Data Structures for Trip Chain Modeling Presented in the Manuscript Titled "Marketing and Analytics of Consumer Trip Chaining"

For the reader interested in a different computational environment for producing a TC, the following is offered. The trip chain data supporting the demonstrations and displays in the narrative resided in the form of seven data structures consisting of strings, lists and arrays. They are referenced in this section as F1,…,F7. The primary among them is the string representation of a TC denoted herein as F1. Once acquainted with F1-F7, the interested reader may adopt, modify or integrate them in migrating to another computational environment. A Python (PY) computational environment may have appeal to readers interested in utilizing its graphics and data visualization features as well as its libraries. For discussion of treating PY as an Excel Add-in, see Kinnestrand (2023).

In the demonstrations of the narrative, F1-F7 were populated iteratively in pursuit of successively better trip chaining solutions beginning with the TC composed according to the NNR heuristic. If an exact method is used to produce a first TC solution, the methods demonstrated here still have value in identifying alternative TC solutions within a user-defined acceptable tolerance. Because Excel is such a ubiquitous computational engine, it was the choice for the demonstrations presented here. An Excel-Python integration in the form of an Excel Add-in may be a portal to making use of the best features of each environment.

In moving from iteration to iteration in the demonstrated Excel environment, there is much hands-on user interaction with the data. It derives from visual inspections of periodic results and deciding to implement/not a tested perturbation candidate; to continue/not with another iteration; to wait/not at a procurement site in advance of its earliest time availability; to bifurcate/not a TC; and to identify/not the depot as the location for customer order distribution. As shown in the demonstrations, the occasions for doing so arise frequently enough to prompt consideration of how machine learning could assist. Demonstration of such is beyond the scope of this narrative. However, machine learning and PY/Excel integration for the 3P in search of appealing TC solutions is substance for ongoing research.

Discussion of F1-F7 follow and are based on the trip chaining environment with an 8:00 AM departure time from the depot; one initial touring vehicle; the first best-found trip chain $TC^{bf} = TC^{NNR}$ = {15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,26,6,17, 16,18,} with travel distance 110.88 miles. The NNR is discussed in the Demonstration section of this narrative. Accordingly, the F1-F6 data structures had the following appearances at this early point in the investigation. Although the content of F1-F6 appears redundant with some of the content of Tables 1 and 2 in the narrative, formalizing the sources of the displayed content is the intention here. In few words, F1-F7 were the structural depositories of the data that were calculated, stored, retrieved, updated and consulted in moving from one iteration to another. They are presented for the purpose of assisting the reader how to structure similar data forms in a different computational environment.

Starting with the Initial Best-found Trip Chain, TC^{bf}

F1 = TC^{bf} =
{15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,6,17,16,18}
Let TC^{bf} (SRi) denote the form of TC^{bf} where the argument SRi is highlighted. In red.

Instances of the type 1 perturbation of site reference 6 in the current best-found trip chain,

TC^{bf} (SR6) =
{15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,6,17,16,18}
F2 = type 1 perturbation (TC^{bf}(SR6)) =

6,15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	129.08
15,6,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	128.80
15,22,6,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	128.84
15,22,21,6,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	123.19
15,22,21,23,6,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	117.22
15,22,21,23,14,6,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,	122,40

…

15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,6,9,11,29,17,16,18,	121.44
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,6,11,29,17,16,18,	119.41
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,6,29,17,16,18,	104.61
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,6,17,16,18,	110.88
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,6,16,18,	149.86
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,6,18,	152.47
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,17,16,18,6,	127.15

Performance measures of the best result of F2 = type 1 perturbation (TC^{bf}(SR6)), i.e. repositioning site reference 6 as type 1 perturbation 11,6,29:
F3 = PFM(type 1 perturbation (TC^{bf}(6))) =

Vehicle	Site reference i	Distance from preceding site	Procurement volume	Arrival time at site i (ATS_i), site i first availability (FAS_i), site i last availability ($LASi$) , feasible arrival time at site i ($FEAS_i$) 0=no, 1=yes)
1	15	0.66	3.38 cu’	8:01 AM, 8:00 AM, 1
1	22	0.43	3.38 cu’	8:02 AM, 7:00 AM, 1
1	21	0.57	3.38 cu’	8:03 AM, 9:00 AM, 0
1	23	0.88	3.38 cu’	8:06 AM, 7:30 AM, 1
1	14	2.67	3.38 cu’	8:12 AM, 6:00 AM, 1
1	30	0.60	3.38 cu’	8:13 AM, 6:00 AM, 1

…

1	11	1.74	3.38 cu’	9:15 AM, 10:00 AM, 0
1	6	14.19	3.38 cu’	9:49 AM, 10:00 AM, 0
1	29	11.74	3.38 cu’	10:17 AM, 9:00 AM, 1
1	17	20.28	3.38 cu’	11:06 AM, 7:00 AM, 1
1	16	2.81	3.38 cu’	11:12 AM, 8:00 AM, 1
1	18	6.04	3.38 cu’	11:27 AM, 7:30 AM, 1
1	0	18.23	-	12:11 PM, 8:00 AM, 1
Summary measures	18, last visited site-	104.61 fleet travel distance	108.16 cu’,	number of early arrival times = 8, arrival time at last visited site (18) 11:27 AM arrival time at depot 12:11 PM

Instances of the type 2 perturbation of site reference 6 in the current best-found trip chain, TC^{bf} (6):
F4 = type 2 perturbation (TC^{bf}(6)) =

15,22,21,23,14,30,28,32,20,7,6,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,1,17,16,18,	133.67

15,22,21,23,14,30,28,32,20,7,1,6,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,2,17,16,18,	127.89
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,6,31,8,25,5,13,24,10,9,11,29,3,17,16,18,	128.64
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,6,3,31,8,25,5,13,24,10,9,11,29,4,17,16,18,	124.56
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,6,13,24,10,9,11,29,5,17,16,18,	120.45
N/A	-
15,22,21,23,14,30,28,32,20,6,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,7,17,16,18,	141.75

…

15,22,21,23,14,30,28,32,20,7,1,2,19,6,26,12,4,3,31,8,25,5,13,24,10,9,11,29,27,17,16,18,	131.64
15,22,21,23,14,30,6,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,28,17,16,18,	146.90
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,6,29,17,16,18,	104.61
15,22,21,23,14,6,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,30,17,16,18,	143.30
15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,6,8,25,5,13,24,10,9,11,29,31,17,16,18,	121.22
15,22,21,23,14,30,28,6,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,32,17,16,18,	137.26

Performance measures of the best result of F3 = type 2 perturbation ($TC^{bf}(6)$), i.e. positional interchange of site references 6,29:

F5 = PFM(type 2 perturbation ($TC^{bf}(6)$)) =

Vehicle	Site reference i	Distance from preceding site	Procurement volume	Arrival time at site i (ATS_i), site i first availability (FAS_i), site i last availability (LAS_i) , feasible arrival time at site i ($FEAS_i$) 0=no, 1=yes)
1	15	0.66	3.38 cu’	8:01 AM, 8:00 AM, 1
1	22	0.43	3.38 cu’	8:02 AM, 7:00 AM, 1
1	21	0.57	3.38 cu’	8:03 AM, 9:00 AM, 0
1	23	0.88	3.38 cu’	8:06 AM, 7:30 AM, 1
1	14	2.67	3.38 cu’	8:12 AM, 6:00 AM, 1
1	30	0.60	3.38 cu’	8:13 AM, 6:00 AM, 1
1	11	1.74	3.38 cu’	9:15 AM, 10:00 AM, 0
1	6	14.19	3.38 cu’	9:49 AM, 10:00 AM, 0
1	29	11.74	3.38 cu’	10:17 AM, 9:00 AM, 1
1	17	20.28	3.38 cu’	11:06 AM, 7:00 AM, 1
1	16	2.81	3.38 cu’	11:12 AM, 8:00 AM, 1
1	18	24.27	3.38 cu’	11:27 AM, 7:30 AM, 1
1	0	18.23	-	12:11 PM, 8:00 AM, 1
Summary measures	18, last visited site-	104.61 fleet travel distance	108.16 cu’,	number of early arrival times = 8, arrival time at last visited site (18) 11:27 AM arrival time at depot 12:11 PM

Candidate list of Iteration 1: After F1-F6 were evaluated for all i=1,…,32.

F6 = CL(Iteration 1) =

Ranked Best Type 1[2] Perturbations and Related Travel Distances		Ranked Best Type 2[2] Perturbations and Related Travel Distances		Candidate List		
				Perturbation	Travel Distance upon Testing	Perturbation Implemented?
Beginning TC: 15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,12,4,3,31,8,25,5,13,24,10,9,11,29,6,17,16,18 with distance 110.88						
11,6,29	104.61	6,29	104.61	6,29	104.61	yes

6,11,17	107.74	8,11	110.08		11,6,29	104.61	already in place after implementation 6,29
,12,	108.77				6,11,17	See below	-
6,8,17	109.01				6,11,29,17	119.41	no
					6,29,11,17	111.82	no
					,12,	102.50	yes
					6,8,17	See below	-
					6,8,29,17	114.49	no
					6,29,8,17	106.04	no
					8,11	102.56	no
Ending TC: 15,22,21,23,14,30,28,32,20,7,1,2,19,27,26,4,3,31,8,25,5,13,24,10,9,11,6,29,17,16,18,12, with distance 102.50							

F7 is the two-way table of distances between any two-sites in the TC scenario treated here. When the distance between sites i and j denoted as $d_{i,j}$ is assumed identical to the distance $d_{j,i}$, the array has an upper triangle appearance. This is the situation for the scenario treated in the Demonstration section. F7 is a static data structure for retrieving any distance $d_{i,j}$, i,j = 0,1,…,n and j>i. TC distance among multiple sites is expressed as the sum of the $d_{i,j}$ constituting the TC of interest and their look-ups in F7. F7 for the trip chaining scenario of the Demonstration section in abbreviated form appears below.

F7 = { $d_{i,j}$, i,j = 0,1,…,n and j>i} =

Distance from i / to j	0	1	2	3	4	5	…	28	29	30	31	32
0	-	2.04	3.22	3.90	5.14	4.64	…	4.57	17.63	4.11	4.25	2.61
1		-	3.10	4.43	4.75	5.17	…	6.06	18.17	5.60	4.78	2.47
2			-	1.19	3.18	1.95	…	7.15	11.51	6.69	1.56	5.68
3				-	4.22	0.84	⋯	7.38	10.40	6.92	0.45	6.63
4					-	8.07	⋯	8.77	13.03	8.31	4.60	7.20
5						-	⋯	8.11	9.74	7.65	0.63	7.35
…							…	…	…	…	…	…
28								-	19.04	0.73	7.63	3.55
29									-	19.23	10.23	19.76
30										-	7.44	2.92
31											-	6.99
32												-