A SYSTEM DYNAMICS APPROACH
TO LONG-RANGE RAILROAD EQUIPMENT PLANNING

by

RANDALL RICHARD REYFF

B.Bus., Western Illinois University
(1971)

SUBMITTED IN PARTIAL FULFILLMENT
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Signature of Author

Alfred P. Sloan School of Management
May 2, 1980

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Edward B. Roberts
Thesis Supervisor

Accepted by

ARCHIVES Chairman, Department Committee

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Submitted to the Alfred P. Sloan School of Management
on May 2, 1980 in partial fulfillment of the
requirements for the degree of Master of Science
in Management

ABSTRACT

The railroad management task of long-range equipment
planning is complex and made difficult because of the
numerous influences and factors which shape the ultimate
size and composition of a carrier's freight car fleet. The
job must be approached thoughtfully and professionally,
however, because of the operating, marketing, and financial
role which freight car equipment plays in the company's
successful conduct of business. Continuing refinement of
freight car equipment planning and analytical methodology
is important in view of the major portion of railroad
property investment accounted for by railcars, the fact that
railroad rate of return on investment is (in most cases)
relatively low compared to alternative investments, and
because of the important role which carrier-owned freight
car equipment may play in the successful marketing (and
revenue generation) of the carrier's service.

Freight car ownership formulas which have been devel-
oped from time to time are generally inadequate because they
rest on the assumption that a static model to guide future
action can be built by examining past performance. In
reality, the equipment planning task must go forward in a
dynamic environment of changing technology, economics,
markets, and competition. System dynamics methodology,
thoughtfully applied, may prove to be a powerful analytical
aid in the equipment planning process given its ability to
deal with "hard issues" such as equipment and money flow as
well as "soft issues" such as management decision delays
both within the company and in its markets.
The equipment planning model developed in the thesis is but a "first cut" at applying system dynamics modeling to equipment planning issues. The model attempts to generate railcar supply in response to market demand for railcar capacity. Delay in perception of and reaction to market activity as evidenced by shipper orders for railcar placement is built into railroad management decision making. Delayed reaction to the carrier's successful or unsuccessful placement of equipment upon demand is built into shipper management decision making. Among numerous model output variables are a level of equipment ownership or control which is implied by market demand at any point in time and the net present value of operating income generated over the model's five-year simulation run. Working from this beginning point the model could be developed to much greater levels of sophistication to provide increasing insight and more guidance to carrier management as they plan for future equipment needs.

Thesis Supervisor: Dr. Edward B. Roberts

Title: David Sarnoff Professor of the Management of Technology
ACKNOWLEDGEMENTS

My primary motivation for undertaking this project was the result of exposure to System Dynamics provided by Professor Edward B. Roberts in his course, 15.880, at the M.I.T. Alfred P. Sloan School of Management. Dr. Roberts' assistance with conceptualizing the problem was invaluable and helped to give the project the direction it needed. Special mention should also be made of Mr. Alex Makowski of Pugh-Roberts Associates, Inc., whose timely advice on technical matters was most appreciated. Finally, but certainly not least, my typist, Marilyn Gardner, did an excellent job on relatively short notice to put this paper in final form.
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INTRODUCTION

General Objective of the Thesis

The objective of this thesis is to apply system dynamics analytical methodology to one aspect of long-range railroad freight car planning. "Long range" is defined as five years, and the planning aspect of interest is the timely matching of railcar supply with demand for railcar capacity. Given any forecast of anticipated demand (growth, stasis, or decline), railroad management must concern itself with the size and composition of its railcar fleet, recognizing that the fleet performs three essential functions for the company:

- a marketing function
- a financial function
- an operating function

The marketing function of a common carrier freight car fleet is to provide a given shipper transportation vehicle capacity which will encourage the use of the providing carrier's line haul service, i.e. the providing carrier should be specified in the shipper's routing instructions. The financial function of a railcar is, of course, to provide the carrier a maximum amount of transportation
revenue and, if interline movement is involved, car-hire revenue while the equipment is in the possession of a "foreign line." The operating function of the railcar, in addition to providing the basic unit of capacity, is to increase carrier productivity by decreasing maintenance requirements, generating more serviceable car days per year, and increasing payload per car.

The system dynamics program developed in this thesis focuses narrowly on a railroad freight car's marketing function. Given additional time and thoughtful attention the program could be expanded to incorporate more input from the operating and financial functions as well. System dynamics methodology has great potential for providing, and to some extent quantifying, management insight concerning the interaction between the railcar-owning carrier and the capacity-demanding market. The methodology is also well suited to deal with environmental issues such as industry and market shifts, inter- and intramodal competition, regulation, and the numerous other factors which fashion the marketing forecast to which the equipment fleet must attempt to respond. The model herein takes a marketing forecast as a "given" and reacts to it. It is conceivable, in other words, that a system dynamics model could be developed to generate a forecast and then suggest how the carrier can respond to it in light of the company's marketing, finance,
and operating goals. That sort of effort is well beyond the scope of this thesis.

Problem Discussion and Background Information

The task of estimating the proper size and composition of an individual carrier's freight car fleet has never been an easy matter. Much to the contrary, controversy about how many cars, and of what type, a carrier "should" own is nearly as old as the railroad industry itself. "Car shortages," or the difference between the number of cars shippers can load on a daily basis and the number provided, have been the focus of carrier-shipper-regulator debate on a continuing basis since the 19th century, when railroads had an effective monopoly in many transportation markets. Interestingly enough, the erosion of the rail monopoly position during the 20th century has not eliminated the car shortage phenomenon. It can be persuasively argued that, as a general proposition, car shortages are more a function of inadequate control of various elements of a freight car's load-empty-load utilization cycle than of inadequate fleet size per se. Certainly to the degree that demurrage penalties, car-hire charges, AAR Car Service Rules, I.C.C. car service orders, and improvements in general carrier operating capabilities can lead to improved car utilization, the overall capacity of a given size fleet will increase.
However, even when freight car utilization is as good as it possibly can be, railroad management will still have the task of deciding how many cars of a given type to own in light of a demand forecast, an existing fleet, and whatever utilization factor(s) appears most reasonable to assume for planning purposes.

Through the years, many attempts have been made to structure generally applicable railcar ownership formulas. The objectives were usually (1) to meet the equipment needs of shippers originating traffic on a given carrier's line destined to intraline points, and (2) to provide a pro rata share of the equipment obligations resulting from interline business, i.e. shipments routed over more than one railroad in order to reach their destination. General ownership formulas have not been accepted by individual carriers more often than not because they would lead, in management's judgement, to the acquisition of more equipment than could be loaded in view of market conditions and car service rules. The fundamental reason why general car ownership formulas don't work, however, is that they are based upon the assumption that a satisfactory static guideline to new freight car acquisition can be built from past performance. In 1966, Burton N. Behling, then vice-president of the Association of American Railroads (AAR), summed up the industry view of
ownership formulas in the following way:

No amount of such historical analysis of statistics, nor any wishful thinking that the problems can be solved by resort to some kind of normative, automatic formula drawn from data of the past can erase the fact that estimating the size and composition of the freight car supply needed for the future is, in a changing environment, essentially a matter of forecasting...

No matter how well designed in principle or as a matter of equitable shares of responsibility any generalized formula might be, it can do no more than to provide a rough guide or starting point for the consideration of particular and ever-changing circumstances.

Such a static view ignores the significance of changing conditions with respect to technology, equipment designs, traffic patterns, shipper demands, shifts of industry locations and markets, and other dynamic factors now so much in evidence.

Whether or not the formula approach to freight car acquisition was ever a good idea, it would certainly appear to be inappropriate in today's railroad industry environment where management is under increasing pressure to scrutinize new investment in any and all assets more carefully than ever before. Carrier management concern over all aspects of railcar planning (acquisition, distribution, utilization, and control) is justified when seen in the context of the railroad industry's overall financial condition, marketing effectiveness, equipment ownership trends, and

---

investment in equipment relative to other assets.

Railroad industry rate of return on net investment in selected years since 1929 is shown in Table 1.1. Rate of return represents the relationship of net railway operating income to net investment in transportation property, including cash and materials inventories. Net investment represents original cost, less accrued depreciation and amortization, as recorded under the accounting regulations of the Interstate Commerce Commission. The relatively low level of ROR, and certainly the overall trend, suggest management must concentrate, of course, upon generation of net income and rational acquisition of all assets which make up their firm's net investment.

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>Eastern District</th>
<th>Southern District</th>
<th>Western District</th>
</tr>
</thead>
<tbody>
<tr>
<td>1929</td>
<td>5.30%</td>
<td>6.03%</td>
<td>4.27%</td>
<td>4.85%</td>
</tr>
<tr>
<td>1939</td>
<td>2.56</td>
<td>3.14</td>
<td>2.77</td>
<td>1.85</td>
</tr>
<tr>
<td>1944</td>
<td>4.70</td>
<td>4.37</td>
<td>5.45</td>
<td>4.82</td>
</tr>
<tr>
<td>1955</td>
<td>4.22</td>
<td>4.19</td>
<td>5.45</td>
<td>3.86</td>
</tr>
<tr>
<td>1965</td>
<td>3.69</td>
<td>3.32</td>
<td>4.16</td>
<td>3.87</td>
</tr>
<tr>
<td>1975</td>
<td>1.20</td>
<td>def.</td>
<td>3.98</td>
<td>2.65</td>
</tr>
<tr>
<td>1976</td>
<td>1.64</td>
<td>def.</td>
<td>4.68</td>
<td>3.63</td>
</tr>
<tr>
<td>1977</td>
<td>1.26</td>
<td>def.</td>
<td>5.23</td>
<td>3.73</td>
</tr>
</tbody>
</table>

def. - Deficit
The railroad's share of the intercity freight tonmile "market" has been declining as well since 1929. However, the absolute amount of railroad revenue tonmile work has been increasing. The apparent disparity is explained by the fact that the growth of total transportation tonmile activity has been greater than railroad tonmile growth per se. The relative growth rate of the principal modes, as measured by a compound annual percentage, as well as their respective tonmile total, is illustrated in Table 1.2. Of significance is that railroad growth is consistently lower than its most frequent "closest competitor": the intercity motor carrier. While defining the market in such an aggregate manner as "total intercity freight tonmiles" masks the success, or failure, of individual carrier marketing plans in more closely defined market segments, such as specific regional traffic flows, it is reasonable to assume that railroad marketing organizations are under consistent pressure to expand their traffic base both in terms of revenue and tonmile activity.

Focusing on railroad equipment, it is useful to look at trends in the size and capacity of freight car fleets, ownership, and the amount of investment taking place relative to physical plant, i.e. roadway and structures. Insofar as fleet size and capacity are concerned, the trends are shown in Table 1.3. The absolute number of units has been
Table 1.2
MODAL SHARE OF INTERCITY REVENUE TONMILE ACTIVITY

<table>
<thead>
<tr>
<th></th>
<th>Rail</th>
<th>Motor</th>
<th>All Other*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>56.2%</td>
<td>16.3%</td>
<td>27.5%</td>
</tr>
<tr>
<td>1960</td>
<td>44.1</td>
<td>21.7</td>
<td>34.2</td>
</tr>
<tr>
<td>1970</td>
<td>39.8</td>
<td>21.3</td>
<td>38.9</td>
</tr>
<tr>
<td>1977</td>
<td>36.0</td>
<td>23.8</td>
<td>40.2</td>
</tr>
</tbody>
</table>

MILLIONS OF REVENUE FREIGHT TONMILES BY MODE

<table>
<thead>
<tr>
<th></th>
<th>Rail</th>
<th>Motor</th>
<th>All Other*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>596,940</td>
<td>172,860</td>
<td>292,837</td>
<td>1,062,637</td>
</tr>
<tr>
<td>1960</td>
<td>579,130</td>
<td>285,483</td>
<td>449,657</td>
<td>1,314,270</td>
</tr>
<tr>
<td>1970</td>
<td>771,168</td>
<td>412,000</td>
<td>752,855</td>
<td>1,936,023</td>
</tr>
<tr>
<td>1977</td>
<td>831,000</td>
<td>549,000</td>
<td>930,000</td>
<td>2,310,000</td>
</tr>
</tbody>
</table>

COMPOUND ANNUAL GROWTH RATE OF TONMILE ACTIVITY

<table>
<thead>
<tr>
<th></th>
<th>Rail</th>
<th>Motor</th>
<th>All Other*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950-1960</td>
<td>(0.3%)</td>
<td>5.1%</td>
<td>4.4%</td>
<td>2.1%</td>
</tr>
<tr>
<td>1960-1970</td>
<td>2.9</td>
<td>3.7</td>
<td>5.3</td>
<td>3.9</td>
</tr>
<tr>
<td>1970-1977</td>
<td>1.1</td>
<td>4.2</td>
<td>3.1</td>
<td>2.6</td>
</tr>
<tr>
<td>1950-1977</td>
<td>1.2</td>
<td>4.4</td>
<td>4.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**"All Other" includes Great Lakes, Rivers and Canals, Oil Pipelines, and Air**

### Table 1.3

**U.S. FREIGHT CAR FLEET: NUMBER AND CAPACITY**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Freight Cars</th>
<th>Ave. NT Capy./Car</th>
<th>Net Ton Fleet Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947</td>
<td>2,025,008</td>
<td>51.5</td>
<td>104,287,912</td>
</tr>
<tr>
<td>1955</td>
<td>1,996,443</td>
<td>53.7</td>
<td>107,208,989</td>
</tr>
<tr>
<td>1965</td>
<td>1,800,662</td>
<td>59.7</td>
<td>107,499,521</td>
</tr>
<tr>
<td>1970</td>
<td>1,784,181</td>
<td>67.1</td>
<td>119,718,545</td>
</tr>
<tr>
<td>1975</td>
<td>1,723,605</td>
<td>72.9</td>
<td>125,650,805</td>
</tr>
<tr>
<td>1977</td>
<td>1,666,533</td>
<td>75.5</td>
<td>125,823,242</td>
</tr>
</tbody>
</table>

**NT** - Net Ton of 2000 lbs.

### Table 1.4

**U.S. FREIGHT CAR FLEET: OWNERSHIP**

<table>
<thead>
<tr>
<th>Year</th>
<th>Class 1 Carriers</th>
<th>O/T Class 1 Carriers</th>
<th>Car Companies &amp; Shippers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947</td>
<td>85.6%</td>
<td>1.3%</td>
<td>13.1%</td>
</tr>
<tr>
<td>1955</td>
<td>85.1</td>
<td>1.2</td>
<td>13.7</td>
</tr>
<tr>
<td>1965</td>
<td>82.1</td>
<td>2.1</td>
<td>15.9</td>
</tr>
<tr>
<td>1970</td>
<td>79.8</td>
<td>1.7</td>
<td>18.5</td>
</tr>
<tr>
<td>1975</td>
<td>78.9</td>
<td>1.7</td>
<td>19.4</td>
</tr>
<tr>
<td>1977</td>
<td>77.2</td>
<td>2.4</td>
<td>20.3</td>
</tr>
</tbody>
</table>

**Source:** Association of American Railroads

*Yearbook of Railroad Facts - 1978 Edition*
declining steadily through the post-World War II period and the capacity per unit has been increasing. The net effect is an increase in aggregate fleet capacity. Ownership of the national freight car fleet has been shifting somewhat, as can be seen in Table 1.4. The proportion owned by Class 1 carriers (those with annual operating revenues in excess of $50 million) has been declining principally because of an increase in the number of cars owned by railcar companies and shippers themselves, as well as because of the Class 1 retirement rate. New capital investment in equipment during the past ten years has been heavy when compared to that in physical plant. As indicated in Table 1.5, the cumulative equipment investment (both motive power and freight cars) for the ten-year 1968-1977 period was approximately $10.6 billion compared to $4.6 billion in physical plant. Since the industry's capital requirements well exceed internally-generated funds each year, a common method of financing equipment acquisition is through the issuance of equipment trust certificates. By the end of 1976 outstanding railroad equipment obligations were approximately $5.4 billion.\textsuperscript{1} Consequently, it is clear that while there are somewhat fewer railcars in the current national freight car fleet than in past years, the railroad industry is

Table 1.5
CLASS 1 RAILROADS
CAPITAL EXPENDITURES ON EQUIPMENT AND PLANT ($ MILLIONS)

<table>
<thead>
<tr>
<th></th>
<th>Equipment</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>1968</td>
<td>$818.7</td>
<td>$368.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$1187.0</td>
</tr>
<tr>
<td>1969</td>
<td>1088.7</td>
<td>420.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1509.4</td>
</tr>
<tr>
<td>1970</td>
<td>993.1</td>
<td>358.3</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>1351.4</td>
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<tr>
<td>1971</td>
<td>863.5</td>
<td>314.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1177.6</td>
</tr>
<tr>
<td>1972</td>
<td>847.6</td>
<td>368.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1215.6</td>
</tr>
<tr>
<td>1973</td>
<td>892.7</td>
<td>449.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1342.1</td>
</tr>
<tr>
<td>1974</td>
<td>1038.1</td>
<td>527.3</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>1565.4</td>
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<tr>
<td>1975</td>
<td>1303.3</td>
<td>486.4</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1789.7</td>
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<tr>
<td>1976</td>
<td>1174.8</td>
<td>549.9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1724.7</td>
</tr>
<tr>
<td>1977</td>
<td>1540.3</td>
<td>750.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2291.1</td>
</tr>
<tr>
<td></td>
<td>$10,560.8</td>
<td>$4,593.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$15,154.1</td>
</tr>
</tbody>
</table>

Table 1.6
REVENUE TONMILES PER CAR LOADED

<table>
<thead>
<tr>
<th></th>
<th>United States</th>
<th></th>
<th>Eastern District</th>
<th></th>
<th>Southern District</th>
<th></th>
<th>Western District</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>26,335</td>
<td></td>
<td>23,947</td>
<td></td>
<td>21,004</td>
<td></td>
<td>31,606</td>
</tr>
<tr>
<td>1977</td>
<td>35,462</td>
<td></td>
<td>28,811</td>
<td></td>
<td>26,939</td>
<td></td>
<td>45,433</td>
</tr>
</tbody>
</table>

Source: Association of American Railroads
Yearbook of Railroad Facts - 1978 Edition
continuing to make heavy investment in equipment and the ownership of the preponderance of equipment still rests with the Class 1 carriers.

To gain perspective on how much of a railroad's total property investment is in freight train cars (as opposed to locomotives, highway equipment, work equipment, and road/structures), a carrier's annual report to the I.C.C. can be examined. Taking the Atchison, Topeka, and Santa Fe Railway as the example, the following figures are observed:¹

<table>
<thead>
<tr>
<th>Percentage of Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total for &quot;Road&quot; : $1.245 billion</td>
</tr>
<tr>
<td>Locomotives : .432 &quot;</td>
</tr>
<tr>
<td>Freight train cars: 1.128 &quot;</td>
</tr>
<tr>
<td>Other equipment : .119 &quot;</td>
</tr>
<tr>
<td>General : .031 &quot;</td>
</tr>
<tr>
<td>Construction work : .007 &quot;</td>
</tr>
<tr>
<td>Leased property : .001 &quot;</td>
</tr>
<tr>
<td>Grand Total : $2.963 billion</td>
</tr>
</tbody>
</table>

Freight Train Cars % of Total Equipment: 67.2%

The Santa Fe Railway's investment in freight train cars is substantial whether measured in absolute terms or as a percentage of total property used in transportation service.

How productive is freight car equipment and what are

¹1978 Annual Report to the Interstate Commerce Commission, R-1 Atchison, Topeka, and Santa Fe Railway Company Schedule 335B, "Investment in Railway Property Used in Transportation Service."
the trends in utilization? From the standpoint of operating management, freight car productivity has been steadily increasing. There are basically two reasons for this: heavier loads are being handled in cars of increasing capacity and the average haul distance is increasing as well. "Revenue Tonmiles Per Car Loaded" have increased by nearly 35% in the last decade, as can be seen in Table 1.6. However, gains in car utilization have been less significant and, in fact, were it not for gains in "Average Daily Car Mileage" made in the Western District, the national average would be essentially flat during the 1968-1977 time frame. Table 1.7 recaps the statistics.

Table 1.7

<table>
<thead>
<tr>
<th>Year</th>
<th>United States</th>
<th>Eastern District</th>
<th>Southern District</th>
<th>Western District</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>53.5</td>
<td>41.6</td>
<td>52.2</td>
<td>66.6</td>
</tr>
<tr>
<td>1969</td>
<td>54.9</td>
<td>41.6</td>
<td>54.5</td>
<td>69.2</td>
</tr>
<tr>
<td>1970</td>
<td>54.6</td>
<td>41.2</td>
<td>51.2</td>
<td>70.4</td>
</tr>
<tr>
<td>1971</td>
<td>53.3</td>
<td>39.7</td>
<td>49.2</td>
<td>68.8</td>
</tr>
<tr>
<td>1972</td>
<td>56.1</td>
<td>41.3</td>
<td>52.1</td>
<td>72.2</td>
</tr>
<tr>
<td>1973</td>
<td>57.7</td>
<td>41.9</td>
<td>53.4</td>
<td>74.6</td>
</tr>
<tr>
<td>1974</td>
<td>57.4</td>
<td>41.9</td>
<td>54.2</td>
<td>73.4</td>
</tr>
<tr>
<td>1975</td>
<td>53.5</td>
<td>40.2</td>
<td>49.6</td>
<td>66.9</td>
</tr>
<tr>
<td>1976</td>
<td>56.6</td>
<td>41.1</td>
<td>51.9</td>
<td>72.3</td>
</tr>
<tr>
<td>1977</td>
<td>58.0</td>
<td>40.5</td>
<td>52.6</td>
<td>75.3</td>
</tr>
</tbody>
</table>

As mentioned earlier, in addition to its operating/production function, a railroad freight car performs an
important marketing function as well. In most major manufacturing areas rail service is provided by multiple carriers. Between most origin and destination stations multiple routes are frequently available for a shipper's specification. Given the regulated nature of most railroad pricing, the transportation rate in effect between stations will generally apply without discrimination over each of several possible routes. While giving due consideration to transit time and service consistency, a shipper is frequently able to offer his business to the serving carrier who is able to provide the specified good-order railcar in a timely manner. Indeed, one of the most frequently cited reasons for a carrier salesman's failure to get "X amount of business from ABC Company" is the inability to provide the right car(s) at the right time. The carrier who successfully supplies its own equipment will, in addition to gaining the shipper's outbound routing, usually receive his "longest haul" consistent with the general direction of the shipment, i.e. the carload may bypass the first possible interchange with the destination-serving carrier (assuming an interline movement) in favor of a farther point. Since length of haul essentially correlates with a carrier's division of through revenue, the ability to secure maximum long-haul routing is no small matter.

Railcar equipment supply is important enough to show
up as a significant factor in shipper perceptions of overall rail service quality. A comprehensive survey, "Industrial Shipper Survey (Plant Level)", conducted by the U.S. Department of Transportation as part of the 1974 National Transportation Study involved 193 industrial manufacturers, each employing over 100 people, in 19 major metropolitan areas throughout the United States. Twenty-five percent of rail shippers interviewed described service as "minimally acceptable." Nine percent termed it "unsatisfactory." Sixty-six percent of rail users described their service as "adequate" or better. In contrast, 97 percent of motor carrier users, 95 percent of water carrier users, and 95 percent of air carrier users considered their service to be "adequate" or better. Selected results from the survey are presented in Table 1.8.\(^1\) Investigation into the reasons for relative shipper dissatisfaction with rail service revealed the following complaints about various service factors:

- Late delivery: 36% of shippers
- Unavailability of specific equipment: 35%
- Late pickup: 27%
- Arrivals with loss or damage: 17%

The problems encountered in marketing rail service

\(^1\)U.S. Department of Transportation, A Prospectus for Change in the Freight Railroad Industry (October 1978), p. 20.
Table 1.8

INDUSTRIAL SHIPPER SURVEY
(Plant Level)

Part A. Shipper evaluation of service

<table>
<thead>
<tr>
<th>Mode</th>
<th>Excellent (%)</th>
<th>Quite good (%)</th>
<th>Adequate (%)</th>
<th>Minimally acceptable (%)</th>
<th>Unsatisfactory (%)</th>
<th>Total using mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>10.4</td>
<td>56.5</td>
<td>30.6</td>
<td>2.1</td>
<td>0.5</td>
<td>193</td>
</tr>
<tr>
<td>Rail</td>
<td>5.4</td>
<td>16.3</td>
<td>44.2</td>
<td>24.8</td>
<td>9.3</td>
<td>129</td>
</tr>
<tr>
<td>Air</td>
<td>16.9</td>
<td>51.5</td>
<td>26.9</td>
<td>4.6</td>
<td>0.0</td>
<td>130</td>
</tr>
<tr>
<td>Water</td>
<td>8.9</td>
<td>25.0</td>
<td>60.7</td>
<td>5.4</td>
<td>0.0</td>
<td>56</td>
</tr>
</tbody>
</table>

Part B. Shipper evaluation by performance factor

| On-time Pickup | Motor | 27 | 42 | 25 | 5 | 2 |
|                | Rail  | 23 | 31 | 19 | 20 | 7 |
| On-time Delivery: | Motor | 15 | 37 | 39 | 7 | 2 |
|                | Rail  | 7  | 25 | 32 | 22 | 14 |
|                | Air   | 29 | 42 | 20 | 7  | 2 |
|                | Water | 32 | 30 | 27 | 3  | 2 |
| Arrival without loss, shortage or damage: | Motor | 31 | 44 | 18 | 5 | 2 |
|                | Rail  | 20 | 39 | 23 | 11 | 6 |
|                | Air   | 49 | 37 | 10 | 2  | 1 |
|                | Water | 51 | 29 | 15 | 5  | 0 |
| Specified equipment availability: | Motor | 31 | 35 | 25 | 5 | 2 |
|                | Rail  | 16 | 23 | 24 | 18 | 17 |

Part C. Aggregated city-pair data showing on-time delivery, by mode

<table>
<thead>
<tr>
<th>Shipment size</th>
<th>Observations</th>
<th>Average % on time</th>
<th>Average % 1 day late</th>
<th>Average % 2 or more days late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor, private</td>
<td>TL</td>
<td>50</td>
<td>96</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>LTL</td>
<td>21</td>
<td>97</td>
<td>2</td>
</tr>
<tr>
<td>Motor, common</td>
<td>TL</td>
<td>186</td>
<td>89</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>LTL</td>
<td>238</td>
<td>82</td>
<td>8</td>
</tr>
<tr>
<td>Rail, co-load</td>
<td>122</td>
<td>65</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Rail, TOFC COFC</td>
<td>32</td>
<td>87</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Air</td>
<td>19</td>
<td>93</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

are nothing if not complex. The marketing function exists to relate the capabilities of the carrier to the demands of the market. In a service-oriented business such as transportation, the interrelationship between operating capability, equipment investment policies, marketing tasks such as selling and pricing, and financial performance are numerous and dynamically connected. Financial success is driven by marketing success which is fed by operational and equipment capability. Over time these capabilities, relative to competition, improve or not because of financial success. Equipment availability is one determinant of shipper satisfaction with rail service. New equipment investment (both motive power and freight cars) has been nearly 70 percent of total railroad capital investment during the past decade. One of the most notable features about the railroad industry is its incredibly low rate of return on its net investment. Equipment investment is necessary for carriers to protect their marketing position vis-a-vis each other on both an inter- and intramodal basis. And perhaps unique to the railroad business, the timely placement of a carrier's own railcar equipment in response to shipper orders can be a principal determinant of (1) which road gets the routing and (2) how much of the through routes and revenue the carrier will enjoy.
Methodology

The author of this thesis is a carrier marketing professional with a minimum level of exposure to and practice with system dynamics modeling. As a result, the research into this effort consisted of a reasonable measure of literature search of railroad industry periodicals, government reports, and carrier operating statistics and a large measure of study (some might call it "immersion") of basic system dynamics modeling structure, existing models, and the DYNAMO modeling language. The literature search was done basically to support the general problem description and to ascertain whether the focus of the thesis should be industry-wide or carrier-specific. In the final analysis, a judgment was made that the focus should be on the car supply-demand issues of a single carrier, although not a specifically identified company. In other words, the basic viewpoint herein is that of carrier management who are attempting to optimize, to the degree possible, decisions which come together to affect their company's ability to meet demand for transportation capacity in a timely manner. Relationships which are described in this paper should be viewed as typical for a rail carrier in general rather than company-specific. Actual carrier data was studied in order to get a sense for what relationships between one variable and another ought to be for modeling purposes; however, the
relationships quantified are generalized in order to preserve the confidential or proprietary nature of specific company data.

The emphasis of this thesis is on how a dynamic model works in this situation rather than on how a model solved a particular carrier's equipment planning problems. The model recognized both an internal (to the company) goal and an external goal (toward the market). The principal external marketing goal is to respond to railcar equipment demand in a competitive manner while meeting the internal goal of not "over-investing" in equipment assets.
CHAPTER I

SYSTEM DYNAMICS - A BRIEF REVIEW

In interviews with various people during the research phase of this project, it became clear that relatively few had an awareness of what was meant by a "System Dynamics" approach to a given problem. It may be useful, therefore, to briefly define "System Dynamics" and discuss its underlying philosophy and principles. In doing so, this section borrows heavily from the introduction chapter of M.I.T. Professor Edward B. Roberts' book, Managerial Applications of System Dynamics (The M.I.T. Press, 1978). The objective here is to provide a reader some knowledge and context for understanding later sections' discussion of the equipment planning model and its development.

A Definition

Basically, system dynamics involves the application of feedback control systems principles and techniques to managerial, organizational, and socioeconomic problems. For the investigation of managerial concerns, the system dynamics approach attempts to integrate the several functional areas of a business organization into a conceptual and meaningful
whole. The objective is to provide an organized and quanti-
tative basis for reviewing and designing more effective
organizational policy. Within this thesis, the system
dynamics approach is used to integrate the marketing, oper-
ating, and financial functions of a railroad into a mean-
ingful whole for the purpose of dealing with the demands
of the market.

The system dynamics philosophy essentially rests on
two premises. First, there is the belief that the behavior
(or time history) of an organization is principally caused
by the organization's structure. Elements of the structure
include not only the physical aspects of plant and the
production process but, more importantly, both the tangible
and intangible policies and traditions that fashion decision
making in the organization. Secondly, the system dynamics
philosophy holds that an organization is most effectively
viewed in terms of its common underlying "flows" instead of
in terms of its separate functions. The flows of people,
money, materials, orders, and capital equipment, and the
integrating flows of information can be identified in all
organizations. Once identified, the flow structure allows
the analyst to cross over an organization's subfunctional
boundaries in a meaningful manner.
The Modeling Process

Recognizing the previously described philosophy, the system dynamics approach begins with an effort to understand the system of forces that has created a problem and continues to sustain it. As research develops an understanding of a problem, a formal model is also developed. The initial model format is a set of logical diagrams showing cause and effect relationships. When feasible, the diagrams are converted into mathematical equations which in turn allow computer simulation of the relationships which have been built. Central to the process is a continuing exposure of a model to criticism which results in two things: (1) an improved model and (2) successively better understanding of the problem by people who are involved in the process of trying to solve it.

Computer simulation using a system dynamics model can be a powerful conceptual device which has the implicit goal of strengthening the role of reason, at the expense of rhetoric, in the determination of organizational policy. Perhaps one of the most important things to bear in mind about a model, however, is that it is not, nor is it intended to be, a perfectly accurate representation of reality that can be trusted to make better decisions than people are able to make. "It is," in Dr. Roberts' words, "a flexible tool that forces the people who use it to think harder and to confront
one another, their common problems and themselves, directly and factually."

Dr. Roberts' summary of the modeling process cites seven advantages of computer modeling, as a part of managerial policy making, which are usefully repeated here:

1. It (a computer model) requires managerial policy makers to improve and complete fully the rough mental sketch of the causes of a problem that they inevitably have in their heads.

2. In the process of formal model-building the builders discover and resolve various self-contradictions and ambiguities among their implicit assumptions about the problem.

3. Once the model is running, even in rudimentary fashion, logical "bootstrapping" becomes possible. The consequences of promising but tentative formulations are tested in the model. Observation of model behavior gives rise to new hypotheses about structure.

4. Once an acceptable standard of validity has been achieved, formal policy experiments reveal quickly the probable outcomes of many policy alternatives; novel policies may be discovered; "what if" situations can be explored.

5. An operating model is always complete, though in
a sense never completed. Unlike many planning aids, which tend to be episodic and terminal (they provide assistance only at the moment the "report" is presented, not before or after), a model is organic and iterative. At any moment, the model contains in readily-accessed form the present best understanding of the problem.

6. Sensitivity analysis of the model reveals the areas in which genuine debate (rather than caviling) is needed and guides empirical investigation to important questions. If the true value of many parameters is unknown (which is generally the case in corporate strategic planning), the ones that most affect model behavior need to be investigated first.

7. An operating model can be used to communicate with people who were not involved in building the model. By experimenting with changes in policies and model parameters and observing the effects of these changes on behavior, these people can be helped to better understand the dynamic forces at work in the real-world system.

**General Model Development**

System Dynamics models are essentially mathematical representations, using a dynamically-oriented language, of
what are called "feedback systems." A feedback system is defined as one or more interconnected "feedback loops."
A feedback loop exists whenever an action-taker is later influenced by the consequences of his actions. For instance, a basic feedback loop in this thesis relates the decision to acquire freight car equipment to marketing success which in turn leads to further acquisition of equipment, assuming a growing market and the meeting of certain marketing success criteria. In this feedback loop, the existence and timely placement of rail cars is causally related to marketing success and vice versa. The size of the rail car fleet and the level of marketing success are key system variables.

Feedback loops are characterized in two ways: positive or negative. Positive feedback loops act to reinforce variable change in the same direction as the change, contributing to sustained growth or decline in loop variables. Negative feedback loops act to resist or counter variable changes, thereby pushing to a direction opposite a change, contributing to fluctuation or to maintaining the equilibrium of the loop. In the railcar example, the fleet investment-marketing success-fleet investment loop is positive. A negative loop(s) can be structured by introducing countervailing forces to marketing success such as inadequate rail car fleet size, fleet utilization problems, late placement of equipment for loading relative to competition, line haul
service inconsistency, or inadequate pricing action.

A key concept of system dynamics is that of time delay. In any feedback system where an action-taker will be later influenced by the consequences of his actions, the consequences may occur quickly and be readily apparent or may surface less quickly and perhaps not be apparently related to the initial action, at least in the eyes of the action-taker. One of the challenges in developing a system dynamics model is to successfully trace cause and effect relationships through a time continuum to come back to an initial action thereby "closing the loop." The ability to do so, however, combined with mathematical representation of the actions, delay time, and consequences, is what gives this type of analysis its "dynamic" characteristics and sets system dynamics methodology apart from more static types of models.

Kinds of Variables and Their DYNAMO Equations

From a system dynamics perspective all systems can be represented in terms of level and rate variables, with auxiliary variables used for added clarity and simplicity. The DYNAMO (DYNAmic MOdels) compiler-simulator language used in system dynamics models is maintained by Alexander L. Pugh, III and Pugh-Roberts Associates, Inc. of Cambridge, Massachusetts. System dynamics models can be simulated using other compilers/languages such as CSMP or FORTRAN, but the
model builder must be much more competent in computer techniques and the mathematics of his system to use these other languages, with no apparent advantage provided by these alternatives. DYNAMO does not require the user to have any prior knowledge of computer programming, and translates equations of the form shown here into the needed computer code for simulating the model and producing its output printouts and plots.

A **level** is an accumulation, or an integration over time, of flows or changes that come into and go out of the level. Inventories, cash balances, manpower pools, order backlogs are levels respectively, of materials or goods, money, people, and order flows. Inventories accumulate units received less units delivered. Cash balances integrate over time the flow of receipts less expenditures. Manpower pools reflect hiring rates minus firing/quit rates, accumulated over some period of time.

Level equations describe the system's state at each point in time in terms of DYNAMO notations. As shown in Figure 1.1, .K refers to the current point in time, .J refers to the previous point in time (one time interval ago), and .L represents the next point in time (one time interval into the future). The most recent time interval is denoted by .JK and the next time interval by .KL. Each time interval has the duration DT (Delta Time), whose value is specified at the
FIGURE 1.1
DYNAMO Time Notation
outset of each simulation of a model.

There are two types of level equations. One type represents measurable quantities such as the level of inventory, knowledge, or number of employees. Equations for this type of level take the following form:

\[
L \text{LEVEL}.K = \text{LEVEL}.J + (DT)(\text{RATEIN}.JK - \text{RATEOUT}.JK)
\]

The equation form indicates that the level at the current point in time (.K) is equal to the value at the previous point in time (.J) plus the net change that took place over the past time interval (.JK). Net change is the resultant of flows into and out of the level multiplied by the appropriate time interval.

The second type of level equation represents an average of another quantity that serves as a descriptor of the system's state. Such a quantity might be either a level or an auxiliary variable. One use of this type of level equation is to simulate the delay between the time a condition develops in a system and the time it is perceived by a decision maker. Another use is to average a rate of change, since rates of change cannot be observed at any one point in time and must be measured by the effect they have over time. This type of level equation takes the following form:

\[
L \text{LEVEL}.K = \text{LEVEL}.J + (DT)(\frac{1}{TA})(\text{QUANT}.J - \text{LEVEL}.J)
\]
or:

\[ L \text{ LEVEL.K} = \text{LEVEL.J} + (DT)(1/TA)(\text{RATE.JK} - \text{LEVEL.J}) \]

These forms indicate that the value of the level at the present point in time is equal to the level at the previous point in time adjusted by a change over the last time interval. That change is some fraction (1/TA), where TA represents the time for adjustment of the average or perception, of the difference between the value of the quantity or rate of change being averaged and the previous value of the level, multiplied by the time interval being used.

**Rate equations** are based on the state of the system at the current point in time (.K) and indicates rates of change that will occur over the next time interval (.KL). These equations take the following form:

\[ R \text{ RATE.KL} = f(\text{LEVEL.K}, \text{AUX.K}) \]

As indicated, rates during the next time period are functions of level and/or auxiliary variable values at the current point in time.

**Auxiliary equations** represent informational concepts that are used as inputs to other auxiliary equations or the rate equations. They take the following form:

\[ A \text{ AUX.K} = f(\text{LEVEL.K}, \text{AUX.K}) \]
Auxiliaries are computed at the current point in time from level and other auxiliary values at the current point in time.

Most formats for auxiliary and rate equations in system dynamics models are straightforward algebraic expressions, as indicated previously. One equation form which is very useful and appears in the model documented later in this paper does, however, require some explanation. It is the following special tabular, rather than algebraic, expression:

\[ A \, Y.K = \text{TABLE}(YTB, X.K, L, H, I) \]

or:

\[ R \, Y.KL = \text{TABLE}(YTB, X.K, L, H, I) \]

This type of equation indicates a functional relationship between an independent variable (X) and a dependent variable (Y). L, H, and I describe the low end L, high end H, and interval I between points in a set of independent variable values. YTB is an associated table (designated by T) of constant values of the dependent variable that correspond to each of the values of the X variable. Consequently,

\[ A \, Y.K = \text{TABLE}(YTB, X.K, 0, 5, 1) \]

\[ T \, YTB = 3, 7, 9, 11, 13, 14 \]
would represent the following functional relationships:

\[
\begin{array}{ccccccc}
X & 0 & 1 & 2 & 3 & 4 & 5 \\
Y & 3 & 7 & 9 & 11 & 13 & 14 \\
\end{array}
\]

Graphically, this equation would appear as in Figure 1.2.

There are many other functional relationships which are of use in constructing system dynamics models. The equations described in this section are rather fundamental and at least serve to acquaint a reader with the basic DYNAMO notations which appear later in this paper. For a more complete explanation of DYNAMO, the reader should see Alexander L. Pugh's DYNAMO User's Manual, fifth edition, published by The M.I.T. Press, 1977.
FIGURE 1.2
Sample DYNAMO Table Function
CHAPTER II

DEVELOPMENT OF THE EQUIPMENT PLANNING MODEL

Types of Railcar Equipment Planning Situations

The complexity of the railcar equipment planning job is influenced in large part by the type of rail service within which the equipment is expected to function. There are three general situations which exist: unit train, assigned, and general or "free-running" service.

Unit train equipment planning is the easiest to deal with. A unit train is a regularly scheduled operation which, on a consistent year-around basis, moves a large volume of usually only one commodity (such as coal, ore, or aggregates) between a single origin and single destination. Unit trains are developed in response to long-run market opportunities which result in reasonably predictable equipment lives, transportation cycles, and intensive equipment utilization. As a result, the recovery of invested capital per carload (or whatever productivity measurement is used) is low relative to the transportation operating cost per carload. Railcar equipment in unit train service is most often part of a discrete equipment pool which has been specially built for the service and has reasonably predictable maintenance characteristics.
From virtually every management standpoint, the planning of unit train equipment needs entails less risk and uncertainty than is the case with equipment in "assigned" and/or "general" service.

"Assigned service" can refer to the fact that equipment is assigned either to a specific shipper or agency for their exclusive loaded use. Assigned cars are frequently specially equipped with certain interior complements to suit the product/commodity being transported, such as "load divider" bulkheads and bars for blocking and bracing boxed goods or interior racks for securing automobile part stampings. A carrier usually puts a railcar into assignment in order to protect a regular movement and/or to secure a certain proportion of business from a large shipper who has access to many competitive line cars and who will assign routings to those roads which contribute to a car pool. Assigned cars make regular trips, often over specified routes, and are usually returned empty over the same route. Assigned cars differ from unit train cars essentially in terms of utilization. Assigned cars move in regular train service and must be interchanged and classified en route. Delays inherent in the system reduce the potential for annual trips. In addition, cars assigned to pools may experience more time "queuing up" for loads at their origin stations than is the case with unit train equipment. As utilization deteriorates from the optimum level suggested by
unit train service, capital recovery per carload increases relative to operating cost. To the degree that capital and operating costs together approach revenue earned by the assigned car, the risk of investment in cars for assignment increases. As a general matter, however, planning for assigned service is less complex than is the case for free-running equipment.

"Free-runner" is the term used to describe railcars which, when made empty, may be loaded toward the owning, or "home," road in accordance with AAR Car Service Rules rather than be returned empty in reverse routing as is normally the case with assigned equipment. Planning for the acquisition of free-running equipment is complicated because utilization is a function of so many factors: car service rules, seasonal demand, inter- and intramodal competition, and the variable operating capabilities of numerous railroads the car may move across. Utilization of free-running equipment may tend to be lower than that experienced in assigned service and the revenue-generating freight rates for the various commodities which are handled by general service equipment vary over a wide range, producing difficulty in estimating the cash flow a general service car will generate. In planning general service freight car acquisition, carrier management is often making projections based on mean factors which are derived from probability distributions with relatively broad areas of
standard deviation. A well thought out system dynamics equipment planning model with its intrinsic capability to quickly "rerun" and test the ultimate effects of changing parameters could be a valuable management tool in the effort to better plan the acquisition of general service railcar equipment.

The overall complexity of a given railroad's equipment planning task is largely a function of how much equipment it owns in each of the three service categories and, of course, its expectations of what future demands will be. As a general proposition, to the degree that free-running equipment makes up the freight car fleet, a railroad's planning job increases in complexity. The percentages vary from company to company and over time. Again using the Santa Fe Railway as an example, in November 1979 the ATSF owned 67,749 freight cars. Of that total, 8,645 units were in assigned or unit train service, leaving 59,104 cars, or 87.2 percent of the Santa Fe fleet, as free runners.¹

Model Scope

The initial step in model development is to define the scope of interest or boundaries of the problem to be investigated. As mentioned in the Introduction, the scope of the model developed here is relatively narrow when compared to all of the possible factors which in one way or another

¹Santa Fe Railway, Market Development and Research Department, Chicago.
could be causally linked to the problem of long-range equipment planning. Problem scope in this case involved decisions regarding:

- the aspects of fleet planning to be addressed, i.e. size; composition (how many cars of each type); utilization factors; optimum distribution.

- the determination of exogenous and endogenous variables. To what degree would factors beyond management's scope of direct control be incorporated? Should the model address equipment supplier problems? Or general economic activity as an influence on the market forecast? Or the effects of various rules and regulations on equipment utilization? Or the financial incentives to supply railcars which stem from the level of car-hire charges?

In the final analysis, the decision to develop a model which investigates the job of joining railcar demand with railcar supply over a five-year time frame was influenced by two main factors. First, such a model would focus on a legitimate management concern; namely the acquisition of assets in a business where return on assets is generally a problem. The question of equipment acquisition (when acquisition implies "new investment") is a matter of current railroad management concern, not only because of relatively low Rate of Return on
existing properties, but also because of the continuing inability of the industry to finance new equipment out of retained earnings. This has the consequence of increasing debt service and aggravating the already serious problem many carriers have covering fixed charges to the satisfaction of the financial community. Second, the model talks about "railcars" in a generic sense (rather than by specific type) to encourage development of a format which is generally applicable as a management planning aid and can be used regardless of the specific car type requirements being forecast.

The determination of exogenous and endogenous variables is largely a function of (1) the writer's system dynamics expertise at the beginning of this project, and (2) the fact that even a rudimentary model reasonably conceived can be a good base for "bootstrapping" both in terms of scope of interest and internal model quality. At the time of this writing it is clear, given the working model as it is, where model scope could be expanded and how this could be done, at least hypothetically.

As a result, the model described herein focuses on events and variables relatively close to the railcar supply-demand interaction such as:

- Carrier management's perception of market potential as near term customer car orders.
- An equipment utilization factor which varies over the planning period.

- Car-builder's shop backlog (or, more accurately, an acquisition delay factor) held as a constant over the planning period.

- The market's reaction to the carrier's success, or lack of, in placing equipment for loading upon demand, in keeping to transit schedule expectations, and in pricing the use of the carrier's serviceable fleet.

- The "bad order" condition of the car fleet given the cash flow which can be directed toward equipment maintenance vis-a-vis what is considered to be, by experience, an optimum maintenance level.

**Equipment Planning Model Format**

The model treats railcar equipment supply basically as a marketing problem where the carrier is attempting to react to market demand for cars and the market in turn reacts to the carrier's success, or lack of, in supplying the demanded cars in a timely manner. A general schematic of the model is shown in Figure 2.1. The model consists of three general feedback loops which can be further subdivided to reveal minor feedback loops at work as well. In general concept the equipment planning model is somewhat similar to the "Market Growth" model developed by M.I.T. Professor
Jay W. Forrester in 1967.¹ Both "Market Growth" and this equipment planning model tie the marketing success of a business firm to its investment policies. The actual model structures differ; however, they essentially address the same issues.

The equipment planning model can probably be best explained by proceeding through the major feedback loops in step-by-step fashion. As mentioned previously, there are three such major loops: equipment acquisition, marketing effectiveness, and equipment maintenance.

The Equipment Acquisition Loop

A schematic of the equipment acquisition loop is shown in Figure 2.2. It is a positive feedback loop which says in effect that customer railcar orders are generated by the combination of a carrier's serviceable equipment fleet and net marketing effectiveness. Railcar orders flow into an order backlog which is reduced by a given rate of car supply from the carrier. Insofar as new equipment acquisition is concerned, the concept of "indicated serviceable equipment fleet" is generated at any and all points in time by dividing the level of railcar order backlog by an expected car utilization estimate. "Indicated equipment acquisition" is the

FIGURE 2.2
The Equipment Acquisition Loop

Total Equipment Fleet (TEF) → Serviceable Equipment Fleet (SEF) → Net Marketing Effectiveness (NME)

Utilization Rate (EGR) → Transportation Capacity (TC) → Railcars Ordered By Market (CO)

Equipment Acquired (EQA) → Indicated Serviceable Equipment Fleet (ISEF)

Equipment Ordering (EQOR) → Indicated Equipment Acquisition (IEQA) → Railcar Supply Rate (CSR)
difference between the "indicated serviceable equipment fleet" and the existing serviceable equipment fleet at any point in time. ISEF and IEQA can be either positive or negative values; a negative value suggesting that the carrier has a surplus of equipment relative to demand rather than a shortage. "Equipment Ordering" is a level which essentially represents the time a carrier takes to react to the value of IEQA. "Equipment Acquired" is the rate at which new carrier equipment orders reach the carrier's existing total equipment fleet. To close the loop, the serviceable equipment fleet is the number of railcars in the total equipment fleet less the amount of "bad order" (in need of repair) equipment. Delays around the loop can occur at the car order backlog COBL (while the carrier processes a customer car request), equipment ordering EQOR (while the carrier decides internally how to react to car shortages/surplus), and in the rate of new equipment acquisition EQA (as the car builder's backlog prevents immediate incorporation of carrier's orders into the total fleet). The general function of the equipment acquisition loop is to seek additional railcars as long as they are justified by an excess of demand over supply and to divest the carrier of excess capacity when car supply exceeds demand by the market.

The operating equations and character definitions are as follows:
\[ R \quad \text{CO.KL} = (\text{SEF.K})(\text{NME.K}) \]

- **CO** - car Orders by customers (carloads per month)
- **SEF** - Serviceable Equipment Fleet (railcar units)
- **NME** - Net Marketing Effectiveness (number of carloads sold per serviceable car per month)

\[ L \quad \text{COBL.K} = \text{COBL.J} + (\text{DT})(1/\text{BLAT})(\text{COJK} - \text{COBL.J}) \]

- **COBL** - Customer car Order BackLog (carloads per month)
- **DT** - computation interval (Delta Time, months)
- **BLAT** - BackLog Averaging Time (months)
- **ICOBL** - Initial Car Order BackLog (units per month)

\[ N \quad \text{COBL} = \text{ICOBL} \]
\[ C \quad \text{ICOBL} = 10000 \]
\[ C \quad \text{BLAT} = 1 \]

\[ A \quad \text{TC.K} = (\text{SEF.K})(\text{EQUK}) \]
\[ C \quad \text{EQUK} = 2.5 \]

- **TC** - Transportation Capacity (carloads per month)
- **EQUK** - Equipment Utilization Rate (trips/car/month)
- **SEF** - Serviceable Equipment Fleet (railcar units)

\[ A \quad \text{ISEF.K} = \text{COBL.K}/\text{EQUK} \]

- **ISEF** - Indicated Serviceable Equipment Fleet (railcar units)
- **COBL** - Customer car Order BackLog (carloads per month)
- **EQUK** - Equipment Utilization Rate (trips/car/month)

\[ R \quad \text{IEQA.KL} = \text{ISEF.K} - \text{SEF.K} \]

- **IEQA** - Indicated Equipment Acquisition (railcar units)
- **ISEF** - Indicated Serviceable Equipment Fleet (railcar units)
- **SEF** - Serviceable Equipment Fleet (railcar units)

\[ L \quad \text{EQOR.K} = \text{EQOR.J} + (\text{DT})(1/\text{ORDT})(\text{IEQA.JK} - \text{EQOR.J}) \]

- **EQOR** - Equipment ORdering (railcar units)
- **DT** - Delta Time (months)
- **ORDT** - internal ORdering Delay Time (months)
- **IEQA** - Indicated Equipment Acquisition (railcar units)
EQA.KL = (1/BBL)(EQOR.J)
BBL = 1
EQA = Equipment Acquired (railcar units)
BBL = car Builder's BackLog (months)
EQOR = Equipment ORDERing (railcar units)

TEF.K = TEF.J + (DT)(EQA.JK)
TEF = 4103
TEF = Total Equipment Fleet (railcar units)
DT = Delta Time (months)
EQA = Equipment Acquired (railcar units)

SEF.K = TEF.K - BOEQ.K
SEF = Serviceable Equipment Fleet (railcar units)
TEF = Total Equipment Fleet (railcar units)
BOEQ = Bad Order EQUIPMENT (railcar units)

The Marketing Effectiveness Loop

A schematics of the marketing effectiveness loop appears in Figure 2.3. It is a negative feedback loop which introduces countervailing forces to the increasing customer car ordering tendencies generated by the equipment acquisition loop. The marketing effectiveness loop also contains the marketing forecast which is the maximum possible level of the carrier's business activity at any time.

The countervailing forces to carrier marketing success are conceptualized as car supply delay, transportation delay, and pricing effectiveness. Values for these concepts are generated from the interaction between car supply and demand. As supply and demand values are constantly changing,
FIGURE 2.3
THE MARKETING EFFECTIVENESS LOOP

Net Marketing Effectiveness (NME) +
Carrier Carload Market (CCLM) +
Marketing Effectiveness Multiplier (MEM) +

Railcars Ordered by Market (CO) +
Market Maximum (MKTM)

Railcar Order Backlog (COBL) +
Car Supply Delay Minimum (CSDM)

Railcar Supply Rate (CSR) +
Transportation Capacity Fraction (TCF)

Supply Rate Average (CSRA) +

Delay in Equipment Placement Multiplier (DEPM) −

Supply Delay Recognized by Market (SDRM) +

Car Supply Delay Indicated (CSDI) +

Transportation Delay Multiplier (TRDM) −

Transp. Delay Recognized by Mkt. (TDRM) +

Transp. Delay Indicated (TDI) +

Revenue Per Carload (RPCL) +

Pricing Effectiveness Multiplier (PEM) −
so are the values calculated for car supply delay, trans-
portation delay, and pricing effectiveness. The principal
constraint, the market forecast, is nothing more complicated
than a forecast by the railroad's marketing department as
to the maximum amount of business potentially available on
the assumption that car supply would not be a problem. It
is, in other words, a forecast of market potential rather
than a forecast of maximum loadings based on any presump-
tion of fleet size.

The loop is initiated, as was the equipment acquisi-
tion loop, by the combination of the carrier's serviceable
equipment fleet and "net marketing effectiveness" which is
defined as the number of carloads "sold" per car in the SEF
during the month. The customer car order backlog is gener-
at and from that factor, along with the carrier's existing
transportation capacity, a value for "car supply delay min-
imum" (CSDM) is calculated. As an example, if the carrier's
serviceable fleet of 4,000 cars is capable of averaging 2.5
trips per car per month, the carrier fleet has a theoretical
capacity of 10,000 carloads per month. Should customer car
orders during a month total 11,000 carloads, the value of
CSDM is 1.1, indicating that the carrier requires a minimum
of 1.1 months to fill a one-month demand for railcar capa-
city. From the calculated value of CSDM, the "transporta-
tion capacity fraction" is generated by using a table


function as illustrated in Figure 2.4. The actual car supply rate into the market (CSR) is a function of the carrier's fleet capacity and the fraction of the capacity being demanded up to, of course, a TCF of 1.0. The car supply rate average, which is the short term average of car supply rate, becomes the driving variable for calculating both the "equipment maintenance optimum" and the flow of operating revenue, both of which will be discussed in the Equipment Maintenance Budget loop.

The ratio of car order backlog (COBL) to car supply rate average (CSRA) becomes the car supply delay indicated (CSDI). This is essentially the present condition of car supply which is perceived in the carrier's market. The reaction time of the market to supply condition is conceptualized by the level "supply delay recognized by the market" (SDRM). The SDRM in turn generates a value for the "delay in equipment placement multiplier" (DEPM) which becomes an important input to the carrier's total marketing effectiveness. The table function relating SDRM to DEPM is shown in Figure 2.5.

Transportation delay and/or inconsistent service is incorporated in the marketing effectiveness loop, although in a somewhat arbitrary and rather simple fashion. Car supply delay minimum (CSDM) is the driving variable for "transportation delay indicated" (TDI). This is accomplished
FIGURE 2.4
Transportation Capacity Fraction

TCF

CSDM
FIGURE 2.5
Delay in Equipment Placement Multiplier

DEPM

0  7  14  days

SDRM

TDEPM
through the table function illustrated in Figure 2.6. This function suggests that no delay is indicated as long as the carrier's railcar fleet is not utilized to full capacity. As demand begins to exceed capacity, the TDI begins to increase. It is not useful to think of this particular representation in too literal a sense. Rather, the function portrays a delay potential when the rail system becomes badly "overloaded" in the short term showing such symptoms as classification yard congestion, interchange delays, motive power shortages, repair track backlogs, and the like. Only to the degree that the utilization patterns of this particular equipment type (whichever is chosen) happen to correlate to seasonal logistics problems (both those of the carrier and the shippers/receivers who interface with the carrier), would this representation be correct in any sense. Its inclusion here is for the purpose of illustrating that the concept can be incorporated, however it is calculated, when system dynamics methodology is used. As is the case with car supply delay indicated (CSDI), the TDI is recognized, after some time lag, and becomes part of the carrier's overall marketing effectiveness. See Figure 2.7.

The marketing effectiveness loop also generates the revenue per carload (RPCL) and a concept of "pricing effectiveness" (PEM). In the current railroad pricing regulatory environment, freight rates tend to be static in the sense
FIGURE 2.6
Transportation Delay Indicated

TDI

TTDI

CSDM
FIGURE 2.7
Transportation Delay Multiplier

![Graph showing Transportation Delay Multiplier (TTRDM) vs. TDRM]

- TRDM
- TTRDM

TDRM

0 0.25 0.5 0.75 1.0

1 2 3 4 5 6 7
that they are not quoted as a function of available carrier capacity at a given moment in time. An exception to that is in the transportation of perishables (fresh fruits, vegetables, produce) where rail service and pricing was essentially deregulated in May 1979. In view of this dichotomy, the equipment planning model in general, and the marketing effectiveness loop in particular, must be designed to handle pricing done on either a regulated static basis and/or a deregulated flexible basis. This is accomplished by driving RPCL from the transportation capacity fraction TCF. The relationship is illustrated in Figure 2.8. $930 per carload is an average rate for the use of the railcar fleet. $685 is nearly down to the estimated level of variable operating cost, while $1630 represents a pricing officer's judgement as to the maximum constant dollar revenue which could be charged under maximum demand conditions. These are, of course, hypothetical values. The point, once again, is to illustrate how the concepts they represent could be incorporated using system dynamics methodology. The pricing effectiveness multiplier is a function of the revenue per carload realized. Figure 2.9 illustrates that it too can be either variable or static.

Marketing effectiveness (ME) is the sum of the three multipliers which have been described: delay in equipment placement (DEPM), transportation delay (TRDM), and pricing
FIGURE 2.8
Revenue Per Carload

Variable Pricing

Static Pricing

TCF
FIGURE 2.9

Pricing Effectiveness Multiplier

[Diagram showing a graph with axes labeled PEM on the y-axis and RPCL on the x-axis. The graph compares Static Pricing and Variable Pricing, with a downward trend from left to right.]
effectiveness (PEM). Given the illustrative purpose of this model, the multipliers are all given equal weight, i.e. they have a maximum individual value of 1.0 and an aggregate maximum value of 3.0. A belief that one of the multipliers is, in fact, more important relative to the others can be incorporated simply by changing the scale of that one in relation to the aggregate maximum value.

To translate marketing effectiveness (ME) into the carrier's carload market demand for a given month, the concept of "marketing effectiveness multiplier" (MEM) is built. The aggregate value of DEPM, TRDM, and PEM (in other words "ME") is related to an MEM by the use of yet another table function as illustrated in Figure 2.10. The carrier's carload market demand (CCLM) is arrived at by multiplying the derived MEM value against the market forecast (MKTM) for the period. The forecast is introduced into the model by a table function which uses TIME as the independent variable. See Figure 2.11.

Finally, the marketing effectiveness loop is closed when "net marketing effectiveness" (NME) has been calculated. The derived CCLM is divided by the number of railcars in the carrier's serviceable equipment fleet SEF. The result is the number of carloads sold per SEF unit in the period.

In all, the marketing effectiveness loop is goal seeking. The loop attempts to adjust the level of customer
FIGURE 2.10
Marketing Effectiveness Multiplier

![Graph showing the relationship between MEM and TMEM with the x-axis labeled ME and the y-axis labeled MEM. The graph shows a curve starting at (0,0) and increasing to (3.0, 1.0).]
car orders to the capacity the carrier can make available.

Equations of the marketing effectiveness loop are as follows:

A \[ CSDM.K = \frac{COBL.K}{TC.K} \]

- CSDM - Car Supply Delay Minimum (months)
- COBL - Customer car Order BackLog (carloads/month)
- TC - Transportation Capacity (carloads/month)

A \[ TCF.K = TABHL(TTCF, CSDM.K, 0, 2.0, 1.0) \]

- TTCF = 0, 1.0, 1.0
- TCF - Transportation Capacity Fraction (percentage)
- TABHL - Table for Transportation Capacity Fraction
- CSDM - Car Supply Delay Minimum (months)

R \[ CSR.KL = (TC.K)(TCF.K) \]

- CSR - Rail Car Supply Rate (carloads per month)
- TC - Transportation Capacity (carloads per month)
- TCF - Transportation Capacity Fraction (percentage)

L \[ CSRA.K = CSRA.J + (DT)(1/\text{SRAT})(\text{CSR.JK} - \text{CSRA.J}) \]

- CSRA - Car Supply Rate Average (carloads per month)
- CSR - Rail Car Supply Rate (carloads per month)
- SRAT - Supply Rate Averaging Time (months)
- DT - Delta Time (computational interval)

A \[ CSDI.K = \frac{COBL.K}{CSRA.K} \]

- CSDI - Car Supply Delay Indicated (months)
- COBL - Customer car Order BackLog (carloads per month)
- CSRA - Car Supply Rate Average (carloads per month)
L SDRM.K = SDRM.J + (DT)(1/TSDRM)(CSDI.J - SDRM.J)
N SDRM = CSDI
C TSDRM = 1

SDRM - Supply Delay Recognized by Market (months)
TSDRM - Time for Supply Delay Recognized by Market
CSDI - Car Supply Delay Indicated (months)
DT - Delta Time (computational interval)

A DEPM.K = TABHL(TDEPM, SDRM.K, 1.0, 1.46, 0.33)

DEPM - Delay in Equipment Placement Multiplier
TDEPM - Table for Delay in Equipment Placement Multiplier
TABHL - DYNAMO Hi-Lo table function
SDRM - Supply Delay Recognized by the Market (months)

A TDI.K = TABHL(TTDI, CSDM.K, 0, 2.0, .2)
T TTDI = 0/0/0/0/0/0/0/.5/1.0/2.0/4.0/7.0

TDI - Transportation Delay Indicated (days)
TTDI - Table for Transportation Delay Indicated
TABHL - DYNAMO Hi-Lo table function
CSDM - Car Supply Delay Minimum (months)

L TDRM.K = TDRM.J + (DT)(1/TTDRM)(TDI.J - TDRM.J)
N TDRM = TDI
C TTDRM = 1

TDRM - Transportation Delay Recognized by the Market (days)
TTDRM - Time for Transportation Delay Recognized
TDI - Transportation Delay Indicated (days)
DT - Delta Time (computation interval)

A TRDM.K = TABHL(TTRDM, TDRM.K, 0, 7, 1)
T TTRDM = 1/.95/.8/.75/.5/.25/.2/.1

TRDM - Transportation Delay Multiplier
TTRDM - Table for Transportation Delay Multiplier
TABHL - DYNAMO Hi-Lo table function
TDRM - Transportation Delay Recognized by the Market (days)
RPCL.K = TABHL(TRPCL, TCF.K, 0, 1.0, .2)

TRPCL = 685/745/840/930/1160/1630

RPCL - Revenue Per CarLoad (dollars)
TRPCL - Table for Revenue Per CarLoad
TABHL - DYNAMO Hi-Lo table function
TCF - Transportation Capacity Fraction

PEM.K = TABHL(TPEM, RPCL.K, 685, 1630, 189)

TPEM = 1/.95/.9/.85/.7/.5

PEM - Pricing Effectiveness Multiplier
TPEM - Table for Pricing Effectiveness Multiplier
TABHL - DYNAMO Hi-Lo table function
RPCL - Revenue Per CarLoad (dollars)

ME.K = DEPM.K + TRDM.K + PEM.K

ME - Marketing Effectiveness
DEPM - Delay in Equipment Placement Multiplier
TRDM - TRansportation Delay Multiplier
PEM - Pricing Effectiveness Multiplier

MEM.K = TABHL(TMEM, ME.K, 0, 3.0, 1.0)

TMEM = 0/.25/.8/1.0

MEM - Marketing Effectiveness Multiplier
TMEM - Table for Marketing Effectiveness Multiplier
TABHL - DYNAMO Hi-Lo table function
ME - Marketing Effectiveness

CCLM = (MEM.K)(MKTM.K)

CCLM - Carrier CarLoad Market (carloads per month)
MEM - Marketing Effectiveness Multiplier
MKTM - MarKeT Maximum (carloads per month)

MKTM.K = TABHL(TMAX, TIME.K, 0, 60, 6)

TMAX = 10000 through 14000 as an example

MKTM - MarKeT Maximum (carloads per month)
TMAX - Table for market MAXimum
TABHL - DYNAMO Hi-Lo table function
TIME - DYNAMO time interval (months)
A \[\text{NME.K} = \frac{\text{CCLM.K}}{\text{SEF.K}}\]

NME - Net Marketing Effectiveness (carloads/car/month)
CCLM - Carrier CarLoad Market (carloads per month)
SEF - Serviceable Equipment Fleet (railcars)

A \[\text{MKTSH.K} = \frac{\text{CSPA.K}}{\text{MKTM.K}}\]

MKTSH - MarKeT SHare (percentage)
CSRA - Car Supply Rate Average (carloads/month)
MKTM - MarKeT Maximum

The Equipment Maintenance Loop

The principal function of the equipment maintenance loop (Figure 2.12) is to calculate the level of "bad order" equipment in the carrier's total equipment fleet TEF. This is accomplished by:

- calculating the equipment maintenance budget based on the railcar supply rate average and a historical equipment maintenance spending average.

- comparing the actual maintenance expenditure to a management-estimated optimum expenditure which would be appropriate to minimize the fleet's bad order ratio.

The loop is initiated by calculating operating revenue (OPR) from the car supply rate average (CSRA) and the revenue per carload (RPCL). This revenue flows into an operating revenue average (OPRA) level at a rate somewhat modified by the carrier's average receivables collection time. The
FIGURE 2.12
The Equipment Maintenance Loop

- Bad Order Equipment (BODEQ) +
  - Rail Order Rate (BORDR) +
    - Equipment Maintenance Condition (EMC)
      - Equipment Maintenance Average (EMCA)
        - Equipment Maintenance Cash Flow (EMCF)

- Serviceable Equipment Fleet (SEF) +
  - Railcars Ordered (CO)
    - Car Order Backlog (COBL)
      - Transportation Capacity Fraction (TEF)
        - Revenue Per Carload (RPCL)
          - Operating Revenue (OPR)

- Equipment Optimum (EMOPT) +
  - Car Supply Rate (CSR)
    - Car Supply Rate Average (CSRA)
      - Operating Cost (OPC)
        - Operating Revenue Average (OPRA)
          - Operating Income (OPIN)
equipment maintenance cash flow (EMCF) is estimated by applying an equipment maintenance fraction (EQMF) against the OPRA. The EQMF may be the historical percentage of operating revenue spent on equipment maintenance or some other appropriate estimation. The average equipment expenditure made (EQMA) is compared to an equipment maintenance optimum (EMOPT) which represents a mechanical department officer's judgement as to the level of maintenance expenditure per car which should be made to minimize the car fleet's bad order ratio. From the comparison between EQMA and EMOPT a bad order ratio is generated (as a percentage) which is applied to the total equipment fleet TEF. The carrier's serviceable equipment fleet SEF is, of course, the total equipment fleet TEF less the number of bad order cars BOEQ at any given time.

Delay around the equipment maintenance loop may occur at the operating revenue average, from receivables collection delays, and at the equipment maintenance expenditure average, from delay in actual allocation of funds. The loop is negative, i.e. increasing operating cash flow will result in decreasing bad order ratios.

The equations in the equipment maintenance loop are as follows:
R  OPR.KL = (CSRA.K)(RPCL.K)

OPR  - Operating Revenue (dollars per month)
CSRA  - Car Supply Rate Average (carloads per month)
RPCL  - Revenue Per CarLoad (dollars per carload)

L  OPRA.K = OPRA.J + (DT)(1/ARAT)(OPR.K - OPRA.J)
D  OPRA  = OPR
C  ARAT  = 1.4

OPRA  - Operating Revenue Average (dollars per month)
ARAT  - Accounts Receivable Averaging Time (months)
OPR  - Operating Revenue (dollars per month)
DT  - Delta Time (computation interval)

A  OPC.K = (CSRA.K)(VCCL)
C  VCCL  = 682

OPC  - variable Operating Cost (dollars per month)
CSRA  - Car Supply Rate Average (carloads per month)
VCCL  - Variable operating Cost per CarLoad (dollars)

A  OPIN.K = OPRA.K - OPC.K

OPIN  - Operating Income (dollars per month)
OPRA  - Operating Revenue Average (dollars per month)
OPC  - variable Operating Cost (dollars per carload)

R  EMCF.KL = (OPRA.K)(EQMF)

EMCF  - Equipment Maintenance Cash Flow (dollars per month)
OPRA  - Operating Revenue Average (dollars per month)
EQMF  - Equipment Maintenance Fraction (percentage)

L  EQMA.K = EQMA.J + (DT)(1/TEQMA)(EMCF.JK - EQMA.J)
N  EQMA  = EMCF
C  TEQMA  = 1

EQMA  - Equipment Maintenance Average (dollars per month)
TEQMA  - Time for Equipment Maintenance Average
EMCF  - Equipment Maintenance Cash Flow
DT  - Delta Time (computation interval)
A EMOPT.K = (CSRA.K)(EMCON)
C EMCON = 112

EMOPT - Equipment Maintenance OPTimum (dollars/carload)
CSRA - Car Supply Rate Average (carloads/month)
EMCON - Equipment Maintenance CONstant (dollars/carload)

A EQMC.K = EQMA.K/EMOPT.K

EQMC - EQuipment Maintenance Condition (percentage)
EQMA - EQuipment Maintenance Average (dollars/month)
EMOPT - EQuipment Maintenance OPTimum (dollars/month)

A BODR.K = TABHL(TBODR, EQMC.K, .7, 1.0, .1)
T TBODR = .1/.07/.04/.025

BODR - Bad OrDer Ratio (percentage)
TBODR - Table for Bad OrDer Ratio
EQMC - EQuipment Maintenance Condition (percentage)
TABHL - DYNAMO Hi-Lo table function

A BOEQ.K = (BODR.K)(TEF.K)
N BOEQ = IBOC
C IBOC = 103

BOEQ - Bad Order EQuipment (railcars)
BODR - Bad OrDer Ratio (percentage)
TEF - Total Equipment Fleet (railcars)
IBOC - Initial Bad Order Cars (railcars)

The entire model, in equation form, is shown in Appendix A.
CHAPTER III

ANALYSIS WITH THE EQUIPMENT PLANNING MODEL

In Chapter I, "System Dynamics - A Brief Review," it was stated that a simulation model is always complete but in a sense never completed. Certainly that is the case here where a model has been developed, is "up and running," contains a reasonable number of dynamically-related system variables, but is not (nor does it purport to be) a completed model which perfectly represents the issues and interrelations which are of importance to the railroad equipment planning process. A later chapter, Chapter IV, will suggest some of the areas of the model which should be further refined in order to improve its potential as a management tool. This chapter will simply take the equipment planning model which exists at this writing, explain how it operates in general terms, and suggest where it is providing insight which may be of value in the long-range planning endeavors of railroad management.

It is useful to keep in mind at all times what the model is attempting to do. Fundamentally, the equipment planning model is trying to equate railcar supply with
demand for railcar capacity. It is constrained from perfectly achieving its goal by various "delays" which exist and represent both railroad and customer management perceptions as well as environmental constraints concerning:

- the number of serviceable railcars which are required (or are available) at any time.

- the time required to decide whether additional (or fewer) railcars should be required (or divested).

- the time required to receive new capacity (or to get rid of it).

- the success, or lack of, in placing the demanded number of cars at the time they are ordered by customers and the effect of that success on future customer orders.

- the effect of transportation delay, or inconsistency, upon customer reordering of the offending carrier's capacity.

- the effect of higher (or lower) freight rate quotations upon subsequent railcar demands.

- the effect of reduced levels of equipment maintenance upon the railcar fleet's bad order ratio and consequently the number of serviceable cars which can be made available.

- the maximum amount of business available in the
market at a point in time and its near term, as well as long term, rate of growth or decline.

In anything resembling a real world condition where potential demand for railcars ebbs and flows producing seasonal or business cycle-related "peaks and valleys" on a month-by-month basis, the constraints and conditions mentioned above will almost certainly insure that market potential, customer orders, and carrier railcar supply will seldom, if ever, meet in perfect fashion. Customer car orders placed with one carrier will usually be something less than the full market potential. The rate at which the carrier supplies railcars will fluctuate around the level of car orders; sometimes higher (a "surplus" from the carrier's standpoint) or oftentimes lower (a "shortage"). The experience of the moment then provides the basis for the next decision by both shipper and carrier. In addition to keeping the model's goal in mind, it is also important to bear in mind that the marketing situation which has been "built in," for this model version, suggests that competition (for the carrier) exists and as a result shipments for which capacity cannot be provided are lost, i.e. a competitor will secure them.

The Standard Run

A system dynamics model's "standard run" is an initial
simulation for the purpose of exhibiting model behavior in its as-written state. Reruns can then be made after changing model elements to reflect changing assumptions or to test new assumptions. There are, of course, a multitude of model factors which can be asked for in output tables and plots. To be at once illustrative and reasonably uncomplicated, the example plots shown in this paper will focus on only major output variables of the model. Output tables will quantify the plot data every third month in order to give the reader a quick, reasonably precise fix on the values actually being plotted on a monthly basis.

The standard run of the equipment planning model contains minimum delays throughout. Most delays occur because carrier and customer management are making decisions based upon reports of near past activity which has to be observed, compiled, and reported through their respective organizations. Major delay factors of carbuilder backlog (BBL) and carrier new car ordering delay (ORDT) are set at "1" implying that no real delay exists other than short term processing and reporting.

In order to measure the relative success of the carrier's endeavor to supply railcars under changing assumptions, the net present value is calculated of operating income over the five-year planning period (NPVOI). A 15 percent discount rate has been incorporated.
The standard run plot is illustrated in Figure 3.1 and accompanying values in Table 3.A. The plot values identified are:

"T" - Total Equipment Fleet
"S" - Car Supply Rate
"O" - Customer Car Order
"M" - Market Maximum (Forecasted potential)

The X-axis is time in months, 0 through 60, while the appropriate scales are identified on the Y-axis.

The reader will note that the market forecast M has pronounced cyclical variations while generally trending upward during the five-year period. Starting with a value of 10,000 carloads per month, the potential market will reach a maximum of 16,000 carloads in month 54 while falling as low as 8,000 carloads in month 12. Given the series of rapid ascents followed by pronounced downturns, this is an extremely difficult market to which the carrier must respond.

The carrier's success in responding to the market can be gauged by (1) examining the interaction of Car Supply Rate "S" and Customer Car Orders "O" and (2) looking at S and O as they relate to M. In the first instance Car Supply Rate is tracking Customer Car Orders very closely. There are very short-term periods of car surplus or car shortage; however, the carrier is generally responding well to demand as evidenced by customer car orders. Regarding the second
### Table 3.A

**THE STANDARD RUN - TABLE**

- **P- 2 RUN-EQSUPP EQSUPP**

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comparison, however, customer car orders and carrier supply lag market potential when the market is rising, although they do close the gap when the market is falling. The first conclusion to be drawn perhaps is that, given the equipment ownership which the carrier sees as "necessary" based upon its short-term perception of market demand, it will be leaving money on the table, so to speak, as this market moves through periods of rapid growth.

What is the equipment ownership required by the carrier to (1) enjoy the level of business suggested by O and S and (2) what would be required to "close the gap" between actual orders and market potential during a rising market? "Ownership" in the sense used here should mean "control." The carrier can acquire the use of railcars without having title to them by leasing and by having a certain amount of foreign line equipment made empty in its territory and available for loading in compliance with the appropriate car service rules. Consequently, when the term "ownership" is used in this paper, it is defined as the total number of railcars required at the moment whether they be carrier-owned, carrier-leased, or foreign line empties which can be loaded without violating car service rules which govern their return to "home road." The car ownership level which enables the carrier to supply railcars to the degree necessary to generate "S" carloads at a given time is represented
by the line "T". Starting at 4,569 cars in time 0, i.e. the initial fleet size, the level falls to about 3,300 cars in month 15 and rises as high as 9,473 cars required in month 57. To close the gap between car supply and market potential during periods of rapidly rising market activity, additional equipment would be required which, when utilized at some rate, would generate additional carload capacity over and above that actually supplied. A first order approximation of that additional equipment level can be estimated by the equation:

\[
\text{ADDEQ}_K = \frac{(\text{MKTM}_K - \text{CSRA}_K)}{\text{EQUR}_K}
\]

- \text{ADDEQ} - Additional equipment (railcars)
- \text{MKTM} - Market maximum (carloads/month)
- \text{CSRA} - Car supply rate average (carloads/month)
- \text{EQUR} - Equipment utilization rate (trips/month)

The value of ADDEQ at every third month is shown in Table 3.A. Table 3.A suggests that the carrier would have used some 760 to 930 additional units during the rising market of months 1 through 6, approximately 1150 to 1540 in months 12 through 24, approximately 1130 to 1570 during months 30 through 42, 1870 to 2250 during months 48 through 54. Approximations are appropriately used in these estimates because they are derived from the difference between the maximum market estimate and the car supply rate short term average. The equipment utilization figure represents a judgement or
perhaps some value derived from regression analysis, i.e. an average relationship between independent and dependent variables. Consequently, the analyst should refrain from ascribing too much precision to the numbers generated by this system dynamics model. The model's analytical purpose is to suggest how carrier and market are reacting to each other over the planning period. As the model suggests values for total equipment fleet TEF, ADDEQ, and other parameters, these values are an "order of magnitude" figure rather than precise answers to management questions.

The four values plotted on Figure 3.1 (Market Maximum MKTM, Car Supply Rate CSR, Customer Car Orders CO, and Total Equipment Fleet TEF) are also shown as they occur every third month on Table 3.A. Additionally, Table 3.A indicates other values which are useful to the analyst. Market Share MKTSH is the ratio of car supply rate average CSRA to market maximum MKTM and indicates how well the carrier is doing vis-a-vis potential at any point in the run. Revenue per Carload RPCL is variable, for the purposes of this analysis, because it is being generated by the relative demand for the carrier's railcar capacity. The model suggests that there will be times when rate adjustments will be necessary and that the maximum value of $1630/CL will not always be realized. Operating Income OPIN represents the contribution margin generated above variable operating cost
not including the cost of capital. The cost of capital and replacement cost of equipment could be included in the model, given more development time, and OPIN could become contribution margin over and above what some financially progressive railroads refer to as "long run variable cost."

The Net Present Value of Operating Income NPVOI is of course the accumulating discounted value of operating income per period as the model progresses through its run. The final value of "402.96" suggests that the net discounted value of operating income flow over the 60-month period came to approximately $402,960,000.

Rerun Number One

Once the standard run has been completed, any number of reruns can be made as the analyst changes assumptions concerning system variables. Changes in overall model behavior can then be ascribed to specific changes in variables. For illustrative purposes this rerun introduces significant delay into the Equipment Acquisition Loop in the form of Order Delay Time ORDT and Carbuilder Backlog BBL. The standard run sets ORDT and BBL equal to 1. This rerun will set ORDT = 6 and BBL = 12. In effect, this creates a condition where internal carrier delay in effecting car acquisition or disinvestment decisions is about six months, and the time required to fully bring additional capacity into the
system (or to get it out) is one year. In the real world this might be a situation where a significant number of additional railcars simply is not available for short term supplement to a carrier's existing capacity. Should that situation exist in the face of market potential such as suggested by MKTM, the carrier's participation in the market and the equipment fleet which will exist is illustrated in Figure 3.2 and Table 3.B.

This scenario assumes that carrier management is making capacity acquisition decisions based on the level of shipper car orders they experience rather than on the marketing department's forecast of market potential. The number of railcars required will grow significantly from an initial fleet of 4,569 units to approximately 9,000 by the end of year five. Carrier carloadings will increase during the period and from that standpoint alone management can point to evidence of marketing success. The shortfall between actual car supply and market potential during periods of rapidly increasing activity will, however, be greater than in the case where carrier management could acquire, with relative ease, a significant amount of additional capacity. This difference is reflected by the higher values occurring under ADDEQ in Table 3.B and by the NPVOI of $366,310,000 which occurred by month 60 in the rerun as opposed to $402,960,000 in the standard run.
Table 3.B

RERUN NUMBER ONE - TABLE

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<table>
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</thead>
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Rerun Number Two

The second rerun illustrates model behavior when the previously described delays in ORDT and BBL are maintained and, in addition, delay is introduced into the Marketing Effectiveness Loop. The marketing effectiveness delays which can be adjusted are Time for Supply Delay Recognized by the Market TSDRM and Time for Transportation Delay Recognized by the Market TTDRM. By increasing both of these values from 1 to 4, a simulated delay of about four months is introduced to shipper reaction time to carrier car supply and schedule consistency.

It is a double-edged sword, however. Shippers react more slowly to a carrier's ability to supply equipment and provide reliable service both on the upside and downside. The result is an exacerbation of periodic car shortages and surplus. Figure 3.3 and Table 3.C illustrate. The effect is most noticeable, in Figure 3.3, at months 5, 8, 19-20, 23-24, 39, 44, 54, and 57. Interestingly enough, the carrier's total equipment fleet keeps building up in spite of what appear to be significant downturns in customer car orders in certain short term periods. The reason for this is, of course, that the carrier's reaction to customer car orders is being delayed as well by ORDT and BBL. The railcar "supply side" delay is, in this case, a positive influence because it prevents carrier divestment of equipment in the
FIGURE 3.3
Rerun Number Two - Plot
Table 3.C

RERUN NUMBER TWO - TABLE

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CHANGES FOR RERUN -

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face of what is, in fact, a rather strong and rising market. From about the tenth month the carrier's total equipment fleet is maintaining a higher level than in the first rerun when market delays were at a minimum. However, the Net Present Value of Operating Income for the second rerun is $347.23 million or some 5 percent lower than the NPVOI for rerun one. This suggests that the higher fleet level did not result in better financial results for the carrier than occurred in the first rerun. Part of the reason why NPVOI fell in the second rerun may be explained by looking at Revenue Per CarLoad RPCL in Table 3.C. It appears that relatively greater rate reductions were made in months 12–15, 27–36, 45–51, and 60 than was the case in the first rerun.

Summary

The foregoing explanation and analysis of the equipment planning model's standard run and two illustrative reruns is just "the tip of the iceberg." Additional analysis could be described concerning any featured variable of the model to answer questions such as:

- When does delay in equipment placement take place, to what level of severity, and how long does it last?
- How frequently can transportation delay be observed and what effect does it have upon overall marketing
effectiveness (vis-a-vis equipment placement and pricing)?

- How variable can pricing be and what are the effects of variable pricing on cash flow over time?

- What level of equipment maintenance funds will be generated during the planning period and to what degree do maintenance budgeting decisions affect the bad order condition of a carrier's fleet?

To what degree does the increasing bad order rate affect (a) the carrier's ability to participate in the market and (b) the necessity to secure other equipment from "outside" sources?

- What effect does an increase in builder's backlog from 12 months to 18-24 months have on the maximum level of business the carrier can enjoy during the planning period?

- What happens to total fleet requirements as utilization potential improves or deteriorates?

- What occurs in all of these areas if the marketing forecast changes (as has been known to happen on occasion)?

The model can quickly react to these questions and generate output to analyze in search of the answers. For the sake of brevity that will not be done here as the model
does after all represent a purely hypothetical carrier-
shipper-market situation in this instance. The time in-
volved in making the program changes and reruns is measured in minutes. The insight which can be gained concerning the system's interactions in just a short time would take significantly longer, if it could be gained at all, using static analytical techniques.
CHAPTER IV

FURTHER DEVELOPMENT OF THE EQUIPMENT PLANNING MODEL

As it stands, the equipment planning model is a very general and rudimentary attempt to deal with railcar supply and demand factors. Further development, which is of course necessary before the model could be of much use as a planning aid, would center (1) on breaking down the model's simplifying assumptions and (2) altering the model structure somewhat to allow management to test various equipment acquisition and investment strategies. The latter would be, in effect, the opposite of what the model is doing now, i.e. the model now derives fleet size as a function of continuous interaction between carrier and market. A hypothetical equipment acquisition strategy could be imposed on the model by generating another input into the "total equipment fleet" TEF by way of a DYNAMO table function which describes a new equipment acquisition plan as a function of TIME. The success of the acquisition in meeting demand at any point in the planning period could be seen and the net present value of the proposal could be compared to other alternatives.
The process of breaking down simplifying assumptions consists of both adding to the model and constructing new interrelationships where they appear warranted between existing system variables. A good place to start would be in the concept of total equipment fleet. As mentioned in the previous chapter, equipment "ownership" should be viewed more appropriately as equipment "control". At any given time the freight cars which are under a carrier's control, for transportation purposes, consist of system cars (carrier-owned/leased), foreign line cars, and private cars (shipper owner/leased). While all of these vehicles are performing a service which provides the carrier transportation revenue, they differ in terms of utilization potential and cost incurred by the common carrier for their use. Cost and utilization assumptions which stem from car-hire charges, mileage payments, and the application of car service rules can be incorporated into the model to break the "total fleet" down into its component parts. To the degree that a given system car type earns car hire revenue while "off line," that too can be factored in.

The rate at which equipment can be utilized is a function of numerous factors having at once to do with the carrier(s), the regulatory environment, the shipper and/or receiver, and conditions in the shipper/receiver market. Utilization potential may suffer seasonally or may in some
cases be rather uniform. Whichever, various ways of influencing the equipment utilization rate can be constructed in the model.

A given car type may perform service in more than one commodity market, implying that revenue earned will not fall easily within a tight range because of differing rate-making criteria which exist. To deal with that, multiple revenue possibilities accruing to portions of a fleet could be structured.

A much more detailed look at equipment maintenance can be modeled. A delay factor could be used to represent the time between a decision to reduce maintenance and the actual occurrence of defects which would lead to "bad-ordering" of a railcar. If such a decision were to be made, a backlog of bad order equipment awaiting repair would build up and be constrained from re-entering service by repair shop capacity. The extra costs involved in increasing shop capacity to deal with the condition could be incorporated as well.

In the model as it stands, the occurrence of transportation delay is not treated in a particularly sophisticated way. Transportation delay, of the type envisioned here which leads shippers to route "adverse" next time, is caused by the fact that the carrier is experiencing operating problems of its own or through its connections due to seasonal
heavy traffic which taxes critical points in the system. Transportation delay could be treated solely as a function of TIME or it could be tied to some of the same factors which are built to fashion overall car utilization such as pronounced seasonal logistics problems which are in the nature of the shipper's market, e.g. grain movement.

Variable operating cost must in fact be variable within the model structure rather than an assumed fleet average constant unless, of course, the loading characteristics, average haul, and empty return ratio of the fleet under study are virtually constant over time. It would not be difficult to incorporate changing assumptions concerning all of these elements and generate a somewhat more believable variable carload cost. By factoring in the replacement cost of railcars and the carrier's cost of capital, a "long run variable cost" function could be established and the evaluation feature now in the model, "net present value of operating income NPVOI," could be restructured as "net present value of contribution margin over long run variable cost."

Whatever can be done to bring the model up to its next level of sophistication, one thing appears certain: that won't be the end of the process. Even when the point in time is reached where the model structure appears to be reasonably "complete" and satisfying in the sense that it is acceptable as a planning aid, there will be always some
factor whose value must be "assumed" for lack of empirical data or simply because it represents an "unknown" in the environment. Perhaps one of a system dynamics model's most valuable contributions to business management is the methodology's inherent ability to test for the ultimate effect of that unknown factor on the system in an expedient and relatively inexpensive manner.
APPENDIX A

NOTE
NOTE RAILCAR EQUIPMENT SUPPLY PROGRAM
NOTE
NOTE EQUIPMENT ACQUISITION LOOP
NOTE
NOTE
R CO.KL=(SEF.K)(NME.K)
L COBL.K=COBL.J+(DT)(1/BLAT)(COJ.K-CSR.JK)
N COBL=IC0BL
C IC0BL=10000
C BLAT=1
A TC.K=(SEF.K)(EQUP.K)
A ENUP.K=TABIL(TEDUR,MTM.K,8000,16000,2000)
T TEBUR=2.5/2.75/2.0/1.75/1.5
A C5GM.K=CGBL.K/TC.K
A TCF.K=TA04L(TTFC,CSM.K,0.2,0.1,0)
T TTFC=0.1,0.1,0,0,0
R CSR.KL=(TC.K)(TTF.K)
L CSR.K=CSR.J+(DT)(1/SRAT)(CSR.K-CSRA.J)
N CSR=CSR
C SRAT=1
A ISEF.K=COBL.K/EDUR
R IEBA.KL=ISEF.K-SEF.K
L EDUR.K=EDOR.J+(DT)(1/ORDT)(IEBA.KK-EOA.KK)
C O=0T=1
W EDOR=IEBA
R EBA.KL=(1/66L)(EBOR.K)
C 66L=1
L TEF.K-TEF.J+(DT)(EOA.KK)
W TEF=TEF
C TEF=4583
R SEF.K=TEF.K-EOE.K

(continued)
NOTE
NOTE MARKETING EFFECTIVENESS LOOP
NOTE
A CSDI.K=CSDI.K/CSRA.K
L SGRM.K=SGRM.J*(DI/1+SDRM)/(CSDI.J-SGRM.J)
N SGRM=CSDI
C TSCRM=1
A DEPM.K=TABLH(DEPM.SDRM.K,1.0,1.45,.033)
A TDI.K=TABLH(TDI.CEM.K,0.2,0.2)
T TTDI=0/0/0/0/0/5/1.0/2.5/4.0/7.0
L TORM.K=TORM.J+(DI/1+TDRM)TDI.J-TORM.J
N TORM=TDI
C TDRM=1
A TDRM.K=TABLH(TTRAM.TORM.K,0.7/1)
T TTRAM=1/.35/.8/.75/.5/.25/.2/1
A PPCL.K=TABLH(TPPCL.TCP.K,0.1,0.2)
T TRPCL=695/745/840/950/1160/1430
A PEM.K=TABLH(TPEM.RFCL.K,85,1630,189)
T TPEM=1/.55/.9/.85/.7/5
A ME.K=DEPH.K+TREN.K+PEM.K
A PREN.K=TABLH(TREN.ME.K,0.3,0.1)
T TREN=0/2.5/3/1.0
A CCLM.K=(PEM.K)*MATM.K
A MCM.K=TABLH(TMCM.TIME.K,0.6,0.6)
T TMACM=10000/12000/8000/12000/14000/10000/13000/15000/12000/18000/14000
A NME.K=CCLM.K/PEF.K
A HATSM.K=CSRA.K/MATM.K
A ADDEB.K=(MATM.K-CSRA.K)/EBUR.K

(continued)
NOTE
NOTE  EQUIPMENT MAINTENANCE BUDGET & BAD ORDER RATIO
NOTE
R OPR.KL=(CSRA.K)(RPCL.K)
L OPR.A=OPRA.J+(DT)(1/ARAT)(OPR.JK-OPRA.J)
N OPR=OPR
C ARAT=1
A OEC.K=(CSRA.K)(VCCL)
C VCCL=632
R OPIN.KL=OPRA.K-OPC.K
L OPIN.P=OPIN.P+DT(OPIN.JK-OPIN.J)
N OPIN=OPIN
A P.F.K=TAESL(TPF.TIME.K,0.50,12)
T TPF=1.011/1.3225/1.5233/1.7490/2.0115
R PVIN.KL=PVIP.K/PV.F.K
L NPVOI.K=NPVOI.J+DT(PVVOI.JK)
N PVVOI=PVVOI
R EMCF.KL=(OPRA.K)(EQMF)
C EQMF=.12
L EQMA.J=EQMA.J+DT(TEQMA)(EMCF.JK-EQMA.J)
W EQMA=EMCF
C TEGMA=1
A EMPT.K=(CSRA.K)(EMCON)
C EMCON=112
A EMCF.K=EQMA.K/EMPT.K
A BODR.K=TAESL(TBDR.EGHC,K,.7,1.0,.1)
T TBDR=.1/.07/.04/.025
A BODB.K=(BODR.K)(TEF.K)
M BODB=1B0C
C 1B0C=125
NOTE
NOTE  CONTROL STATEMENTS
NOTE
SPEC DT=.25/LENGTH=60/PRTEY=3/PLTPEY=1
PRINT MKTM.CO,CSR,MATEH,TEF,ADDED,RPCL.OPIN,NPV0I
PLOT MKTM=M,CSR=5,CO=010,16000/TEF=T(3000,14000)
OPT TXI=12
RUN EBSUPP
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