THE MARKETING AND ANALYTICS OF CONSUMER TRIP CHAINING

Abstract

This paper addresses the framing of a trip chaining product and details how an entity referred to as a third party (3P) tours n number of sites procuring consumer products at each site on behalf of clients. An efficient and effective sequencing of site visits that meets customer needs and is within the 3P's touring resources is the product. Generally, the needs of more than one client and more than two site visits compose an itinerary. A scenario with 32 site visits and more than one touring vehicle is treated in detail. The narrative demonstrates how marketing analytics assists the 3P in composing a trip chaining product with appealing features. Confounding issues of procuring the desired items are addressed including sites whose inclusion in an itinerary can degrade the time and location availability of all customer orders. Demonstration of perturbation analytics, trip chain bifurcation, alternate order availability sites and times and sites to begin and end the trip chaining is presented with real site data.

Keywords: Data analytics, marketing analytics, Excel base marketing analytics, spreadsheet methods, trip chaining

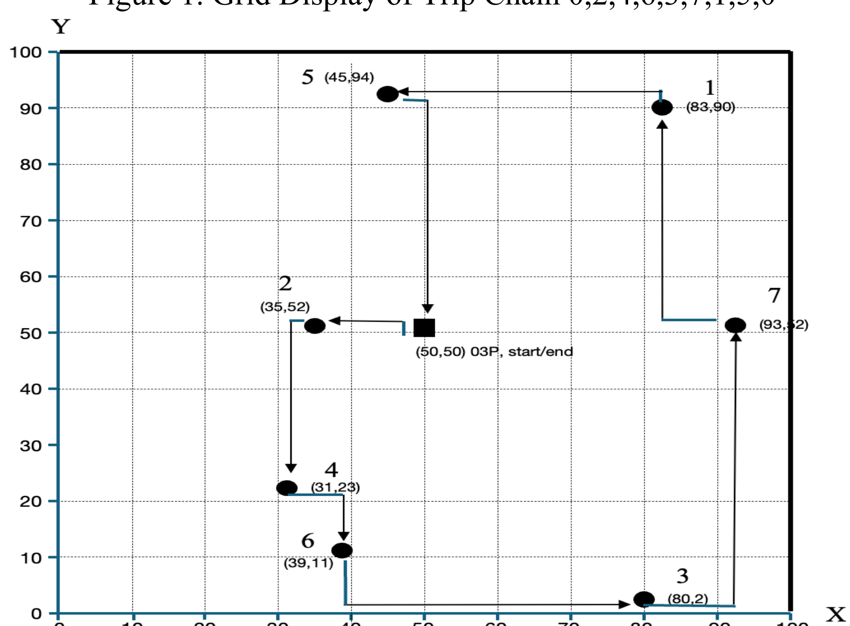
Introduction

The modeling of how consumers fulfill their needs for products and services from a geographical/travel distance perspective has been of longstanding interest to marketers. Early research on this topic was conducted by Reilly (1931) and Converse (1949). Reilly (1931) inspired by the law of gravity formulated the 'law of retail gravitation' to explain the relationship between population density and distance traveled by consumers in pursuit of desired goods and services. With the post-World War II population shift to suburban living and the growth of shopping centers, Bucklin (1967) and Darden and Perreault (1976) modeled consumer travel and buying behavior in high-density retail environments. By 2025, it is estimated that over 66% of the world's population will reside in cities (UN, 2018). Coupled with this evolving population dynamic is a growing interest in the development of smart cities where digital technologies are introduced to improve transportation flow, energy use and improved quality of life, see Gracias, et al. (2023). Given these trends, methodologies that assist consumers in efficiently navigating among retail locations have value. When faced with procuring products and services at multiple locations within their preferred geographic shopping area, many consumers combine site visits traveling from location to location in one trip. They trip chain (TC) and plan in advance the order of site visits. For historical perspectives of trip chaining, the reader is directed to Adler and Ben-Akiva (1979), Thill and Thomas (1987), and Primerano, et al. (2008).

As reviewed in Nica et al. (2022) and Nazir et al. (2023) advances in artificial intelligence and machine learning have significantly impacted consumer purchasing behavior. From marketers' perspective, these methodologies can help identify and profile customer preferences. The ability to now analyze large and complicated amounts of consumer data has led to insights of what, when, where consumers buy, Chandra et al. (2022). Within the smart city framework, there has been a rapid diffusion of smart technologies that has led to the creation of the smart shop retail mode that allows customers to interact with products because of 5G technologies encompassing facial recognition, smart sensors, smart shelves, and self-service checkout, Chang and Chen, 2021. As a result of these technological and methodological innovations in the shopping landscape, personalized product information can be directed to the individual customer. Accordingly, more is known about what the customer wants. In turn, when the consumer trip chains, the 'what, how and when' of doing so has become more complicated but at the same time providing opportunity to facilitate procurement of the desired goods.

By definition, trip chaining may be looked upon as connecting in efficient and effective ways n number of sites/locations for the purpose of procuring at each a desired product, service or commodity. In this narrative, the trip chaining perspective centers on a third party (3P) who tours the sites by vehicle in place of clients who have pre-ordered and pre-paid items for pickup. At the conclusion of the tour, each client's items are bundled and made available at a prescribed time and location made known to each client. The product is the itinerary to be followed in procuring client items. Figure 1 is a display of the geography in which the 3P's trip chain 0,2,4,6,3,7,1,5,0 is to be traversed in procuring customer items at sites referenced as 1,2,…,7. Site 0 is referred to as the start/depot and in this TC example serves as the return location for distribution of customer orders. The travel begins at site 0, proceeds to site 2 then to site 4 followed by visit at stop 6, etc. and concludes with return to site 0. The itinerary is rectilinear following streets and roads and travel distance is computed accordingly. For the latter, see Table A1 in the Appendix.

Figure 1. Grid Display of Trip Chain 0,2,4,6,3,7,1,5,0



Additionally, the 3P may identify personalized marketing opportunities such as price and product promotions along the route that a client may elect to add to the itinerary once so informed. After a history of providing trip chaining service for clients, the 3P may have a database to assist personalizing the experience. An efficient trip chain (TC) procures the desired items in an economizing amount of travel distance, travel time and use of the 3P's touring resources. An effective TC procures and delivers all sought-after items to each client's satisfaction. The 3P may compose the TC in-house or seek it in-part or whole from an external non-competing source such as a GPS service. The 3P may edit an itinerary so sourced to conform to the trip chaining requirements of the day. For the purpose of this narrative, the 3P produces the TC in its entirety.

A data analytic (DA) approach to framing a trip chaining product is presented. The universe of possible trip chain itineraries is the virtual database that is searched in various ways for itineraries that meet customer procurement needs and the limitations of the 3P's procurement resources. Because the cardinality of the database is of order n!, it is not explicitly generated. TCs are produced by manipulating their data elements (site references) in ways to be demonstrated. Each TC so produced is evaluated for travel distance and time as well as arrival time at each procurement site and other features that reflect good trip chaining appeal. The spatial distribution of the procurement sites, variance among the time availability of procurement sites and driver work rules to be observed are some of the challenges facing the framing of a TC product. Analytics to be defined and demonstrated are applied to a string representation of the sequencing of site visits such as the example of Figure 1. The string is an ordered list of site visits. The analytics include manipulation of the string elements by means of permutation, perturbation, and bifurcation. Look upon them as discovery tools and as such analytics to be applied to TC composition.

The objective of marketing analytics (MA) and trip chaining analytics (TCA) is to assist the framing of 'what, how, where, and when' of the product to take to market. An MA investigation usually begins with exploratory data analysis in which relevant data is manipulated and visualized to identify patterns of consumer market behavior. It is followed by formal modeling of the discovered patterns by means of regression, time series, neural networks and other methods. As presented here, TCA begins with knowledge of what the customer wants and where to procure it. The sequencing of site visits by the 3P is visualized and modeled as a string of site references/identifiers indicating the order of site visitations. Each TC is analyzed for the essential features of good trip chaining such as minimal travel distance and time. Both MA and TCA manipulate, visualize and summarize data. Winston (2014, p.3) characterizes MA as 'slicing and dicing' data. It will be demonstrated that the characterization applies to TCA as well.

Messina and Guiffrida (2024) offered methods for manipulating the site references of an available TC in orderly ways to produce alternative TCs for analysis. They combined TC generation and analytics in searching for TCs with successively better features. In this narrative, it will be shown that at times it may be necessary to consider TCs with non-standard features. For example, order availability at sites other than the starting/home location of the touring vehicle may be a way to meet expected order time availability for some customers. Location sites such as a Walgreen Pharmacy, Staples and other ubiquitous community sites may serve as pickup points for well-known order fulfillment services such as Amazon. They may do the same for fulfilled customer orders procured by a 3P. The 3P may provide lock boxes at selected locations for the same purpose. The TC framing of Messina and Guiffrida (2024) is extended here in various ways to include bifurcating TCs, treatment of difficult-to-accommodate procurement sites, and consideration of non-standard starting and terminating times and locations. A procurement site that is far enough away from the other sites to affect unacceptably the time availability of orders for all customers is a difficult accommodation. The site is referred to as an outlier in the narrative.

The TC and the circumstances of procuring and making customer orders available for pickup constitute the essence of the trip chaining product envisioned here. The demonstrations of composing and improving TCs that follow are intended to show what can be done for customers with the assistance of data analytics.

Composing a TC as demonstrated here begins with an initial solution that may be obtained by a variety of means. It may result from use of a heuristic. If an exact method such as explicit enumeration or implicit enumeration thereof is used, the methods to be demonstrated still have value in producing alternative solution(s) of comparable merit when the scenario calls for such.

Reference in the narrative is made to Excel based calculations. They are intended for replications of demonstrated results by the reader or for a reader's interest in exploring a variation of a cited TC result. The Excel computational environment was selected for its ubiquity and familiarity among marketers, see Winston (2014). For the reader interested in a different computational environment such as Python/Excel, see Kinnestrand (2023) and Zumstein (2021) and http://www.mongrelworks.org/TC. A video that walks the viewer through the Excel TC computational environment is also available there. The video may also help the reader who is interested in applying machine learning to TC composition and analytics.

Method

The trip chaining product is visualized as a string of location identifiers read left to right indicating the order in which sites are to be visited. For example, the string 0,3,2,4,1,5,0 indicates that site visits begin with departure from the home/start/depot location denoted as 0, proceeds with visits to sites 3,2,4,1,5 in that order and concludes with return to the depot where orders are made available for customer pickup. In practice, when the start/return position is the depot, site reference 0 is omitted in the string, e.g. 3,2,4,1,5. Given the string representation, it is clear that permuting each site reference one at a time in a given TC will produce alternative TCs. It is exhaustive enumeration with n! possibilities. Although Excel's 'alldifferent' feature can assist in pursuing this method, it is not the substance of the method presented here.

The n! number of possible trip chains is a challenging aspect of resolving a trip chaining problem (TCP). It is referred to as the 'curse of dimensionality'. For problems so affected, explicit enumeration of all solution possibilities is not generally recommended. Alternatively, heuristics are available to produce a first solution of recognized unknown optimality and in most cases of unknown proximity thereto. An example is the nearest neighbor rule (NNR). When applied to the TCP, it proceeds by linking the start location to the nearest site to be visited. Thereafter, the most recently linked site is successively connected to the closest non-sequenced site. The sequencing continues adding one new site/link at a time and concludes with linkage to the start/return site. The NNR generally provides a TC in relatively less time than other methods.

In the treatment of the TCP presented here, the first-found TC obtained by whatever means is altered by perturbation, bifurcation, and consideration of alternative termination sites where fulfilled orders are made available to customers. When the 3P uses multiple touring vehicles, procured items of a customer's order may be scattered among more than one vehicle. Consequently, it is necessary to seek a common termination site for each vehicle. In the treatment of the TCP discussed here, the termination site may not necessarily be the starting/depot site. A TCP may include visitation of sites far removed from the others. Their visitation can adversely affect the timing of order availability for all customers. As such, their accommodation may call for non-standard treatment.

The method demonstrated in this section begins with an initial TC solution obtained by any means and proceeds iteratively with successively better TC solutions until no further appealing solution is encountered. With each encountered better TC solution, a set of prospective alterations thereto called perturbations is identified. Generally, a perturbation involves positionally changing no more than two site references in the current best-found TC. Of course, for a TC of n site references, there are multiple perturbation possibilities. An appealing prospect is referred to as a candidate. Its merit is confirmed or otherwise by testing, i.e. altering the current best-found TC accordingly. If the outcome is attractive relative to the declared best-found TC at that point in the investigation, the perturbation is left in place and the perturbed TC becomes the best-found TC at that point of the investigation. Otherwise, the perturbation is undone. The investigation then moves on to testing the next perturbation candidate. In each instance of testing, an attractive outcome has travel distance from trip start to trip end smaller than the declared best-found TC. Unless otherwise noted, smaller travel distance is the discriminating criterion for implementation of a TC candidate. The testing continues in this manner until no further candidates are available for testing. The process is referred to as an iteration. At the end of each iteration, the analyst decides to move/not to another iteration starting anew with the best-found TC discovered at the end of the preceding iteration. If no or marginal improvement in travel distance resulted at the end of an iteration, the analyst may decide to stop the investigation. In this way, the best-found TC is carried forward and the process comes to termination. Identification of perturbation candidates is described in the following sub-section. Each time the procedure begins anew it does so not in a random or arbitrary direction but in the vicinity of the most current best-found TC. At times, doing so offers big improvements and at other times marginal or no improvement in trip chaining travel distance.

The following sub-sections address method and analytics to be followed in seeking improvement to a first-available TC.

Perturbing a Trip Chain

A TC string may be perturbed in several ways. Among them, type 1 and type 2 methods are used extensively in this narrative, see Wellington and Lewis (2021) for detail. The methods produce alternative TCs to be examined for features such as travel distance and travel time from depot departure to depot return. Perturbing TCs is a method for extracting TCs from the TC solution universe.

A type 1 perturbation is a repositioning of a site reference b in one of three ways. It may be repositioned to the leftmost position of a string and denoted by b,; between two adjacent site references (a,c) in a TC string and noted as a,b,c; or in the rightmost position of the string as ,b. TCs resulting from type 1 repositioning site reference 3 in the string 4,1,2,3,5 are 3,; 3,4,1,2,5; 4,3,1,2,5; 4,1,3,2,5; 4,1,2,3,5; and 4,1,2,5,3; and ,3. In abbreviated forms, they are noted and to be recognized as type 1 perturbations 3,; as 4,3,1 and 1,3,2 and 2,3,5; and as ,3. The abbreviated forms are unique to type 1 perturbations.

The type 1 repositioning experiment for one location reference i (=1,..,n) produces n number of alternative TCs, i.e. the TCs where site reference i appears left to right in the jth (=1,..,n) position of the TC under examination. The n number of TCs for each site reference i can be collectively produced by means of an Excel one-way data table. Repositioned site reference i in each position j (=1,…n) of the string under investigation would appear in row j of the Excel one-way data table. The associated trip chain features for each TC so produced would appear in the rightmost cell of row j. When TCs with appealing features are found, they and their features are saved. Striking the up arrow of a dedicated Excel spin button initialized with '1' can facilitate moving the investigation to the next location reference i+1 and repopulation of the Excel one-way data table with n-number of newly perturbed TCs. In doing so, what was previously there is overwritten. The type 1 experimentation for a given TC concludes when i=n. Thereafter, the saved type 1 perturbation results are ranked by travel distance smallest to largest for later reference. Note that a better TC due to a type 1 perturbation may not be found.

Type 2 perturbation is a positional interchange of a selected site reference i with each of the other site reference j, j=1,…,n j≠i , one i,j pair at a time in a TC string. For the TC string 4,1,2,3,5 the type 2 positional interchanges of site reference 3 with each of the other location references (1,2,4,5) one pair at a time produce TCs: 4,3,2,1,5 resulting from the positional interchange of site references 1 and 3; 4,1,3,2,5 resulting from positional interchange of site references 2 and 3; 3,1,2,4,5 resulting from the positional interchange of site references 4 and 3; and 4,1,2,5,3 resulting from the positional interchange of site references 5 and 3. A type 2 positional interchange of site references i and j are simply noted as i.j and as such not confused with a type 1 abbreviated perturbation reference.

The n number of TCs resulting from type 2 interchanging of the positions of site reference i with each of the other site references j (j≠i, 1,…,n) one pair at a time can be collectively produced by means of a dedicated Excel one-way data table. The TC resulting from positionally interchanging site references i and j appears in row j of the one-way table, j=1,…,n., j≠i. The calculated trip chain features for each TC so perturbed appears in the rightmost position of row j. Much like type 1 investigation, when a type 2 perturbation produces a TC with appealing features, the results are saved for latter referencing. Striking the up arrow of a nearby type 2 dedicated Excel spin button facilitates moving the investigation to the next location reference i+1 and repopulation of the Excel one-way data table. In doing so, what was previously there is overwritten. The type 2 experimentation for a given TC concludes when i=n. Thereafter, the saved type 2 perturbation information is ranked by travel distance, smallest to largest, for later referencing. Note that a better TC due to a type 2 perturbation may not be found.

Upon completion of all type 1 and type 2 perturbation generation, the ranked best-found type 1 and type 2 results are jointly ranked by travel distance smallest first. The result is the candidate list of perturbations that are to be tested successively one at a time as described in the preceding sub-section.

Bifurcating a Trip Chain

In searching for improvements to a TC under investigation, breaking the string into two parts may help in resolving an unappealing feature of the TC under investigation. Consider the TC 21,15,31,7,1,**25**,3,13,30,8,**23**,**9**,10,**19**,**4**,*2*,**11**,22,20,27,29,14,**24**,6,**5**,16,28,17,26,18,12 with start-to-finish travel distance 113.49 miles. The site references in bold denote locations with incompatibility between vehicle arrival time at the site and the site's availability (open hours), i.e. early vehicle arrival. One way to investigate how to obtain compatible arrival times for all sites is to separate the TC into two sub-chains by arrival time compatibility. One sub-chain references sites with compatible arrival times. The other sub-chain would reference the sites with arrival time incompatibilities. In this way as the visualization shows, the adverse consequences of arrival time incompatibilities do not impact every downstream procurement. The bifurcation allows investigation of remediation possibility to proceed with isolated impact. Type 1 and type 2 investigations can proceed separately for each sub-chain. Once incompatibilities are resolved, the two sub-chains can be reconnected to determine its appeal as a one-vehicle solution. Otherwise, consideration may be given to assigning each sub-chain to a separate touring vehicle. Bifurcation may also assist in accommodating priorities for certain customer orders or site visits. It may also be applied to procuring some items by the 3P and outsourcing difficult-to-accommodate customer requests to another party. Instances of the benefit of bifurcation are illustrated in the Demonstration section.

Identifying Alternative Termination Sites

Seeking TC solutions that meet all customer expectations may be an aspect of promoting the TC product and as such become a necessary feature of the TC solution. Although it is presumed that the TC will begin and end at the start/depot location, it may be difficult to accommodate customer requested times for order availability there. Variations in earliest availability of sites, the degree of geographical dispersion among the n sites to be visited and limitations of the 3P's touring resources may challenge the availability of all customer orders at the same site and same time. Well-known fulfillment services such as Amazon make use of Walgreens, Staples, and other ubiquitous community sites as drop off and pickup points for their customers' orders, Guiffrida and Messina (2024). The availability of such arrangements for the 3P's clients may make timely customer order availability possible. Or completed orders could be alternatively made available at a locker site with electronic access provided to affected customers. They do not have the limitations of time availability that the 3P's depot or a Walgreen site may have. Again, type 1 and type 2 analytics will help in assessing the appeal of alternative order availability sites for customers. Illustration of their utility is included in the Demonstration section.

Treating Difficult-to-Accommodate Procurements

In the course of searching for customer-appealing trip chains, it may be discovered that one or more procurement sites cannot be incorporated in an emerging TC without degrading the procurement and order availability for all customers. The scenario may arise with a site(s) that is geographically remote in relation to the other sites to be visited by the 3P. Treatment of scenarios of this kind in the trip chaining literature is new. Conventional methods of accommodation may not provide an appealing TC. Since order availability for all customers is impacted by fulfillment of the most challenging procurement site(s), the manner of accommodating the latter is very important. When perturbation methods fail to identify accommodating TC solutions, the 3P faces an atypical procurement scenario and may have to examine nonstandard ways of resolution. For example, if the sequencing of site visits calls for a touring vehicle to arrive at a site in advance of its availability, consider the manner of resolution. In the opinion of the analyst, if the wait time is tolerable, staying in place at the site may be a reasonable response. Of course, arrival times at sites downstream in the sequencing would be adjusted accordingly including arrival at the terminus. If the consequence is unappealing, adjusting the departure time from the starting location may resolve more than one early arrival time situation. Analytics will assist determination of the appeal of such a resolution. A scenario of this kind is treated in the next section. Note that at times it may be necessary to consider departing the depot in advance of its first availability to secure the needed procurements.

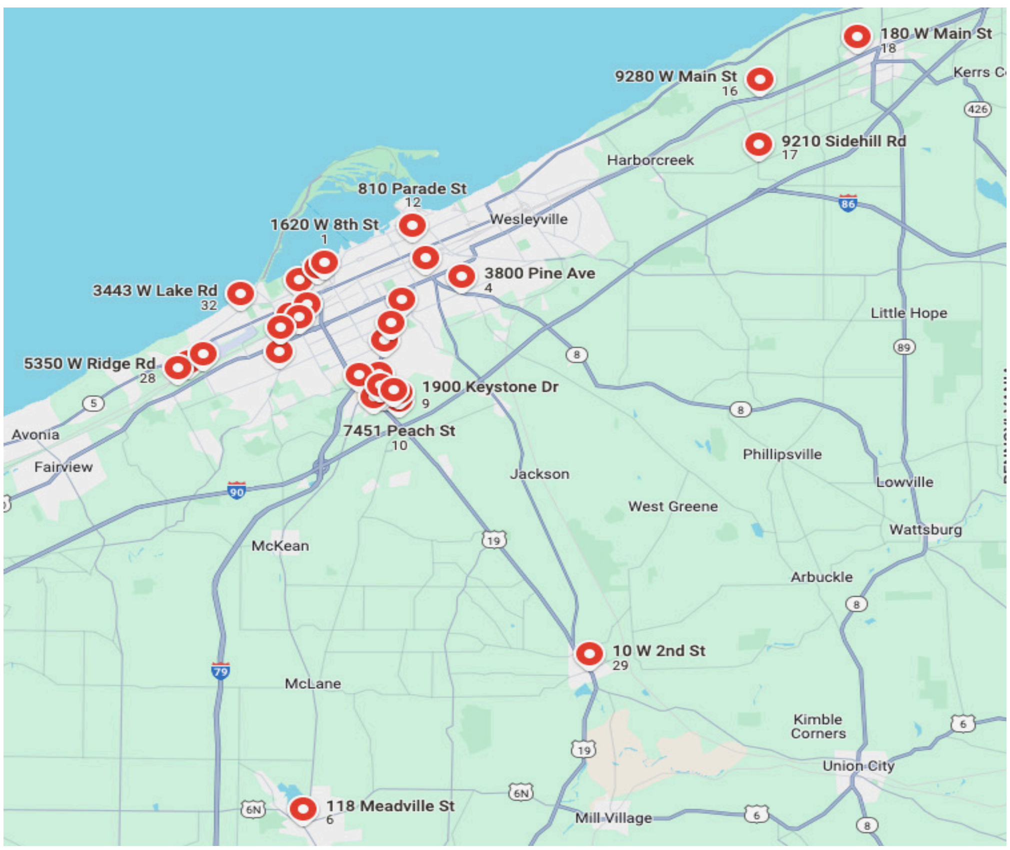
At times, difficult-to-accommodate situations do not become evident until the analyst is well into examining solutions. When they arise, examining TC sequencing with and without the difficult-to-accommodate procurement(s) may be revealing. Doing so indicates the cost/impact of accommodation on all customer orders. When such challenging situations to order procurement arise, analytics in ways to be demonstrated can frame the 3P's response to 'what can done for customers so affected'.

Demonstrations

The methods outlined in the preceding section are demonstrated with a data set taken from a metropolitan area of northwest Pennsylvania. It relates to a trip chaining scenario involving n=32 site visits and as many as two touring vehicles. The data is real site data. The perspective is a 3P seeking trip chaining solutions and resolution of complications that may arise. Figure 2 is a display of the geography.

If the trip chain commences at the 8:00 AM start of the 3P's business day and is intended to end before noon, chaining the n=32 sites may be challenging. Given the 240 minutes of available travel time and 32 sites to visit, there is an average of 7.5 travel time minutes between site visits. The average distance between all site pairs is 7.82 miles. Traveling at 25 mph allows a maximum of 100 miles of travel by noontime. The variance of miles between any two sites is large and as such may provide opportunity for meeting the noontime goal and so does use of multiple vehicles. Analytics to be demonstrated will show how that may happen.

Figure 2. Grid Display of the n=32 Sites to be Trip Chained



Finding a Starting TC

Table 1 is the display of the TC obtained using the NNR. Column 3 displays the earliest time availability of each site and Column 4 shows the arrival time at each site based on an 8:00 AM departure from the depot. The depot's hours are 8:00 AM to 5:00 PM. Calculations are based on vehicle speed of 25 miles per hour. Entries in bold in column 4 denote incompatibility between earliest availability of the site and the vehicle's arrival time there. One way to eliminate the incompatibilities is to advance the departure time from the depot. Column 5 shows that a 9:00 AM departure provides arrival time compatibility for all sites. Closer inspection of the entries in column

5 reveals that fine tuning of the departure time to 8:57 AM also yields compatibility for all sites, see column 6. The TC of column 1 with travel distance of 110.88 miles and depot departure time of 8:57 AM is the TC that will be carried forward for further investigation by the methods and analytics outlined in the preceding section. At this point, the TC of column 1 is the best-found solution.

Table 1. Analysis of TC Derived from Application of NNR for One-Vehicle Solution

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Site Reference	Distance from Preceding Location in Miles	Time of Site's first Availability	Arrival Time at Site 8:00 AM Start	Arrival Time at Site 9:00 AM start	Arrival Time at Site 8:57 AM start
15	0.66	8:00 AM	8:01 AM	9:01 AM	8:58 AM
22	0.43	7:00 AM	8:02 AM	9:02 AM	8:59 AM
21	0.57	9:00 AM	**8:03 AM**	9:03 AM	9:00 AM
23	0.88	7:30 AM	8:06 AM	9:06 AM	9:03 AM
14	2.67	6:00 AM	8:12 AM	9:12 AM	9:09 AM
30	0.60	6:00 AM	8:13 AM	9:13 AM	9:10 AM
28	0.73	6:00 AM	8:15 AM	9:15 AM	9:12 AM
32	3.55	8:00 AM	8:24 AM	9:24 AM	9:21 AM
20	2.08	9:00 AM	**8:29 AM**	9:29 AM	9:26 AM
7	1.03	7:30 AM	8:31 AM	9:31 AM	9:28 AM
1	0.24	8:30 AM	8:32 AM	9:32 AM	9:29 AM
2	3.10	9:30 AM	**8:39 AM**	9:39 AM	9:36 AM
19	0.67	7:30 AM	8:41 AM	9:41 AM	9:38 AM
27	0.79	8:00 AM	8:43 AM	9:43 AM	9:40 AM
26	1.88	9:00 AM	**8:47 AM**	9:47 AM	9:44 AM
12	1.16	8:30 AM	8:50 AM	9:50 AM	9:47 AM
4	2.11	12:01 AM	8:55 AM	9:55 AM	9:52 AM
3	4.22	10:00 AM	**9:05 AM**	10:05 AM	10:02 AM
31	0.45	6:00 AM	9:06 AM	10:06 AM	10:03 AM
8	0.57	7:00 AM	9:08 AM	10:08 AM	10:05 AM
25	0.19	8:00 AM	9:08 AM	10:08 AM	10:05 AM
5	0.50	10:00 AM	**9:09 AM**	10:09 AM	10:06 AM
13	0.20	6:00 AM	9:10 AM	10:10 AM	10:07 AM
24	0.07	9:00 AM	9:10 AM	10:10 AM	10:07 AM
10	0.18	6:00 AM	9:10 AM	10:10 AM	10:07 AM
9	0.05	9:00 AM	9:11 AM	10:11 AM	10:08 AM
11	1.74	10:00 AM	**9:15 AM**	10:15 AM	10:12 AM
29	10.94	9:00 AM	9:41 AM	10:41 AM	10:38 AM
6	11.74	10:00 AM	10:09 AM	11:09 AM	11:06 AM
17	29.80	7:00 AM	11:21 AM	12:21 PM	12:18 PM
16	2.81	8:00 AM	11:27 AM	12:27 PM	12:24 PM
18	24	7:30 AM	11:42 AM	12:42 PM	12:39 PM
0	18.23	5:00 PM	12:26 PM	1:26 PM	1:23 PM

Improving the First-found TC Using Perturbation Analytics

Table 2 below displays the outcomes of performing the first perturbation iteration, Iteration 1, beginning with the TC of Table 1. Four type 1 (column 1) and two type 2 (column 3) perturbations produced travel distances smaller than the 110.88 value for the first-found feasible TC. Their joint ranking composed the candidate list for implementation consideration and testing, see columns 5-7. Recall during the course of a type 1 and type 2 investigation, each generated perturbation is the only change in the current best-found TC, i.e. ceteris paribus. To be cited as a candidate, the associated distance value must be no greater than the declared best-found value (110.88) at that point in the investigation, see columns 1 and 3 for the type 1 and type 2 results of the first iteration. The outcome of testing each perturbation candidate one at a time in ranked order by travel distance are reported in columns 5-7 of Table 2. Note that the type 1 perturbation 11,6,29 of row 2 column 5 was in place after the testing and implementation of the preceding perturbation 6,29 of row 1. Consequently, no testing was required. Note too that the type 1 perturbation 6,11,17 (row 3 column 5) could not be tested as described due to the configuration …,6,29,17,… in place at the time of testing, i.e. site reference 29 was previously positioned between site references 6 and 17. However, site reference 11 could be positioned after site reference 6 in the TC string and tested as perturbation 6,11,29,17 (row 4). Site reference 11 could also be positioned and tested before site reference 17 in the string as perturbation 6,29,11,17 (row 5). The outcomes were travel distances 119.41 (row 4 column 6) and 111.82 (row 5 column 6) respectively. Both values were inferior to the best distance value of 104.61 (row 2) in effect at the time of testing. For this reason, neither was implemented. The situation arises when due to preceding implementations a site reference is currently configured between the two site references defining the type 1 perturbation to be tested. Proceeding as demonstrated is making best use of the perturbation data available at the time of testing. The statement means reference 11 in the vicinity of site references 6 and 17 may have good distance consequence. A similar situation arose with the testing of type 1 candidate 6,8,17 in row 7 column 5 where the configuration at the time of testing included 6,29,17. Rows 8-9 report the treatment where site reference 8 was tested after 6 as perturbation 6,8,29,17 (row 8) with outcome 114.49 and as perturbation 6,29,8,7 (row 9) with distance 106.49. Because both values were inferior to the best-found distance value 102.50 reported in row 6 column 6, neither perturbation was implemented. Testing concluded with a modest improvement in travel distance, i.e. from 110.88 to 102.50. Accordingly, a new iteration began based on the best-found TC at the end of Iteration 1, see row 11 of Table 2.

Table 2. Results of Type 1 and Type 2 Perturbation Analytics Applied to TC Produced by NNR Iteration 1

Row	Trip Chain at Beginning of the Iteration: 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 travel distance 110.88 and depot departure at 8:57 AM.						
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
	Type 1 Perturbation[1]	Distance	Type 2 Perturbation[1]	Distance	Tested Perturbation[1] Candidate[1]	Distance	Perturbation Implemented ?
1	11,**6**,29	104.61	**6,**29	104.61	**6,**29	104.61	yes
2	6,**11**,17	107.74	**8**,11	110.08	11,**6**,29	104.61	Candidate in place
3	,**12**	108.77			6,**11**,17	See below.	See below.
4	6,**8**,17	109.01			6,**11**,29,17	119.41	no
5					6,29,**11**,17	111.82	no
6					,**12**	102.50	yes
7					6,**8**,17	See below.	See below
8					6,**8**,29,17	114.49	no

9					6,29,**8**,17	106.04	no
10					**8**,11	102.56	no
11	Trip chain at end of the iteration: 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, travel distance 102.50 with depot departure moved to 9:00 AM.						

[1]Site reference perturbed in the manner of a type 1 or type 2 perturbation is noted in bold.

During Iteration 1, a greedy pursuit of successively smaller travel distances was followed without addressing early arrivals as encountered. Continuing in the same manner of pursuit produced the results reported in Table 3. Iteration 2 began with the best-found result available at the end of Iteration 1, i.e. the TC of row 11 Table 2. Again, a few implementation considerations are noteworthy. The testing of perturbation 9,**25**,11 (row 3 column 5) produced a very small improvement in travel distance (101.33) compared to the best-found distance value 101.55 (row 2 column 5) in effect at the time of testing. The perturbation was implemented to effect change in the best-found TC in going forward with further investigation. Doing so is the election of the analyst. The testing of perturbation candidate 9,5,11 of row 4 column 5 was preceded by the implementation 9,25,11 (row 3) that prevented testing of 9,5,11 as described. To make best use of the latter, site reference 5 was tested after reference 9 as perturbation 9,5,25,11 (row 5) and before reference 11 as perturbation 9,25,5,11 (row 6). Although the perturbation 9,5,25,11 produced the distance measure 101.33 that was identical to the distance measure for the best-found TC in effect at the time of testing, it was implemented to effect change in the evolving TC. The perturbation 9,25,5,11 (row 6) produced an inferior distance value 101.97. Testing of type 2 perturbation 8,25 concluded Iteration 2 with a modest improvement in TC distance from 102.50 to 101.33. Unfortunately, no better results were found in Iteration 3 and are not reported.

Table 3. Results of Type 1 and Type 2 Perturbation Analytics Applied to TC of Row 11 Table 2 Iteration 2

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Row	Type 1 Perturbation	Distance	Type 2 Perturbation	Distance	Tested Perturbation[1] Candidate[1]	Distance	Perturbation Implemented ?
1	4,**2**,3	101.99	**8**,25	102.39	4,**2**,3	101.99	yes
2	,**20**	102.06			,**20**	101.55	yes
3	9,**25**,11	102.28			9,**25**,11	101.33	yes
4	9,**5**,11	102.35			9,**5**,11	See below	-
5	25,**8**,5	102.39			9,**5**,25,11	101.33	yes
6					9,25,**5**,11	101.97	no
7					25,**8**,5	-	cannot do
8					**8**,25	101.55	no
9	Trip chain at End of the Iteration: 15,22,21,23,14,30,28,32,7,1,19,27,26,4,2,3,31,8,13,24,10,9,5,25,11,6,29,17,16,18,12,20 with travel distance 101.33 and depot departure at 9:03 AM and depot return at 1:06 PM with no early arrivals.						

[1]Site reference perturbed in manner of a type 1 or type 2 perturbation is noted in bold.

At this point, the TC of row 9 Table 3 is the best-found for a one-vehicle touring of the n=32 sites with depot-to-depot travel distance of 101.33. Early arrival times occur with sites 21,26,2,3,5,11,6 that are resolved with advancing departure time at the depot from 8:00 AM to 9:03 AM. This resolution was selected due to the multiple number (=7) of early arrivals. Return time to the depot and customer order availability became 1:06 PM. If the features of the TC are not acceptable, alternative ways of making the procured items available to customers need to be examined. Note the order availability time of 1:06 PM exceeds the noontime goal.

Bifurcation, Alternative Sites for Customer Order Pickup and Difficult-to-Accommodate Procurement Sites

Consider making improvement in the timing of order availability for all customers a priority in proceeding with discovery. In this regard, inspection of Figure 2 is helpful. It shows that sites at the right corner of the service area appear remote. To quantify what appears remote, the distance of each site from the depot appears in the last row of Table 4. The entries are revealing. Inspection shows longer (at least 17.63 miles) distances for sites 29, 18, 16, 6 and 17 and for this reason they stand out. Consider treating these sites as a sub-chain to be referred to as the short sub-chain and the remaining sites as the long sub-chain. Among the sites in the short sub-chain, locations 16, 17 and 18 are mutually proximate, i.e. located in the municipality of North East, PA. Site 6 is in Edinboro, PA and site 29 in Waterford, PA. Collectively, they are not in the political boundaries of the City of Erie where the depot is located and the sites in the long sub-chain. For the moment, look upon each sub-chain as a stand-alone TC for analysis purpose to determine if the bifurcation leads to an improvement in order availability for customers. The bifurcation is a 'divide and conquer' approach to TC discovery, i.e. analysis of the two sub-chains may provide results that the full-size TC could not.

Table 4. Ranked Distance of Each Procurement Site from the Depot

Visit	1	2	3	4	5	6	7	8	9	10	11	12	13
Site	15	22	20	21	7	23	1	32	19	2	27	11	14
Distance	0.66	0.68	1.20	1.25	1.80	1.93	2.04	2.61	3.14	3.22	3.35	3.56	3.68

Visit	14	15	16	17	18	19	20	21	22	23	24	25	26
Site	3	30	31	26	25	8	28	12	5	13	24	10	9
Distance	3.90	4.11	4.25	4.39	4.42	4.53	4.57	4.59	4.64	4.73	4.80	4.91	5.07

Visit	27	28	29	30	31	32
Site	4	29	18	16	6	17
Distance	5.14	17.63	18.23	18.54	20.12	21.83

Consider next the initial sequencing of sites in each sub-chain. Given the best-found TC of row 9 Table 3, sequencing the sites for the short sub-chain in the left-to-right order in which they appear there, i.e. 6, 29, 17, 16 and 18 is a reasonable first sequencing, see row 2. The remaining sites composed similarly constitute the long sub-chain, see row 4 of Table 5.

Table 5. Results of Perturbation Analytics Applied to Bifurcation of Trip Chain of Row 9 Table 3

Row	Trip Chain	Source	Travel Distance to Depot	Start Time	Number of Early Arrivals	Arrival Times at LVS[1], Depot (0)
1	Trip Chain of Row 9 Table 3 15,22,21,23,14,30,28,32,7,1, 19,27,26,4,2,3,31,8,13,24, 10,9,5,25,11,6,29,17,16,18, 12,20	Table 3 row 9	101.33	9:03 AM	None	20, 1:00,PM 0, 1:03 PM
2	First Short Sub-chain 6,29,17,16,18	Bifurcation of the TC of row 1	79.22	9:12 AM	None	18, 11:38 AM 0, 12:22 PM

	Note: 11:38 AM arrival at site 18 + 44 mins. to depot arriving at 12:22 PM.					
3	Best-found Short Sub-chain 16,17,18,29,6,	Perturbation Analytics	83.76	8:00 AM	None	6, 10:32 AM 0, 11:20 AM
	Note: 10:32 AM arrival at site 6 + 48 mins. to depot arriving at 11:20 AM.					
4	First Long Sub-chain 15,22,21,23,14,30,28,32,7, 1,19,27,26,4,2,3,31,8,13,24, 10,9,5,25,11,12,20	Bifurcation of the TC of row 1	39.27	9:03 AM	None	20, 10:34 AM 0, 10:37 AM
	Note: 10:34 AM arrival at site 20 + 3 mins. to depot arriving at 10:37 AM.					
5	Best-found Long Sub-chain 15,22,21,23,14,30,28,32,20, 7,1,26,12,4,27,19,2,3,31,13, 24,10,9,5,8,25,11	Perturbation Analytics	31.98	9:01 AM	None	11, 10:09 AM 0, 10:18 AM
	Note: 10:09 AM arrival at site 11 + 9 mins. to depot arriving at 10:18 AM.					
6	Best-found Short + Best-found Long Sub-chain 16,17,18,29,6,15,22,21,23, 14,30,28,32,20,7,1,26,12,4, 27,19,2,3,31,13,24,10,9,5,8, 25,11	Concatenated sub-chains of rows 3 and 5 sub-chains	114.96	8:00 AM	None	11, 12:27 PM 0, 12:36 PM
7	12,18,16,17,29,6,23,15,22, 21,14,30,28,32,20,7,1,26,4, 27,19,2,3,31,13,24,10,9,5,8, 25,11,	Best-found concatenated TC	102.62	8:19 AM	At site 12 early by 19 mins.	11, 12:16 PM 0, 12:25 PM

[1] Last visited site.

Table 5 is a summary of the investigation to determine the appeal of the bifurcation. In Table 5, the results reported in row 2 are the consequence of eliminating arrival times in advance of first site availability by changing the departure (start) time from the depot to 9:12 AM. Doing so provided a benchmark in pursuing better order availability times for customers. For the short sub-chain, type 1 and type 2 perturbation analytics began with the sub-chain of row 2 and concluded with the best-found result reported in row 3. In the course of the investigations, it was found that departure time from the depot at the standard 8:00 AM time was consistent with the best-found distance result. Perturbation analytics were applied to the long sub-chain beginning with the sequencing of site visits displayed in row 4 and concluded with the best-found long sub-chain of row 5. Unlike the result for the short sub-chain, the departure time from the depot did not revert to 8:00 AM. It became 9:01 AM, see row 5. To make best use of these results, the best-found site sequencings for the two sub-chains were concatenated in the order of the sub-chain of row 3 first followed by the sequencing of row 5. The results appear in row 6. Note that the concatenation allowed the 8:00 AM depot departure time with no early arrival times at any site. Row 7 is the display of the outcome of perturbation analytics applied to TC of row 6. Although the travel distance (102.62) of the TC of row 7 is marginally inferior to the travel distance (101.33) for the TC of Table 3 row 9, the arrival time (12:25 PM) of the former at the depot is superior. The depot arrival time 12:25 PM is the best-found TC that could be assigned to a single touring vehicle. The arrival times at the last visited site (LVS) for the TCs reported in Table 5 are attention getting and prompt the question of how could order availability times be so achievable.

Note the results of rows 3 and 5 in Table 5. Procurements assigned to the short sub-chain are completed at 10:32 AM at the last visited site (6). For those assigned to the long sub-chain, they are complete at 10:09 AM at the last visited site (11). If the site visits of the short sub-chain are assigned to Vehicle 1 and those of the long sub-chain to Vehicle 2, then site 6 or site 11 could be considered as an alternative to the depot for order availability for customers. Recall that the items of any customer order could be scattered about both vehicles. Hence, a common terminus site for each vehicle is needed. If site 11 is the common terminus, orders would be available there at 11:06 AM, the max of the 11:06 AM arrival time there for Vehicle 1 and the 10:09 AM time for Vehicle 2, see Table 6 rows 1-2. If site 6 is the terminus, order availability for all customers becomes 10:45 AM, the max of arrival times 10:32 AM and 10:45 AM for Vehicles 1 and 2 respectively, see Table 6 rows 3-4. Given the analysis of Table 6, site 6 as a terminus offers the best order availability time. For comparison purposes, the results for the depot terminus are displayed in rows 5 and 6 of Table 6. Note in Table 6 for terminus sites 6 or 11, either the short or long sub-chain had an additional link to consider.

Table 6. Results of Investigating Alternative Pickup Sites for Customer

Row	Term.[1]	Trip Chain	Source	Added Travel Distance and Time to Terminus	Start Time	Number of Early Arrivals	Arrival Time at Terminus
1	11	16,17,18,29,6,**11**	Table 5 row 3 with added site 11 as terminus	14 miles 34 mins.	8:00 AM	None	**11:06 AM**
		10:32 AM arrival at site 6 + 34 mins. to site 11 arriving at 11:06 AM.					
2	11	15,22,21,23,14,30,28,32,20, 7,1,26,12,4,27,19,2,3,31,13, 24,10,9,5,8,25,**11**	Table 5 row 5 with no added terminus	None	9:01 AM	None	10:09 AM
3	6	16,17,18,29,**6**	Table 5 row 3 with no added terminus	-	8:00 AM	None	10:32 AM
4	6	15,22,21,23,14,30,28,32,20, 7,1,26,12,4,27,19,2,3,31,13, 24,10,9,5,8,25,11,**6**	Table 5 row 5 with added site 6 as terminus	14 miles 34 mins.	9:01 AM	None	**10:43 AM**
		10:09 AM arrival at site 11 + 34 mins. to site 6 arriving at 10:43 AM.					
5	0	15,22,21,23,14,30,28,32,20, 7,1,26,12,4,27,19,2,3,31,13, 24,10,9,5,8,25,11,**0**	Table 5 row 5 with no added terminus	None	9:01 AM	None	10:18 AM
6	0	16,17,18,29,6,**0**	Table 5 row 3 with no added terminus	None	8:00 AM	None	**11:20 AM**

[1] Terminus site.

If customers are willing to travel to sites 11 or 6 as well as the depot; if a two-vehicle solution is within the 3P's procurement resources; and if arrangements for order distribution at sites 6 or 11 can be made, there are now several solution scenarios. They are the TC of Table 5 row 7 for a one-vehicle solution and the two-vehicle solutions of Table 6.

In deciding the appeal of a terminus site, note the following. Research shows that customers self-shop within some proximity to their homes. For the trip chaining scenario treated here and lacking any additional information concerning customer home locations, distance of procurement sites from the depot is the only available measure. To the extent customer departure locations for order pickup are in proximity to the depot, research offers some considerations. From a 2016 study of consumer willingness to travel for shopping, the following was reported. "In the survey, 93.2% of respondents said they typically travel less than 20 minutes to buy groceries, clothing, gasoline and other routine transactions, while 87% said they won't travel beyond 15 minutes for such purchases. For purchases that consumers make at least once per week, the distance they are willing to travel shrinks even further to 10 minutes.", see CSP (2016). Given this result, it is understandable why some consumers are interested in 3P trip chaining for them and why some locations should not be considered for order distribution. Site 6 is 20.12 driving miles and 48.29 minutes from the depot based on 25 mph vehicle speed. Given the CSP research result, site 6 is not an appealing alternative pickup site for customers. Again, this conclusion assumes the locations of customer departures for the order pickup have some proximity to the depot. Alternatively, site 11 is 3.56 miles and about 8.5 driving minutes from the depot. As such, it makes customer order availability there at 11:06 AM compared to the depot at 11:20 AM Accordingly, it has more appeal as an order pickup location. Note too that Amazon offers order availability for its customers at some UPS Stores and Staples locations. FedEx does so at some Walgreen Pharmacy sites. These sites are commonplace in many communities. They have a history of serving as order drop-off and pickup sites for the cited order fulfillment entities. Table 7 is a display of some sites within the trip chaining area of Figure 2 to consider for order distribution locations. Some are included among the n=32 sites of the trip chaining scenario of demonstration. For the long sub-chain/Vehicle 2, when sites 20, 25, 27 and 28 were evaluated as a terminus location, the best-found long sub-chain was augmented rightmost with the site reference.

Table 7. Alternative Distribution Sites for the Two-vehicle Solution

Row	Terminus Site		Arrival Time of Vehicle[1] at Terminus Site 8:00 AM Start	Arrival Time of Vehicle 2[2] at Terminus Site 9:01 AM Start	Time of Order Availability to All Customers at Terminus Site
	Site Reference	Site Name (Dist. from Depot)			
1	0	Depot (0)	11:20 AM	10:18 AM	11:20 AM
2	11	Jared Jewelers (3.6)	11:06 AM	10:09 AM	11:06 AM
3	20	Pet Supplies Plus (1.2)	11:23 AM	10:20 AM[3]	11:23 AM
4	25	Target Erie (4.4)[3]	11:05 AM	10:11 AM	11:05 AM
5	27	Walgreens (3.4)	11:12 AM	10:16 AM	11:12 AM
6	28	Walmart Supercenter (4.6)	11:12 AM	10:25 AM[4]	11:12 AM

[1] 16,17,18,29,6 [2] 15,22,21,23,14,30,28,32,20,7,1,26,12,4,27,19,2,3,31,13,24,10,9,5,8,25,11
[3] Includes waiting 2 mins. at site 3 . [4] Includes waiting 3 mins. at site 3.

Although some locations of Table 7 do not have histories as a pickup or drop off location for order fulfillment services, their evaluations have value. A locker/lockbox in the nearby vicinity may serve as a geographical site for order distribution locations. A locker would contain the customer's order accessible by an electronic code made known to the customer at the time of order availability. Its access is not limited to typical business hours. In this regard, since sites 11 and 25 have the best order availability times, making order availability there or at a nearby locker attractive and perhaps appealing to customers.

Sites such as locations 6,16,17,18 and 29 are difficult to accommodate and may require searching for and evaluating non-standard features of accommodation such as alternative order pickup points, depot departure times as well as pausing on site in advance of a site's procurement availability and use of multiple touring vehicles. Consider too starting a TC at a non-depot location. If the driver for the best-found one-vehicle solution (Table 5 row 7) can begin the touring at a non-depot point, note what may be possible. Relocating site 12 via the type 1 perturbation 17,12,9 and leaving the rest of the TC as is results in an arrival time at site 11, the last visited site of the TC, at 12:08 PM. With site 18 as the first site visit of the revised TC, a standard 8:00 AM departure is possible rather than 8:19 AM, again see Table 5 row 7. Note too that the distance from the depot to site 18 is 18.23 miles with driving time of 44 minutes. If the trip chaining could begin at some point between the depot and site 18 and require less than forty-four minutes of driving time, arrival time at the last visited site 11 or possibly the depot could be before the noontime goal. Note how the perturbation analytics of relocating site 12 in the original TC assisted in the identification and evaluation of an alternative starting location.

The demonstrated analytics helped in the discovery and assessment of how to accommodate customer needs. Although the utility of bifurcation was demonstrated with remote procurement sites, it may also be a means for accommodating site and customer order priorities in sequencing site visits. Without the analytics, the 3P may not know what can be done for customers with such needs and how the impact on order availability for all customers can be lessened.

Alternative Starting Analytics

Use of the NNR for producing the first TC is not the only available heuristic. The largest link next rule (LLNR) is a heuristic used in bin packing and scheduling jobs on machine(s), see Della Croce and Scatamacchia (2020). The value of investigating the LLNR TC is what it may lead to as alternative TCs. In proceeding with the perturbation analytics applied to the LLNR solution, the objective is discovery of a TC that makes customer orders available before 12:00 PM at a central location that may/not be the depot.

When the LLNR is applied to composing a first TC, the result is not appealing with travel distance 333.33 miles and return to the depot at 9:20 PM. Inspection of the TC is revealing with detail presented in Table 8. A break in the distances between successive sites occurs with Visit 9. The result is due to the waning yield of the greediness of the LLNR. However, the demonstrative break provides an opportunity for bifurcation. To this end, the LLNR TC displayed in Table 8 was bifurcated at site Visit 9 into two sub-chains. One is referred to as the short sub-chain consisting of site references for Visits 1-8 of Table 8. The other is noted as the long sub-chain consisting of site references for Visits 9-32. Each is investigated separately with results reported in Table 9. The outcome of reconnecting them as one TC is reported in rows 7 and 8 of Table 9.

Table 8. Distances from Preceding Site

Visit	1	2	3	5	4	6	7	8	9	10	11	12
Site	17	6	18	30	16	28	29	32	9	4	24	14
Distance	21.83	29.8	35.64	28.78	25.93	25.7	19.04	19.76	7.7	8.09	8.19	7.28

Visit	13	14	15	16	17	18	19	20	21	22	23	24
Site	12	11	20	10	7	13	1	5	21	8	23	25

Distance	7.84	6.6	4.61	5.92	5.5	5.32	5.26	5.17	4.79	4.73	4.8	5.47

Visit	25	26	27	28	29	30	31	32
Site	26	31	15	3	22	27	2	19
Distance	4.9	4.39	4.23	3.89	3.5	3.47	1.39	0.67

Treatment of the long sub-chain is reported in rows 2-3 of Table 9. Application of type 1 and type 2 perturbation analytics produced the sub-chain with travel distance 124.22 and return to the depot at 1:46 PM. In performing the analysis, the departure time from the depot was changed from 8:00 AM to 8:48 AM eliminating any site arrival in advance of first availability. The perturbation results for the short sub-chain are displayed in rows 4-5 concluding with travel distance of 91.74, 8:00 AM standard departure time from the depot and 11:40 AM return time there. When the two best-found sub-chains are concatenated in the manner of the best-found short sub-chain followed by the best-found long sub-chain, the TC with standard departure time of 8:00 AM from the depot, no early arrival times at any site, travel distance 126.83 and return to the depot at 1:04 PM resulted, see row 6. Thereafter, type 1 and type 2 perturbations produced the TC of row 7 with standard 8:00 AM departure time from the depot, no early arrival times at any site, depot-to-depot travel distance 114.99 and 12:31 PM return time at the depot. The 12:31 PM depot return time is beyond the desired 12:00 PM time. However, the investigation is not yet complete.

Table 9. Summary of Perturbation Analytics Applied to LLNR Trip Chain

Row	Trip Chain	Source of the Trip Chain	Distance from and Return to Depot	Start Time, Early Arrival Sites If Any	Arrival Time at LVS[1], Depot
1	LLNR Trip Chain 17,6,18,30,16,28,29,32,9,4,24,14,12, 11,20,10,7,13,1,5,21,8,23,25,26,31, 15,3,22,27,2,19	Application of the LLNR	333.33	8:00 AM,	19, 9:12 PM 0, 9:20 PM
2	First Long LLNR Sub-chain 9,4,24,14,12,11,20,10,7,13,1,5,21,8, 23,25,26,31,15,3,22,27,2,19	Bifurcation of TC of row 2	124.22	8:48 AM[2]	19, 1:38 PM 0, 1:46 PM
3	Best-found Long LLNR Sub-chain: 15,21,14,23,22,4,26,12,20,1,7,25,13, 5,10,9,24,31,8,3,11,2,19,27,	Perturbation Analytics	35.76	8:59 AM[3]	27, 10:16 AM 0, 10:24 AM
4	First Short LLNR Sub-chain 17,6,18,30,16,28,29,32	Bifurcation	209.09	8:00 AM	32, 4:15 PM 0, 4:22 PM
5	Best-found Short LLNR Sub-chain 18,17,16,32,30,28,6,29	Perturbation Analytics	91.74	8:00 AM	29, 10:57 AM 0, 11:40 AM
6	Best-found Short + Best-found Long Sub-chains 18,17,16,32,30,28,6,29,15,21,14,23, 22,4,26,12,20,1,7,25,13,5,10,9,24,31, 8,3,11,2,19,27,	Concatenation	126.83	8:00 AM	27, 12:56 PM 0, 1:04 PM
7	Best-found Concatenated Trip Chain 18,17,16,32,14,30,28,6,29,8,25,11,23, 21,15,22,27,4,26,12,1,7,20,31,13,24, 10,9,5,3,2,19	Perturbation Analytics	114.99	8:00 AM	19, 12:28 PM 0, 12:36 PM

[1] LVS =Last visited site. [2] Due to early arrival times at sites 9,24,11, 48 mins. added to the initial 8:00 AM depot departure time. [3] Due to early arrival times at sites 21,5,3,11, 11 mins added to previous 8:48 AM depot departure time.

If the best-found sub-chains displayed in rows 3 and 5 of Table 9 are assigned to two separate vehicles, the obvious common terminating locations are the depot, site 29 and site 27. Let the short sub-chain be assigned to Vehicle 1 and the long sub-chain to Vehicle 2. If the depot is the common terminus, we know order availability for all customers at the depot would be the max of 10:24 AM (row 3) arrival time for Vehicle 1 there and 11:40 AM (row 5) for Vehicle 2 as displayed in Table 9. Table 10 displays arrival time for a few alternative terminus sites. The order availability time for site 29 (Table 10 rows 1-2) is 11:11 AM (max of 10:57 AM and 11:11 AM) and it is an improvement compared to the depot's time of 11:40 AM. However, site 29 is remote, see Figure 2. It is 17.63 miles and 42 minutes (based on average driving speed of 25 mph) from the depot. As previously noted without further information about the customer departure locations for order pickup, locations in near vicinity of the depot are presumed. Given the research findings of CSP (2016), site 29 is not a good choice for an order pickup site for customers. The order availability time for all customer orders at site 27 is 11:28 AM, see rows 3-4 of Table 10. Among other possible terminus sites, location 3 has appeal with order availability time 11:22 AM, see rows 5-6 in Table 10. Also, see Figure 2 for its geographic appeal.

Table 10. Best-found Two-vehicle Solution Derived from First LLNR Result

Row	Term.[1]	Vehicle	Trip Chain	Departure Time from Depot	Arrival Time at Last Visited Site
1	Site 29[2]	1	18,17,16,32,30,28,6,**29**[2]	8:00 AM	10:57 AM at site 29
2		2	25,8,31,26,4,12,20,1,7,13,24,9,10,5,22,15,21,14,23,11,3,2,19,27,**29**	8:48 AM	**11:11 AM** 10:26 AM at site 27 +14 mins. of wait at site 5 +31 mins. to site 29
3	Site 27[3]	1	18,17,16,32,30,28,6,29,**27**[3]	8:00 AM	**11:28 AM** 10:57 AM at site 29 + 31 mins. to site 27
4		2	25,8,31,26,4,12,20,1,7,13,24,9,10,5,22,15,21,14,23,11,3,2,19,**27**	8:48 AM	10:40 AM 10:26 AM at site 27 + 14 mins. of wait at site 5
5	Site 3[4]	1	18,17,16,32,30,28,6,29,**3**[4]	8:00 AM	**11:22 AM** 10:57 AM at site 29 + 25 mins. to site 3
6		2	25,8,31,26,4,12,20,1,7,13,24,9,10,5,22,15,21,14,23,11,2,19,27,**3**	8:48 AM	10:46 AM 10:32 AM at site 3 + 14 mins. of wait at site 5

[1] Terminus. [2] Waterford Hardware and Services. [3] Walgreens . [4] Site 3 Barnes and Noble.

The 3P now has the best-found one-vehicle and two-vehicle solutions derived from the LLNR TC. If none are appealing, investigation of a locker location may be the next investigation. However, the two-vehicle TCs found by means of bifurcation, perturbation analytics, and investigation of alternative order availability considerations produced solutions within the objective of order availability for all customers before 12:00 PM at an appealing location.

Given the greediness of the NNR and LLNR, it is not surprising that bifurcation opportunities were found. The bifurcation opportunities arose where the yield of the greediness began to wane. Combining perturbation analytics, alternative order distribution locations and varied starting times for the touring vehicle(s), TCs with attractive features were discovered that the 3P may not have otherwise considered. The heuristics provided an initial sequencing of site visits. Alternatively, a mapping of the procurement sites such as Figure 2 may allow the analyst to compose a starting TC via visual inspection. Collectively, as demonstrated here, the analytics and accommodation techniques produce a variety of TC configurations making best use of the data as it emerged in the search. In the words of Winston (2014, p.3), the demonstrated analytics and techniques did indeed ‘slice and dice’ the data in searching for appealing TCs for the scenario of demonstration. Table 11 is a summary of the outcomes. The results for the one-vehicle TC solution point out how much the standard 8:00 AM starting time would have to be adjusted to achieve the desired noontime completion. The analytics produced other TCs with various appeal as reported in Tables 6, 7, 9 and 10.

Table 11. Summary of Overall Best-found Trip Chain Results

One Vehicle Depot Return Site		**One Vehicle** Alternative Return Site	
Start Time, Return Time, Travel Distance to Terminus Site			
Depot, 8:00 AM, 12:25 PM, 102.62 miles		Site 11, 8:00 AM, 12:16 PM, 98.62 miles	
See Table 5 Row 7 for the trip chain		See Table 5 Row 7 for the trip chain	
Two Vehicles Depot Return Site		**Two Vehicles** Alternative Return Site	
Vehicle 1	Vehicle 2	Vehicle 1	Vehicle 2
8:00 AM, 11:20 AM, Depot	9:03 AM, 10:20 AM, Depot	8:00 AM, 11:05 PM, Site 25[2]	9:01 AM, 10:12 AM, Site 25[2]
See row 5-6 of Table 6		See row 4 of Table 7	

[1] Site 11-Jared Jewelers or nearby locker. [2] Site 25-Target Erie or nearby locker.

Summary and Suggestions for Further Investigation

In summary, the narrative has framed and demonstrated the manner in which the trip chaining product can be composed. The role of analytics in doing so was emphasized and demonstrated under several scenarios with an example. The string form of a TC and the demonstrated manner of its perturbation, bifurcation and accommodation of challenging procurements and order distribution features were included in the discussion. Challenges of geographically dispersed procurement sites, wide variation among the first availability of sites to be visited and consideration of alternative locations of customer order-pickup points were addressed. In doing so, the TC product was reframed in standard and non-standard ways to accommodate customer needs and the limitations of the 3P’s trip chaining resources. At each stage of product evolution, analytics were central.

For ease of introduction, the approach was deterministic. Consequently, it can benefit from research related to how traffic density and other inherently variable travel conditions along the TC route can be accounted for. The same is true in accounting for the inherent variability of time consumed in procuring items at each site. Such aspects of a trip chaining scenario may be modeled stochastically, i.e. treating the phenomena alone or jointly as random and incorporating suitable density function(s) of the behavior in the TC modeling. Also, some readers may be interested in a computational environment different from Excel’s as demonstrated here. Excel was chosen for ease of trip chaining composition, its ubiquity as a computational engine and its familiarity to marketers. For readers interested in a Python incarnation of TC modeling or Python as an Excel Add-in, information is provided at http://www.mongrelworks.org/TC.

There are other research opportunities. The scope of the 3P delivery options could be expanded to include hybrid forms involving the use of electric vehicles and drones. The 3P model of trip chaining could be further investigated in terms of its environmental impact, e.g. investigating the carbon emission savings due to 3P trip chaining in comparison to individual consumer self-configured and self-traveled TCs. Recent work by Brown and Bushuev (2024) in demonstrating the utility of non-internal combustion touring vehicles may also have application trip chaining composition. Advanced methods such as machine learning within the context of the 3P's trip chaining model may simplify the needed decision making at various points in the investigation. As shown in the demonstrations, they include deciding to bifurcate/not a TC; employing/not multiple touring vehicles; continuing/not with a new iteration; making/not customer orders available for pickup at the starting point or at an alternative site; waiting/not in advance of a site's availability when early vehicle arrival occurs; and including/not sites remote from the starting point in a trip chaining scenario. Lastly, the multi-layer modeling of Wang et al. (2022) that incorporates last mile delivery considerations may have useful application to trip chaining. They addressed complications of limited urban parking and frequent roadway intersections in composing itineraries similar to trip chaining.

In conclusion, the presentation is intended to introduce the readership of the Journal of Marketing Analytics to trip chaining as a product, the manner of its composition, and the variety of ways customer trip chaining needs can be met. The introduction included discussion and treatment of some of the complications that can arise in meeting customer trip chaining needs. And very importantly, the narrative and demonstrations addressed how data analytics assisted. Excel brings the analyst closest to the data.

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Appendix

Table A1. Calculated Distances for Trip Chain of Figure 1

Trip Chain 0,2,4,3,6,5,1,7,0 for the 3P		
Location Reference	Co-ordinates	Distance from Preceding Location in Co-ordinate Units
0	50,50	-
2	35,52	|50-35| + |50-52| = 17
4	31,23	|35-31| + |52-23| = 33
6	39,11	|31-39| + |23-11| = 20
3	80,2	|39-80| + |11-2| = 50
7	93,52	|80-93| + |2-52| = 63
1	83,90	|93-83| + |52-90| = 48
5	45,94	|83-45| + |90-94| = 42
0	50,50	|45-50| + |94-50| = 49
Total		322