A Capacitated Clustering-based Method for Newspaper Delivery Routing

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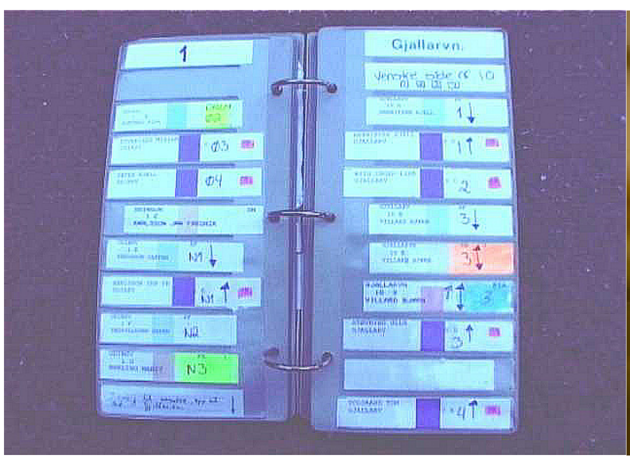
Outline

- Context
- The Newspaper Delivery Routing Problem
- A Clustering-based solution method
- Results
- Conclusions and further work

Technology for a better society

Newspaper distribution

- Subscription newspapers, home delivery
- Decreasing revenues
- Distribution costs > 40% of total costs
- Route revision very costly and time-consuming
- Reduce costs – Increase revenues



A: PASSPORT - Session1

File Edit Transfer Options Session Macro Help

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=>PF2=TILBAKE,PF5=ENDRE,PF6=SLETT,PF10=BLANKER,PF11=RUTEKONS,PF12=TILLEGGSOPP
A F T E N P O S T E N    DISTRIBUSJONSSYSTEM    KOSTNADS- OG TIDSBEREGNING
Rute: 21509 Utg.: M Ukedag: 0 Pr. dato: 221105              Betjenes med: G
 Ant.l0nn:  265 -Ant. abo og andre,      0  -Ant. pressede  Sone: 3  O/U: U
  265 +     0 =  265 a kr.   23,76 +    0 Spes.abo a kr.    0,00   = kr   6296,40
 Avstandsl0nn:   3,3 km a kr.   52,80                              = kr    174,24
 Vintertillegg:  5 mnd. a kr.  291,00 :12                          = kr    121,25
 Sum l0nn                                                    *MIN* = kr   6892,17
  26,00 % tillegg for feriepenger og arb.avgift                    = kr   1791,96
 Sykkelgodtgj.                                                     = kr      0,00
 Transp.godtgj.    3,3 km x 26,00 dager x kr.:     0,00            = kr      0,00
 Transp.strekn.    0,0 km x 26,00 dager x kr.:     0,00            = kr      0,00
 Sum l0nn, sos.kostn. og transp.godtgj.                      *MIN* = kr   8684,13
 Kostnad pr. abonnement pr. mÅned                                  = kr     32,77
1. Klargj0ring f0r start           =        15 min | Dekn.%:   44,69
2. Avstand     3,3 km        a  12,00 =   39,60 min | Beregnet tid  128,13 min.
3.   0 oppg. uten n0kkel a   0,35 =    0,00 min | Reell    tid  128,13 min.
4.  53 oppg. med n0kkel  a   0,50 =   26,50 min | Beregn. dagl0nn  248,87 kr
5. 206 etasjer            a   0,35 =   72,10 min | Reell   dagl0nn  260,42 kr
6.    0 lev. i enebolig   a   0,15 =    0,00 min | Beregn. timel0nn  116,54 kr
7.  63 lev. i rekkehus    a   0,20 =   12,60 min | Reell   timel0nn  121,95 kr
8.   4 lev. i FK (ute)    a   0,15 =    0,60 min | Timetillegg o/18 ....... kr
9.   0 fellesleveringer   a   0,00 =    0,00 min | Antall husstander     593
Totalt                             =  166,40 min |
TB                                  A2--Session1   R 4   C 1        3:22p 22/11/05
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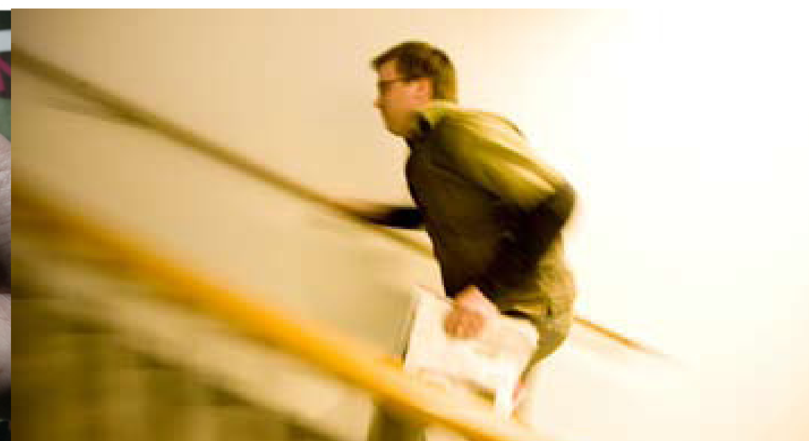
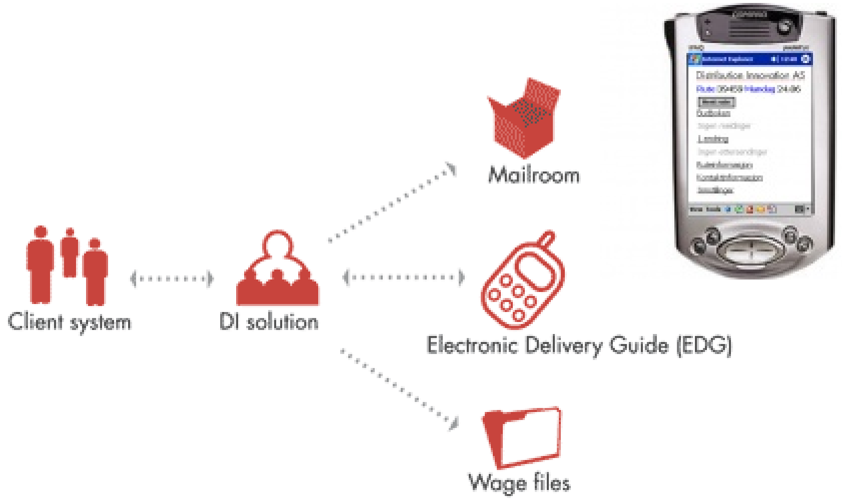
Reduce costs – Increase revenues

- More efficient carrier routes
- More efficient route revision
- Better utilization of distribution system
- Additional products
- Necessitates better communication, flexibility, dynamics



RTD Collaboration since 1999

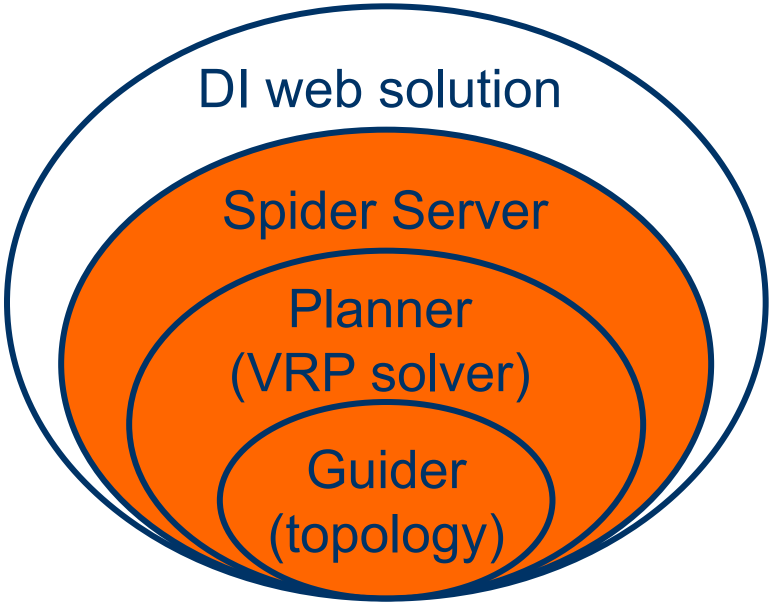
- Newspapers and their distribution companies
- PDA/Smartphone based delivery book
- Cloud computing based distribution management system
- Establishment of Distribution Innovation AS (DI) 2001
  http://www.di.no
- The DI solution, web based “cloud computing”



Distribution Innovation solution

- > 80% of newspaper etc. home deliveries in Norway
- Magazines, books ...
- > 6.200 carriers download their route every night
- > 1 million deliveries per day
- > 30 companies Norway, Finland, Sweden, Denmark, Poland
- Integrated route construction and revision
- Spider VRP solver

System architecture



Distribution Innovation 10år

Rutenett | Adresse | Rapporter

Søk rute | Modul | Forfall | **Rutemåltall** | Optimalisering

Ruteutvalg

Distribusjon: M1-6

Velg geografi

Rutesøk:

Region: -Velg-

Område: -Velg-

Forfall: 21 Edda Distribusjon Sørvest - RNO#2326

Velg måltall / tidsmodus

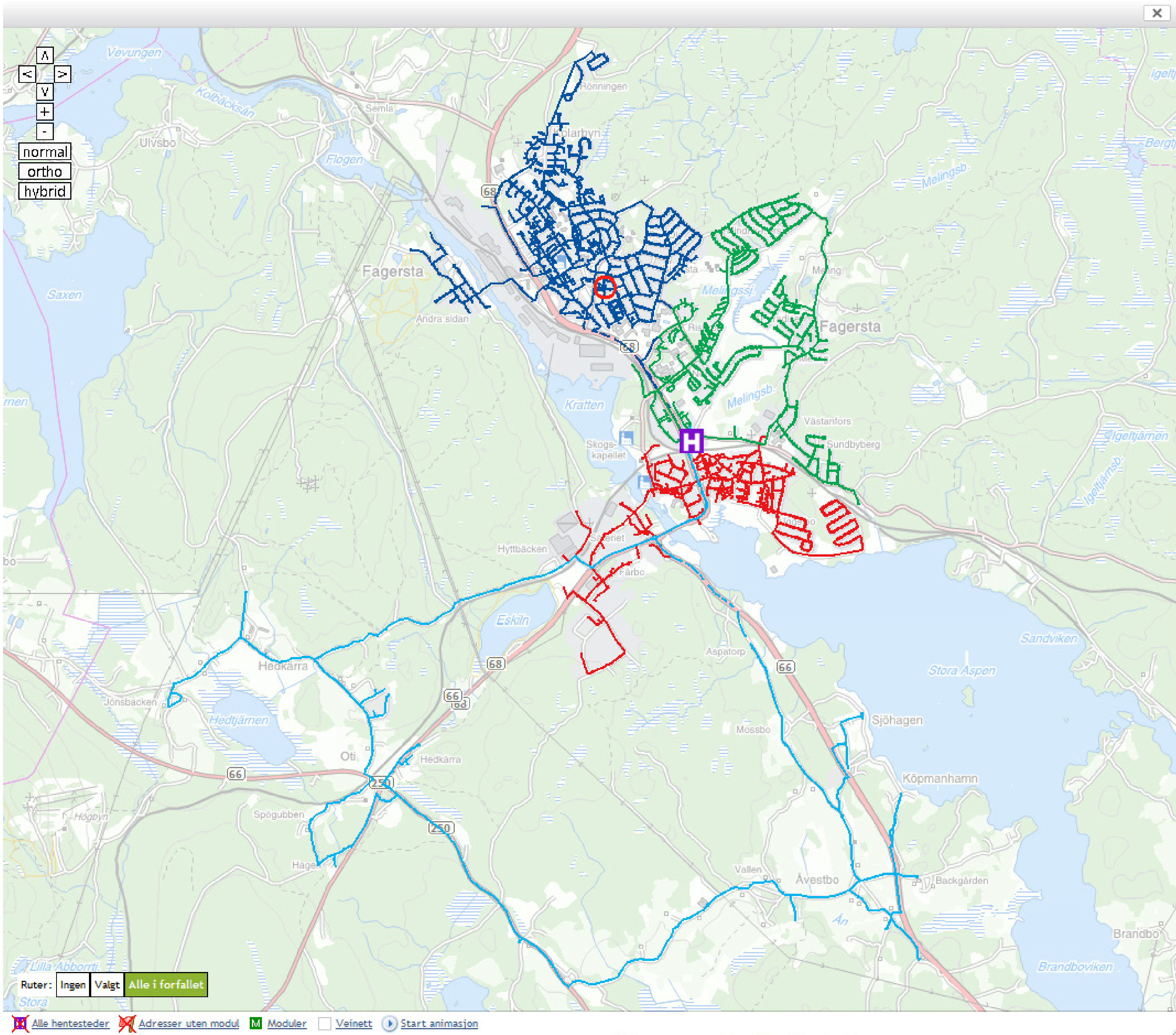
Måltall: LE | LT | OM | RL | TB | D% | LEV | Δ OM | Δ RL

Tidsmodus: Snitt | Man | Tirs | Ons | Tors | Fre | Lør | Søn

Søk

Oversikt | Produksjon | Forfall

	Lev.eff. (lev/min)	Lev.tett. (lev/km)	Omb.tid (min)	Rutelengde (km)	Tidsbuff. (min)	Dekn.grad (%)	Lev. (ant)
Produksjon (3)	1,64	8,9	232 *Σ:695*	42,5 *Σ:127,4*	68	27,7	379,2
Optimering (4)	1,84	10,8	137 *Σ:548*	23,4 *Σ:93,4*		24,8	252,4
Forfall (4)	1,84	10,8	137 *Σ:548*	23,4 *Σ:93,4*		24,8	252,4


normal
ortho
hybrid
Vevungen
Kolbäcksån
Semla
Rönningen
Kolarbyn
Ulvsbo
Flogen
Melingsb.
Bergtjä
Igeltjä
Fagersta
Saxen
Andra sidan
Melingssj.
Fagersta
Kratten
Melingsb.
Västanfors
Sundbyberg
Igeltjärnen
Igeltjärnsb.
Skogs-
kapellet
Hyttbäcken
Färbo
Eskiln
Sandviken
Stora Aspen
Aspatorp
Hedkärra
Jönsbacken
Hedtjärnen
Sjöhagen
Mossbo
Oti
Hedkärra
Köpmanhamn
Spögubben
Högbyn
Hage
Vallen
Åvestbo
Backgården
Ån
Brandbo
Brandboviken
Lilla Abborrt.
Stora
Ruter: Ingen Valgt Alle i forfallet
Alle hentesteder
Adresser uten modul
Moduler
Veinett
Start animasjon

Problem characteristics (1)

- Two-echelon distribution: from printing works to subscriber
- Focus on “last mile” carrier distribution: From drop point to subscriber doorsteps
- Node-based VRP with idiosyncrasies
- Possibly very large number (thousands) of points
- Aggregation -> CARP on a mixed graph (Node Edge and Arc Routing Problem (NEARP))
- Mixture of pedestrian routes and car routes
- Car routes open, pedestrian routes closed (in Sweden: the opposite ...)
- Service time often large part of total time
- Retardation and acceleration
- Alternative pickup points
- Requires detailed road topologies, accurate travel and service time models
- Meandering (“zigzagging”) not allowed for cars (in Norway, they do not care ...)
- Topography, keys, ...

Problem characteristics (2)

- Main objectives
  - cost, closely related to # routes, total duration of routes
  - route balancing (duration), within +/- 10%
  - “visual beauty”
    - non-overlapping routes
    - compact routes
- Constraints
  - route duration
  - # routes
  - meandering, topography, keys, ...

Relevant literature

- Multi-objective VRP
  - Jozefowiez et al (2008) Multi-objective VRP. Survey, some 70 references
- Route balancing
  - Tsouros et al. (2006): Routing-Loading Balance Heuristic Algorithms for a Capacitated Vehicle Routing Problem
  - Jozefowiez et al. (2007): An evolutionary algorithm for the vehicle routing problem with route balancing
  - Pasia et al. (2007): Solving a Bi-objective Vehicle Routing Problem by Pareto-Ant Colony Optimization
  - Borgulya (2008): An algorithm for the capacitated vehicle routing problem with route balancing
- Visual beauty
  - Lu & Dessouky (2005): A new insertion-based construction heuristic for solving the pickup and delivery problem with time windows
  - Hao & Miller-Hooks (2006): Interactive Heuristic for Practical Vehicle Routing Problem with Solution Shape Constraints
  - Matis (2008) DSS for the street routing problem
- Route balancing and visual beauty
  - Kim et al. (2005): Waste collection vehicle routing problem with time windows
  - He et al. (2009): Balanced K-means Algorithm for Partitioning Areas in Large-Scale Vehicle Routing Problem

Approach (1)

- Main idea: create a solution with the desired structure
  - duration balance
  - visually appealing (compactness, non-overlapping)
- Simple
- Fast
- New construction heuristic: “Clusterer”

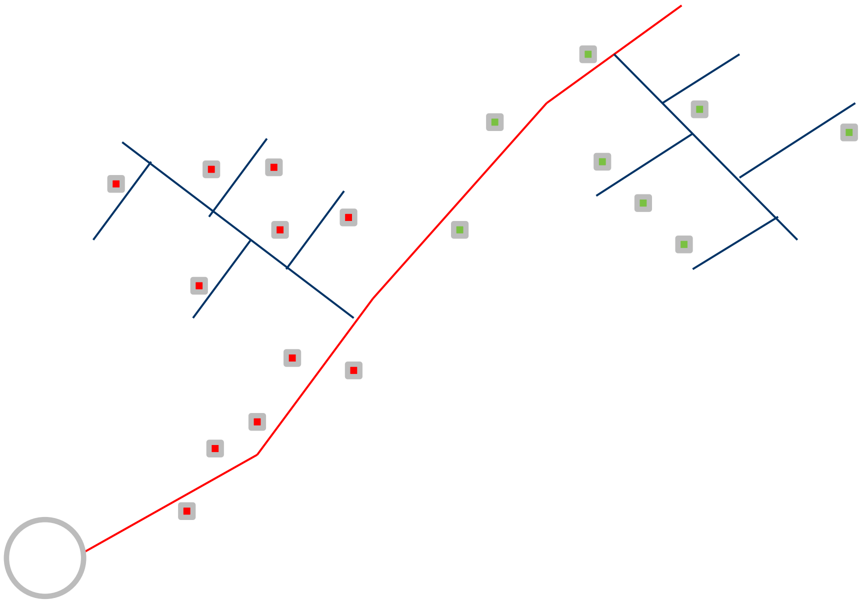
- Continuation with “standard” machinery

Approach (2)

- Estimate # routes needed
- Solve balanced capacitated (duration) clustering problem
  - Modified K-means algorithm
  - Fast TSP solver to find duration of each cluster (2-opt, relocate)
- Restart with better # routes
- After-burner: Intra-route optimization (3-opt)

- Possibly: Further iterative improvement
  - constraints on deterioration of balance and beauty

Road topology challenges



- Central road from depot to clusters
- Orders on central road may be serviced by any route without extra costs
- Makes the optimizer very proficient at creating overlapping routes and destroying existing clusters when running without cluster objective.
- “No meandering”: travel cost varies with direction

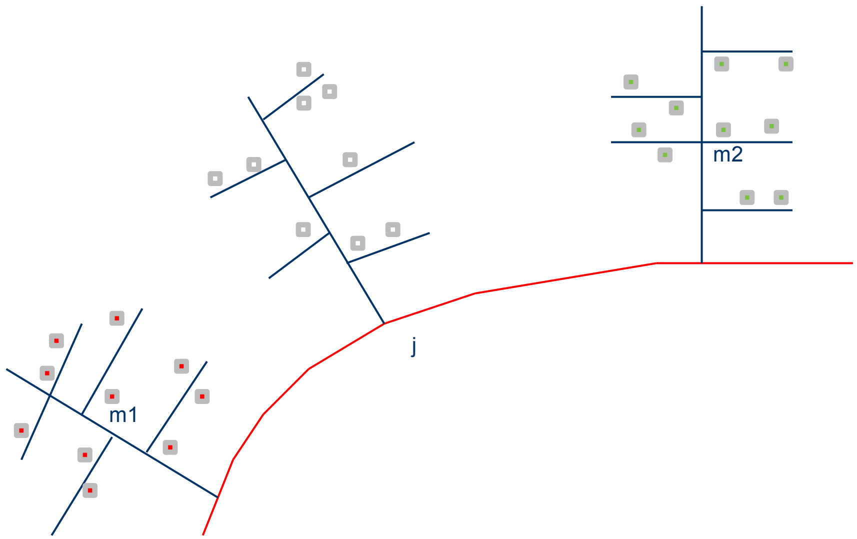
K-means algorithm

1. Select a random location as first centre m_1^0
2. For each additional cluster $i = 2 \dots k$ pick the location furthest away from previously selected centres $m_0^0 \dots m_{i-1}^0$ and make it centre for this cluster, m_i^0
3. $t = 0$
4. Assign each location to the cluster who has the closest centre, i.e. cluster can be expressed as:
$$C_i^t = \left\{ \{ x_j : \|x_j - m_i^t\| \leq \|x_j - m_{i^*}^t\| \ \forall i^* \in \{1 \dots k\} \right\}$$
5. Update each centre to new centroid:
$$m_i^{t+1} = \frac{1}{\|C_i^t\|} \sum_{x_j \in C_i^t} x_j$$
6. $t = t + 1$ and go back to step 4 until $C_i^{t+1} = C_i^t \ \ \forall i \in \{1 \dots k\}$

Adaptations to our problem

- Cluster center: closest location to centroid (Euclidean distance)
- Non modified K-means to generate a (unbalanced) starting solution
- Estimate cluster size (duration) with simple and quick TSP heuristic
- Balance routes by introducing an offset o_i^t when assigning locations to cluster:
  $C_i^t = \left\{\{x_j : \|x_j - m_i^t\| - o_i^t \leq \|x_j - m_{i^*}^t\| - o_{i^*}^t \ \forall i^* \in \{1 \ldots k\}\right\}$
- Modify offset for the most unbalanced cluster
- Normal K-means when balance is stable
- Terminate on timeout or balance ok and estimated durations feasible

Road topology balancing problem



- 2 clusters, splitting of the middle branch
- Travel through junction *j* regardless of whether we come from centre m_1 or m_2
- All orders have same difference in distance to centre m_1 and m_2
- All orders in middle branch assigned to same cluster depending on offsets

- Solution: use a linear sum of travel distance and Euclidian distance

Minimizing number of routes

1. e_r lower bound, total service time of all orders versus available time on tours
2. Find plan e_r number of tours
3. If the plan with e_r tours is not feasible, set e_r to new estimate (increase with minimum 1) for how many tours are needed and go back to step 2
4. If the plan can be feasibly clustered with this number of routes, then calculate slack to estimate how many tours can be saved and subtract this number (or minimum 1) from e_r and go back to step 2
5. Terminate at step 3 or 4 when $e_r - 1$ tours are infeasible but e_r tours are feasible

Experimental results

- 2%-30% improvement of cost
- Better balance
- Good clustering
- No “bad” cases (imbalanced, ugly), reported so far

Further work

- Iterative improvement
  - Inter-route operators
  - Limit on deterioration of balance and beauty
  - Beauty hard to quantify
- Parallelization
- Research on (stylized) NEARP
  - LB
  - New heuristics
  - New instances based on industrial data
  - NEARP extensions
    - Distance
    - Balance
- Large DCVRP instances …

Conclusions

- Construction / revision of home delivery routes very complex
  - large size
  - multiple criteria
  - idiosyncratic constraints
- Rich Node, Edge, and Arc Routing Problem
- Duration constraints
- Minimize total duration (economy)
- Route balance and “visual beauty” very important
- Clustering-based method works well
- 2-30% reduction of costs relative to manual plans
- Route plans more balanced and prettier
- Drastic reduction of time and manpower for revision

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