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TRANSIT RELIABILITY INFORMATION PROGRAM (TRIP)

APPROACH TO K-FACTOR DEVELOPMENT

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1. INTRODUCTION

By definition, "K-factors" are conversion factors used in the computation, analysis and interpretation of transit operations and maintenance data in order to normalize this data over various properties and vehicle types. For example, if one property has a station spacing of 9 stations per mile with four doors per side on a vehicle, and another property has a station spacing of 2 stations per mile with three doors per side on a vehicle, failure rates for the door system of 36 failures per 1,000 miles and 6 failures per 1,000 miles, respectively could be interpreted as equivalent failure rates given that all other factors such as the ambient environment are equal.

In terms of TRIP, K-factors are multipliers that will be applied to the "dynamic" data in order to account for differences in the following four categories: equipment design, configuration, operation, and operating environment. Dynamic data consist of information covering the utilization and maintenance of transit vehicles and equipment. This data provides the basis for determining revenue service reliability which is reported in various forms in the output reports currently generated by TRIP.

Not only is the dynamic data essential in the development of K-factors, but, the "reference" data[1] collected and stored by TRIP will be used in the computation of K-factors. This reference data is information which describes the configuration, characteristics, and operation of a transit system, vehicle type, or equipment on a vehicle type. Currently, such reference information is used to initialize the Data Bank to accept data from a source, and indirectly and externally used to interpret the output reports currently generated by TRIP.

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[1] Ref. DRC Document R-339, <u>TRIP Participants Guidelines</u>, pp 47, 48

2. TECHNICAL APPROACH

2.1 SYSTEMS ANALYSIS

The approach developed to derive K-factors from the available dynamic and reference data is shown in Figure 1. The first step in the development of K-factors is to identify relevant factors which independently affect the performance of each equipment item (system of vehicle) in each of the four previously mentioned categories of equipment design, configuration, operation, and operating environment. Of particular importance in the category of operating environment are environmental factors due to equipment configuration, such as vibration measurements, i.e. a suspended assembly vs an assembly that is fixed to the car body, as well as ambient environmental factors such as temperature and humidity. This identification or system analysis will include determining the index of comparison (IOC) for each of these variables. For instance, the door system's IOC is usually cycles, whereas the IOC for the auxiliary electrical system would be time (i.e. operating hours).

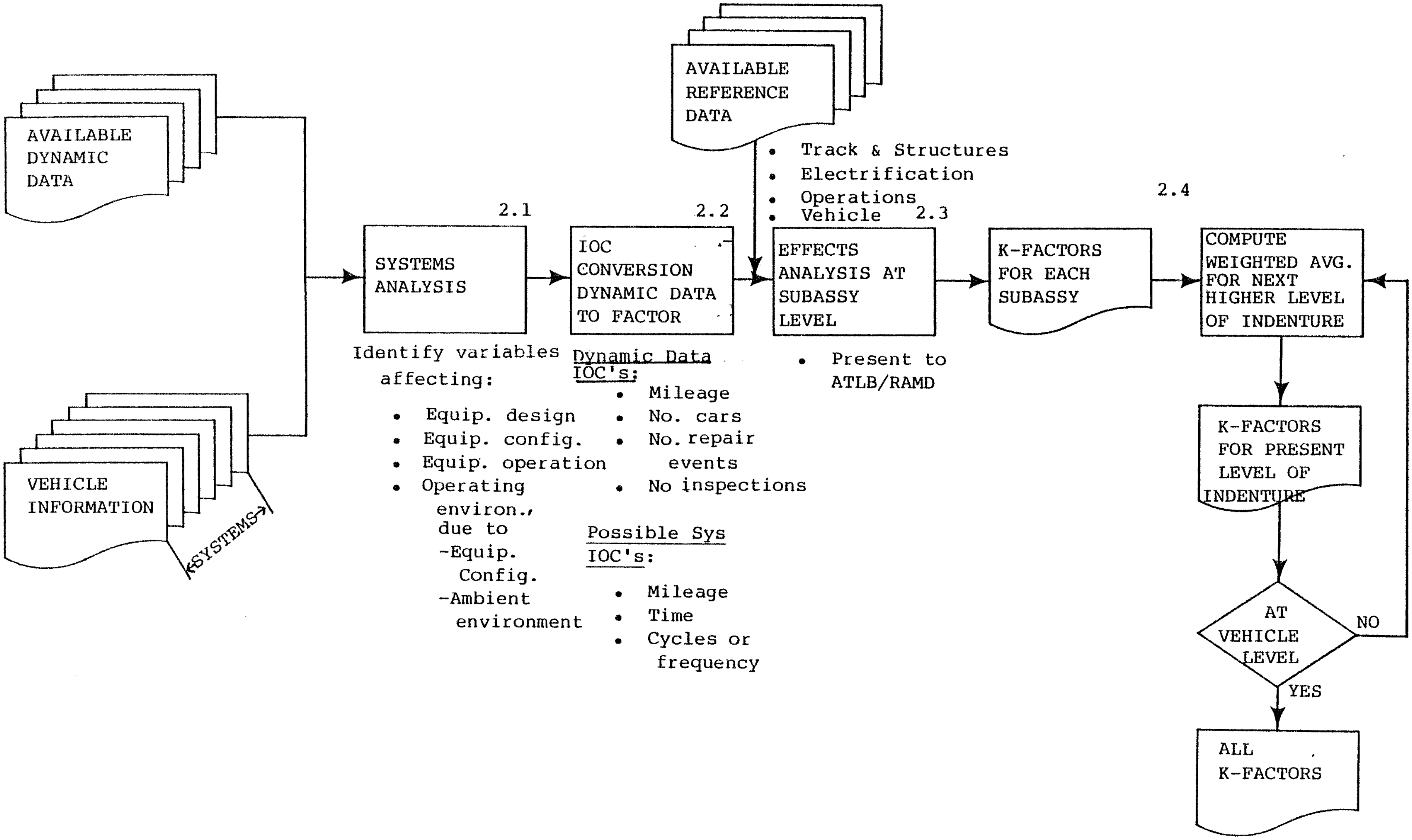
2.2 INDEX OF COMPARISION CONVERSION

The next step in the approach is to develop equations that will convert the available dynamic data, which includes mileage, number of cars, number of repair events, and number of inspections, to the system IOC for each variable identified in the previous step in the approach. For example, for the door system, an equation will be developed to convert from the existing dynamic data element, which is mileage, to the index of door cycles.

2.3 EFFECTS ANALYSIS

The results of the systems analysis performed in the first step of the approach were "unquantified" variables that affect the performance of the equipment. Dynamic data was used in this analysis. But, in order to quantify these variables, the reference data must be employed. This step of the approach is basically an effects analysis, in which the effects of specific reference data on the variables identified in step "one" are analyzed.

FIGURE 1. APPROACH TO K-FACTOR DEVELOPMENT



In order to perform the effects analysis, the reference data will be gathered and divided into the following categories: track and structures configuration data, electrification configuration data, operations data, and vehicle specification data. Once this division is performed, the effects of the referenced data in each category on the variables identified in step one will be examined at the subassembly level. For instance, the effect of station spacing on the door system subassembly reliability is determined. This quantification will consist of utilizing appropriate mathematical techniques.

Typical reference data types that affect the three vehicle systems reported on by TRIP is shown in Table 1.

At this point, the variables identified in step one and quantified in this step will be presented to the APTA/TRIP Liaison Board for their evaluation and comments.

2.4 K-FACTOR COMPUTATION AND AGGREGATION

Once each variable is quantified, the actual K-Factors for each subassembly can be computed. First, for each variable the norm of comparison will be determined. If the IOC for a particular subassembly is "cycles per mile," the dynamic data is in "unscheduled maintenance actions per 10,000 miles", and the "K-factored" data should be in "unscheduled maintenance actions per cycle", then the K-factor should be in miles per cycle, which is the inverse of the IOC.

In order to develop K-factors for the next higher level of indenture (assembly level), a weighted average of K-factors of all subassemblies within each assembly will be computed. This process will be performed for each level of indenture, up to the vehicle level. The output of this compilation will be one K-factor for the vehicle (all systems), and K-factors for each system, subsystem, assembly, and subassembly.

Once this overall approach is approved by the APTA/TRIP Liaison Board, a test case will be performed using one of the following options[2]:

- K-factors developed for all TRIP systems in one EDB property; or
- K-factors for one system across all EDB properties.

Pending a timely review and approval of the approach, the results of the chosen test case will be presented at the first APTA/TRIP Liaison Board Meeting in 1982. The resultes presented will include the "raw" (unfactored) output data along with the "K-factored" data.

[2] This option will be chosen at the 13th ATLB meeting on December 15, 1981.

TABLE 1

REFERENCE DATA ELEMENTS AFFECTING SYSTEM RELIABILITY

SYSTEM REFERENCE DATA ELEMENT	FRICTION BRAKE	DOORS AND DOOR CONTROLS	PROPULSION
Station Spacing	X	X	X
Signal Spacing	X		X
Number of door operators per car		X	
Number of cars in the fleet		X	
Cycles per door operator per station		X	
Average operating speed	(X)		X
Acceleration			X
Vehicle size and weight	(X)		(X)

( ) indicates that the element is not used in the examples in Section 3.

3. EXAMPLES

It should be noted that while the approach to K-factor development presented herein considers effects at the subassembly level and then, through appropriate techniques, aggregates up to the system level, the examples presented which are for discussion purposes, bypass this detailed analysis procedure and only considers K-factors at the system level for the three systems currently reported by TRIP; friction brakes, doors and door controls, and propulsion.

Also, it should be noted that K-factors developed in this paper are for utilization only, i.e. K_u which consist of factors describing acceleration, deceleration, passenger loading, etc... In actuality, K-factors consist of not only K_u, but of the following:

- K_D, the K-factor for system design;
- K_M, the K-factor for maintenance, including factors describing:
  - Preventive maintenance
  - Personnel training, and
  - Facilities;
- K_E, the K-factor for the environment, including factors describing:
  - Track environment,
  - Temperature, and
  - Humidity.

For each example, the assumptions will be clearly stated, along with the relevant reference data and the dynamic data that the resultant K-factor will be applied to. Also, due to the complexity of calculating the effects of kinetic force (F = ma) on the friction brake and propulsion systems, these calculations have been omitted for these examples.

EXAMPLE 1: FRICTION BRAKE SYSTEM K-FACTOR$_u$

The first step in the development of this K-factor is to determine the index of comparison for the friction brake system. Since the use of this system is based on each brake application, the index of comparison should be "number of brake-applications per mile." (Also, given that the dynamic data for this system is reported in "unscheduled maintenance actions (USMA) per 10,000 miles", multiplying this by the inverse of the index of comparison, that is, "miles per brake application", will yield the appropriate K-factored data in "USMA per brake application.")

The assumptions used for this example are as follows:

- Given that maximum grades in transit systems are 3.0 - 3.5% on average, grades are assumed to have no significant effect on the friction brake system;

- Signal spacing, in addition to signals at stations, is proportional to station spacing 2.0 signals per station;

- It is assumed that the brakes are applied at the following percentages of total number of signals:
  -BART - 10%
  -CTA - 15%
  -NYCTA - 12%
  -PATCO - 8%
  -WMATA - 10%

- Curves have no significant effect on friction brake use, assuming that dynamic braking is used for curves;

- Speed has no effect on friction brake use, assuming that friction brakes are applied when the vehicle is travelling below 10 mph.

As mentioned before, the dynamic data is currently reported as USMA per 10,000 miles.

Finally, before the calculations are performed, the relevant reference data must be listed. In this case, it is the following:

- Station spacing, in stations/mile; and
- Signal spacing, in signals/mile.

The calculations are as follows (Table 2)

TABLE 2 - FRICTION BRAKE SYSTEM - K-FACTOR$_u$ CALCULATION

	A	B	C	D	E	F	G
PROPERTY	Stations per mile[1]	Signals per mile[2]	Signals at which brakes applied per mile[3]	Brake applications per mile[4]	Miles per brake application[5]	USMA per 10K miles[6]	USMA per 10K brake applications[7]
BART	0.43	0.87	0.09	0.52	1.92	0.4	0.77
CTA	1.61	3.23	0.48	2.09	0.48	0.7	0.34
NYCTA	2.00	4.00	0.48	2.48	0.40	1.8	0.72
PATCO	0.83	1.65	0.13	0.96	1.04	1.1	1.14
WMATA	1.08	2.15	0.22	1.30	0.77	2.0	1.54

[1] Obtained from Railway Age, September 28, 1981 p.49.

[2] Calculated from assumption that 2.0 signals/station = 2A

[3] Calculated from assumptions of percentage of signals at which brakes applied = percentage times B

[4] Brake applications/mile = A + C

[5] Inverse of D = $^1/_D$ = K-factor

[6] From May, 1981 TRIP OUTPUT REPORT

[7] G = E x F

EXAMPLE 2: DOORS AND DOOR CONTROLS K-FACTOR$_u$

The index of comparision for this system is "door cycles per mile." Again, multiplying the inverse of this, that is, "miles per door cycle", by the dynamic data, which is "USMA per 10,000 miles" will yield "USMA per door cycle."

The assumptions used in this example are as follow:

- A door operator is equated to the door system;
- Only doors on one side of a vehicle open at each station;
- There are no ambient environmental effects on the door operators; and
- Assume that there are 1.2 cycles per door operator per station (and that all vehicles have sensitive edges).

The relevant reference data for this example is:

- Station spacing, in stations per mile;
- Number of door operators per car;
- Number of cars in the fleet; and
- Cycles per operator per station.

The calculations are as follows:

TABLE 3 - DOOR SYSTEM - K-FACTOR$_u$ CALCULATION

PROPERTY	A Stations per mile	B Door operators per car side[1]	C Number[2] cars in fleet	D Cycles/ operator/ station	E Cycles[3] per mile	F $\frac{\text{Miles} \times 10^4}{\text{Cycles} \times 10^7}$[4]	G USMA per 10K miles[5]	H USMA per 10M cycles[6]
BART	0.43	4	423	1.2	873	1.15	0.3	0.35
CTA	1.61	2	194	1.2	750	1.33	0.8	1.06
NYCTA	2.00	8	288	1.2	5530	0.18	3.1	0.56
PATCO	0.83	3.	119	1.2	356	2.81	1.3	3.65
WMATA	1.08	6	300	1.2	2333	0.43	0.6	0.26

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[1] From the Roster of North American Rapid Transit Cars 1945 to 1980, APTA, July 1980.

[2] Number of cars reported in TRIP system

[3] $E = A \times B \times C \times D$

[4] Inverse of $E = (^{1}/E) \times 10^{3}$ = K-factor

[5] From May, 1981 TRIP Output Report

[6] To provide a reference point, the following depicts how many fleet miles at each property must be accumulated to achieve 10 million door cycles:

-BART	11,455 miles
-CTA	13,333 miles
-NYCTA	1,808 miles
-PATCO	28,090 miles
-WMATA	4,286 miles

EXAMPLE 3: PROPULSION SYSTEM K-FACTOR$_u$

The index of comparison for this example is "acceleration time per mile." The inverse of this index multiplied by the dynamic data, "USMA per 10,000 miles" will yield "USMA per acceleration time."

The assumptions are as follows:

- Given that maximum grades in transit systems are 3.0 - 3.5% on average, grades are assumed to have no significant effect on the propulsion system;
- Signal spacing in addition to signals at stations is proportional to station spacing; 2.0 signals per station;
- It is assumed that acceleration from a full stop (red light) occurs at the following percentages of all signals:
  - -BART - 10%
  - -CTA - 15%
  - -NYCTA - 12%
  - -PATCO - 8%
  - -WMATA - 10%
- It is assumed that acceleration from a slow down (yellow light) occurs at the following percentages of signals:
  - -BART - 40%
  - -CTA - 60%
  - -NYCTA - 48%
  - -PATCO - 32%
  - -WMATA - 40%
- Curves that result in subsequent acceleration are assumed to be spaced at 1 per mile; and
- Acceleration from a full stop is twice as long as acceleration from a slow down.

The relevant reference data is as follows:

- Station spacing, in stations per mile
- Signal spacing, in signals per mile
  - -resulting in acceleration from stop (red light)
  - -resulting in acceleration from slow down (yellow light)
- Average speed, in miles per hour
- Acceleration in miles per hour per second.

The calculations are as follows(Table 4)

TABLE 4 - PROPULSION SYSTEM K-FACTOR$_u$ CALCULATION

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Sta. per mi	Signals per mi	Red Signal per mi	Yellow signal per mi	Curves per mi	Accels. from stop per mi (1)	Accels. from slowdown per mi (2)	Accel (3)	Avg. speed (4)	Period of accel from stop (5)	Period of accel slow-down (6)	Accel. time per mi from stop (7)	Accel time per mi slow-down (8)	Total accel time per mi (9)	Mile per accel (10)	USMA per 10Kmi (11)	USMA per 100 HRS accel time (12)
BART	0.43	0.87	0.09	0.35	1.0	0.52	1.35	3	43.5	14.5	7.25	7.54	9.79	17.33	0.06	1.3	2.70
CTA	1.61	3.23	0.48	1.94	1.0	2.09	2.94	3.2	26.0	8.13	4.06	16.99	11.94	28.93	0.03	1.5	1.87
NYCTA	2.00	4.00	0.48	1.92	1.0	2.48	2.92	2.5	24.5	9.80	4.90	24.30	14.31	38.61	0.03	2.4	2.24
PATCO	0.83	1.65	0.13	0.53	1.0	0.96	1.53	3.0	39.0	13.00	6.50	12.48	9.95	22.43	0.04	2.8	4.49
WMATA	1.08	2.15	0.22	0.86	1.0	1.30	1.86	3.0	35.0	11.67	5.83	15.17	10.84	26.01	0.04	3.8	5.26

[1] F = A + C

[2] G = D + E

[3] Taken from Roster of North American Rapid Transit Cars 1945 to 1980, APTA, July 1980.

[4] Taken from Railway Age, September 28, 1981, p. 49.

[5] J = I/H

[6] K = (1/2) (I/H)

[7] L = F x J

[8] M = G x K

[9] N = L + M

[10] Inverse of N = K-factor, O = 1/N

[11] Taken from May, 1981 TRIP Output Report

[12] $Q = O \times P \times \frac{360{,}000\ \text{secs}}{100\ \text{hrs accel time}}$