
	(1982)	14,217	3,426	4.15
Seattle	(1979)	3,704	2,174	1.70
	(1980)	3,956	1,812	2.18
	(1981)	4,133	2,286	1.81
	(1983)	5,649	2,758	2.05
Chicago	(1979-80)	2,273	3,448	0.66
Phoenix	(1979-80)	2,941	6,667	0.44
Portland	(1984)	1,025	2,943	0.35
L.A.	(1983-84)	890	3,192	0.28
Pittsburgh	(1983-84)	2,132	3,340	0.64
San Jose	(1984)			
M.A.N.		5,759	2,890	1.99
Crown		1,834	2,890	0.63
Oakland	(1984)	1,471	2,227	0.66

It is apparent that the road call list varies widely, probably due to a great number of local factors, age of the fleet, definitions of road calls and reporting conventions, and differences in maintenance procedures. The Twin Cities clearly and consistently has had exceptional road call experience with its artics. Seattle likewise has consistently experienced fewer road calls with its artics than with its conventional buses. Los Angeles and Portland, it would appear, have had unusually bad experience with artics. Chicago, in 1979-80 showed more road calls on artics (i.e., fewer miles between road calls) than standards. However, by 1983-84 Chicago reported 2,990 miles between road calls for standard buses, and a larger number (fewer road calls per mile) on artics.

Seattle and Portland's artics do not have air conditioning whereas all the other systems shown in the above table do.

Phoenix's standard buses are 1979 GM RTS-II's, as are Los Angeles'. Seattle's and Chicago's standard fleets are largely 1976 vintage (AMG's and GM's respectively), and the greater age there may account for the relatively poor road call performance of their standards as compared to Phoenix's and Los Angeles'. Because of definitional differences, one is cautioned to pay more attention to the relative ratios from each property rather than absolute numbers of miles. One clear observation is that the properties which use their air-conditioning systems most frequently (e.g., Phoenix and Los Angeles) are among the lowest in mileage between road calls.

V

Other Startup Issues

V. Other Startup Issues

While the provision of maintenance facilities is the most critical of startup issues in articulated bus deployment, several other provisions should be made for effective artic operations. Even though most of these are commonly referred to as operating issues, they really are legitimate start-up costs which should be considered in the decision of whether to procure articulated buses.

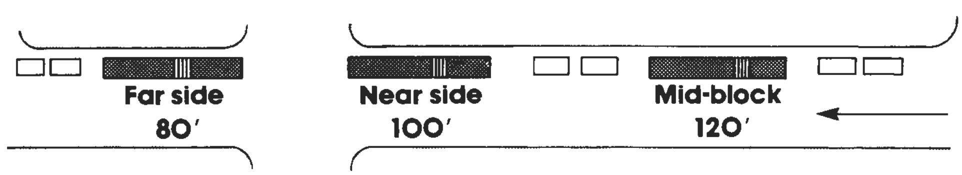
Driver training. The most important non-maintenance issue is driver training. Most agencies owning artics train 100 percent of the drivers in each base operating artics. Usually, no special incentive is required, except that drivers are paid their normal wage for the training time. Typically, artic training consists of 45 minutes to 2 hours of classroom time and two to five hours of on-the-road practice, followed by special certification. Most agencies have reported that artics are no more or less difficult to drive than standard transit buses. There are no overall discernible driver preferences, though some individual drivers favor artics and others prefer standard buses.

Bus stop length. Most properties find that articulated buses cannot effectively use standard bus stop zones without obstructing a lane of traffic in either the travelling street or the intersecting street. If zones are not lengthened, drivers will have a tendency to stop entirely within the traffic lane to avoid complicated maneuvers. Figure V-1 shows suggested minimum bus zone lengths needed for one articulated bus to pull entirely out of the traffic stream.

If traffic lanes are narrow, or if the bus must turn before or after the stop, it is advisable to add 20 or more feet to these suggested lengths. Lengthening of a bus zone normally involves repainting pavement markings and, occasionally, removing a parking meter. For far-side stops, the bus stop sign should be moved to the new far-end of the zone. In some cases, because of driveway cuts or sidewalk obstructions, it may be necessary to move the entire bus stop to a new location.

Schedule changes. In order to make use of the extra capacity of articulated buses, it is usually necessary to revise bus schedules. Chapter VII discusses this subject in detail. When, as is commonly the case, artics are deployed on existing low-headway routes, it is normal

Figure V-1. Articulated Bus Stop Lengths



practice to replace standard coaches with artics in a fixed ratio, such as 2 for 3, 1 for 2, or 1 for 1. In cases where artics and standard buses are mixed on the same route, schedule adjustments may be necessary to prevent bus bunching because of the tendency of a fully utilized artic to take longer to make the trip. Running time adjustments may also be necessary, because artics in local service typically have longer dwell times than standard buses, and therefore have a lower average speed. The cost of changing a schedule usually involves time spent by schedule-writers, possibly computer time, and the printing and distribution of new public information materials.

Other problems. A final consideration which applies when deploying any new equipment is that all sorts of minor startup problems are bound to occur. Some of these should be searched out in advance; examples are administrative changes, information system changes, parking and curb radius changes where artics have to turn tight corners, and minor equipment changes such as air, water, and fuel hose lengths. Others cannot possibly be anticipated. It is always prudent to make allowances for initial "bugs", and not to be too disappointed or frustrated if things do not work out perfectly on the first day, or even the first year.

VI

Operating Issues

		Page
VI-A.	Turns	37
VI-B.	Acceleration and Hill Climbing	39
VI-C.	Handling	39
VI-D.	Turntable Damage	40
VI-E.	Fare Collection	40

VI. Operating Issues

For the most part, artics are not much more difficult to operate than standard buses. Only a few minor changes in operating procedures may be required. Driver training programs usually emphasize the unique characteristics of articulated buses, showing new artic operators that the equipment is not as intimidating as it may seem.

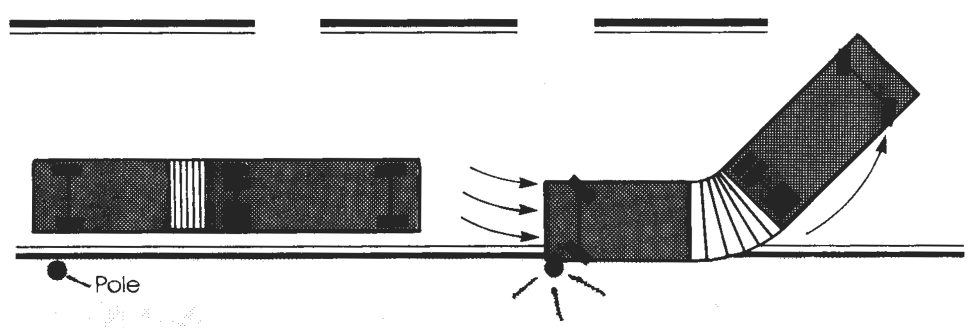
VI-A. Turns

The primary purpose of the hinge in an articulated bus is to allow the larger bus to turn the same corners as a conventional bus can. Generally speaking, a 60-foot artic will turn within the same inner and outer radii as a conventional 40-foot bus, and a 55-foot artic will have turning radii several feet smaller. Several manufacturers (including M.A.N. and Crown-Ikarus) increase the inside turning radius by designing the rear axle to steer into a turn as the center hinge bends. This allows the rear wheels of the bus to follow closely the track of the middle wheels, rather than dragging inside the turn radius of the front section, as occurs with a simple trailer arrangement.

With the steering wheel turned to its maximum position, the outside rear corner of the bus will move some 34 to 42 inches outside the pre-turn position of the bus. This "swing-out" has often caused minor accidents as the back of the bus hits sidewalk fixtures or other vehicles. It is even possible for the rear wheel to climb onto the curb as an artic makes a sharp turn into traffic as illustrated in Figure VI-1.

The problem of swing-out accidents has been reduced somewhat in recent procurements by specifying a tapered rear end, or by setting a limit on rear corner excursion, which has the same effect. Typically, tapering the rear end from 102 inches to 93 inches can reduce swing-out from 34 inches to 25. This significantly reduces the exposure of the outside rear corner to accidents. Of course, increased driver experience with artics likewise reduces swing-out accidents.

Figure VI-1. Swing-Out Accident Caused By Turning Trailer Wheels



Other ways of reducing swing-out accidents include driver training and warning signs with messages such as, "Caution: Bus swings out on turns," posted on the rear of the vehicle. Certain articulated buses, especially pusher designs such as those used by Neoplan and others, do not have steerable rear axles and therefore do not suffer from swing-out accidents, though the tradeoff there is in turning radius.

Accident data from **Seattle** indicate that the overall rate of reported on-the-road accidents is slightly greater for artics than for the rest of the fleet. Only 12 percent of reported accidents with artics are the result of the rear swing-out. Two-thirds of these are collisions with fixed objects, and one-third with other vehicles. None involved pedestrians. It is likely, however, that many minor scratches and bumps were not reported. In fact, drivers are often not aware that any contact was made in minor accidents, since it is not possible to see the outside rear corner while in the midst of a turn. METRO officials believe that the frequency of rear swing-out accidents has been reduced as bus operators and other drivers become more familiar with the articulated bus. Interestingly, a relatively large number of Seattle's artic accidents (18 percent) are in the "front door falling" category. Seattle's artics are wheelchair lift-equipped, and the stepwell configuration to accommodate the lift has accounted for the unusually high frequency of this type of accident.

Chicago's accident experience supports Seattle's; both report no clear difference in accident rates between artics and standard coaches.

Atlanta reports that their Neoplan artics have about the same accident rate as their standard coaches, but they have experienced a higher accident rate with their M.A.N. artics with the steering rear axle.

Most **other agencies** have reported somewhat worse accident experience with artics than with standard buses:

		Miles per Accident		
		Artic	Standard	Ratio
Seattle	(1983)	15,444	16,266	0.95
Twin Cities	(1979)	5,833	18,700	0.31
	(1980)	14,786	19,314	0.77
	(1981)	20,631	26,091	0.79
Phoenix	(1979-80)	12,987	26,315	0.49
L.A.	(1983-84)	6,372	17,692	0.36
Oakland	(1983-84)	10,229	22,854	0.45

SCRTD in Los Angeles indicated that one of their "unexpected" costs associated with artics was the heavy public liability/damage costs (self-insured) because of the high artic accident rate. These costs have been estimated at 32.6 cents per mile for their artics, as opposed to 15.4 cents for their standard buses. Contributing to this are SCRTD's predominantly local service usage and the older-design trailer sections which are not tapered.

VI-B. Acceleration and Hill-Climbing

A fully-loaded articulated bus can weigh up to 1.55 times as much as a fully-loaded 40-foot bus. However, practical considerations such as space limitation place a limit on the total engine power which can be supplied. As a result, artics generally have less power for their weight than the 8-cylinder buses which many systems currently operate, although the power-to-weight ratio is comparable to many standard 6-cylinder buses. The lack of power and poor acceleration of artics is a common complaint of drivers at some agencies.

In normal operation in level terrain, the slower acceleration of artics does not affect operations or running times. However, the lack of power can be a factor on steep grades or in heavy traffic. For this reason, some systems avoid scheduling artics on hilly routes. Articulated bus manufacturers now offer optional lower final drive ratios or higher horsepower engines for agencies which are concerned about acceleration.

In 1982, **San Francisco MUNI** tested a 305 horsepower M.A.N. artic (drive axle gear ratio of 5.22:1) and a 350 horsepower Crown-Ikarus artic (gear ratio 6.63:1) on some of its most hilly routes. MUNI found that the artics could climb grades of up to 24 percent, even with passenger load factors of 1.5. However, significant delays were experienced on such steep routes. The larger engine on the Crown test vehicle made a great difference in the time needed to climb hills. When tested on a street with two successive 1-block-long grades of 24 percent, the Crown was able to climb the hill almost twice as fast as the less-powerful M.A.N. bus (94 sec. vs. 169 sec.).

VI-C. Handling

Several agencies have reported a tendency of artics to "fishtail" at highway speeds, causing some discomfort to passengers seated or standing in the trailer section. Seattle's METRO placed a 50 mph speed limit on artics to reduce this action. The problem has been attributed to the habit of some drivers to make frequent course corrections with a small, sharp turn of the wheel, which is then amplified by the steering rear axle. Directives to drivers have largely eliminated this problem.

Another handling problem experienced at some properties is unusual sliding under slippery conditions.

Pittsburgh's PAT, for example, does not dispatch artics during sleet or snowstorms. Although the buses are equipped with drive-wheel sanders, PAT believes that the weight on the drive axle is not enough to provide the necessary traction to climb hills under these extreme conditions.

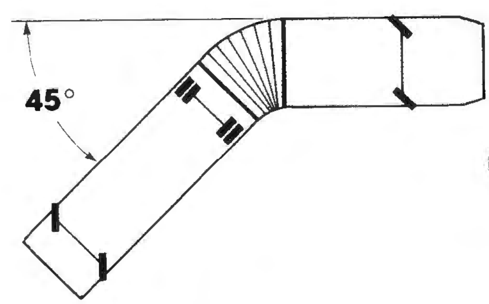
Seattle's METRO instructs drivers to turn off the automatic transmission retarder during poor traction conditions to avoid jacknifing of the trailer. While this practice leads to increased brake wear, it does not interfere with safe operation.

The **Twin Cities' MTC** reported that artics are much more susceptible to getting stuck in snow and ice.

Finally, the **Chicago Transit Authority** has noted that the trailer portion of its artics responds especially poorly to deteriorated road conditions at high speeds.

VI-D. Turntable Damage

The turntable between the front and rear sections, particularly on artics with steered rear axles, is vulnerable to damage when operated in reverse by inexperienced personnel. This problem is especially important for maintenance personnel who must maneuver the vehicles around the garages. The maximum bend for an articulated bus is between 38 and 48 degrees, depending on the manufacturer. If the maximum is exceeded, the brakes are typically designed to lock up automatically. However, if the bus is backing up at more than two or three miles per hour, the lock-up may not stop the bus in time to prevent turntable damage. It is very important to train all drivers and mechanics on this point.



VI-E. Fare Collection

The double-width doors typically provided on articulated buses can greatly improve loading and unloading efficiency over standard coaches, but this advantage can be realized only if fare collection procedures allow it. If the front door becomes a bottleneck for all boarding passengers, dwell times at heavily-used stops may be greatly increased, thus reducing the overall efficiency of operations.

The front door bottleneck is of particular concern on outbound routes during the evening rush hour. On inbound routes, a pay-as-you-board policy minimizes dwell times by allowing passengers to exit from any door at the crowded downtown stops. However, on outbound runs, there is no clearly-preferred fare collection strategy. If a pay-as-you-board strategy is used, loading of passengers at crowded downtown stops is slowed by the need to use the front door and the need for standing passengers already on the bus to repeatedly shift toward the rear while the bus waits. (On inbound runs, this shifting is more likely to occur while the bus is in motion, since fewer passengers board at any particular stop.) If a pay-as-you-leave policy is used on outbound runs, passengers in the rear of the bus must go all the way to the front in order to get off, often while the bus waits for them. Neither of these policies makes complete use of the articulated bus' door capacity.

An alternative which has been tested in **Portland** is self-service fare collection. In this system, passengers are allowed to board and alight through all doors. In fact, Portland's artics are equipped with three sets of doors to further increase loading and unloading speeds. Passengers are expected at all times to carry a proof of payment, which may be a monthly pass, a validated ticket (ticket validation machines are located on-board at each door), or a fare receipt (which must be issued by the driver, using another machine). Fare inspectors occasionally ride each bus to check for proof of payment and issue citations, similar to traffic tickets, to passengers who have not paid.

Portland's self-service program was phased out in June of 1984 after nearly two years of operation, partly because dwell time reductions were not enough to lead to an actual reduction in operating costs. However, Tri-Met still uses all three doors for boarding in its downtown fare-free area.

While Portland's use of self-service fare collection was partly motivated by the desire to own articulated buses, there is no evidence that any other transit agency has changed its fare policy to accommodate artics.

VII

Scheduling of Articulated Buses

Page

VII-A. Running Times 43
VII-B. Mixing Artics With Standard Buses 44
VII-C. Alternative Service Types 46
VII-D. Peak-Only versus All-Day Service 46

VII. Scheduling of Articulated Buses

Part of the cost of bringing articulated buses into the fleet is the need to adjust schedules to match the added capacity to demand. Because of the cost and disruption of schedule changes, some agencies perform only incremental changes to gradually adjust for artics over time. Others, whether because of planned major service changes or because of a desire to realize immediate operating cost savings, will rewrite the whole schedule at once. In any case, if a reasonable estimate of eventual operating cost savings is to be developed, it is important to make at least a rough cut, on paper, of the eventual schedule.

VII-A. Running Times

In certain kinds of service, the articulated bus is somewhat slower than conventional buses providing the same total route capacity.

AC Transit (Oakland), in their 1981 Cost-Effectiveness Report, indicated that articulated buses took up to 10 percent longer on local routes.

SCRTD (Los Angeles) found that artics took 7 percent longer on a heavy local route.

The **Metropolitan Transit Commission (Twin Cities),** in their 1982 Cost Effectiveness Report on Articulated Buses and again in recent comments, stated that it was a slight problem, but had not accurately quantified it; they had increased the scheduled running time on one express route when artics were used.

Seattle METRO indicated no significant running time differences, at least none requiring schedule adjustments.

MUNI (San Francisco), in a brief experiment with three different makes of articulated buses each operating in three weeks of regular service on their heavily traveled Geary Boulevard route, showed artics taking 6 percent to 15 percent longer. They are now adding about 10 percent to the scheduled running time on routes served by their new artics.

Chicago Transit Authority has reported that there is no appreciable difference between artic and standard bus on-time performance.

Portland added 3 to 6 percent to the scheduled running times of its city routes, but none to its suburban routes.

Four different factors contribute to this reduction in overall speed:

Slower acceleration
Longer dwell times
More frequent stops
Difficulty of merging with traffic

Acceleration. An articulated bus equipped with its standard engine has a power-to-weight ratio similar to the least powerful standard coach. On level terrain, this lack of power does not have a very significant effect on running times, but on hills the degradation can be large.

Dwell times. The time required for an artic to make a stop is longer than that required for a standard bus because the double-width doors take longer to open (typically 2.5 seconds more per stop), and because, if the load is to be greater, more passengers board and alight at each stop. The latter factor results if the artics have managed to attract more passengers, or if headways have been

increased to take advantage of the extra capacity. The dwell time can be reduced somewhat if the vehicle has three doors instead of the standard two, or if self-service fare collection is used.

Both **AC Transit** and **SCRTD** originally had double width rear doors, separating alighting passengers into two streams by using a center stanchion in the stairwell. However, with the doors opening inward, there were a number of reported incidents of feet or umbrellas becoming caught in the opening door. Both agencies retrofitted their rear doors by taking out the center stanchion and adding shields or guards in front of the area into which the doors opened to avoid this problem. However, it also limited the alighting passengers to a single stream.

Frequency of stops. In normal service, buses can often bypass stops where no one is waiting to be picked up or let off. With greater passenger loads, the articulated bus will have a greater probability of having to stop at each bus stop, and these extra stops will have a direct impact on travel time. The time required for a bus to decelerate to a stop and accelerate again to normal speed (excluding time to open the door and board passengers) is typically 8 to 12 seconds.

Merging with traffic. On routes where general traffic is heavy, articulated buses may require additional time to wait for a sufficient break in traffic to enter the traffic stream. While bus drivers seem to be aware of this problem, it has a significant impact on travel time only in the most extreme cases.

Overall, the speed differential between artics and standard coaches in local service is seldom more than 10 percent, or 6 minutes in a one-hour trip. This is less than the amount of schedule recovery time normally given to a route, but large enough that running time adjustments may be desirable, especially on hilly routes.

VII-B. Mixing Artics with Standard Buses

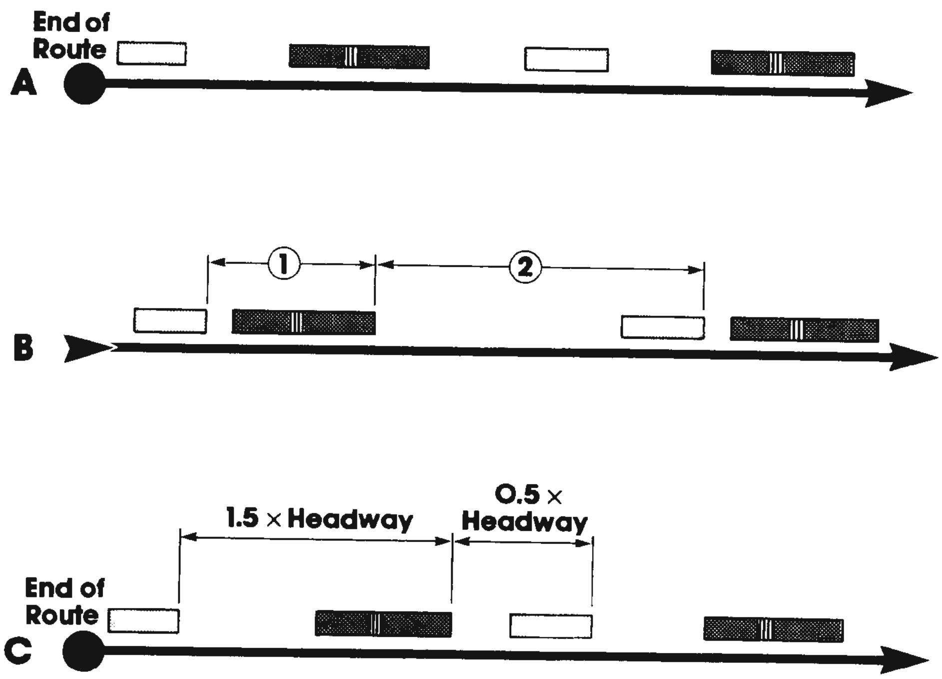
If articulated and standard buses are mixed in the same service on a short-headway route, the difference in running times between them can sometimes degrade overall service quality. For example, if artics and standard coaches are dispatched alternately from the same point, they will initially be spaced evenly along the route, as shown in Figure VII-1(a). But soon the artics will begin to fall behind. Because of the short distance (1) between each standard coach and the artic ahead of it, the standard bus won't have many passengers to pick up and will begin to catch up with the artic. Also, because of the long distance (2) between the artic and the standard bus ahead of it, the artic will have more passengers to pick up and will fall further behind. Finally, the standard bus will overtake the artic. This is demonstrated graphically in Figure VII-1(b).

Bus bunching is normally a problem only on long routes with short headways and many stops. As a rule of thumb, for a speed difference of 5 percent between artics and standard buses, bunching should be a concern if the headway is less than 10 percent of the running time between layover points. Even in these cases, simple measures can be taken to prevent bunching:

- **Buses can be allowed to pass each other;**
- **Additional running time can be added to the schedule and the standard bus requested to adhere to it; or**
- **Artics can be released slightly ahead of schedule, as shown in Figure VII-1(c).**

With these measures available, few artic agencies have reported significant unresolved problems with bunching.

Figure VII-1. Scheduling a Mixture of Articulated and Standard Buses on a Route



VII-C. Alternative Service Types

So far, artic service has been assumed to be local service over an entire route length, but this does not have to be the only option. Often, if artics are to be mixed with standard coaches on the same route, it is possible to use an alternative mode such as:

Express
Short-Line
Limited stop

Using the two different vehicle types on two different kinds of schedules can reduce problems with speed differentials and bunching; can decrease travel times; and can make the service more attractive and easily understood for passengers.

Express. A very common use of artics is in express service. These tend to be the most expensive routes for a transit agency to operate, and so they benefit greatly when the number of runs is reduced by articulated bus service. Since passenger loading and unloading is concentrated at the ends of the trip, artics do not have significantly longer running times than standard coaches on express routes.

Short-line. If bus bunching is a problem on particularly long routes, the effect of speed differentials can be reduced by turning certain runs around at intermediate points along the route. The shorter trips have less trouble keeping to the schedule, and provide higher levels of service on the more heavily travelled inner portions of radial routes. When a bus has turned around at a short-turn point, it can be released on a fixed schedule or on a run-as-directed basis. In the latter case it can be used to fill a gap between buses, to stabilize headways on inbound service.

Limited stop. Another way to reduce the number of stops and to separate artic from standard coach service is to run one of the vehicle types in limited-stop mode. This is a useful technique on heavy trunk routes where there are clearly-identifiable concentrations of ons and offs spaced evenly along the line. Limited-stop trips can be made attractive to riders by providing passenger shelters, special signs, and other amenities at each stop. The more permanent these facilities are made, the more attractive they become to passengers, at the expense of operating flexibility. The marketability of this service can be enhanced if the limited stops are shown clearly on route maps distributed to passengers, in much the same way that rail lines and their stations are usually shown. Normally, limited-stop trips have faster running times than local trips, because they are allowed to freely pass local buses and because they can often use special right-of-way provisions, signal pre-emption, or short-cuts.

VII-D. Peak-Only vs. All-Day Service

Although artic substitution is usually most effective during peak periods, where headways are lowest, runs are most expensive, and passenger loads warrant the extra capacity, it may often be desirable to keep the equipment in service all day. Reasons for this might include:

- **High deadheading costs**
- **High base-period ridership**
- **Desire to keep a uniform service level all day**

However, the most common strategy is to send artics out as trippers during peak periods and use standard coaches to provide all base service.

Unless the artic's capacity can be fully utilized during the base period, part of the operating cost savings attributable to artics may be lost if they are operated during that time. However, this loss of benefits may still be less than the cost of deadheading the vehicles back to the garage. Moreover, the mid-day extra cost may be much less than the savings to be gained during the morning and evening peaks. If artics are to be operated all day, it is important that any cost savings computation include the additional cost of fuel, tires, and depreciation caused by the use of artics, rather than standard coaches, in off-peak service. Again, the definitive economic analysis must be done on a route-specific, situation-specific basis. Such an analysis is presented in the Chapter VIII worksheets.

In mixed peak service, the artics can be removed after the peak, leaving the standards to service the base period. In all-artic peak service, if artics must be replaced by standard coaches in the off-peak, the most direct way is to deadhead the artic to the garage at the end of the A.M. peak, deadhead a standard bus out to the route, and then repeat this process in reverse just before the P.M. peak. This can be so expensive that it is seldom practical. A less expensive way is to deadhead the artic to the garage at the end of the A.M. peak and replace it immediately by a standard coach which was interlined from peak service on an intersecting route. This process can then be reversed just before the evening peak begins. Where this can be done, the cost is no greater than that for a full-time standard coach plus an artic tripper.

Because of high off-peak ridership, **Portland** schedules its mixed artic-standard service in just the opposite way. Artics operate all base-period service (except at night), and standard buses are used as peak-period trippers.

Because artics tend to be used largely in peak conditions, they are not normally utilized for as many miles per year as the average standard bus. Some examples of average annual mileage per bus are:

Average Annual Mileage Per Bus

	Artic	Standard	Ratio
Seattle (1980)	34,898	40,151	0.87
Seattle (1981)	36,049	40,655	0.89
Seattle (1983)	29,786	30,906	0.96
Louisville (1983)	18,000	36,000	0.50
L.A. (1983-4)	23,360	47,600	0.46
Oakland (1980)	24,852	46,136	0.54
Atlanta (1982-3)	27,573	38,479	0.72
Portland (1983-4)	33,000	36,800	0.90
Chicago (1984)	30,938	32,366	0.96
San Jose (1984)			
M.A.N.	26,667	35,000	0.76
Crown	13,333	35,000	0.38

VIII

Economic Analysis Worksheets

		Page
VIII-A.	Introduction to Worksheets	49
VIII-B.	Example Run	56
VIII-C.	Using a Simplified Cost Model to Screen Potential Artic Routes	83
VIII-D.	Worksheets and Supporting Data	91

VIII. Articulated Bus Economic Analysis Worksheets

VIII-A. Introduction to Worksheets

Once the transit operator has concluded that further consideration of articulated buses is warranted, and ideas have been formulated on a candidate set of routes and service schemes for utilizing the artics, it is very helpful to carry out an economic analysis on a route-by-route basis to determine whether or not artic substitution is cost-effective. Whether or not artics make sense on a particular route will depend on route characteristics, current ridership levels, and the transit system's cost structure. The purpose of the following worksheets is to aid the transit analyst in carrying out the necessary calculations to determine this. The analyst should go through the worksheets for each route and time period separately and determine on a case-by-case basis whether artic substitution makes economic sense.

Calculations covered by the worksheets consist of passing through four steps. These worksheet steps are outlined in flow chart form in Figure VIII-1. In Step I, route characteristics are determined, and information about existing levels of bus service is assembled, including analysis of passenger loads. One result obtained by passing through Step I is the calculation of a current level of service parameter in terms of passenger-to-seat ratio or "seating standard." If this level of service is not adequate, and a higher seating standard is desired, then the transit analyst can pass through an optional Step II to determine costs of upgrading conventional bus service necessary to meet the desired seating standard. In Step III, the costs of artic bus service necessary to meet that desired seating standard are determined. In Step IV, differences in costs among the alternatives are calculated for:

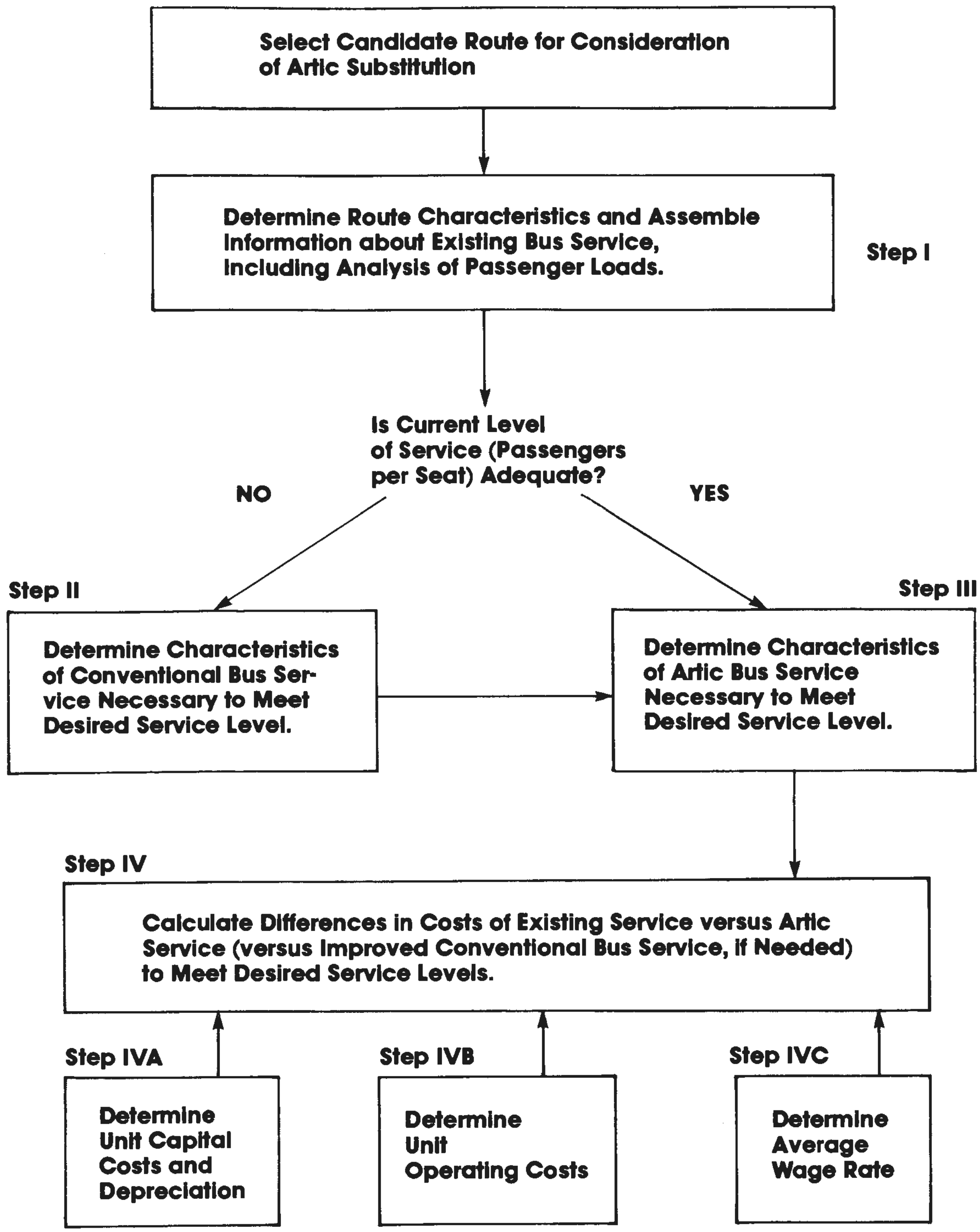
- **Existing conventional bus service**
- **Upgraded conventional service needed to meet desired service level**
- **Articulated service needed to meet desired service level**

Conventional and articulated bus costs should be compared at the same desired service level, rather than the existing level, in order to evaluate the tradeoff between the two bus technologies.

There are three optional worksheets, located in the white section at the end of this Handbook, to assist in the Step IV cost calculations: Step IVA helps the analyst determine the average operator wage rate per hour during the analysis period. Step IVB helps determine unit operating costs per vehicle-mile for fuel, tires, servicing, and maintenance. Step IVC helps determine unit capital cost per vehicle per day. In the case of each of Steps IVA-IVC, the analyst has the choice of using

- **Unit cost parameters from his own system,**
- **Default values provided on the worksheets,**
- **Unit cost parameters selected from a list of those parameters obtained directly from various agencies operating artics, or**
- **Unit cost information obtained from UMTA Section 15 data.**

Figure VIII-1. Flow Chart of Artic Substitution Worksheet Process



Optional Modules to be Used if Needed

The default values suggested are included in the right-hand column on each worksheet. Table VIII-1 on the following page gives some unit wage rate and fringe benefit information for various agencies from Section 15 data. This table is repeated again on the page following Step IVA for convenience when filling out the worksheets.

Table VIII-2 shows unit cost data for artics and standard buses, and their ratios, from various agencies operating artics. This table is repeated on the page opposite from Step IVB for convenience when filling out the worksheets. Because of differences in definitions as well as differences in time, care should be taken in using absolute values, though ratios should still be quite valid.

To amplify on the concept of using the artic-to-standard-bus cost ratios rather than absolute values: if an agency knows its own unit cost figure for standard buses, it should use a ratio of artic:conventional unit costs from other systems (or equivalently the ratio of default values) as a factor to tailor the artic figure to local conditions, rather than use its own unit operating cost figure for conventional buses and a default value for artics. These ratios are presented in Table VIII-2 along with the unit cost values for the various systems surveyed.

Finally Table VIII-3 presents non-labor unit cost information for a representative sample of transit systems from Section 15 data. This table, too, is repeated in the worksheets, as a separate pull-out page following Worksheet Step IVB. The Section 15 data does not distinguish artic costs from standard costs, but gives a basis for unit cost comparisons among a wide range of transit systems and a greater commonality of definitions among systems.

Artics can be substituted for standard buses in many ways, ranging from partial substitution (mixed artic and standard bus service) during peak periods, all the way up to complete all-day substitution.

Three of the most common strategies are presented in the three different sets of worksheets contained at the back of this Handbook. Once these three substitution strategies or scenarios have been reviewed, it should be a simple extension to analyze other substitution schemes.

Scenario 1 (blue worksheets) covers the classic case of complete artic substitution for conventional buses during the weekday peak periods, but no artic substitution off-peak. The analyst inputs route, ridership, and unit cost information for one peak only (AM or PM), and the worksheets effectively double the relevant cost items to account for the second peak as well. (Since the worksheets assume the length of the peak periods to be equivalent, adjustments should be made if peaks vary in length.) The objective of the analysis is to determine whether the artic substitution alternative can provide the required service at lower cost than the current standard buses.

This analysis assumes that the current ridership level stays fixed. However, the worksheet procedure allows for an examination of the

Table VIII-1.
UMTA Section 15 Year 4
Unit Labor Operating Cost Data

(price adjusted (value actually reported) to fiscal year ending 12/31/83)

A

Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Operator Wages/ Veh Hr	Operator Wg&Frgs/ Veh Hr	Fringe Burden
4022	Atlanta, GA	6-30-82	640	$12.03	$16.72	0.390
9036	Anaheim, CA	6-30-82	362	12.22	17.41	0.425
1003	Boston, MA	12-31-81	763	14.44	23.47	0.625
5066	Chicago, IL	12-26-81	1990	14.63	21.62	0.478
5012	Cincinnati, OH	12-31-81	342	10.67	15.46	0.449
5016	Columbus, OH	12-31-81	228	10.23	14.59	0.426
6004	Dallas, TX	9-30-81	403	8.95	12.68	0.417
8006	Denver, CO	12-31-81	526	12.82	17.78	0.387
5031	Detroit, MI	6-30-82	802	11.12	20.94	0.883
2008	New York, NY	6-30-82	3124	13.73	22.02	0.604
9014	Oakland, CA	6-30-82	732	13.84	20.90	0.510
3019	Philadelphia, PA	6-30-82	1095	10.03	14.50	0.446
3022	Pittsburgh, PA	6-30-82	775	12.87	18.88	0.467
6011	San Antonio, TX	2-28-82	372	7.62	10.58	0.388
9026	San Diego, CA	6-30-82	196	13.56	20.43	0.507
7006	St. Louis, MO	6-30-82	670	12.47	17.98	0.442
5027	St. Paul, MN	12-31-81	850	12.76	19.25	0.509
1	Seattle, WA	12-31-81	762	11.67	15.97	0.368
1001	Providence, RI	6-30-82	208	10.96	$15.51	0.415
3006	Richmond, VA	6-30-82	152	10.79	14.17	0.313
2013	Rochester, NY	3-31-82	187	11.41	16.65	0.459
9019	Sacramento, CA	6-30-82	157	12.51	18.53	0.481
4041	Tampa, FL	9-30-81	67	5.49	7.77	0.415
8001	Salt Lake City, UT	12-31-81	234	8.50	11.47	0.349
9008	Santa Monica, CA	6-30-82	92	10.99	14.50	0.319
5022	Toledo, OH	12-31-81	175	9.46	12.84	0.357

B

Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Operator Wages/ Veh Hr	Operator Wg&Frgs/ Veh Hr	Fringe Burden
3010	Allentown, PA	6-30-82	51	$11.22	$15.22	0.357
5010	Akron, OH	12-31-81	97	9.12	14.05	0.541
4042	Birmingham, AL	9-30-82	120	10.32	16.70	0.618
2004	Buffalo, NY	3-31-82	369	10.97	15.28	0.393
4008	Charlotte, NC	6-30-82	92	10.76	13.85	0.287
5025	Duluth, MN	12-31-82	73	9.58	14.75	0.540
6006	El Paso, TX	8-31-81	75	6.61	8.99	0.360
5032	Flint, MI	9-30-81	37	10.04	14.32	0.426
6007	Ft. Worth, TX	9-30-81	105	7.24	9.15	0.264
3004	Hampton, VA	6-30-82	79	7.33	10.23	0.396
1048	Hartford, CT	6-30-82	215	11.94	16.58	0.389
9002	Honolulu, HI	6-30-82	336	11.44	17.39	0.520
4040	Jacksonville, FL	9-30-81	168	9.05	12.38	0.368
7005	Kansas City, MO	12-31-81	260	12.05	16.08	0.334
9023	Long Beach, CA	6-30-82	124	11.79	11.79	0.000
4003	Memphis, TN	6-30-82	204	10.32	14.97	0.451
4004	Nashville, TN	6-30-82	117	10.71	16.32	0.524
3005	Norfolk, VA	9-30-81	137	9.80	13.61	0.389
6017	Oklahoma City, OK	6-30-82	68	6.76	8.40	0.243
5056	Peoria, IL	12-31-81	42	8.22	11.17	0.359

	Operator Wages/ Veh Hr	Operator Wg&Frgs/ Veh Hr	Fringe Burden
Mean-Level A	$12.19	$18.28	0.500
Northeast	12.77	19.72	0.544
Southeast	12.03	16.72	0.390
Midwest	11.88	18.37	0.546
South Central	9.68	13.75	0.420
West	12.96	18.70	0.443
Mean-Level B	$10.00	$13.88	0.388
Northeast	11.01	15.29	0.389
Southeast	10.23	13.67	0.336
Midwest	9.28	13.42	0.446
South Central	8.17	10.66	0.305
West	11.05	14.73	0.333
Mean-Levels A & B	$10.70	$15.15	0.416
Northeast	11.65	15.69	0.347
Southeast	10.53	15.16	0.440
Midwest	10.13	15.90	0.570
South Central	8.81	11.98	0.360
West	12.23	16.22	0.326

Table VIII-2.

Some Actual Agency Values for Unit Cost Parameters

Fuel Economy (Mpg.)

	Artic	Std.	Ratio
Twin Cities (1979)	3.42	3.78	0.90
Twin Cities (1980)	3.12	3.78	0.83
Twin Cities (1981)	3.36	3.84	0.88
Twin Cities (1982)	3.57	3.78	0.94
Chicago (1979)	2.66	3.12	0.85
Seattle (1980)	3.62	3.97	0.91
Seattle (1981)	3.80	4.17	0.91
Seattle (1982):			
280 H.P.	3.85	4.35	0.89
310 H.P.	3.47	4.35	0.80
Seattle (1983):			
280 H.P.	4.01	4.39	0.91
310 H.P.	3.65	4.39	0.83
Phoenix (1979-80)	3.11	3.44	0.90
Oakland (1980)	3.30	4.90	0.67
Portland (1982)	3.93	4.10	0.96
Portland (1983-84)	3.51	4.12	0.85
Los Angeles (1983-84)	1.97	2.71	0.73
Pittsburgh (1979-80)	2.76	n.a.	
Atlanta (1983-84)	2.40	2.80	0.86*
	1.90	2.30	0.83**
Twin Cities:			
Summer (1979)	3.06	3.86	0.79
Summer (1980)	2.99	3.91	0.76
Summer (1981)	3.01	3.89	0.77
Winter (1979)	3.63	3.70	0.98
Winter (1980)	3.33	3.72	0.90
Winter (1981)	3.41	3.77	0.90
San Jose (1984)			
M.A.N.	3.10	3.65	0.85
Crown	3.30	3.65	0.90

*Without Air Conditioning
**With Air Conditioning

Fuel Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Twin Cities (1979)	.189	.171	1.11
Twin Cities (1981)	.321	.281	1.14
Twin Cities (1982)	.226	.224	1.01
Seattle (1980)	.273	.245	1.11
Seattle (1981)	.266	.242	1.10
Seattle (1982)	.269	.230	1.09
Seattle (1983)	.286	.247	1.16
Los Angeles (1983-84)	.388	.282	1.37
Oakland (1980)	.304	.203	1.50
Portland (1983-84)	.256	.220	1.17

Tire Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.016	.022	0.73
Seattle (1981)	.036	.024	1.50
Seattle (1982)	.040	.027	1.47
Seattle (1983)	.046	.036	1.28
Twin Cities (1979-82)	.047	.022	2.14
Los Angeles (1983-84)	.067	.035	1.91
Portland (1983-84)	.087	.039	2.20

Maintenance Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.219	.206	1.06
Seattle (1981)	.313	.407	0.77
Seattle (1982)	.413	.433	0.95
Seattle (1983)	.377	.512	0.74
Oakland (1980)	.218	.066	3.30

Servicing Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.043	.035	1.23
Seattle (1981)	.050	.059	0.85
Seattle (1982)	.065	.067	0.97
Seattle (1983)	.072	.067	1.07

Table VIII-3.
UMTA Section 15 Year 4
Per Mile Operating Cost Data (value actually reported)

	Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
A	4022	Atlanta, GA	6-30-82	640	$0.521	$0.076	$0.337	$0.012	$0.945
	9036	Anaheim, CA	6-30-82	362	0.373	0.078	0.298	0.038	0.786
	1003	Boston, MA	12-31-81	763	1.556	0.361	0.330	0.019	2.267
	5066	Chicago, IL	12-26-81	1990	1.078	0.168	0.394	0.020	1.659
	5012	Cincinnati, OH	12-31-81	342	0.538	0.157	0.336	0.030	1.061
	5016	Columbus, OH	12-31-81	228	0.314	0.103	0.268	0.019	0.705
	6004	Dallas, TX	9-30-81	403	0.356	0.049	0.315	0.022	0.742
	8006	Denver, CO	12-31-81	526	0.519	0.062	0.284	0.037	0.902
	5031	Detroit, MI	6-30-82	802	0.664	0.166	0.308	0.023	1.161
	2008	New York, NY	6-30-82	3124	3.382	0.418	0.325	0.034	4.159
	9014	Oakland, CA	6-30-82	732	0.356	0.088	0.227	0.034	0.705
	3019	Philadelphia, PA	6-30-82	1095	1.153	0.150	0.341	0.031	1.676
	3022	Pittsburgh, PA	6-30-82	775	0.701	0.149	0.301	0.032	1.184
	6011	San Antonio, TX	2-28-82	372	0.294	0.040	0.319	0.023	0.676
	9026	San Diego, CA	6-30-82	196	0.534	0.082	0.272	0.031	0.920
	7006	St. Louis, MO	6-30-82	670	0.575	0.098	0.289	0.021	0.983
	5027	St. Paul, MN	12-31-81	850	0.629	0.003	0.309	0.026	0.967
	1	Seattle, WA	12-31-81	762	0.431	0.062	0.241	0.027	0.761
B	3010	Allentown, PA	6-30-82	51	$0.299	$0.036	$0.233	$0.017	$0.585
	5010	Akron, OH	12-31-81	97	0.268	0.061	0.317	0.024	0.670
	4042	Birmingham, AL	9-30-82	120	0.375	0.132	0.357	0.040	0.904
	2004	Buffalo, NY	3-31-82	369	0.568	0.089	0.303	0.025	0.985
	4008	Charlotte,NC	6-30-82	92	0.287	0.108	0.357	0.039	0.790
	5025	Duluth, MN	12-31-82	73	0.288	0.099	0.301	0.017	0.704
	6006	El Paso, TX	8-31-81	75	0.273	0.065	0.366	0.027	0.732
	5032	Flint, MI	9-30-81	37	0.470	0.105	0.290	0.021	0.885
	6007	Ft. Worth, TX	9-30-81	105	0.256	0.054	0.312	0.022	0.644
	3004	Hampton, VA	6-30-82	79	0.292	0.073	0.291	0.034	0.690
	1048	Hartford, CT	6-30-82	215	0.521	0.103	0.303	0.018	0.946
	9002	Honolulu, HI	6-30-82	336	0.561	0.063	0.371	0.044	1.040
	4040	Jacksonville, FL	9-30-81	168	0.262	0.097	0.323	0.034	0.716
	7005	Kansas City, MO	12-31-81	260	0.466	0.120	0.329	0.036	0.950
	9023	Long Beach, CA	6-30-82	124	0.266	0.046	0.349	0.039	0.699
	4003	Memphis, TN	6-30-82	204	0.328	0.074	0.278	0.028	0.708
	4004	Nashville, TN	6-30-82	117	0.297	0.111	0.277	0.029	0.714
	3005	Norfolk, VA	9-30-81	137	0.341	0.071	0.322	0.039	0.774
	6017	Oklahoma City, OK	6-30-82	68	0.315	0.055	0.268	0.033	0.670
	5056	Peoria, IL	12-31-81	42	0.179	0.076	0.251	0.013	0.519
	1001	Providence, RI	6-30-82	208	0.264	0.084	0.243	0.026	0.616
	3006	Richmond, VA	6-30-82	152	0.348	0.094	0.346	0.031	0.820
	2013	Rochester, NY	3-31-82	187	0.602	0.109	0.338	0.030	1.079
	9019	Sacramento, CA	6-30-82	157	0.439	0.087	0.254	0.024	0.804
	4041	Tampa, FL	9-30-81	67	0.209	0.056	0.312	0.014	0.592
	8001	Salt Lake City, UT	12-31-81	234	0.585	0.070	0.286	0.033	0.974
	9008	Santa Monica, CA	6-30-82	92	0.363	0.051	0.380	0.027	0.821
	5022	Toledo, OH	12-31-81	175	0.161	0.101	0.275	0.023	0.559

	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
Mean-Level A	$0.642	$0.099	$0.311	$0.027	$1.095
Northeast	1.698	0.270	0.324	0.029	1.709
Southeast	0.521	0.076	0.337	0.012	0.945
Midwest	0.645	0.120	0.323	0.024	1.111
South Central	0.408	0.062	0.308	0.022	0.800
West	0.416	0.076	0.270	0.037	0.798
Mean-Level B	$0.344	$0.080	$0.308	$0.028	$0.760
Northeast	0.405	0.089	0.297	0.028	0.812
Southeast	0.293	0.096	0.317	0.031	0.737
Midwest	0.273	0.088	0.287	0.019	0.667
South Central	0.328	0.074	0.319	0.029	0.749
West	0.443	0.063	0.328	0.033	0.868
Mean-Levels A & B	$0.427	$0.088	$0.309	$0.027	$0.851
Northeast	0.604	0.120	0.313	0.028	1.056
Southeast	0.293	0.093	0.320	0.028	0.767
Midwest	0.390	0.115	0.295	0.022	0.803
South Central	0.362	0.069	0.314	0.026	0.771
West	0.433	0.068	0.306	0.035	0.841

sufficiency of current service levels for the ridership volume relative to that agency's seating standard or policy. It permits carrying through an optional intermediate analysis of the costs of upgrading service levels to the desired standard using additional conventional buses, then carries through the cost calculations for artics to provide that same level of service. Thus three different transit service alternatives can be costed out for each route and time period:

- **Existing conventional service**
- **Conventional service improved to meet the system's desired seating standards**
- **Artic service designed to meet the same desired standards**

Scenario 2 worksheets (yellow sheets) cover the special case where a **mixture** of artics and conventional buses is used on a particular route, again during the peak period only. The inherent assumption in Scenario 2 is that, on the candidate route, the transit operator will add a number of artics during the peaks to that number of standard buses which was required to service the base (between peaks) period anyway; when the (AM) peak is over, the artics will return to the garage, but the conventional buses will remain to provide base service. Of course, the analysis of any other mixture of artics and conventional buses including the addition of artic trippers can be done with only minor adjustments to the worksheets for Scenario 2.

Scenario 3 (pink sheets) represents the substitution of artics during the peaks **and** the base period.

Scenario 1 may be desired for routes with high peak to base ratios (such as commuter express routes) and where deadheading costs are low. Scenario 2 may be desired for routes with average or high peak to base ratios and high deadheading costs. Scenario 3 may be desired for routes with high off-peak ridership, typically high density arterial routes. In all three scenarios, a cost comparison is made between the conventional buses at the current service level, conventional buses at the desired service level, and artics at the desired service level.

VIII-B. Example Run

To illustrate the use of the Articulated Bus Economic Analysis Worksheets, a Scenario 1 example is presented on the following pages.

In Step I, information is assembled about the route and existing service being considered for substitution by artic buses, including analysis of passenger volumes. In this example, 15 conventional buses, 45 operator hours, and 540 bus in-service miles were required to provide the existing level of service in one (three hour) peak period. A key result generated from Step I is the passenger per seat ratio at the peak load point, found to be 1.48.

In order to determine peak load point volumes for the target time period, it is necessary to obtain ridership counts, at the peak load point, for each successive run during this period. If heavy loads are limited to a much shorter time period and scheduling permits, one might want to reconsider (shorten) the time period being considered for artic substitution or consider individual artic trippers instead of full substitution. In any event, it is unlikely that passenger volumes will be uniform throughout the time period, so it is likely that a resourceful scheduler will vary headways slightly to better match demand. However, using average assumptions here should not materially affect the economic analysis if the subject time period is judiciously chosen based on ridership counts.

In Step II, it was determined that this 1.48 passenger per seat ratio was above the system's service standard. A lower ratio of 1.2 passengers per seat at the peak load point was desired. The additional conventional bus service necessary to provide this seating standard was determined; in this example, 19 conventional buses (vs. 15 currently) operating at 3.24 minute average headways (vs. 4 minutes currently) was needed.

Similarly, in Step III, the articulated bus service necessary to provide this seating standard of 1.2 passengers per seat was determined (15 artics; 4.59 minutes average headways). To provide this desired seating standard under the conventional bus solution, 19 conventional buses, 56 in-service operator hours, and 667 in-service miles were required. Under the artic solution, only 15 artic buses, 43 in-service operator hours, and 471 in-service miles were required to service one of the two peak periods. It might be noted that the artic was assumed to take 10 percent longer to make each trip (Line 29).

In the beginning of Step IV, the relevant input figures from the previous three steps are copied over for convenience for the three alternatives being costed out: the original conventional bus service, the improved (to desired seating standard) conventional bus service, and the desired level of articulated service. For each of these alternatives, Step IV then traces through the calculations of total daily and annual cost as the sum of driver labor costs (the per-hour costs) + non-labor operating costs (the per-mile costs) + capital costs (the per-vehicle costs).

Step IVA guides the planner through the determination of the average driver labor rate to be input to Line 45. The opposite page shows Section 15 data for various other systems for reference, but we chose to use the system-specific value of $12.85 per hour. In our example, no premium was assumed to be paid to artic operators, so the average wage rate plus fringes of $17.73 is common to all three alternatives.

Step IVB assists in pulling together the unit operating costs for fuel, tires, servicing and maintenance, the four cost components making up the total non-labor operating costs. In Line IVB-2, the system-specific value of 3.90 mpg was used for the conventional bus, and the artic value was obtained by using the default ratio of 0.92 (artic fuel economy is found to be about 92 percent of conventional bus fuel economy in most systems), i.e. (3.90) (0.92) =(3.60). It was assumed neither vehicle was air-conditioned. Were the artic, say, to be air-conditioned, the difference in the artic default values (3.65 mpg without air-conditioning, 3.1 mpg with air-conditioning) would be examined, and the approximate percentage of the year the air-conditioning would be in effect (say 50 percent) would be used to determine an average annual fuel economy, about 3.35 mpg. Fuel cost per mile was calculated using those fuel economy estimates and $0.85 per gallon.

The default values were used for each of the other cost categories (tires, servicing, and maintenance). However, the page opposite to Step IVB contains actual values reported directly by various agencies which could be used; and the following page, which pulls out, shows tabulations of unit cost data for each of these categories from Section 15 data. It might be noted that for both of these supporting unit cost schedules and the corresponding wage rate supporting data opposite Step IVA, the individual observations are for different points in time, so care must be taken in comparing or using these figures.

Step IVC helps the planner determine annual capital costs per vehicle. The initial capital costs per vehicle assumed ($120,000 for conventional buses and $203,000 for artics) were the default values, which themselves came from a trend analysis done on recent award prices. One-hundred percent of the capital cost is assumed even though the local agency might only have to pick up the local 20 percent share. A 12-year life was assumed in each case, although there is some argument for assuming a longer life for artics because they put on fewer miles per year (only 50-70 percent of the average annual miles for conventional buses). Furthermore, a capital recovery factor was applied using a 10 percent interest rate (Line IVC-3) to calculate the "opportunity cost" of having to pay the full capital costs up front rather than in future annual installments. A table of capital recovery factors (annual capital cost per $1 of bus purchased) is shown on the page opposite from Step IVC for convenience. All of these factors combine to put heavy emphasis on capital cost in this economic analysis.

Returning to Step IV, it can be seen from Line 47i that the per-hour costs favor the artic, $862 vs. $1109 for the desired level of conventional bus service and $895 for the current level of conventional bus service. From Line 47ii, it can be seen that the artic alternative is less costly than the desired level of conventional service as far as per-mile operating costs go ($671 for the artic service, $710 for desired level of conventional service), but more expensive than the current service ($572). It can also be seen that generally the labor costs are actually slightly larger than the per-mile operating costs. All of these figures then are multiplied by 2 in Line 47iv to cover the second peak of the day to produce daily labor and operating costs for each alternative.

EXAMPLE

Articulated Bus Substitution – Economic Analysis Worksheet

Scenario #1: Scenario 1 represents the main set of worksheets. Scenario 1 worksheets cover the classic case of complete artic substitution for conventional buses during the weekday peak periods, but no artic substitution off-peak. Input information for one peak only (AM or PM), and the worksheets effectively double the relevant cost items to account for the second peak as well. Worksheets assume the length of the peak periods to be equivalent. Adjustments to worksheet calculations should be made if peaks vary in length.

Step I: Assemble Information About the Route and Service Being Considered for Substitution by Articulated Buses

Route: MELROSE - KENDALL SQUARE

Line	Units	Value	Reference/Notes
1. **Time Period of Interest** – Length of Time on Average Weekday for Considering Artic Substitution (Enter value in minutes)	(minutes)	1. 180	Enter length of time for one peak only (A.M. or P.M.); Calculations assume the use of artics on the other peak as well.
2. **Average Headway During This Period** (Enter headway in minutes)	(minutes)	2. 4.00	
3. **Number of Trips During This Period** (Enter specific number from schedule or divide line 1 by line 2)	(no. trips)	3. 45	
4. **Round Trip Run Time for This Route During This Time Period** (Enter time in minutes)	(minutes)	4. 60.0	Includes layover and recovery times.
5. **Round Trip Distance for This Route** (Enter distance in miles)	(miles)	5. 12.0	
6. **No. Conventional Buses Needed to Provide This Service** (Divide line 4 by line 2 and round up to nearest integer)	(no. vehicles)	6. 15	
7. **Operator Hours** (Multiply line 3 by line 4 and divide by 60)	(hours)	7. 45.0	
8. **Bus In-Service Miles** (Multiply line 3 by line 5)	(miles)	8. 540.0	
9. **Total Passenger Volume at Peak Load Point, Peak Direction During This Period** (Sum up peak load point passenger counts for each trip during this period)	(passengers)	9. 3200	Itemize on reverse side if desired.

Line	Units	Value	Reference/Notes
10. **Average Passenger Volume Per Bus At Peak Load Point During This Period** (Enter estimated average value or divide line 9 by line 3)	(passengers per bus)	10. 71.11	
11. **Seating Capacity of Bus Used in This Service** (Enter no. seats per bus)	(seats per bus)	11. 48	Use 48 as default value.
12. **Passengers Per Seat at Peak Load Point** (Divide line 10 by line 11)	(passengers per seat)	12. 1.48	
13. **Deadheading Time from Garage to Route at Beginning of Period**	(minutes)	13. 10	
14. **Deadheading Time from Route to Garage at End of Period**	(minutes)	14. 12	
15. **Deadheading Distance from Garage to Route at Beginning of Period**	(miles)	15. 4.0	
16. **Deadheading Distance from Route to Garage at End of Period**	(miles)	16. 5.0	

Go To Step II (Line 17)

Scenario #1 *(continued)*

Step II: If Current Level of Service Provided on This Route During This Period is Inadequate, Determine Additional Conventional Bus Service Required to Meet Service Standard

Line	Units	Value	Reference/Notes
17. **Desired Passenger/Seat Service Level** (Line 12 is the passenger per seat ratio at the peak load point or, equivalently, the fraction of seated capacity at which the average trip is operating; if a higher standard (lower ratio) is desired, enter this ratio here and go to line 18; if not, go to STEP III (line 24))	(passengers per seat)	17. 1.20	
18. **Average Passengers Per Trip at Peak Load Point Under Desired Service Level** (Multiply line 11 by line 17)	(passengers per bus)	18. 57.6	
19. **Number of Conventional Bus Trips Required to Meet Desired Service Level** (Divide line 9 by line 18)	(no. trips)	19. 55.56	
20. **Average Headway for Conventional Bus Service at Desired Service Level** (Divide line 1 by line 19)	(minutes)	20. 3.24	
21. **Number of Conventional Buses Needed to Provide Desired Service Level** (Divide line 4 by line 20 and round up to nearest integer)	(no. vehicles)	21. 19	
22. **Operator Hours Needed for Desired Level of Conventional Bus Service** (Multiply line 4 by line 19 and divide by 60)	(hours)	22. 55.56	
23. **Conventional Bus In-Service Miles for Desired Level of Conventional Bus Service** (Multiply line 5 by line 19)	(miles)	23. 666.7	

Go To Step III (Line 24)

Scenario #1 *(continued)*

Step III: Determine the Articulated Bus Service Required To Fully Replace Conventional Buses During the Defined Period at the Desired Service Level (Passengers/Seat)

Line	Units	Value	Reference/Notes
24. **Desired Passenger/Seat Service Level for Artics** (Enter value on line 17 or alternative policy standard if desired; if line 17 is blank, enter value on line 12)	(passengers per seat)	24. 1.20	
25. **Seating Capacity of Artics** (Enter no. of seats per articulated bus)	(no. seats per artic)	25. 68	Use 68 as default value.
26. **Average Passengers Per Artic at Peak Load Point** (Multiply line 24 by line 25)	(passengers per artic)	26. 81.6	
27. **No. of Artic Trips Needed** (Divide line 9 by line 26)	(no. trips)	27. 39.2	
28. **Average Headway for Artics at Desired Service Level** (Divide line 1 by line 27)	(minutes)	28. 4.59	
29. **Relative Speed Factor of Artics vs. Conventional Buses: Ratio of Running Times** (Artic:Conventional) **for Routes of This Type**	(unitless, should be ≥ 1.0)	29. 1.10	Use 1.10 as default for local service, 1.0 for express service (See report for further discussion.)
30. **Round Trip Run Time for This Route for Artics** (Multiply line 4 by line 29)	(minutes)	30. 66.0	Include recovery and layover times.
31. **No. of Artics Needed to Provide Desired Level of Service** (Divide line 30 by line 28 and round up to nearest integer)	(no. artics)	31. 15	
32. **Operator Hours for Artic Service** (Multiply line 27 by line 30 and divide by 60)	(hours)	32. 43.14	
33. **Artic In-Service Miles for Provision of Desired Service Level** (Multiply line 27 by line 5)	(miles)	33. 470.6	
34. **Artic Deadheading Time from Garage to Route at Beginning of Period**	(minutes)	34. 10	
35. **Artic Deadheading Time from Route to Garage at End of Period**	(minutes)	35. 12	
36. **Artic Deadheading Distance from Garage to Route at Beginning of Period**	(miles)	36. 5.0	
37. **Artic Deadheading Distance from Route to Garage at End of Period**	(miles)	37. 6.0	

Go To Step IV (line 38)

Step IV: Calculate Differences in Costs of Serving Selected Route with Artics Instead of Conventional Buses

Changes in costs for changes in service on any route can be computed generally as changes in cost per hour (for operator labor) plus changes in costs per vehicle (for capital costs) plus changes in costs per vehicle-mile (for fuel, tires, servicing of vehicles, and maintenance of vehicles). Optional Step IVA outlines how a transit planner can calculate changes in labor costs; it also defines what all is included in "average labor costs per hour." Optional Step IVB outlines how a transit planner can determine the per-mile costs for fuel, tires, servicing and maintenance; it also defines what all is included in each category. Optional Step IVC outlines how capital costs can be computed and translated into costs per vehicle per day. All of these optional steps are located in the white section at the end of this Handbook.

For each of these unit-cost categories, four alternative methods are provided to determine the unit costs to be used in this analysis:

1. Use agency-specific values where they are readily available or can be determined easily.
2. Use default values supplied on the worksheet.
3. Select unit cost values from the listing on the page opposite the appropriate worksheet page which tabulates unit cost values compiled directly from selected operators.
4. Select unit cost values from information obtained from UMTA Section 15 data listed on the page following the worksheet page.

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service (if applicable)	Value: Artics Desired Service	Reference/Notes
(Lines 38-40: Copy Over Relevant Information from STEPS I-III for Convenience)					
38. No. Vehicles Required	(no. vehicles)	38a. 15 (line 6)	38b. 19 (line 21)	38c. 15 (line 31)	
39. No. In-Service Operator Hours Required	(hours)	39a. 45.00 (line 7)	39b. 55.56 (line 22)	39c. 43.14 (line 32)	
40. No. In-Service Vehicle-Miles Required	(miles)	40a. 540.0 (line 8)	40b. 666.7 (line 23)	40c. 470.6 (line 33)	
41. No. Deadheading Hours Required (Multiply line 38 by the deadheading time, the sum of line 13 and line 14 (line 34 and line 35 for artics), then divide the product by 60)	(hours)	41a. 5.50	41b. 6.97	41c. 5.50	
42. No. Deadheading Miles Required (Multiply line 38 by the deadheading distance, the sum of line 15 and line 16 (line 36 and line 37 for artics))	(miles)	42a. 135.0	42b. 171.0	42c. 165.0	

Line	Units	Value			Reference/Notes
		Conventional Bus Existing Service	Conventional Bus Desired Service (if applicable)	Artics Desired Service	
43. **Platform Hours** (line 39 + line 41)	(hours)	43a. 50.50	43b. 62.52	43c. 48.64	
44. **Total Vehicle-Miles** (line 40 + line 42)	(miles)	44a. 675.0	44b. 837.7	44c. 635.6	
45. **Operator Wage Rate Plus Fringes per Platform Hour**	($/hour)	45a. 17.73	45b. 17.73	45c. 17.73	See **Step IVA** at end of Handbook.
46. **Unit Operating Cost per Vehicle-Mile for Fuel, Tires, Servicing, and Maintenance**	($/vehicle-mile)	46a. 0.848	46b. 0.848	46c. 1.056	See **Step IVB** at end of Handbook.
47. **Total Operating Cost for Service** (i) Multiply line 43 by line 45 (ii) Multiply line 44 by line 46 (iii) Add above two figures together (iv) Multiply by 2 for two peak periods per day	($/day)	47a. 895 572 1467 2934	47b. 1109 710 1819 3638	47c. 862 671 1533 3066	
48. **Unit Capital Cost per Vehicle per Day** (Multiply by 1.10 to account for spares, if desired)	($/day/vehicle)	48a. 70.45	48b. 70.45	48c. 119.17	See **Step IVC** at end of Handbook.
49. **Total Capital Costs** (Multiply line 48 by line 38)	($/day)	49a. 1057	49b. 1339	49c. 1788	
50. **Total Costs Per Day** (Add line 47 and line 49)	($/day)	50a. 3,992	50b. 4,977	50c. 4,855	
51. **Effective No. Days Per Year** (No. of weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	51a. 250	51b. 250	51c. 250	Use 250 days per year as default value.
52. **Total Costs Per Year in Thousands of Dollars** (Multiply line 50 by line 51 and divide by 1000)	($1000/year)	52a. 998.0	52b. 1244.3	52c. 1213.8	

Optional Steps for Scenarios 1 through 3

Step IVA: Calculate Operator Wage Rate Plus Fringes Per Platform Hour

Average operator wage rate can be defined as (garage or system) total wages paid operators divided by total platform hours of bus service provided. Total wages include scheduled premium pay (overtime, split shift premium, late shift premium, etc.), intervening, reporting, turning in, paid break, travel allowance and guaranteed make-up time, plus unscheduled overtime and the cost of extra board drivers. Total wages do not include vacation or holiday pay or any other fringe benefits, supervisor time, starter time, or the time of any non-operator.

Fringe benefits include vacation, holiday, sick time, medical or other insurance coverage, pension plan, and uniform costs. Thus defined, average wage rates include premium pay and full-time as well as part-time operators. It is not necessary that these conventions be followed precisely, as long as the same definitions are used consistently for all calculations.

Total platform hours include in-service time and deadheading time, but not time spent out of the vehicle such as travel allowance time.

The peaked nature of transit demand requires more buses and operators during the peak periods. Since work rules generally require premium payment for overtime and spread time plus eight-hour guarantees, and since the excess requirements of the peak period result in more of these premium pay runs involving the peak periods, the average operator wage rate for the peak period may, in fact, be significantly higher than the all-day average wage rate for systems with limitations or exclusions on the use of part-time drivers. If operating policies permit the extensive use of part-time operators, then the average wage rate (and fringes) for part-time operators should be used in the calculations, since it is these operators who will be "saved" if peak vehicle requirements are reduced. Alternatively, the average wage rate over the day (dollars per platform hour) and fringe benefit percentage for all operators can be used. If part-time operators are not permitted, the following procedure may be used to calculate the (higher) wage rate for the peak period:

1. Obtain a set of runs cut for all routes operating out of the garage in question.
2. For each run or piece of work operating out of that garage, divide pay hours posted for that run or piece of work by the number of platform hours entailed to get an average hourly wage rate scaling factor for that run or piece of work. This factor of course will be larger than 1.0.
3. For each run operating wholly or partially within the period being analyzed, determine the actual number of platform hours within that period only.
4. Multiply the values found in Step 3 by the hourly wage rate scaling factor determined for that run or piece of work in Step 2 to get the effective pay-hours within the subject time period for each run or piece of work.
5. Sum up the effective pay-hours across all runs operating within the subject time period, i.e., sum up the values calculated in Step 4. Add to this the pay-hours paid to the extra board during that period.
6. Sum up the actual number of platform hours across all runs operating within the subject time period, i.e., sum up the values calculated in Step 3.
7. Divide the result of Step 5 above by the result of Step 6 above to determine the average hourly operator wage rate scaling factor for the subject period.
8. Multiply the above factor times the normal average hourly wage paid operators in that system to get an average hourly operator wage rate for the subject time period.

Table VIII-1.
UMTA Section 15 Year 4
Unit Labor Operating Cost Data

(price adjusted (value actually reported) to fiscal year ending 12/31/83)

	Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Operator Wages/ Veh Hr	Operator Wg&Frgs/ Veh Hr	Fringe Burden
A	4022	Atlanta, GA	6-30-82	640	$12.03	$16.72	0.390
	9036	Anaheim, CA	6-30-82	362	12.22	17.41	0.425
	1003	Boston, MA	12-31-81	763	14.44	23.47	0.625
	5066	Chicago, IL	12-26-81	1990	14.63	21.62	0.478
	5012	Cincinnati, OH	12-31-81	342	10.67	15.46	0.449
	5016	Columbus, OH	12-31-81	228	10.23	14.59	0.426
	6004	Dallas, TX	9-30-81	403	8.95	12.68	0.417
	8006	Denver, CO	12-31-81	526	12.82	17.78	0.387
	5031	Detroit, MI	6-30-82	802	11.12	20.94	0.883
	2008	New York, NY	6-30-82	3124	13.73	22.02	0.604
	9014	Oakland, CA	6-30-82	732	13.84	20.90	0.510
	3019	Philadelphia, PA	6-30-82	1095	10.03	14.50	0.446
	3022	Pittsburgh, PA	6-30-82	775	12.87	18.88	0.467
	6011	San Antonio, TX	2-28-82	372	7.62	10.58	0.388
	9026	San Diego, CA	6-30-82	196	13.56	20.43	0.507
	7006	St. Louis, MO	6-30-82	670	12.47	17.98	0.442
	5027	St. Paul, MN	12-31-81	850	12.76	19.25	0.509
	1	Seattle, WA	12-31-81	762	11.67	15.97	0.368
B	3010	Allentown, PA	6-30-82	51	$11.22	$15.22	0.357
	5010	Akron, OH	12-31-81	97	9.12	14.05	0.541
	4042	Birmingham, AL	9-30-82	120	10.32	16.70	0.618
	2004	Buffalo, NY	3-31-82	369	10.97	15.28	0.393
	4008	Charlotte, NC	6-30-82	92	10.76	13.85	0.287
	5025	Duluth, MN	12-31-82	73	9.58	14.75	0.540
	6006	El Paso, TX	8-31-81	75	6.61	8.99	0.360
	5032	Flint, MI	9-30-81	37	10.04	14.32	0.426
	6007	Ft. Worth, TX	9-30-81	105	7.24	9.15	0.264
	3004	Hampton, VA	6-30-82	79	7.33	10.23	0.396
	1048	Hartford, CT	6-30-82	215	11.94	16.58	0.389
	9002	Honolulu, HI	6-30-82	336	11.44	17.39	0.520
	4040	Jacksonville, FL	9-30-81	168	9.05	12.38	0.368
	7005	Kansas City, MO	12-31-81	260	12.05	16.08	0.334
	9023	Long Beach, CA	6-30-82	124	11.79	11.79	0.000
	4003	Memphis, TN	6-30-82	204	10.32	14.97	0.451
	4004	Nashville, TN	6-30-82	117	10.71	16.32	0.524
	3005	Norfolk, VA	9-30-81	137	9.80	13.61	0.389
	6017	Oklahoma City, OK	6-30-82	68	6.76	8.40	0.243
	5056	Peoria, IL	12-31-81	42	8.22	11.17	0.359
	1001	Providence, RI	6-30-82	208	10.96	$15.51	0.415
	3006	Richmond, VA	6-30-82	152	10.79	14.17	0.313
	2013	Rochester, NY	3-31-82	187	11.41	16.65	0.459
	9019	Sacramento, CA	6-30-82	157	12.51	18.53	0.481
	4041	Tampa, FL	9-30-81	67	5.49	7.77	0.415
	8001	Salt Lake City, UT	12-31-81	234	8.50	11.47	0.349
	9008	Santa Monica, CA	6-30-82	92	10.99	14.50	0.319
	5022	Toledo, OH	12-31-81	175	9.46	12.84	0.357

	Operator Wages/ Veh Hr	Operator Wg&Frgs/ Veh Hr	Fringe Burden
Mean-Level A	$12.19	$18.28	0.500
Northeast	12.77	19.72	0.544
Southeast	12.03	16.72	0.390
Midwest	11.88	18.37	0.546
South Central	9.68	13.75	0.420
West	12.96	18.70	0.443
Mean-Level B	$10.00	$13.88	0.388
Northeast	11.01	15.29	0.389
Southeast	10.23	13.67	0.336
Midwest	9.28	13.42	0.446
South Central	8.17	10.66	0.305
West	11.05	14.73	0.333
Mean-Levels A & B	$10.70	$15.15	0.416
Northeast	11.65	15.69	0.347
Southeast	10.53	15.16	0.440
Midwest	10.13	15.90	0.570
South Central	8.81	11.98	0.360
West	12.23	16.22	0.326

	Line	Units	Value	Reference/Notes
IVA-1.	**Determine Average Operator Wage Rate per Hour** (Total Operator Wages paid divided by total platform hours) or (pay hour: platform hour ratio times average operator base wage per hour)	($/hour)	IVA-1. 12.85	Use numbers calculated explicitly for this agency as outlined above or select an appropriate average wage rate from the list compiled for several agencies on the opposite page from this sheet or use the default value of $10.25 per hour basic rate times 1.25 (pay hour to platform hour ratio or scaling factor) = $12.85 per hour.
IVA-2.	**Determine Fringe Benefits as a Fraction of Hourly Wages**	(unitless)	IVA-2. 0.38	Use numbers calculated explicitly for this agency or use a default value of 38%.
IVA-3.	**Determine Average Hourly Operator Labor Cost** (Multiply [1 + line IVA-2] by line IVA-1 and input this result to STEP IV—Conventional Bus Service (Existing and Desired))	($/hour)	IVA-3. 17.73	Default Value: $17.75/hr.
IVA-4.	**Will Any Premium Pay Per Hour Be Paid for Driving an Artic?** (Enter, if so; if not, input line IVA-3 value to STEP IV—Artic Desired Service and return to STEP IV.)	($/hour)	IVA-4. 0	
IVA-5.	**Determine Average Hourly Artic Operating Labor Costs** (Multiply [1 + line IVA-2] by [line IVA-1 + line IVA-4], input answer to STEP IV—Artic Desired Service and return to STEP IV)	($/hour)	IVA-5. 17.73	

Step IVB: Calculate Unit Operating Costs Per Vehicle-Mile

Fuel costs include fuel and oil consumed by revenue vehicles whether in revenue service or deadheading; they do not include fuel for service vehicles. Both fuel costs and tire costs should be relatively straightforward to calculate from existing agency data.

Servicing of revenue vehicles includes fueling the vehicle, washing the vehicle and cleaning the inside of the vehicle. (This corresponds to functional categories 51 and 52 in the Section 15 reporting requirements under reporting levels A and B, respectively.) Since most agencies do this on a daily basis regardless of the miles of service each vehicle performs each day, servicing costs should logically be expressed on a per vehicle, rather than a per vehicle mile basis. However, it has been included here on a per vehicle-mile basis because this is the conventional practice. Vehicle-miles are total vehicle-miles, including revenue-service and deadheading mileage.

Maintenance is revenue vehicle inspection and maintenance (including parts and labor), revenue vehicle maintenance administration, accident repairs, and vandalism repairs; these items correspond to functional categories 61, 41, 62 and 71 and functional categories 60, 41, 62 and 70 in the section 15 reporting requirements under reporting levels A and B, respectively. Not included in this unit cost category are maintenance of any facilities or service vehicles or the cost of any maintenance facilities.

Three additional considerations are worth noting here. First, fuel economy may vary from city to city depending on the nature of service, number of hills, climate, presence of air conditioners, etc. If an agency knows its own conventional bus fuel economy figure, it should use a ratio of artic:conventional fuel economy figures from other agencies (or the ratio of default values) as a factor to tailor the artic mpg figure to local conditions rather than use its own conventional bus mpg and a default mpg value for artics. Second, and similarly, other cost categories, such as maintenance cost, may be defined differently from agency to agency, so, if the local figure is known for conventional buses, ratios from other agencies should be used to obtain the equivalent figure for artics.

Table VIII-2.

Some Actual Agency Values for Unit Cost Parameters

Fuel Economy (Mpg.)

	Artic	Std.	Ratio
Twin Cities (1979)	3.42	3.78	0.90
Twin Cities (1980)	3.12	3.78	0.83
Twin Cities (1981)	3.36	3.84	0.88
Twin Cities (1982)	3.57	3.78	0.94
Chicago (1979)	2.66	3.12	0.85
Seattle (1980)	3.62	3.97	0.91
Seattle (1981)	3.80	4.17	0.91
Seattle (1982):			
280 H.P.	3.85	4.35	0.89
310 H.P.	3.47	4.35	0.80
Seattle (1983):			
280 H.P.	4.01	4.39	0.91
310 H.P.	3.65	4.39	0.83
Phoenix (1979-80)	3.11	3.44	0.90
Oakland (1980)	3.30	4.90	0.67
Portland (1982)	3.93	4.10	0.96
Portland (1983-84)	3.51	4.12	0.85
Los Angeles (1983-84)	1.97	2.71	0.73
Pittsburgh (1979-80)	2.76	n.a.	
Atlanta (1983-84)	2.40	2.80	0.86*
	1.90	2.30	0.83**
Twin Cities:			
Summer (1979)	3.06	3.86	0.79
Summer (1980)	2.99	3.91	0.76
Summer (1981)	3.01	3.89	0.77
Winter (1979)	3.63	3.70	0.98
Winter (1980)	3.33	3.72	0.90
Winter (1981)	3.41	3.77	0.90
San Jose (1984)			
M.A.N.	3.10	3.65	0.85
Crown	3.30	3.65	0.90

*Without Air Conditioning
**With Air Conditioning

Fuel Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Twin Cities (1979)	.189	.171	1.11
Twin Cities (1981)	.321	.281	1.14
Twin Cities (1982)	.226	.224	1.01
Seattle (1980)	.273	.245	1.11
Seattle (1981)	.266	.242	1.10
Seattle (1982)	.269	.230	1.09
Seattle (1983)	.286	.247	1.16
Los Angeles (1983-84)	.388	.282	1.37
Oakland (1980)	.304	.203	1.50
Portland (1983-84)	.256	.220	1.17

Tire Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.016	.022	0.73
Seattle (1981)	.036	.024	1.50
Seattle (1982)	.040	.027	1.47
Seattle (1983)	.046	.036	1.28
Twin Cities (1979-82)	.047	.022	2.14
Los Angeles (1983-84)	.067	.035	1.91
Portland (1983-84)	.087	.039	2.20

Maintenance Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.219	.206	1.06
Seattle (1981)	.313	.407	0.77
Seattle (1982)	.413	.433	0.95
Seattle (1983)	.377	.512	0.74
Oakland (1980)	.218	.066	3.30

Servicing Cost/Mile ($/Mi.)

	Artic	Std.	Ratio
Seattle (1980)	.043	.035	1.23
Seattle (1981)	.050	.059	0.85
Seattle (1982)	.065	.067	0.97
Seattle (1983)	.072	.067	1.07

Line	Units	Conventional Bus Value	Artic Value	Reference/Notes
IVB-1. Fuel Economy	(miles/gallon)	IVB-1. 3.90	IVB-1. 3.60	**Default Values:** Conventional: 3.9 mpg Conv (w/AC): 3.4 mpg Artic Bus: 3.65 mpg Artic (w/AC): 3.1 mpg Ratio: .092
IVB-2. Fuel Price	($/gallon)	IVB-2. 0.85	IVB-2. 0.85	**Default Val:** $.85/gal
IVB-3. Fuel Cost Per Mile (Divide line IVB-2 by line IVB-1)	($/mile)	IVB-3. 0.218	IVB-3. 0.236	**Default Values:** Conventional: $.22/mi. Conv(w/AC): $.25/mi. Artic Bus: $.24/mi. Artic(w/AC): $.27/mi. Ratio: 1.12
IVB-4. Tire Cost Per Mile	($/mile)	IVB-4. 0.035	IVB-4. 0.055	**Default Values:** Conventional: $.035/mi. Artic Bus: $.055/mi. Ratio: 1.60
IVB-5. Servicing Cost Per Mile	($/mile)	IVB-5. 0.095	IVB-5. 0.115	**Default Values:** Conventional: $.095/mi. Artic Bus: $.115/mi. Ratio: 1.20
IVB-6. Maintenance Cost Per Mile	($/mile)	IVB-6. 0.500	IVB-6. 0.650	**Default Values:** Conventional: $.50/mi. Artic Bus: $.65/mi. Ratio: 1.33
IVB-7. Total Per-Mile Operating Costs (Add lines IVB-3, IVB-4, IVB-5, and IVB-6, input answers to STEP IV as Unit Operating Cost per vehicle-mile, and return to STEP IV)	($/mile)	IVB-7. 0.848	IVB-7. 1.056	**Default Values:** Conventional: $.85/mi. Conv(w/AC): $.88/mi. Artic Bus: $1.06/mi. Artic(w/AC): $1.09/mi.

Table VIII-3.

UMTA Section 15 Year 4 Per Mile Operating Cost Data (value actually reported)

Level	Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
A	4022	Atlanta, GA	6-30-82	640	$0.521	$0.076	$0.337	$0.012	$0.945
A	9036	Anaheim, CA	6-30-82	362	0.373	0.078	0.298	0.038	0.786
A	1003	Boston, MA	12-31-81	763	1.556	0.361	0.330	0.019	2.267
A	5066	Chicago, IL	12-26-81	1990	1.078	0.168	0.394	0.020	1.659
A	5012	Cincinnati, OH	12-31-81	342	0.538	0.157	0.336	0.030	1.061
A	5016	Columbus, OH	12-31-81	228	0.314	0.103	0.268	0.019	0.705
A	6004	Dallas, TX	9-30-81	403	0.356	0.049	0.315	0.022	0.742
A	8006	Denver, CO	12-31-81	526	0.519	0.062	0.284	0.037	0.902
A	5031	Detroit, MI	6-30-82	802	0.664	0.166	0.308	0.023	1.161
A	2008	New York, NY	6-30-82	3124	3.382	0.418	0.325	0.034	4.159
A	9014	Oakland, CA	6-30-82	732	0.356	0.088	0.227	0.034	0.705
A	3019	Philadelphia, PA	6-30-82	1095	1.153	0.150	0.341	0.031	1.676
A	3022	Pittsburgh, PA	6-30-82	775	0.701	0.149	0.301	0.032	1.184
A	6011	San Antonio, TX	2-28-82	372	0.294	0.040	0.319	0.023	0.676
A	9026	San Diego, CA	6-30-82	196	0.534	0.082	0.272	0.031	0.920
A	7006	St. Louis, MO	6-30-82	670	0.575	0.098	0.289	0.021	0.983
A	5027	St. Paul, MN	12-31-81	850	0.629	0.003	0.309	0.026	0.967
A	1	Seattle, WA	12-31-81	762	0.431	0.062	0.241	0.027	0.761
B	3010	Allentown, PA	6-30-82	51	$0.299	$0.036	$0.233	$0.017	$0.585
B	5010	Akron, OH	12-31-81	97	0.268	0.061	0.317	0.024	0.670
B	4042	Birmingham, AL	9-30-82	120	0.375	0.132	0.357	0.040	0.904
B	2004	Buffalo, NY	3-31-82	369	0.568	0.089	0.303	0.025	0.985
B	4008	Charlotte,NC	6-30-82	92	0.287	0.108	0.357	0.039	0.790
B	5025	Duluth, MN	12-31-82	73	0.288	0.099	0.301	0.017	0.704
B	6006	El Paso, TX	8-31-81	75	0.273	0.065	0.366	0.027	0.732
B	5032	Flint, MI	9-30-81	37	0.470	0.105	0.290	0.021	0.885
B	6007	Ft. Worth, TX	9-30-81	105	0.256	0.054	0.312	0.022	0.644
B	3004	Hampton, VA	6-30-82	79	0.292	0.073	0.291	0.034	0.690
B	1048	Hartford, CT	6-30-82	215	0.521	0.103	0.303	0.018	0.946
B	9002	Honolulu, HI	6-30-82	336	0.561	0.063	0.371	0.044	1.040
B	4040	Jacksonville, FL	9-30-81	168	0.262	0.097	0.323	0.034	0.716
B	7005	Kansas City, MO	12-31-81	260	0.466	0.120	0.329	0.036	0.950
B	9023	Long Beach, CA	6-30-82	124	0.266	0.046	0.349	0.039	0.699
B	4003	Memphis, TN	6-30-82	204	0.328	0.074	0.278	0.028	0.708
B	4004	Nashville, TN	6-30-82	117	0.297	0.111	0.277	0.029	0.714
B	3005	Norfolk, VA	9-30-81	137	0.341	0.071	0.322	0.039	0.774
B	6017	Oklahoma City, OK	6-30-82	68	0.315	0.055	0.268	0.033	0.670
B	5056	Peoria, IL	12-31-81	42	0.179	0.076	0.251	0.013	0.519
B	1001	Providence, RI	6-30-82	208	0.264	0.084	0.243	0.026	0.616
B	3006	Richmond, VA	6-30-82	152	0.348	0.094	0.346	0.031	0.820
B	2013	Rochester, NY	3-31-82	187	0.602	0.109	0.338	0.030	1.079
B	9019	Sacramento, CA	6-30-82	157	0.439	0.087	0.254	0.024	0.804
B	4041	Tampa, FL	9-30-81	67	0.209	0.056	0.312	0.014	0.592
B	8001	Salt Lake City, UT	12-31-81	234	0.585	0.070	0.286	0.033	0.974
B	9008	Santa Monica, CA	6-30-82	92	0.363	0.051	0.380	0.027	0.821
B	5022	Toledo, OH	12-31-81	175	0.161	0.101	0.275	0.023	0.559

	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
Mean-Level A	$0.642	$0.099	$0.311	$0.027	$1.095
Northeast	1.698	0.270	0.324	0.029	1.709
Southeast	0.521	0.076	0.337	0.012	0.945
Midwest	0.645	0.120	0.323	0.024	1.111
South Central	0.408	0.062	0.308	0.022	0.800
West	0.416	0.076	0.270	0.037	0.798
Mean-Level B	$0.344	$0.080	$0.308	$0.028	$0.760
Northeast	0.405	0.089	0.297	0.028	0.812
Southeast	0.293	0.096	0.317	0.031	0.737
Midwest	0.273	0.088	0.287	0.019	0.667
South Central	0.328	0.074	0.319	0.029	0.749
West	0.443	0.063	0.328	0.033	0.868
Mean-Levels A & B	$0.427	$0.088	$0.309	$0.027	$0.851
Northeast	0.604	0.120	0.313	0.028	1.056
Southeast	0.293	0.093	0.320	0.028	0.767
Midwest	0.390	0.115	0.295	0.022	0.803
South Central	0.362	0.069	0.314	0.026	0.771
West	0.433	0.068	0.306	0.035	0.841

Capital Recovery Factor

Economic Life of Bus In Years (N)	Interest Rate (I)									
	0.050	0.075	0.100	0.110	0.120	0.130	0.140	0.150	0.175	0.200
1	1.050	1.075	1.100	1.110	1.120	1.130	1.140	1.150	1.175	1.200
2	0.538	0.557	0.576	0.584	0.592	0.599	0.607	0.615	0.635	0.655
3	0.367	0.385	0.402	0.409	0.416	0.424	0.431	0.438	0.456	0.475
4	0.282	0.299	0.315	0.322	0.329	0.336	0.343	0.350	0.368	0.386
5	0.231	0.247	0.264	0.271	0.277	0.284	0.291	0.298	0.316	0.334
6	0.197	0.213	0.230	0.236	0.243	0.250	0.257	0.264	0.282	0.301
7	0.173	0.189	0.205	0.212	0.219	0.226	0.233	0.240	0.259	0.277
8	0.155	0.171	0.187	0.194	0.201	0.208	0.216	0.223	0.241	0.261
9	0.141	0.157	0.174	0.181	0.188	0.195	0.202	0.210	0.229	0.248
10	0.130	0.146	0.163	0.170	0.177	0.184	0.192	0.199	0.219	0.239
11	0.120	0.137	0.154	0.161	0.168	0.176	0.183	0.191	0.211	0.231
12	0.113	0.129	0.147	0.154	0.161	0.169	0.177	0.184	0.205	0.225
13	0.106	0.123	0.141	0.148	0.156	0.163	0.171	0.179	0.200	0.221
14	0.101	0.118	0.136	0.143	0.151	0.159	0.167	0.175	0.195	0.217
15	0.096	0.113	0.131	0.139	0.147	0.155	0.163	0.171	0.192	0.214
16	0.092	0.109	0.128	0.136	0.143	0.151	0.160	0.168	0.189	0.211
17	0.089	0.106	0.125	0.132	0.140	0.149	0.157	0.165	0.187	0.209
18	0.086	0.103	0.122	0.130	0.138	0.146	0.155	0.163	0.185	0.208
19	0.083	0.100	0.120	0.128	0.136	0.144	0.153	0.161	0.184	0.206
20	0.080	0.098	0.117	0.126	0.134	0.142	0.151	0.160	0.182	0.205
21	0.078	0.096	0.116	0.124	0.132	0.141	0.150	0.158	0.181	0.204
22	0.076	0.094	0.114	0.122	0.131	0.139	0.148	0.157	0.180	0.204
23	0.074	0.093	0.113	0.121	0.130	0.138	0.147	0.156	0.179	0.203
24	0.072	0.091	0.111	0.120	0.128	0.137	0.146	0.155	0.179	0.203
25	0.071	0.090	0.110	0.119	0.127	0.136	0.145	0.155	0.178	0.202

Step IVC: Calculate Capital Costs per Vehicle: Equivalent Annual or Daily Costs

Two methods of determining the amortized capital costs per vehicle are commonly used – one mileage-based and the other years-of-life based – we recommend the latter because of its simplicity. The recommended method defines the useful life of a bus in years and, using the number of effective days of service per year, the purchase price of the vehicle, and a capital recovery factor (interest rate), translates purchase price into capital cost per vehicle per year and per day.

	Line	Units	Conventional Bus Value	Artic Value	Reference/Notes
IVC-1.	**Purchase Price of Vehicle** (P)	($)	IVC-1. 120,000	IVC-1. 203,000	**Default Values:** Conventional: $120,000 Conv (w/AC): $130,000 Artic Bus: $203,000 Artic (w/AC): $236,000
IVC-2.	**Economic Life of Bus (Years)** (N)	(years)	IVC-2. 12	IVC-2. 12	**Default Values:** Conventional: 12 years Artic Bus: 12 years
IVC-3.	**Interest Rate (Per Year)** (i)	(decimal percent)	IVC-3. .10	IVC-3. .10	**Default Value:** .10
IVC-4.	**Capital Recovery Factor**		IVC-4. 0.147	IVC-4. 0.147	**From table on opposite page.**
IVC-5.	**Capital Cost Per Vehicle Per Year** (Multiply line IVC-1 by line IVC-4)	($/bus/year)	IVC-5. 17,612	IVC-5. 29,793	
IVC-6.	**Effective No. of Days Per Year** (No. of weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	IVC-6. 250	IVC-6. 250	**Default Value:** 250 days
IVC-7.	**Capital Cost Per Vehicle Per Day** (Divide line IVC-5 by line IVC-6, input answers to STEP IV as Unit Capital Cost, and return to STEP IV)	($/bus/day)	IVC-7. 70.45	IVC-7. 119.17	

Line 49 then introduces the third cost component, the per-vehicle capital costs. Here the artic solution is more expensive than the conventional bus solution ($1788 per day for the artics vs. $1339 per day for the desired number of conventional buses).
Line 50 then summarizes Total Costs Per Day. In our example:

(Per Day)	Current Conventional	Desired Conventional	(%)	Desired Artic	(%)
Labor Costs	$1,790	$2,218	(44.6)	$1,724	(35.5)
Operating Costs	1,144	1,420	(28.5)	1,342	(27.6)
Capital Costs	1,057	1,339	(26.9)	1,788	(36.8)
	$3,992	$4,977	(100.0)	$4,855	(100.0)

Comparing just the two alternative approaches designed to provide the desired seating standard, it can be seen from the numbers in this example that the artic is just slightly less expensive than the desired conventional bus alternative. It can also be seen that the artic saves on labor and operating cost but at the expense of capital cost.

There is no analysis of ridership (and therefore revenue) impact included in the worksheets because of the lack of quantitative evidence. In this example, it is likely that the ridership will improve considerably by going to either of the desired seating standard solutions. The desired artic solution provides 4.59 minute headways vs. 3.24 minute headways with the desired conventional bus solution. The artic may be preferred on comfort and image grounds, but it would seem likely that, on balance, the headway difference would lead to ridership being higher with the conventional bus solution, possibly by more than enough to offset the 2.5 percent cost saving offered by the artic solution.

VIII-C. Using a Simplified Cost Model to Screen Potential Artic Routes

If you are examining a large number of prospective routes for artic deployment, you may find it helpful to use a simple screening model to help in choosing a deployment strategy and estimating cost savings. The models described in this section are the same ones that are used in the more detailed worksheets in Section VIII-D, except that default values are used in certain places where data are not likely to be available, and a few other simplifying assumptions are made. The two simplified models are:

Break-even substitution ratio. This model computes the number of standard buses on a given route which would have to be replaced by one artic in order to cause total costs (operating + capital) to remain unchanged from current levels. Typically, this substitution ratio ranges from 1.1 to 1.6. Since the ratio of artic seats to standard bus seats is typically 68:45 or 1.51, a break-even substitution ratio less than 1.51 indicates that artic substitution can increase the route's carrying capacity without changing total costs. In deploying artics on your route, if you substitute artics at a rate greater than break-even, but less than 1.51, you may find that you can increase capacity and save costs at the same time. (A substitution ratio greater than 1.0 implies increased headways, and so ridership may be reduced.) The equation for this model is:

$$R = \frac{H/60 + 1.24 \cdot M \cdot D/T + 119/P}{H/60 + M \cdot D/T + 71/P}$$

where: R = Break-even substitution ratio (standard buses per artic)

H = Hourly labor cost (\$/bus-hr., includes fringes)

M = Total per-mile cost (\$/bus-mi., includes fuel, tires, servicing, and maintenance)

D = Round-trip distance of route (mi.)

T = Round-trip run time of route (min., includes layover and recovery)

P = Time period of proposed artic service each day (min., includes both peaks)

The model assumes that:

1. Artic hourly labor cost is the same as standard bus hourly labor cost.
2. Artic per-mile cost is 1.24 times standard bus per-mile cost, the average ratio based on actual artic operating experience to date.
3. Standard bus unit cost is $120,000, and artic unit cost is $203,000.
4. Capital costs are discounted at a 10 percent rate for a 12-year lifetime.
5. The service is in operation 250 days per year.
6. All artic and standard buses to be used in the proposed service must be purchased new, and are not used on any other service. That is, all capital costs are fully allocated to this service in this time period.
7. The same spares ratio is used for both artics and standard buses.
8. All available buses (except spares) are in service during the entire time period. Thus, the model applies only to peak-period substitution (scenarios 1 and 2 in the detailed worksheets). For off-peak substitution, remove the third term in both the numerator and denominator of the above equation, since capital cost is fully allocated to the peak period.
9. There are no binding limits on headways.
10. Artic running times are the same as standard bus running times on this route.
11. Differences in deadheading time are ignored.

Be sure to check these assumptions carefully before using this model.

Cost savings. If you have already decided on a substitution ratio, this model will compute the resulting total cost (operating + capital) savings per year. The cost savings model uses the same assumptions as the substitution ratio model, so be sure to check these assumptions first to see that they apply to your particular situation. The model will give a result greater than zero for substitution ratios greater than the break-even ratio given by the model above.

$$S = 250 \cdot V/R \cdot ((R-1) \cdot H \cdot P/60 + (R-1.24) \cdot M \cdot P \cdot D/T + (R-1.69) \cdot 71)$$

where: S = Cost savings with artic substitution ($/year)

R,H,M,D,T and P are as defined above

V = Number of standard buses currently in service on the route

The following two pages show worksheets for computing break-even substitution ratios and cost savings using the above models. For unit cost figures, consult the worksheets and tables for STEP IVA, B, and C in the white section at the end of this Handbook.

Articulated Bus Substitution — Simple Substitution Ratio

This one-page worksheet gives you a simple way to estimate the number of standard buses on a specific route which may be replaced by one articulated bus at the economic break-even point, i.e., where total costs (capital + operating) are left unchanged.

Route: ____

Line	Symbol	Units	Value	Notes
1. **Round-trip distance for this route**	D	(mi.)	1. ________	
2. **Round-trip run time for this route**	T	(min.)	2. ________	Includes layover and recovery.
3. **Average speed** (divide line 1 by line 2)		(mi./min.)	3. ________	
4. **Total per-mile operating costs for standard buses** (include fuel, tires, servicing, and maintenance; use the STEP IVB worksheet or accompanying tables)	M	($/bus-mi.)	4. ________	Default = 0.85
5. **Hourly labor cost for standard buses** (include fringes; use the STEP IVA worksheet or accompanying tables)	H	($/bus-hr.)	5. ________	Default = 17.75
6. **Time period of operation of proposed artic service each day** (include both peaks, if applicable)	P	(min.)	6. ________	
7. **Artic equivalent total cost per minute**				
7a. First (hourly cost) term (divide line 5 by 60)		($/bus-min.)	7a. ________	
7b. Second (per-mile cost) term (multiply line 3 by line 4 by 1.24)		($/bus-min.)	7b. ________	
7c. Third (capital cost) term (divide 119 by line 6)		($/bus-min.)	7c. ________	For off-peak, enter zero.
7d. Artic equivalent total cost per minute (add lines 7a, 7b and 7c)		($/bus-min.)	7d. ________	
8. **Standard bus total cost per minute**				
8a. First (hourly cost) term (divide line 5 by 60)		($/bus-min.)	8a. ________	
8b. Second (per-mile cost) term (multiply line 3 by line 4)		($/bus-min.)	8b. ________	
8c. Third (capital cost) term (divide 71 by line 6)		($/bus-min.)	8c. ________	For off-peak, enter zero.
8d. Standard bus total cost per minute (add lines 8a, 8b and 8c)		($/bus-min.)	8d. ________	
9. **Break-even substitution ratio** (divide line 7d by line 8d)	R	(standard buses per artic)	9. ________	

Articulated Bus Substitution – Simple Cost Savings

This one-page worksheet gives you a simple way to estimate the cost savings which might be realized with articulated bus substitution. It draws on the same assumptions and data as the previous worksheet, but also requires you to know the number of standard buses currently in service and the proposed substitution ratio.

Route:____

Line	Symbol	Units	Value	Notes
1. **Round-trip distance for this route**	D	(mi.)	1. ________	
2. **Round-trip run time for this route**	T	(min.)	2. ________	Includes layover and recovery.
3. **Time period of operation of proposed artic service each day** (include both peaks, if applicable)	P	(min.)	3. ________	
4. **Route miles travelled per day** (multiply line 1 by line 3, then divide by line 2)		(mi./day)	4. ________	
5. **Total per-mile operating costs for standard buses** (includes fuel, tires, servicing, and maintenance; use the STEP IVB worksheet or accompanying tables)	M	($/bus-mi.)	5. ________	Default = 0.85
6. **Hourly labor cost for standard buses** (include fringes; use the STEP IVA worksheet or accompanying tables)	H	($/bus-hr.)	6. ________	Default = 17.75
7. **Substitution ratio** (enter the number of standard buses you propose to replace by each artic)	R	(standard buses per artic)	7. ________	To leave capacity unchanged, use 1.51
8. **Number of standard buses now in service to be replaced by artics**	V	(buses)	8. ________	
9. **Cost savings per artic per day**				
9a. First (hourly cost) term (subtract 1.0 from line 7, divide by 60, then multiply by line 3 by line 6)		($/artic/day)	9a. ________	
9b. Second (per-mile cost) term (subtract 1.24 from line 7, then divide by line 2, then multiply by line 3 by line 1 by line 5)		($/artic/day)	9b. ________	
9c. Third (capital cost) term (subtract 1.69 from line 7, then multiply by 71.0)		($/artic/day)	9c. ________	For off-peak, enter zero.
9d. Cost savings per artic per day (add lines 9a, 9b and 9c)		($/artic/day)	9d. ________	
10. **Cost savings per day** (multiply line 8 by line 9d by 250, then divide by line 7)	S	($/year)	10. ________	

VIII-D. Worksheets and Supporting Data

The following pages contain the worksheets for the three substitution scenarios:

Number	Page Color	Scenario
1.	**Blue**	All artic substitution, peak period only
2.	**Yellow**	Mixture of artics and standard buses, peak period only
3.	**Pink**	All artics, all day

Following the Blue, Yellow, and Pink sections is a white section containing optional steps IVA, IVB, and IVC, and their accompanying cost tables, for estimating operating and capital costs. These optional steps are applicable to the worksheets for all three scenarios.

Virtually any combination of artics and standards, any time periods, and any operating strategies, e.g. short-lining or limited stop service with artics, can be analyzed using essentially these same procedures, with only minor modifications to the worksheets.

1. PEAK ONLY SUBSTITUTION

Articulated Bus Substitution – Economic Analysis Worksheet

Scenario #1: Scenario 1 represents the main set of worksheets. Scenario 1 worksheets cover the classic case of complete artic substitution for conventional buses during the weekday peak periods, but no artic substitution off-peak. Input information for one peak only (AM or PM), and the worksheets effectively double the relevant cost items to account for the second peak as well. Worksheets assume the length of the peak periods to be equivalent. Adjustments to worksheet calculations should be made if peaks vary in length.

Step I: Assemble Information About the Route and Service Being Considered for Substitution by Articulated Buses

Route:____

Line	Units	Value	Reference/Notes
1. **Time Period of Interest** – Length of Time on Average Weekday for Considering Artic Substitution (Enter value in minutes)	(minutes)	1. ________	Enter length of time for one peak only (A.M. or P.M.); Calculations assume the use of artics on the other peak as well.
2. **Average Headway During This Period** (Enter headway in minutes)	(minutes)	2. ________	
3. **Number of Trips During This Period** (Enter specific number from schedule or divide line 1 by line 2)	(no. trips)	3. ________	
4. **Round Trip Run Time for This Route During This Time Period** (Enter time in minutes)	(minutes)	4. ________	Includes layover and recovery times.
5. **Round Trip Distance for This Route** (Enter distance in miles)	(miles)	5. ________	
6. **No. Conventional Buses Needed to Provide This Service** (Divide line 4 by line 2 and round up to nearest integer)	(no. vehicles)	6. ________	
7. **Operator Hours** (Multiply line 3 by line 4 and divide by 60)	(hours)	7. ________	
8. **Bus In-Service Miles** (Multiply line 3 by line 5)	(miles)	8. ________	
9. **Total Passenger Volume at Peak Load Point, Peak Direction During This Period** (Sum up peak load point passenger counts for each trip during this period)	(passengers)	9. ________	Itemize on reverse side if desired.

Line	Units	Value	Reference/Notes
10. **Average Passenger Volume Per Bus At Peak Load Point During This Period** (Enter estimated average value or divide line 9 by line 3)	(passengers per bus)	10. ________	
11. **Seating Capacity of Bus Used in This Service** (Enter no. seats per bus)	(seats per bus)	11. ________	Use 48 as default value.
12. **Passengers Per Seat at Peak Load Point** (Divide line 10 by line 11)	(passengers per seat)	12. ________	
13. **Deadheading Time from Garage to Route at Beginning of Period**	(minutes)	13. ________	
14. **Deadheading Time from Route to Garage at End of Period**	(minutes)	14. ________	
15. **Deadheading Distance from Garage to Route at Beginning of Period**	(miles)	15. ________	
16. **Deadheading Distance from Route to Garage at End of Period**	(miles)	16. ________	

Go To Step II (Line 17)

Scenario #1 *(continued)*

Step II: If Current Level of Service Provided on This Route During This Period is Inadequate, Determine Additional Conventional Bus Service Required to Meet Service Standard

Line	Units	Value	Reference/Notes
17. **Desired Passenger/Seat Service Level** (Line 12 is the passenger per seat ratio at the peak load point or, equivalently, the fraction of seated capacity at which the average trip is operating; if a higher standard (lower ratio) is desired, enter this ratio here and go to line 18; if not, go to STEP III (line 24))	(passengers per seat)	17. ________	
18. **Average Passengers Per Trip at Peak Load Point Under Desired Service Level** (Multiply line 11 by line 17)	(passengers per bus)	18. ________	
19. **Number of Conventional Bus Trips Required to Meet Desired Service Level** (Divide line 9 by line 18)	(no. trips)	19. ________	
20. **Average Headway for Conventional Bus Service at Desired Service Level** (Divide line 1 by line 19)	(minutes)	20. ________	
21. **Number of Conventional Buses Needed to Provide Desired Service Level** (Divide line 4 by line 20 and round up to nearest integer)	(no. vehicles)	21. ________	
22. **Operator Hours Needed for Desired Level of Conventional Bus Service** (Multiply line 4 by line 19 and divide by 60)	(hours)	22. ________	
23. **Conventional Bus In-Service Miles for Desired Level of Conventional Bus Service** (Multiply line 5 by line 19)	(miles)	23. ________	

Go To Step III (Line 24)

Scenario #1 *(continued)*

Step III: Determine the Articulated Bus Service Required To Fully Replace Conventional Buses During the Defined Period at the Desired Service Level (Passengers/Seat)

Line	Units	Value	Reference/Notes
24. Desired Passenger/Seat Service Level for Artics (Enter value on line 17 or alternative policy standard if desired; if line 17 is blank, enter value on line 12)	(passengers per seat)	24. ________	
25. Seating Capacity of Artics (Enter no. of seats per articulated bus)	(no. seats per artic)	25. ________	Use 68 as default value.
26. Average Passengers Per Artic at Peak Load Point (Multiply line 24 by line 25)	(passengers per artic)	26. ________	
27. No. of Artic Trips Needed (Divide line 9 by line 26)	(no. trips)	27. ________	
28. Average Headway for Artics at Desired Service Level (Divide line 1 by line 27)	(minutes)	28. ________	
29. Relative Speed Factor of Artics vs. Conventional Buses: Ratio of Running Times (Artic:Conventional) **for Routes of This Type**	(unitless, should be ≥ 1.0)	29. ________	Use 1.10 as default for local service, 1.0 for express service (See report for further discussion.)
30. Round Trip Run Time for This Route for Artics (Multiply line 4 by line 29)	(minutes)	30. ________	Include recovery and layover times.
31. No. of Artics Needed to Provide Desired Level of Service (Divide line 30 by line 28 and round up to nearest integer)	(no. artics)	31. ________	
32. Operator Hours for Artic Service (Multiply line 27 by line 30 and divide by 60)	(hours)	32. ________	
33. Artic In-Service Miles for Provision of Desired Service Level (Multiply line 27 by line 5)	(miles)	33. ________	
34. Artic Deadheading Time from Garage to Route at Beginning of Period	(minutes)	34. ________	
35. Artic Deadheading Time from Route to Garage at End of Period	(minutes)	35. ________	
36. Artic Deadheading Distance from Garage to Route at Beginning of Period	(miles)	36. ________	
37. Artic Deadheading Distance from Route to Garage at End of Period	(miles)	37. ________	

Go To Step IV (line 38)

Scenario #1 *(continued)*

Step IV: Calculate Differences in Costs of Serving Selected Route with Artics Instead of Conventional Buses

Changes in costs for changes in service on any route can be computed generally as changes in cost per hour (for operator labor) plus changes in costs per vehicle (for capital costs) plus changes in costs per vehicle-mile (for fuel, tires, servicing of vehicles, and maintenance of vehicles). Optional Step IVA outlines how a transit planner can calculate changes in labor costs; it also defines what all is included in "average labor costs per hour." Optional Step IVB outlines how a transit planner can determine the per-mile costs for fuel, tires, servicing and maintenance; it also defines what all is included in each category. Optional Step IVC outlines how capital costs can be computed and translated into costs per vehicle per day. All of these optional steps are located in the white section at the end of this Handbook.

For each of these unit-cost categories, four alternative methods are provided to determine the unit costs to be used in this analysis:

1. Use agency-specific values where they are readily available or can be determined easily.
2. Use default values supplied on the worksheet.
3. Select unit cost values from the listing on the page opposite the appropriate worksheet page which tabulates unit cost values compiled directly from selected operators.
4. Select unit cost values from information obtained from UMTA Section 15 data listed on the page following the worksheet page.

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service (if applicable)	Value: Artics Desired Service	Reference/Notes
(Lines 38-40: Copy Over Relevant Information from STEPS I-III for Convenience)					
38. No. Vehicles Required	(no. vehicles)	38a. ________ (line 6)	38b. ________ (line 21)	38c. ________ (line 31)	
39. No. In-Service Operator Hours Required	(hours)	39a. ________ (line 7)	39b. ________ (line 22)	39c. ________ (line 32)	
40. No. In-Service Vehicle-Miles Required	(miles)	40a. ________ (line 8)	40b. ________ (line 23)	40c. ________ (line 33)	
41. No. Deadheading Hours Required (Multiply line 38 by the deadheading time, the sum of line 13 and line 14 (line 34 and line 35 for artics), then divide the product by 60)	(hours)	41a. ________	41b. ________	41c. ________	

Line	Units	Value			Reference/Notes
		Conventional Bus Existing Service	Conventional Bus Desired Service (if applicable)	Artics Desired Service	
42. No. Deadheading Miles Required (Multiply line 38 by the deadheading distance, the sum of line 15 and line 16 (line 36 and line 37 for artics))	(miles)	42a. ________	42b. ________	42c. ________	
43. Platform Hours (line 39 + line 41)	(hours)	43a. ________	43b. ________	43c. ________	
44. Total Vehicle-Miles (line 40 + line 42)	(miles)	44a. ________	44b. ________	44c. ________	
45. Operator Wage Rate Plus Fringes per Platform Hour	($/hour)	45a. ________	45b. ________	45c. ________	See **Step IVA** at end of Handbook.
46. Unit Operating Cost per Vehicle-Mile for Fuel, Tires, Servicing, and Maintenance	($/vehicle-mile)	46a. ________	46b. ________	46c. ________	See **Step IVB** at end of Handbook.
47. Total Operating Cost for Service	($/day)	47a.	47b.	47c.	
(i) Multiply line 43 by line 45		________	________	________	
(ii) Multiply line 44 by line 46		________	________	________	
(iii) Add above two figures together		________	________	________	
(iv) Multiply by 2 for two peak periods per day		________	________	________	
48. Unit Capital Cost per Vehicle per Day (Multiply by 1.10 to account for spares, if desired)	($/day/vehicle)	48a. ________	48b. ________	48c. ________	See **Step IVC** at end of Handbook.
49. Total Capital Costs (Multiply line 48 by line 38)	($/day)	49a. ________	49b. ________	49c. ________	
50. Total Costs Per Day (Add line 47 and line 49)	($/day)	50a. ________	50b. ________	50c. ________	
51. Effective No. Days Per Year (No. of weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	51a. ________	51b. ________	51c. ________	Use 250 days per year as default value.
52. Total Costs Per Year in Thousands of Dollars (Multiply line 50 by line 51 and divide by 1000)	($1000/year)	52a. ________	52b. ________	52c. ________	

2. PEAK ONLY - MIXED SERVICE

Articulated Bus Substitution – Economic Analysis Worksheet

Scenario #2: Scenario 2 worksheets cover the special case where a mixture of artics and conventional buses is used on a particular route during a peak period. The inherent assumption in Scenario 2 is that, during the peaks and for a particular route, the transit operator will add a number of artics to that number of conventional buses which was required to service the base (between peaks) period anyway; when the (AM) peak is over, the artics will return to the garage, but the conventional buses will remain to provide base service. Of course the analysis of any other mixture of artics and conventional buses can be done with only minor adjustments to the worksheets for Scenario 2. Input information for one peak only (AM or PM), and the worksheets effectively double the relevant cost items to account for the second peak as well. Worksheets assume the length of the peak periods to be equivalent. Adjustments to worksheet calculations should be made if peaks vary in length.

Step I: Assemble Information About the Route and Service Being Considered for Substitution by Articulated Buses

Route:____

Line	Units	Value	Reference/Notes
1. **Time Period of Interest** – Length of Time on Average Weekday for Considering Artic Substitution (Enter value in minutes)	(minutes)	1. ________	Enter length of time for one peak only (A.M. or P.M.); Calculations assume the use of artics on the other peak as well.
2. **Average Headway During This Period** (Enter headway in minutes)	(minutes)	2. ________	
3. **Number of Trips During This Period** (Enter specific number from schedule or divide line 1 by line 2)	(no. trips)	3. ________	
4. **Round Trip Run Time for This Route During This Time Period** (Enter time in minutes)	(minutes)	4. ________	Includes layover and recovery times.
5. **Round Trip Distance for This Route** (Enter distance in miles)	(miles)	5. ________	
6. **No. Conventional Buses Needed to Provide This Service** (Divide line 4 by line 2 and round up to nearest integer)	(no. vehicles)	6. ________	
7. **Operator Hours** (Multiply line 3 by line 4 and divide by 60)	(hours)	7. ________	

Line	Units	Value	Reference/Notes
8. **Bus In-Service Miles** (Multiply line 3 by line 5)	(miles)	8. ________	
9. **Total Passenger Volume at Peak Load Point, Peak Direction During This Period** (Sum up peak load point passenger counts for each trip during this period)	(passengers)	9. ________	Itemize on reverse side if desired.
10. **Average Passenger Volume Per Bus At Peak Load Point During This Period** (Enter estimated average value or divide line 9 by line 3)	(passengers per bus)	10. ________	
11. **Seating Capacity of Bus Used in This Service** (Enter no. seats per bus)	(seats per bus)	11. ________	Use 48 as default value.
12. **Passengers Per Seat at Peak Load Point** (Divide line 10 by line 11)	(passengers per seat)	12. ________	
13. **Deadheading Time from Garage to Route at Beginning of Period**	(minutes)	13. ________	
14. **Deadheading Time from Route to Garage at End of Period**	(minutes)	14. ________	
15. **Deadheading Distance from Garage to Route at Beginning of Period**	(miles)	15. ________	
16. **Deadheading Distance from Route to Garage at End of Period**	(miles)	16. ________	

Go To Step II (Line 17)

Scenario #2 *(continued)*

Step II: If Current Level of Service Provided on This Route During This Period Is Inadequate, Determine Additional Conventional Bus Service Required to Meet Service Standard

Line	Units	Value	Reference/Notes
17. **Desired Passenger/Seat Service Level** (Line 12 is the passenger per seat ratio at the peak load point or, equivalently, the fraction of seated capacity at which the average trip is operating; if a higher standard (lower ratio) is desired, enter this ratio here and go to line 18; if not, go to STEP IIB (line 24))	(passengers per seat)	17. ________	
18. **Average Passengers Per Trip at Peak Load Point Under Desired Service Level** (Multiply line 11 by line 17)	(passengers per bus)	18. ________	
19. **Number of Conventional Bus Trips Required to Meet Desired Service Level** (Divide line 9 by line 18)	(no. trips)	19. ________	
20. **Average Headway for Conventional Bus Service at Desired Service Level** (Divide line 1 by line 19)	(minutes)	20. ________	
21. **Number of Conventional Buses Needed to Provide Desired Service Level** (Divide line 4 by line 20 and round up to nearest integer)	(no. vehicles)	21. ________	
22. **Operator Hours Needed for Desired Level of Conventional Bus Service** (Multiply line 4 by line 19 and divide by 60)	(hours)	22. ________	
23. **Conventional Bus In-Service Miles for Desired Level of Conventional Bus Service** (Multiply line 5 by line 19)	(miles)	23. ________	

Go To Step IIB (Line 24)

Step IIB: Determine Base and Excess Shares of Conventional Bus Service Required to Meet Service Standard During Period

Line	Units	Value: Base Service	Value: Excess Service	Reference/Notes
24. **No. of Conventional Buses Needed to Provide Base/Excess Service** (For base, enter (should be less than or equal to line 6); for excess, subtract line 24a from line 21 [line 6, if line 21 is blank])	(no. vehicles)	24a.________	24b.________	
25. **No. of Conventional Bus Trips Required to Meet Desired Service** (For base, multiply line 1 by line 24a and divide by line 4; for excess, subtract line 25a from line 19 [line 3, if line 19 is blank])	(no. trips)	25a.________	25b.________	
26. **No. In-Service Operator Hours Required** (Multiply line 25 by line 4 and divide by 60)	(hours)	26a.________	26b.________	
27. **No. In-Service Vehicle Miles Required** (Multiply line 25 by line 5)	(miles)	27a.________	27b.________	

Go To Step III (line 28)

Step III: Determine the Articulated Share of Services Provided at Desired Passenger/Seat Service Level

Line	Units	Value: Base Conventional Vehicles	Value: Excess Artic Vehicles	Value: Total Base Conventional and Excess Artic Vehicles	Reference/Notes
28. Desired Passenger/Seat Service Level (Enter value on line 17 or alternative policy standard if desired (if line 17 is blank, either value on line 12))	(passengers per seat)			28c. ________	
29. Seating Capacity of Vehicles (For base conventionals, enter value on line 11; for excess artics, enter own or default value)	(no. seats per bus)	29a. ________	29b. ________		Use 68 as default value.
30. Average Passengers Per Bus at Peak Load Point (Multiply line 28c by line 29)	(passengers per bus)	30a. ________	30b. ________		
31. Total Passenger Volumes at Peak Load, Peak Direction During Period (For total peak, enter value on line 9; for base conventionals, mutliply line 25a by line 30a; for excess artics, subtract line 31a from line 31c)	(passengers)	31a. ________	31b. ________	31c. ________	
32. No. of Bus Trips Needed (For base conventionals, enter value on line 25a; for excess artics, divide line 31b by line 30b; for total peak, sum of line 32a and line 32b)	(no. trips)	32a. ________	32b. ________	32c. ________	
33. Average Headway During This Period (Divide line 1 by line 32c and input answer to line 33c)	(minutes)			33c. ________	

Scenario #2 *(continued)*

Line	Units	Value: Base Conventional Vehicles	Value: Excess Artic Vehicles	Value: Total Base Conventional and Excess Artic Vehicles	Reference/Notes
34. **Relative Speed Factor of Artics vs. Conventional Buses: Ratio of Running Times** (Artic:Conventional) **for Routes of This Type** (Enter value for line 34c)	(unitless, should be ≥ 1.0)			34c. ________	Use 1.10 as default value for local service, 1.0 for express service. (See report for further discussion.)
35. **Round Trip Run Time for This Route** (Multiply line 4 by line 34c and input answer to line 35c)	(minutes)			35c. ________	Include recovery and layover times.
36. **No. of Buses Needed to Provide Desired Level of Service** (For total peak, divide line 35c by line 33c and round up to nearest integer; for base conventionals, enter value on line 24a; for excess artics, subtract line 36a from line 36c)	(no. vehicles)	36a. ________	36b. ________	36c. ________	
37. **Operator Hours for Artic Added Service** (Multiply line 32 by line 35c and divide by 60)	(hours)	37a. ________	37b. ________	37c. ________	
38. **In-Service Miles for Provision of Desired Service Level** (Multiply line 32 by line 5)	(miles)	38a. ________	38b. ________	38c. ________	
39. **Artic Deadheading Time from Garage to Route at Beginning of Period**	(minutes)		39b. ________		
40. **Artic Deadheading Time from Route to Garage at End of Period**	(minutes)		40b. ________		
41. **Artic Deadheading Distance from Garage to Route at Beginning of Period**	(miles)		41b. ________		
42. **Artic Deadheading Distance from Route to Garage at End of Period**	(miles)		42b. ________		

Go To Step IV (line 43)

Step IV: Calculate Differences in Costs of Serving Selected Route with Artics Instead of Conventional Buses

Changes in costs for changes in service on any route can be computed generally as changes in cost per hour (for operator labor) plus changes in costs per vehicle (for capital costs) plus changes in costs per vehicle-mile (for fuel, tires, servicing of vehicles, and maintenance of vehicles). Optional Step IVA outlines how a transit planner can calculate changes in labor costs; it also defines what all is included in "average labor costs per hour." Optional Step IVB outlines how a transit planner can determine the per-mile costs for fuel, tires, servicing and maintenance; it also defines what all is included in each category. Optional Step IVC outlines how capital costs can be computed and translated into costs per vehicle per day. All of these optional steps are located in the white section at the end of this Handbook.

For each of these unit-cost categories, four alternative methods are provided to determine the unit costs to be used in this analysis:

1. Use agency-specific values where they are readily available or can be determined easily.
2. Use default values supplied on the worksheet.
3. Select unit cost values from the listing on the page opposite the appropriate worksheet page which tabulates unit cost values compiled directly from selected operators.
4. Select unit cost values from information obtained from UMTA Section 15 data listed on the page following the worksheet page.

		Value			
Line	Units	Conventional Bus Existing Service	Conventional Bus Desired Service	Conventional and Articulated Bus Desired Service	Reference/Notes
(Lines 43-48: Copy Over Relevant Information from STEPS I-III for Convenience)					
43. No. Standard Vehicles Required	(no. vehicles)	43a. ______ (line 6)	43b. ______ (line 21)	43c. ______ (line 36a)	
44. No. Articulated Vehicles Required	(no. vehicles)			44c. ______ (line 36b)	

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service	Value: Conventional and Articulated Bus Desired Service	Reference/Notes
(Lines 43-48: Copy Over Relevant Information from STEPS I-III for Convenience)					
45. No. In-Service Operator Hours Required for Standard Vehicles	(hours)	45a. ______ (line 7)	45b. ______ (line 22)	45c. ______ (line 37a)	
46. No. In-Service Operator Hours Required for Articulated Vehicles	(hours)			46c. ______ (line 37b)	
47. No. In-Service Vehicle-Miles Required for Standard Vehicles	(miles)	47a. ______ (line 8)	47b. ______ (line 23)	47c. ______ (line 38a)	
48. No. In-Service Vehicles-Miles Required for Articulated Vehicles	(miles)			48c. ______ (line 38b)	
49. No. Deadheading Hours Required for Standard Buses For existing standard bus service: Subtract line 43c from line 43a, divide by 60, then multiply by the sum of lines 13 and 14. For desired standard bus service: Subtract line 43c from line 43b, divide by 60, then multiply by the sum of lines 13 and 14. For mixed desired service: Enter zero.	(hours)	49a. ______	49b. ______	49c. ______	
50. No. Deadheading Hours Required for Artic Buses (For mixed desired service only, add lines 39 and 40, multiply by line 44c, then divide by 60)	(hours)			50c. ______	
51. No. Deadheading Miles Required for Standard Buses (For existing standard bus service: Subtract line 43c from line 43a, then multiply this by the sum of lines 15 and 16. For desired standard bus service: Subtract line 43c from line 43b, then multiply this by the sum of lines 15 and 16. For mixed desired service: Enter zero.	(miles)	51a. ______	51b. ______	51c. ______	

Line	Units	Value			Reference/Notes
		Conventional Bus Existing Service	Conventional Bus Desired Service	Conventional and Articulated Bus Desired Service	
52. No. Deadheading Miles Required for Artic Buses (For mixed desired service only, add lines 41 and 42, then multiply this by line 44c)	(miles)			52c. ______	
53. Platform Hours for Standard Buses (line 45 + line 49)	(hours)	53a. ______	53b. ______	53c. ______	
54. Platform Hours for Artic Buses (For mixed desired service only, line 46 + line 50)	(hours)			54c. ______	
55. Total Vehicle Miles for Standard Buses (line 47 + line 51)	(miles)	55a. ______	55b. ______	55c. ______	
56. Total Vehicle Miles for Artic Buses (For mixed desired service only, line 48 + line 52)	(miles)			56c. ______	
57. Operator Wage Rate Plus Fringes per Platform Hour for Standard Buses	($/hour)	57a. ______	57b. ______	57c. ______	See **STEP IVA** at end of Handbook.
58. Operator Wage Rate Plus Fringes per Platform Hour for Artic Buses	($/hour)			58c. ______	See **STEP IVA** at end of Handbook.
59. Unit Operating Cost per Vehicle-Mile for Fuel, Tires, Servicing, and Maintenance for Standard Buses	($/vehicle-mile)	59a. ______	59b. ______	59c. ______	See **STEP IVB** at end of Handbook.
60. Unit Operating Cost per Vehicle-Mile for Fuel, Tires, Servicing, and Maintenance for Artic Buses	($/vehicle-mile)			60c. ______	See **STEP IVB** at end of Handbook.
61. Total Operating Cost for Service	($/day)	61a.	61b.	61c.	
For conventional existing and conventional desired service:					
(i) Multiply line 53 by line 57		______	______		
(ii) Multiply line 55 by line 59		______	______		
(iii) Add above two figures together		______	______		
(iv) Multiply by 2 for two peak periods per day		______	______		
For mixed desired service:					
(i) Multiply line 53 by line 57				______	
(ii) Multiple line 54 by line 58				______	
(iii) Multiply line 55 by line 59				______	
(iv) Multiply line 56 by line 60				______	
(v) Add above four figures together				______	
(vi) Multiply by 2 for two peak periods per day				______	

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service	Value: Conventional and Articulated Bus Desired Service	Reference/Notes
62. **Unit Capital Cost per Vehicle per Day for Standard Buses** (Multiply by 1.10 to account for spares, if desired)	($/day/vehicle)	62a. ________	62b. ________	62c. ________	See **STEP IVC** at end of Handbook.
63. **Unit Capital Cost per Vehicle per Day for Artic Buses** (Multiply by 1.10 to account for spares, if desired)	($/day/vehicle)			63c. ________	See **STEP IVC** at end of Handbook.
64. **Total Capital Costs Per Day** (For conventional existing and conventional desired service, multiply line 43 by line 62; for mixed desired service, multiply line 43 by line 62, line 44 by line 63, and add these two products together)	($/day)	64a. ________	64b. ________	64c. ________	
65. **Total Costs Per Day** (Add line 61 and line 64)	($/day)	65a. ________	65b. ________	65c. ________	
66. **Effective No. Days Per Year** (No. weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	66a. ________	66b. ________	66c. ________	Use 250 days per year as default value.
67. **Total Costs Per Year in Thousands of Dollars** (Multiply line 65 by line 66 and divide by 1000)	($1000/year)	67a. ________	67b. ________	67c. ________	

3. ALL-DAY SUBSTITUTION

Articulated Bus Substitution – Economic Analysis Worksheet

Scenario #3: **Scenario 3 represents the case of complete artic substitution for conventional buses during the peaks and the base period. Input information for one peak only (AM or PM), and the worksheets effectively double the relevant cost items to account for the second peak as well. Worksheets assume the length of the peak periods to be equivalent. Adjustments to worksheets should be made if peaks vary in length.**

Step I: Assemble Information About the Route and Service Being Considered for Substitution by Articulated Buses

Route:______________________________

Line	Units	Value: Peak	Value: Off-Peak	Reference/Notes
1. **Time Period of Interest – Length of Time on Average Weekday for Considering Artic Substitution** (Enter value in minutes)	(minutes)	1a.______	1b.______	Enter length of time for one peak only; (A.M. or P.M.); Calculations assume the use of artics on the other peak as well.
2. **Average Headway During This Period** (Enter headway in minutes)	(minutes)	2a.______	2b.______	
3. **Number of Trips During This Period** (Enter specific number from schedule or divide line 1 by line 2)	(no. trips)	3a.______	3b.______	
4. **Round Trip Run Time for This Route During This Time Period** (Enter time in minutes)	(minutes)	4a.______	4b.______	Include layover and recovery times.
5. **Round Trip Distance for This Route** (Enter distance in miles)	(miles)	5a.______	5b.______	
6. **No. Conventional Buses Needed to Provide This Service** (Divide line 4 by line 2 and round up to nearest integer)	(no. vehicles)	6a.______	6b.______	
7. **Operator Hours** (Multiply line 3 by line 4 and divide by 60)	(hours)	7a.______	7b.______	
8. **Bus In-Service Miles** (Multiply line 3 by line 5)	(miles)	8a.______	8b.______	
9. **Total Passenger Volumes at Peak Load Point, Peak Direction During This Period** (Sum up peak load point passenger counts for each trip during this period)	(passengers)	9a.______	9b.______	Itemize on reverse side if desired.

Line	Units	Value		Reference/Notes
		Peak	Off-Peak	
10. **Average Passenger Volumes Per Bus at Peak Load Point During This Period** (Enter estimated average value or divide line 9 by line 3)	(passengers per bus)	10a.______	10b.______	
11. **Seating Capacity of Bus Used in This Service** (Enter no. seats per bus)	(seats per bus)	11a.______	11b.______	Use 48 as default value.
12. **Passengers Per Seat at Peak Load Point** (Divide line 10 by line 11)	(passengers per seat)	12a.______	12b.______	
13. **Deadheading Time from Garage to Route at Beginning of Period**	(minutes)		13.______	
14. **Deadheading Time from Route to Garage at End of Period**	(minutes)		14.______	
15. **Deadheading Distance from Garage to Route at Beginning of Period**	(miles)		15.______	
16. **Deadheading Distance from Route to Garage at End of Period**	(miles)		16.______	

Go To Step II (Line 17)

Scenario #3 *(continued)*

Step II: If Current Level of Service Provided on This Route During Peak Period is Inadequate, Determine Additional Conventional Bus Service Required to Meet Service Standard

Line	Units	Value: Peak	Value: Off-Peak	Reference/Notes
17. **Desired Passenger/Seat Service Level** (Line 12 is the passenger per seat ratio at the peak load point or, equivalently, the fraction of seated capacity at which the average trip is operating; if a higher standard (lower ratio) is desired, enter this ratio here and go to line 18; if not, go to STEP III (line 24))	(passengers per seat)	17a.________	17b.________	
18. **Average Passengers Per Trip at Peak Load Point Under Desired Service Level** (Multiply line 11 by line 17)	(passengers per bus)	18a.________	18b.________	
19. **Number of Conventional Bus Trips Required to Meet Desired Service Level** (Divide line 9 by line 18)	(no. trips)	19a.________	19b.________	
20. **Average Headway for Conventional Bus Service at Desired Service Level** (Divide line 1 by line 19)	(minutes)	20a.________	20b.________	
21. **Number of Conventional Buses Needed to Provide Desired Service Level** (Divide line 4 by line 20 and round up to nearest integer)	(no. vehicles)	21a.________	21b.________	
22. **Operator Hours Needed for Desired Level of Conventional Bus Service** (Multiply line 4 by line 19 and divide by 60)	(hours)	22a.________	22b.________	
23. **Conventional Bus In-Service Miles for Desired Level of Conventional Bus Service** (Multiply line 5 by line 19)	(miles)	23a.________	23b.________	

Go To Step III (Line 24)

Step III: Determine the Articulated Bus Service Required to Fully Replace Conventional Buses During the Defined Period at the Desired Service Level (Passengers/Seat)

Line	Units	Value: Peak	Value: Off-Peak	Reference/Notes
24. Desired Passenger/Seat Service Level for Artics (Enter value on line 17 or alternative policy standard if desired; if line 17 is blank, enter value on line 12)	(passengers per seat)	24a.______	24b.______	
25. Seating Capacity of Artics (Enter no. of seats per articulated bus)	(no. seats per artic)	25a.______	25b.______	Use 68 as default value.
26. Average Passengers Per Artic at Peak Load Point (Multiply line 24 by line 25)	(passengers per artic)	26a.______	26b.______	
27. No. of Artic Trips Needed (Divide line 9 by line 26)	(no. trips)	27a.______	27b.______	
28. Average Headway for Artics at Desired Service Level (Divide line 1 by line 27)	(minutes)	28a.______	28b.______	
29. Relative Speed Factor of Artics vs. Conventional Buses: Ratio of Running Times (Artic:Conventional) **for Routes of This Type**	(unitless, should be $\geq$ 1.0)	29a.______	29b.______	Use 1.10 as default value for local service, 1.0 for express service. (See report for further discussion.)
30. Round Trip Run Time for This Route for Artics (Multiply line 4 by line 29)	(minutes)	30a.______	30b.______	
31. No. of Artics Needed to Provide Desired Level of Service (Divide line 30 by line 28 and round up to nearest integer)	(no. artics)	31a.______	31b.______	
32. Operator Hours for Artic Service (Multiply line 27 by line 30 and divide by 60)	(hours)	32a.______	32b.______	
33. Artic In-Service Miles for Provision of Desired Service Level (Multiply level 27 by line 5)	(miles)	33a.______	33b.______	
34. Artic Deadheading Time from Garage to Route at Beginning of Period	(minutes)		34.______	
35. Artic Deadheading Time from Route to Garage at End of Period	(minutes)		35.______	
36. Artic Deadheading Distance from Garage to Route at Beginning of Period	(miles)		36.______	
37. Artic Deadheading Distance from Route to Garage at End of Period	(miles)		37.______	

Go To Step IV (line 38)

Step IV: Calculate Differences in Costs of Serving Selected Route with Artics Instead of Conventional Buses

Changes in costs for changes in service on any route can be computed generally as changes in cost per hour (for operator labor) plus changes in costs per vehicle (for capital costs) plus changes in costs per vehicle-mile (for fuel, tires, servicing of vehicles, and maintenance of vehicles). Optional Step IVA outlines how a transit planner can calculate changes in labor costs; it also defines what all is included in "average labor costs per hour." Optional Step IVB outlines how a transit planner can determine the per-mile costs for fuel, tires, servicing and maintenance; it also defines what all is included in each category. Optional Step IVC outlines how capital costs can be computed and translated into costs per vehicle per day. All of these optional steps are located in the white section at the end of this Handbook.

For each of these unit-cost categories, four alternative methods are provided to determine the unit costs to be used in this analysis:

1. **Use agency-specific values where they are readily available or can be determined easily.**
2. **Use default values supplied on the worksheet.**
3. **Select unit cost values from the listing on the page opposite the appropriate worksheet page which tabulates unit cost values compiled directly from selected operators.**
4. **Select unit cost values from information obtained from UMTA Section 15 data listed on the page following the worksheet page.**

		Value			
Line	**Units**	**Conventional Bus Existing Service**	**Conventional Bus Desired Service**	**Artics Desired Service**	**Reference/Notes**
38. **No. Peak Vehicles Required** (For existing service, enter value on line 6a; for conventional desired service, enter value on line 21a; for artic desired service, enter value on line 31a)	(no. peak vehicles)	38a. ______	38b. ______	38c. ______	
39. **Total No. In-Service Operator Hours Required** (For conventional existing, add twice line 7a to line 7b; for conventional desired, add twice line 22a to line 22b; for artic desired, add twice line 32a to line 32b)	(hours)	39a. ______	39b. ______	39c. ______	
40. **Total No. In-Service Vehicle-Miles Required** (For conventional existing, add twice line 8a to line 8b; for conventional desired, add twice line 23a to line 23b; for artic desired, add twice line 33a to line 33b)	(miles)	40a. ______	40b. ______	40c. ______	

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service	Value: Artics Desired Service	Reference/Notes
41. Total No. Deadheading Hours Required For existing service: Multiply line 38a by 2.0, subtract line 6b, divide the result by 60, then multiply this by the sum of lines 13 and 14. For conventional desired service: Multiply line 38b by 2.0, subtract line 21b, divide the result by 60, then multiply this by the sum of lines 13 and 14. For articulated bus desired service: Multiply line 38c by 2.0, subtract line 31b, divide the result by 60, then multiply this by the sum of lines 34 and 35.	(hours)	41a. ________	41b. ________	41c. ________	
42. Total No. Deadheading Miles Required For existing service: Multiply line 38a by 2.0, subtract line 6b, then multiply by the sum of lines 15 and 16. For conventional desired service: Multiply line 38b by 2.0, subtract line 21b, then multiply by the sum of lines 15 and 16. For articulated bus desired service: Multiply line 38c by 2.0, subtract line 31b, then multiply by the sum of lines 36 and 37.	(miles)	42a. ________	42b. ________	42c. ________	
43. Total Platform Hours (line 39 + line 41)	(hours)	43a. ________	43b. ________	43c. ________	
44. Total Vehicle-Miles (line 40 + line 42)	(miles)	44a. ________	44b. ________	44c. ________	
45. Operator Wage Rate Plus Fringes per Platform Hour	($/hour)	45a. ________	45b. ________	45c. ________	See **STEP IVA** at the end of Handbook.

Line	Units	Value: Conventional Bus Existing Service	Value: Conventional Bus Desired Service	Value: Artics Desired Service	Reference/Notes
46. Unit Operating Cost per Vehicle-Mile for Fuel, Tires, Servicing, and Maintenance	($/vehicle-mile)	46a. ______	46b. ______	46c. ______	See **STEP IVB** at the end of Handbook.
47. Total Operating Cost for Service	($/day)	47a.	47b.	47c.	
(i) Multiply line 43 by line 45		______	______	______	
(ii) Multiply line 44 by line 46		______	______	______	
(iii) Add above two figures together		______	______	______	
48. Unit Capital Cost per Vehicle per Day (Multiply by 1.10 to account for spares, if desired)	($/day/vehicle)	48a. ______	48b. ______	48c. ______	See **STEP IVC** at the end of Handbook.
49. Total Capital Costs (Multiply line 38 by line 48)	($/day)	49a. ______	49b. ______	49c. ______	
50. Total Costs Per Day (Add line 47 and line 49)	($/day)	50a. ______	50b. ______	50c. ______	
51. Effective No. Days Per Year (No. weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	51a. ______	51b. ______	51c. ______	Use 250 days per year as default value.
52. Total Costs Per Year (Multiply line 50 by line 51)	($1000/year)	52a. ______	52b. ______	52c. ______	

OPTIONAL
COST CALCULATIONS

Optional Steps for Scenarios 1 through 3

Step IVA: Calculate Operator Wage Rate Plus Fringes Per Platform Hour

Average operator wage rate can be defined as (garage or system) total wages paid operators divided by total platform hours of bus service provided. Total wages include scheduled premium pay (overtime, split shift premium, late shift premium, etc.), intervening, reporting, turning in, paid break, travel allowance and guaranteed make-up time, plus unscheduled overtime and the cost of extra board drivers. Total wages do not include vacation or holiday pay or any other fringe benefits, supervisor time, starter time, or the time of any non-operator.

Fringe benefits include vacation, holiday, sick time, medical or other insurance coverage, pension plan, and uniform costs. Thus defined, average wage rates include premium pay and full-time as well as part-time operators. It is not necessary that these conventions be followed precisely, as long as the same definitions are used consistently for all calculations.

Total platform hours include in-service time and deadheading time, but not time spent out of the vehicle such as travel allowance time.

The peaked nature of transit demand requires more buses and operators during the peak periods. Since work rules generally require premium payment for overtime and spread time plus eight-hour guarantees, and since the excess requirements of the peak period result in more of these premium pay runs involving the peak periods, the average operator wage rate for the peak period may, in fact, be significantly higher than the all-day average wage rate for systems with limitations or exclusions on the use of part-time drivers. If operating policies permit the extensive use of part-time operators, then the average wage rate (and fringes) for part-time operators should be used in the calculations, since it is these operators who will be "saved" if peak vehicle requirements are reduced. Alternatively, the average wage rate over the day (dollars per platform hour) and fringe benefit percentage for all operators can be used. If part-time operators are not permitted, the following procedure may be used to calculate the (higher) wage rate for the peak period:

1. Obtain a set of runs cut for all routes operating out of the garage in question.
2. For each run or piece of work operating out of that garage, divide pay hours posted for that run or piece of work by the number of platform hours entailed to get an average hourly wage rate scaling factor for that run or piece of work. This factor of course will be larger than 1.0.
3. For each run operating wholly or partially within the period being analyzed, determine the actual number of platform hours within that period only.
4. Multiply the values found in Step 3 by the hourly wage rate scaling factor determined for that run or piece of work in Step 2 to get the effective pay-hours within the subject time period for each run or piece of work.
5. Sum up the effective pay-hours across all runs operating within the subject time period, i.e., sum up the values calculated in Step 4. Add to this the pay-hours paid to the extra board during that period.
6. Sum up the actual number of platform hours across all runs operating within the subject time period, i.e., sum up the values calculated in Step 3.
7. Divide the result of Step 5 above by the result of Step 6 above to determine the average hourly operator wage rate scaling factor for the subject period.
8. Multiply the above factor times the normal average hourly wage paid operators in that system to get an average hourly operator wage rate for the subject time period.

	Line	Units	Value	Reference/Notes
IVA-1.	**Determine Average Operator Wage Rate per Hour** (Total Operator Wages paid divided by total platform hours) or (pay hour: platform hour ratio times average operator base wage per hour)	($/hour)	IVA-1. ________	Use numbers calculated explicitly for this agency as outlined above or select an appropriate average wage rate from the list compiled for several agencies on the opposite page from this sheet or use the default value of $10.25 per hour basic rate times 1.25 (pay hour to platform hour ratio or scaling factor) = $12.85 per hour.
IVA-2.	**Determine Fringe Benefits as a Fraction of Hourly Wages**	(unitless)	IVA-2. ________	Use numbers calculated explicitly for this agency or use a default value of 38%.
IVA-3.	**Determine Average Hourly Operator Labor Cost** (Multiply [1 + line IVA-2] by line IVA-1 and input this result to STEP IV—Conventional Bus Service (Existing and Desired))	($/hour)	IVA-3. ________	Default Value: $17.75/hr.
IVA-4.	**Will Any Premium Pay Per Hour Be Paid for Driving an Artic?** (Enter, if so; if not, input line IVA-3 value to STEP IV—Artic Desired Service and return to STEP IV.)	($/hour)	IVA-4. ________	
IVA-5.	**Determine Average Hourly Artic Operating Labor Costs** (Multiply [1 + line IVA-2] by [line IVA-1 + line IVA-4], input answer to STEP IV—Artic Desired Service and return to STEP IV)	($/hour)	IVA-5. ________	

Line		Units	Conventional Bus Value	Artic Value	Reference/Notes
IVB-1.	**Fuel Economy**	(miles/gallon)	IVB-1. ________	IVB-1. ________	**Default Values:** Conventional: 3.9 mpg Conv (w/AC): 3.4 mpg Artic Bus: 3.65 mpg Artic (w/AC): 3.1 mpg Ratio: .092
IVB-2.	**Fuel Price**	($/gallon)	IVB-2. ________	IVB-2. ________	**Default Val:** $.85/gal
IVB-3.	**Fuel Cost Per Mile** (Divide line IVB-2 by line IVB-1)	($/mile)	IVB-3. ________	IVB-3. ________	**Default Values:** Conventional: $.22/mi. Conv(w/AC): $.25/mi. Artic Bus: $.24/mi. Artic(w/AC): $.27/mi. Ratio: 1.12
IVB-4.	**Tire Cost Per Mile**	($/mile)	IVB-4. ________	IVB-4. ________	**Default Values:** Conventional: $.035/mi. Artic Bus: $.055/mi. Ratio: 1.60
IVB-5.	**Servicing Cost Per Mile**	($/mile)	IVB-5. ________	IVB-5. ________	**Default Values:** Conventional: $.095/mi. Artic Bus: $.115/mi. Ratio: 1.20
IVB-6.	**Maintenance Cost Per Mile**	($/mile)	IVB-6. ________	IVB-6. ________	**Default Values:** Conventional: $.50/mi. Artic Bus: $.65/mi. Ratio: 1.33
IVB-7.	**Total Per-Mile Operating Costs** (Add lines IVB-3, IVB-4, IVB-5, and IVB-6, input answers to STEP IV as Unit Operating Cost per vehicle-mile, and return to STEP IV)	($/mile)	IVB-7. ________	IVB-7. ________	**Default Values:** Conventional: $.85/mi. Conv(w/AC): $.88/mi. Artic Bus: $1.06/mi. Artic(w/AC): $1.09/mi.

Table VIII-3.
UMTA Section 15 Year 4
Per Mile Operating Cost Data (value actually reported)

Level	Transit System ID Code	Transit System	Fiscal Yr. End Date	Peak Vehs	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
A	4022	Atlanta, GA	6-30-82	640	$0.521	$0.076	$0.337	$0.012	$0.945
A	9036	Anaheim, CA	6-30-82	362	0.373	0.078	0.298	0.038	0.786
A	1003	Boston, MA	12-31-81	763	1.556	0.361	0.330	0.019	2.267
A	5066	Chicago, IL	12-26-81	1990	1.078	0.168	0.394	0.020	1.659
A	5012	Cincinnati, OH	12-31-81	342	0.538	0.157	0.336	0.030	1.061
A	5016	Columbus, OH	12-31-81	228	0.314	0.103	0.268	0.019	0.705
A	6004	Dallas, TX	9-30-81	403	0.356	0.049	0.315	0.022	0.742
A	8006	Denver, CO	12-31-81	526	0.519	0.062	0.284	0.037	0.902
A	5031	Detroit, MI	6-30-82	802	0.664	0.166	0.308	0.023	1.161
A	2008	New York, NY	6-30-82	3124	3.382	0.418	0.325	0.034	4.159
A	9014	Oakland, CA	6-30-82	732	0.356	0.088	0.227	0.034	0.705
A	3019	Philadelphia, PA	6-30-82	1095	1.153	0.150	0.341	0.031	1.676
A	3022	Pittsburgh, PA	6-30-82	775	0.701	0.149	0.301	0.032	1.184
A	6011	San Antonio, TX	2-28-82	372	0.294	0.040	0.319	0.023	0.676
A	9026	San Diego, CA	6-30-82	196	0.534	0.082	0.272	0.031	0.920
A	7006	St. Louis, MO	6-30-82	670	0.575	0.098	0.289	0.021	0.983
A	5027	St. Paul, MN	12-31-81	850	0.629	0.003	0.309	0.026	0.967
A	1	Seattle, WA	12-31-81	762	0.431	0.062	0.241	0.027	0.761
B	3010	Allentown, PA	6-30-82	51	$0.299	$0.036	$0.233	$0.017	$0.585
B	5010	Akron, OH	12-31-81	97	0.268	0.061	0.317	0.024	0.670
B	4042	Birmingham, AL	9-30-82	120	0.375	0.132	0.357	0.040	0.904
B	2004	Buffalo, NY	3-31-82	369	0.568	0.089	0.303	0.025	0.985
B	4008	Charlotte,NC	6-30-82	92	0.287	0.108	0.357	0.039	0.790
B	5025	Duluth, MN	12-31-82	73	0.288	0.099	0.301	0.017	0.704
B	6006	El Paso, TX	8-31-81	75	0.273	0.065	0.366	0.027	0.732
B	5032	Flint, MI	9-30-81	37	0.470	0.105	0.290	0.021	0.885
B	6007	Ft. Worth, TX	9-30-81	105	0.256	0.054	0.312	0.022	0.644
B	3004	Hampton, VA	6-30-82	79	0.292	0.073	0.291	0.034	0.690
B	1048	Hartford, CT	6-30-82	215	0.521	0.103	0.303	0.018	0.946
B	9002	Honolulu, HI	6-30-82	336	0.561	0.063	0.371	0.044	1.040
B	4040	Jacksonville, FL	9-30-81	168	0.262	0.097	0.323	0.034	0.716
B	7005	Kansas City, MO	12-31-81	260	0.466	0.120	0.329	0.036	0.950
B	9023	Long Beach, CA	6-30-82	124	0.266	0.046	0.349	0.039	0.699
B	4003	Memphis, TN	6-30-82	204	0.328	0.074	0.278	0.028	0.708
B	4004	Nashville, TN	6-30-82	117	0.297	0.111	0.277	0.029	0.714
B	3005	Norfolk, VA	9-30-81	137	0.341	0.071	0.322	0.039	0.774
B	6017	Oklahoma City, OK	6-30-82	68	0.315	0.055	0.268	0.033	0.670
B	5056	Peoria, IL	12-31-81	42	0.179	0.076	0.251	0.013	0.519
B	1001	Providence, RI	6-30-82	208	0.264	0.084	0.243	0.026	0.616
B	3006	Richmond, VA	6-30-82	152	0.348	0.094	0.346	0.031	0.820
B	2013	Rochester, NY	3-31-82	187	0.602	0.109	0.338	0.030	1.079
B	9019	Sacramento, CA	6-30-82	157	0.439	0.087	0.254	0.024	0.804
B	4041	Tampa, FL	9-30-81	67	0.209	0.056	0.312	0.014	0.592
B	8001	Salt Lake City, UT	12-31-81	234	0.585	0.070	0.286	0.033	0.974
B	9008	Santa Monica, CA	6-30-82	92	0.363	0.051	0.380	0.027	0.821
B	5022	Toledo, OH	12-31-81	175	0.161	0.101	0.275	0.023	0.559

	Maint. Cost/ Veh Mi	Service Cost/ Veh Mi	Fuel Cost/ Veh Mi	Tire Cost/ Veh Mi	Total Per Mi. Oper. Cost
Mean-Level A	$0.642	$0.099	$0.311	$0.027	$1.095
Northeast	1.698	0.270	0.324	0.029	1.709
Southeast	0.521	0.076	0.337	0.012	0.945
Midwest	0.645	0.120	0.323	0.024	1.111
South Central	0.408	0.062	0.308	0.022	0.800
West	0.416	0.076	0.270	0.037	0.798
Mean-Level B	$0.344	$0.080	$0.308	$0.028	$0.760
Northeast	0.405	0.089	0.297	0.028	0.812
Southeast	0.293	0.096	0.317	0.031	0.737
Midwest	0.273	0.088	0.287	0.019	0.667
South Central	0.328	0.074	0.319	0.029	0.749
West	0.443	0.063	0.328	0.033	0.868
Mean-Levels A & B	$0.427	$0.088	$0.309	$0.027	$0.851
Northeast	0.604	0.120	0.313	0.028	1.056
Southeast	0.293	0.093	0.320	0.028	0.767
Midwest	0.390	0.115	0.295	0.022	0.803
South Central	0.362	0.069	0.314	0.026	0.771
West	0.433	0.068	0.306	0.035	0.841

Capital Recovery Factor

Economic Life of Bus In Years (N)	Interest Rate (i)									
	0.050	0.075	0.100	0.110	0.120	0.130	0.140	0.150	0.175	0.200
1	1.050	1.075	1.100	1.110	1.120	1.130	1.140	1.150	1.175	1.200
2	0.538	0.557	0.576	0.584	0.592	0.599	0.607	0.615	0.635	0.655
3	0.367	0.385	0.402	0.409	0.416	0.424	0.431	0.438	0.456	0.475
4	0.282	0.299	0.315	0.322	0.329	0.336	0.343	0.350	0.368	0.386
5	0.231	0.247	0.264	0.271	0.277	0.284	0.291	0.298	0.316	0.334
6	0.197	0.213	0.230	0.236	0.243	0.250	0.257	0.264	0.282	0.301
7	0.173	0.189	0.205	0.212	0.219	0.226	0.233	0.240	0.259	0.277
8	0.155	0.171	0.187	0.194	0.201	0.208	0.216	0.223	0.241	0.261
9	0.141	0.157	0.174	0.181	0.188	0.195	0.202	0.210	0.229	0.248
10	0.130	0.146	0.163	0.170	0.177	0.184	0.192	0.199	0.219	0.239
11	0.120	0.137	0.154	0.161	0.168	0.176	0.183	0.191	0.211	0.231
12	0.113	0.129	0.147	0.154	0.161	0.169	0.177	0.184	0.205	0.225
13	0.106	0.123	0.141	0.148	0.156	0.163	0.171	0.179	0.200	0.221
14	0.101	0.118	0.136	0.143	0.151	0.159	0.167	0.175	0.195	0.217
15	0.096	0.113	0.131	0.139	0.147	0.155	0.163	0.171	0.192	0.214
16	0.092	0.109	0.128	0.136	0.143	0.151	0.160	0.168	0.189	0.211
17	0.089	0.106	0.125	0.132	0.140	0.149	0.157	0.165	0.187	0.209
18	0.086	0.103	0.122	0.130	0.138	0.146	0.155	0.163	0.185	0.208
19	0.083	0.100	0.120	0.128	0.136	0.144	0.153	0.161	0.184	0.206
20	0.080	0.098	0.117	0.126	0.134	0.142	0.151	0.160	0.182	0.205
21	0.078	0.096	0.116	0.124	0.132	0.141	0.150	0.158	0.181	0.204
22	0.076	0.094	0.114	0.122	0.131	0.139	0.148	0.157	0.180	0.204
23	0.074	0.093	0.113	0.121	0.130	0.138	0.147	0.156	0.179	0.203
24	0.072	0.091	0.111	0.120	0.128	0.137	0.146	0.155	0.179	0.203
25	0.071	0.090	0.110	0.119	0.127	0.136	0.145	0.155	0.178	0.202

Step IVC: Calculate Capital Costs per Vehicle: Equivalent Annual or Daily Costs

Two methods of determining the amortized capital costs per vehicle are commonly used – one mileage-based and the other years-of-life based – we recommend the latter because of its simplicity. The recommended method defines the useful life of a bus in years and, using the number of effective days of service per year, the purchase price of the vehicle, and a capital recovery factor (interest rate), translates purchase price into capital cost per vehicle per year and per day.

	Line	Units	Conventional Bus Value	Artic Value	Reference/Notes
IVC-1.	**Purchase Price of Vehicle** (P)	($)	IVC-1. ________	IVC-1. ________	**Default Values:** Conventional: $120,000 Conv (w/AC): $130,000 Artic Bus: $203,000 Artic (w/AC): $236,000
IVC-2.	**Economic Life of Bus (Years)** (N)	(years)	IVC-2. ________	IVC-2. ________	**Default Values:** Conventional: 12 years Artic Bus: 12 years
IVC-3.	**Interest Rate (Per Year)** (i)	(decimal percent)	IVC-3. ________	IVC-3. ________	**Default Value:** .10
IVC-4.	**Capital Recovery Factor**		IVC-4. ________	IVC-4. ________	**From table on opposite page.**
IVC-5.	**Capital Cost Per Vehicle Per Year** (Multiply line IVC-1 by line IVC-4)	($/bus/year)	IVC-5. ________	IVC-5. ________	
IVC-6.	**Effective No. of Days Per Year** (No. of weekdays less holidays unless weekend and/or holiday schedules also require "peak" service)	(days/year)	IVC-6. ________	IVC-6. ________	**Default Value:** 250 days
IVC-7.	**Capital Cost Per Vehicle Per Day** (Divide line IVC-5 by line IVC-6, input answers to STEP IV as Unit Capital Cost, and return to STEP IV)	($/bus/day)	IVC-7. ________	IVC-7. ________	