UN Sustainable Development Goals
Contents

• Two ABW cases
  1. Optimizing food supply chain
  2. Optimizing hospital locations

• ABW-Institute
Optimizing food supply chain WFP
Team that won the Franz Edelman Award 2021

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Introduction to WFP
Hunger Map 2020

CHRONIC HUNGER

If current trends continue, the number of hungry people will reach 840 million by 2030

Prevalence of undernourishment in the total population (percent) in 2017-19
The fact is: there is enough food

- We have a transportation issue

- The United Nations – World Food Programme is supporting 80 Million of the 821 Million beneficiaries

- They ship 4 million metric tons each year!
WFP is active in about 75 countries
Introduction video
Optimization
Core element of success of model

Take also nutrients into account in the supply chain.

Multicommodity min cost flow + Diet model
From source to delivery
From source to delivery

Based on the nutritional requirements of the beneficiaries
The model finds the most cost-effective food basket composition
From source to delivery

Food basket  >  Sourcing

Together with the most efficient sourcing plan
From source to delivery

Food basket > Sourcing > Delivery

And delivery plan from the source
From source to delivery

Food basket > Sourcing > Delivery

Via transshipment points
From source to delivery

Food basket  >  Sourcing  >  Delivery

To the final delivery points
Optimization model

Multicommodity min cost flow

Diet model
Simplified optimisation model [1/2]

**Sets**

- $N$ = Set of Nodes ($i, j \in N$)
- $N_S$ = Set of Suppliers
- $N_P$ = Set of Ports
- $N_W$ = Set of Warehouses
- $N_B$ = Set of Beneficiary Camps
- $K$ = Set of Commodities ($k \in K$)
- $L$ = Set of Nutrients ($l \in L$)

**Parameters**

- $dem_i$ = Number of beneficiaries at node $i \in N_B$
- $hc_i$ = Costs ($^\$/kg) of handling at node $i \in N \setminus N_S$
- $pc_{ik}$ = Cost ($^\$/kg) of procuring commodity $k \in K$ from node $i \in N_S$
- $tc_{ijk}$ = Cost ($^\$/kg) of transporting commodity $k \in K$ from node $i \in N$ to node $j \in N$
- $nutreq_l$ = Nutritional requirements of a beneficiary for nutrient $l \in L$
- $nutval_{kl}$ = Nutritional value (per kg) of commodity $k \in K$ for nutrient $l \in L$

**Variables**

- $F_{ijk}$ = Amount (kg) of commodity $k \in K$ sent from node $i \in N$ to node $j \in N$
- $R_k$ = Ration size (kg) of commodity $k \in K$
Simplified optimisation model [2/2]

\[
\min_F \sum_{i \in N_{S},j,k} p_{c_{ik}} \cdot F_{ijk} + \sum_{i,j,k} t_{c_{ijk}} \cdot F_{ijk} + \sum_{i,j,k} h_{c_{j}} \cdot F_{ijk}
\]

Such that:

1. Flow is preserved
   \[\sum_{i} F_{ijk} = \sum_{i} F_{jik}, \quad \forall j \in N_{p} \cup N_{w}, \forall k \in K\]

2. All beneficiaries receive a food basket
   \[\sum_{i} F_{ijk} \geq dem_{j} \cdot R_{k}, \quad \forall j \in N_{B}, \forall k \in K\]

3. Nutritional requirements
   \[\sum_{k} nutval_{kl} \cdot R_{k} \geq nutreq_{l}, \quad \forall l \in L\]

4. Flows and Rations are non-negative
   \[R_{k}, F_{ijk} \geq 0, \quad \forall i \in N, j \in N, k \in K\]
Extensions of the simplified model (1)

- Multiperiod
- Seasonal price windows / season basket
- Different beneficiary types
  - Adults / children / pregnant women / …
- Ration differentiation by location
- Cash Based Transfers
- Cash / Commodity Vouchers / Value Vouchers
- Donor restrictions
## Extensions of the core model (2)

- **Palatable restrictions**

<table>
<thead>
<tr>
<th>Food Group</th>
<th>Min rat (g/p/d)</th>
<th>Max rat (g/p/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals &amp; Grains</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Pulses &amp; Vegetables</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td>Oils &amp; Fats</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>Mixed &amp; Blended Foods</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>Meat &amp; Fish &amp; Dairy</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>

- **International / Regional / Local**

- **Different and multiple objectives**

- **Dietary diversity score, development, agility (e.g. max lead time)**
Software: Optimus

Can be accessed online, allows users to interact with data from a wide range of sources in order to optimize their operation.
Applications and Benefits
Application to Iraq - 2015

500,000 beneficiaries per month - 6.57 million USD per month

With the new food basket:

- Save 17% of the total costs: 1.12 million USD per month
- Or supply 85,000 more beneficiaries
Application to Syria - 2016

We could show that there are food baskets possible of:
- 96.0% nutritional value at 74% of the cost
- 97.5% nutritional value at 85% of the cost

The first option is chosen by WFP in Syria for 2016 and therefore, with the same budget, we can feed 1 Million people more than the 4 Million in 2015!
Application to El Nino crisis

Sourcing strategy

- EU: Nutributter, Plumpy Doz, Plumpy Sup, Soya Bean Oil, Split Yellow Peas, CSB+, CSB++
- Asia: 25% Broken Rice, Canned Fish, High Energy Biscuits, Micronutrition Powder, Palmolen Oil
- Africa: Cow Peas, Iodised Salt, Micronutrition Powder, Pigeon Peas, Red Beans (Small Kidney), CSB+, Plumpy Sup, White Maize, White Maize Meal

Mexican White Maize
Argentina White Maize
International
Regional/Local
Hospital location optimization in Timor-Leste
Timor-Leste
Find optimal locations of new hospitals

... maximize number of people that can reach a hospital within 5 kilometers travel distance.
Reachability of health care is important

There is a direct link between the distance patients must travel and the reduction of illness and suffering in a country.

If health facilities are located close to patients instead of far away, they tend to use them more.

The distance factor is especially significant in rural Third World settings.
GEOSPATIAL PLANNING & BUDGETING PLATFORM

This interactive site allows users to examine key spatial layers related to facility location, road network consolidations, population distribution, administrative boundaries, risk layers (e.g., flooding), and satellite imagery.

- TIMOR-LESTE BASIC HEALTH CARE ACCESS
- VIETNAM STROKE VICTIM HEALTH CARE ACCESS
Necessary data layers

- Beneficiaries
- Currently located hospitals
- Potential hospital locations
- Road network
Merging road networks

Combining OSM and eStrada. This is very usefull.
Problem: they have overlap, but with different coordinates

• Resulting in roads being included twice in the dataset

• Roads don’t have the exact same coordinates, but refer to the same road
Optimization model

• Uncapacitated facility location model
• Mixed integer linear optimization model
• Large problem: 15,000 possible locations, 40,000 household locations
• Solver: Gurobi
• Time: < 1 minute
Number of existing facilities: 344

82.7% for a distance of 2 KM
58% for a distance of 5 KM

No. of Health Facilities

% of coverage for households

Distance in KM

Blue line: 2
Red line: 5
Ermera

Households within 2 kilometers (green) or 5 kilometers (green + blue) from existing hospitals
Ermera

Add 5 hospitals, 2km travel distance

Add 10 hospitals, 2km travel distance
Stroke Centers in Vietnam
- existing (blue)
- new (red)
UN Sustainable Development Goals
ABW - Institute

- Impactful projects
- Worldwide seminar series
- Repository
- Academy
- Scientific journal
- Courses in Bachelor and Master Programs
Thank you!

Acknowledgement: Several of the slides are (adapted) from slides made by Hein Fleuren and Koen Peters.
Optimization of dike heights
Optimization of radiotherapy
Optimization Brachytherapy
Analytics for Zero Hunger
Investment infrastructure Timor Leste
Optimal Locations UN Humanitarian Response Depots
Optimizing feed for cattle for small farmers

Total FeedCalculator users

3107

Source: FeedCalculator website
Optimizing blood supply chain in NL

Source: Sanquin website
Thank you!

Acknowledgement: Several of the slides are (adapted) from slides made by Hein Fleuren and Koen Peters.
Comparing procurement costs of a flexible basket to a fixed basket plan

Scenario: The price of Peas increases by 30 percent regionwide in month 2
When prices rise, the flexible food basket adapts to be most cost-effective

**Scenario:** The price of Peas increases by 30 percent regionwide in month 2

<table>
<thead>
<tr>
<th></th>
<th>Month 1</th>
<th>Month 2</th>
<th>Procurement Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed basket</strong></td>
<td>$0.56</td>
<td>+30%</td>
<td>$11.07 / beneficiary / month</td>
</tr>
<tr>
<td><strong>Flexible basket</strong></td>
<td>$11.07</td>
<td></td>
<td>- $0.56 / beneficiary / month</td>
</tr>
</tbody>
</table>

*Procurement Cost: $11.07 / beneficiary / month - $0.56 / beneficiary / month*
When prices rise, the flexible food basket adapts to be most cost-effective

**Scenario:** The price of Peas increases by 30 percent regionwide in month 2

<table>
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<td>$ 11.07 / beneficiary / month</td>
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</table>

- $ 0.56 / beneficiary / month
Extensions for future

• Take flooding into account
Extensions for future

• Where should roads be added or improved to improve hospital accessibility?
Extensions for future

- Use the tool for other kinds of facility locations, e.g. schools
Extensions for future

- Apply to other countries:
  - Vietnam: Stroke & Heart Attack centres
  - Nepal: Covid-19 test centres
Mathematical Model

Hospital location optimization in Timor-Leste
The goal is that as many people as possible are able to reach a healthcare facility within a preset maximum travel distance.

**Step 1:**
Define the variables needed for the model.
Variables & Parameters

Sets
\[ I = \text{Index set of households, } i = 1, \ldots, n \]
\[ J = \text{Index set of all hospital sites, where indexes } j = 1, \ldots, m \text{ are corresponding to the already existing hospitals and indexes } j = m + 1, \ldots, M \text{ are corresponding to potential hospital locations} \]

Parameters
\[ v_i = \text{the number of people in household or cluster of households } i \]
\[ d_{ij} = \text{travel distance from household (or cluster) } i \text{ to hospital facility } j \]
\[ S = \text{the maximum travel distance from a household to a hospital} \]
\[ p = \text{the number of additional hospitals located} \]

Variables
\[ x_j = \begin{cases} 1 & \text{if hospital } j \text{ is opened} \\ 0 & \text{otherwise} \end{cases} \]
\[ y_{ij} = \begin{cases} 1 & \text{if demand at node } i \text{ is served by hospital } j \text{ and } d_{ij} \leq S \\ 0 & \text{otherwise} \end{cases} \]
Step 2: Define the objective of the model
Objective

- The goal is that as many people as possible are able to reach a healthcare facility.
- We maximize the number of people that are served by a healthcare facility.

\[ \max \sum_{i \in I} \sum_{j \in J} v_i y_{ij} \]
Step 3:
Define the constraints of the model
Optimization model

\[ \text{max} \sum_{i \in I} \sum_{j \in J} v_i y_{ij} \]

Such that:
1. The already existing hospitals are included in the model as opened
   \[ x_j = 1 \quad \forall j = 1, ..., m \]
2. The number of hospitals additionally opened is at most \( p \)
   \[ \sum_{j=m+1}^{M} x_j \leq p \]
3. Only assign people to a facility if that facility is opened
   \[ \sum_{i \in I} y_{ij} \leq nx_j \quad \forall j \in J \]
4. People can only be assigned to one hospital
   \[ \sum_{j \in J} y_{ij} \leq 1 \quad \forall i \in I \]
5. People are not served by a facility if the travel distance to the facility is higher than the maximum travel distance
   \[ y_{ij} = 0 \quad \forall i \in I, \forall j \in J, d_{ij} > S \]
6. The decision variables are binary
   \[ x_j, y_{ij} \in \{0,1\} \quad \forall i \in I, \forall j \in J \]