A Review of Food Accessibility Measures and Decision Support Models

Franseira Maldonado[1], Laila Cure Ph.D. [1], Aaron Bowen[6], Nikki Keene Woods Ph.D. [2], Ajita Rattani Ph.D. [3], Twyla Hill Ph.D. [4], Rhonda Lewis Ph.D. [5], Janet Twomey Ph.D.[1]

[1]Industrial, Systems and Manufacturing Engineering, [2]Public Health Sciences, [3]Computer Science, [4]Sociology, [5]Psychology, [6]University Libraries

WICHITA STATE UNIVERSITY

INTRODUCTION

Background

- Diet was reported to cause 11 million deaths in 2017.[1]
- The food environment has been found to be a key factor in individuals' diet. [2]
- Around 23.5 million people live in **food deserts**, i.e., areas with low access to appropriate food. [3]
  - ➥ Malnourishment
  - ➥ "Substitution effect": inexpensive, energy-dense foods replace healthier foods [4],
    - ➥Increasing Body Mass Index (BMI)
      - ➥Increases chances to develop chronic diseases. [5]

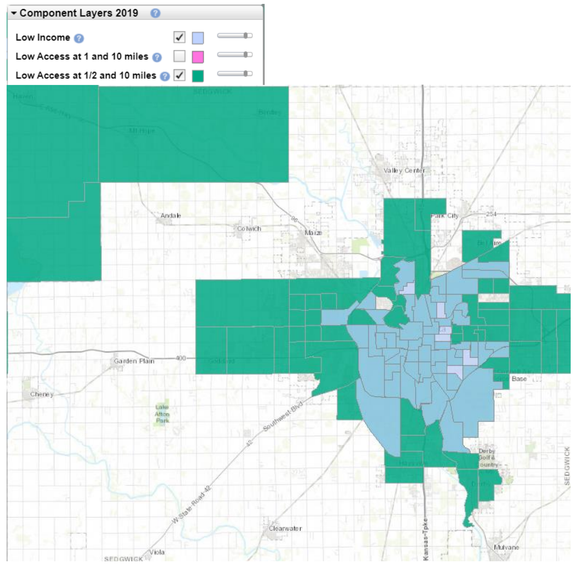

Figure 1: Food Deserts in Sedgwick County [6]

- Interest in food access research has increased over time.
  - Developing methods to measure food accessibility
    - Simple measure used by USDA
    - Many measures proposed by researchers
  - Assessing disparities
  - Evaluating novel policies
- Industrial and Systems Engineers use results of assessments and data to support actionable decisions.

OBJECTIVES

To review published articles involving measures or models of food accessibility to identify:

- Actionable decisions to improve food accessibility that have been studied through mathematical models
- Metrics and models used to measure food accessibility

METHODS

- Systematic review
- Databases: PubMed, CINAHL, ProQuest Nursing & Allied Health Source, Consumer Health Complete, Scopus
- Keywords: {models, statistical} AND {food access, food proximity, food desert, food insufficiency, food insecurity, food security, supermarkets}

RESULTS

Search Results

- Records from database: 81; records from other sources: 23; duplicates: 6; screened: 98; excluded after review: 32; included: 54.
- Reasons for exclusion: qualitative discussion about food desert terminology, does not include quantitative accessibility measure, focus on act of eating, focus on food acceptance/choice, focus on nutrition, among others.

Notation:

Parameters defined by analysts:

δ: radius of analysis around a consumer

τ: time of the day

$\mathcal{F}$: factors other than spatial accessibility

ω_f: weight of factor $f \in \mathcal{F}$

Consumers and food outlets:

$\mathcal{I}$: set of consumer points, indexed by i

$\mathcal{C}$: set of classes of food outlets (healthy/unhealthy, large/small, free/paid, brand, etc.), indexed by c

$\mathcal{J}$: set of food outlets, indexed by j. $\mathcal{J}_c \subset \mathcal{J}$ is the subset of food outlets of type/class c

$\mathcal{M}$: set of transportation modes considered, indexed by m. $\mathcal{G}$: Geographical movement data

Parameters obtained from data:

d_{ij}: measure of distance between points i and j.

s_{ij}: binary parameter, $d_{ij} \leq \delta$ ($s_{ij} = 1$) if not ($s_{ij} = 0$)

r_i: probability of consumer point not having a vehicle

p_i: size of the consumer point i

p_{ij}: subpopulation that commutes between locations i and j

h_j: binary indicator of healthy options ($h_j = 1$) or not ($h_j = 0$)

o_{jt}: binary indicator of a food outlet being open at time t

y_{fi}: value of factor f corresponding to consumer point i

Decisions and Models

Mathematical Optimization

Optimal location of food outlets

- Mobile markets [7]
- Independent grocers [8]

Computer Simulation

Evaluating potential impact of behavior-changing policies

- Ensuring that consumers use farmers markets as the preferred shopping location when available
- Changing some infrequent shoppers into weekly shoppers (e.g., transportation support, weekly SNAP benefits)
- Ensuring all convenience stores sell fruits and vegetables (e.g., incentives) [9]
- Increasing the number of bus routes
- Improving pedestrian infrastructure to increase willingness to walk
- Increasing the number of grocery stores [10]

Accessibility Measures

Table 1: Methods to Assess Food Accessibility

Measure name	Equation
Nearest outlet	$A1 = \min_{j \in \mathcal{J}} d_{ij} = d_{i[1]}$
Diversity	$A7_i = \frac{A1_i\|_{\mathcal{J}_{brand\ 1}} + A1_i\|_{\mathcal{J}_{brand\ 2}} + \cdots + A1_i\|_{\mathcal{J}_{brand\ r}}}{3}$
Inaccessibility measure	$A14_i = \sum_{i \in J} d_{i[1]}\, r_i p_i$
Dichotomous	$A2_i = \begin{cases} 1 & \text{if } A1_i \leq \delta \\ 0 & \text{otherwise} \end{cases}$
Efficient Access to food retailers at time t	$A13_{it} = \bigcup_{j \in \mathcal{J}} \pi \delta^2 s_{ij}$
n-1-n measure	$A4_i = \sum_{m \in \mathcal{M}} \sum_{i' \in \mathcal{I} \setminus \{i\}} p_{ii'm}(1 - A2_{im})(1 - A2_{i'm})$
MRFEI	$A8_i = \frac{\sum_{j \in \mathcal{J}} s_{ij} h_j}{A3_i}$
Density of the 3 nearest outlets	$A9_i = d_{i[1]} + d_{i[2]} + d_{i[3]}$
Density	$A3_i = \sum_{j \in \mathcal{J}} s_{ij}$
GIS-based MCDM	$A6_i = \omega_0 A2_i + \sum_{f \in \mathcal{F}} w_f y_{fi}$
n-n-n measure	$A5_i = \frac{\sum_{m \in \mathcal{M}} \sum_{i' \in \mathcal{I} \setminus \{i\}} p_{ii'm}\, S(i, i', m)}{\sum_{m \in \mathcal{M}} \sum_{i' \in \mathcal{I} \setminus \{i\}} p_{ii'm}}$
Potential accessibility index	$A10_i = \sum_{j \in \mathcal{J}} \mathrm{f}(d_{ij})$
Commuter potential accessibility	$A11_{ii'} = (A10_i + A10_{i'}) \cdot \left(1 - \gamma(d_{ii'})\right)$
Network-based TGDE	$A12_i = \sum_{j \in \mathcal{J}} \lvert\mathcal{G}\rvert^{-1} \sum_{g \in \mathcal{G}} \hat{\mathrm{f}}(x_{ij})' s_{jj'} O_j$
Super Market Interaction Potential	$A15_i = \sum_{i'} p_{ii'} \frac{\sum_{j=[1]}^{[5]} SMIP_{ii'j}}{n}$

- Consumer's perception of food access has also been examined. Surveys are performed asking qualitative questions about their personal experience with food access.

DISCUSSION AND FUTURE RESEARCH

Conclusions

- Food security has many dimensions, one of which is accessibility.
- There are documented disparities in food accessibility
- Food accessibility studies do not include preference of consumers (appropriateness of food resources)
- Food accessibility research focuses most heavily on assessment and measurement methods
- There are different ways in which accessibility can be measured
  - The most appropriate depends on the use of the resulting information
- Most available data and assessments are at the census tract level, which generalizes individual behaviors
  - Assessments and models reflecting individuals' behaviors and preferences are needed.
- Published research involving explicit decision-support is limited.
  - Focused only on the accessibility objective
  - Generalizes individuals over geographical areas
- Despite the number of studies, food security, and food accessibility, is still a problem in most places.

Opportunities

Related to models reviewed:

- Grocers and other food vendors can use existing modeling techniques to support facility location decisions that consider accessibility, along with other organizational, and community objectives
- Policy-makers can collaborate with system modelers to evaluate the potential effects of policies.
  - Rule out non-promising solutions
  - Identify most promising areas to further explore

Other opportunities:

- Identify other resource allocation decisions commonly made by grocers, communities, and policy makers that can be solved through data-driven and systems modeling techniques.
- Explore the impact of aggregated decisions on individuals and how individual-based data can be used in better support higher-level decisions.

REFERENCES

1. Hobbs, M., Mackenbach, J. D., Wiki, J., Marek, L., McLeod, G. F. H., & Boden, J. M. (2021). Investigating change in the food environment over 10 years in urban New Zealand: A longitudinal and nationwide geospatial study. *Social Science and Medicine*, *269*. https://doi.org/10.1016/j.socscimed.2020.113522
2. Maguire, E. R., Burgoine, T., Penney, T. L., Forouhi, N. G., & Monsivais, P. (2017). Does exposure to the food environment differ by socioeconomic position? Comparing area-based and person-centred metrics in the Fenland Study, UK. *International Journal of Health Geographics*, *16*(1). https://doi.org/10.1186/s12942-017-0106-8
3. Bao, K. Y., & Tong, D. (2017). The Effects of Spatial Scale and Aggregation on Food Access Assessment: A Case Study of Tucson, Arizona. *Professional Geographer*, *69*(3), 337–347. https://doi.org/10.1080/00330124.2016.1252271
4. Cheung, H. C., Shen, A., Oo, S., Tilahun, H., Cohen, M. J., & Berkowitz, S. A. (2015). Food insecurity and body mass index: A longitudinal mixed methods study, Chelsea, Massachusetts, 2009-2013. *Preventing Chronic Disease*, *12*(8). https://doi.org/10.5888/pcd12.150001
5. Alviola, P. A., Nayga, R. M., & Thomsen, M. (2013). Food deserts and childhood obesity. *Applied Economic Perspectives and Policy*, *35*(1), 106–124. https://doi.org/10.1093/aepp/pps035
6. USDA Economic Research Service, ESRI. For more information: https: //www.ers.usda.gov/data-products/food-access-research-atlas/documentation
7. Widener, M.J., Metcalf, S.S. & Bar-Yam, Y. Developing a Mobile Produce Distribution System for Low-Income Urban Residents in Food Deserts. *J Urban Health* **89,** 733–745 (2012). https://doi.org/10.1007/s11524-012-9677-7
8. Yang Bao, K., Tong, D., Plane, D. A., & Buechler, S. (2020). Urban Food Accessibility and Diversity: Exploring the Role of Small Non-Chain Grocers.
9. Widener, M. J., Metcalf, S. S., & Bar-Yam, Y. (2012). Developing a mobile produce distribution system for low-income urban residents in food deserts. *Journal of Urban Health*, *89*(5), 733–745. https://doi.org/10.1007/s11524-012-9677-7
10. Abel, K. C., & Faust, K. M. (2020). Modeling complex human systems: An adaptable framework of urban food deserts. *Sustainable Cities and Society*, *52*. https://doi.org/10.1016/j.scs.2019.101795