**How long 'til we get there, Mom?'**
**Modeling travel time to markets and its application in analyzing flood impacts on transport**

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## Executive Summary

The Humanitarian Information Unit (HIU) refined an existing analytical model and applied it to the Horn of Africa (HOA) in order to answer questions concerning market access from a regional perspective, travel time to market (TTM) in cross-border trade, and the catchment areas of key markets[*]. The results of the analyses are closely related to anecdotal information on travel times and reported impacts of localized phenomena. We conducted three analyses of market access:

Three test analyses were conducted for market access travel time: first for nine major capital cities and ports; second for 43 key cities and town; and third for the impact of heavy flooding on regional access.

The first analysis revealed overall travel times to capital cities and key ports to be, not unexpectedly, closely related to terrain considerations and the availability of all-weather roads. The analysis of capital cities and key ports revealed extensive market catchment areas for Somali locations that extended deep into Ethiopian territory, a significant implication for addressing livestock trade in Somali ethnic areas, as well as for the development of regional trade policies in the HOA.

The second analysis revealed overall travel times to 43 major cities and towns. The results from this analysis were similar to the first, but demonstrate a more detailed market network. This market network may be considered as a secondary level where goods are collected from smaller towns and the countryside for transshipment to the key markets described in the first analysis.

In the third, applied analysis, we considered a case that looked at the impacts of heavy flooding in the region in November-December 2006. This analysis conveyed an adjusted interpretation of market access impact based on a travel time analysis that showed that travel routes were affected well beyond the actual geographic extent of the flooding.

Looking ahead, the model has potentially broader applications in addressing humanitarian emergencies. For example, it can be used to consider the impacts of ethnic population composition and distribution on trade, the identification of optimal transportation routes for the transport of relief supplies, as well as the movement of populations and livestock herds as a result of climatic or other events. Such a representation may reflect linkages between tribes and clans as well as the ongoing or residual impact of ethnic conflict. The model can also be easily modified for other regions beyond the HOA given adequate data for analysis.

These market analyses were an outgrowth of the HIU's Mission to the HOA (October 9 to November 2, 2006) to conduct an information needs assessment related to the pastoralist crisis affecting the Greater Mandera Triangle region. The full report and annexes, issued in January

[*] The market "catchment areas" describe the zones of influence for major markets whereby travel within the zone are always toward the market within that zone.

2007, containing various products is available on the HIU website. Click on: http://hiu.state.gov/index.cfm?fuseaction=public.display&id=28a1096f-fe9b-447e-9bcb-2b931320de5c.

**Rationale**

Trade is recognized as a key factor in mitigating shocks to livelihood systems and sustaining post-conflict stabilization policies. Efforts to improve trade can be enhanced through an effective analysis of transportation costs. Studies by members of the Consultative Group for International Agricultural Research have shown that travel time is an effective means for estimating the cost and efficiency of marketing strategies.

Current and proposed USAID activities have, as one of their aims, increased trade and the promotion of trade policy, including through the support of such organizations as the Common Market for East and Southern Africa (COMESA). IFPRI has performed market access analyses for Ethiopia and has a mandate to do so on a regional basis, focusing on market access for domestic trade, but no comprehensive analysis of market access has been performed for the Horn of Africa region as a whole. The tool developed here will aid in planning optimal routes to markets. In addition, it is useful for logistical planning of relief efforts.

**Analytical Questions:**

- How can we measure the overall accessibility to markets in the Horn of Africa (Ethiopia, Eritrea, Somalia, Djibouti, and Kenya)?
- What are the effects of localized phenomena in terms of time to market in cross-border trade?
- What are the market catchments of key ports and metropolitan centers for livestock in the Horn of Africa?

**The Analytical Model**

The HIU refined a model developed by the Centro Internacional de Agricultura Tropical (CIAT) and the International Food Policy Research Institute, that has been employed in a number of instances in Africa as well as used to demonstrate the impacts of Hurricane Mitch on market access in Honduras. This model uses data describing terrain, road conditions, and related barriers to transport to estimate travel time between any point in the area of analysis and key market cities. HIU used the logic of the CIAT model and applied it in the ModelBuilder component of ARCGIS 9. Further refinements were made in calculations and through the addition of a "drag" function in calculating the effects of slope on travel time.[**]

We present three analyses of travel time to market below: two that describe general models of market access for the Horn of Africa and one that describes the effects of a major flood event in the region. It is anticipated that the primary constraints to market access will be road conditions, distances to markets, and barriers created by localized events. The effect of barriers will be evaluated by varying the friction values at border crossings and elsewhere. Transit time across border checkpoints also presents a significant constraint, but is not included in the analysis. Access to markets will be determined according to three classes of markets that are defined by population, or by pre-determined market classifications.

[**] The slowing effect of slope is not linear. Rather, the slowing effect of slope increases at an increasing rate as slope increases, thus we have developed a "drag" function to account for this effect.

## Initial Analyses – General Models of Market Access

An initial map of access to key port cities and metropolitan centers was developed. Access was largely determined by road coverage. In this case, only primary and secondary roads were considered due to the lack of a consistent data set on tracks and trails. The Cost Allocation function in ArcInfo allowed market catchment areas for these locations to be identified. Both are shown in Figure 1.

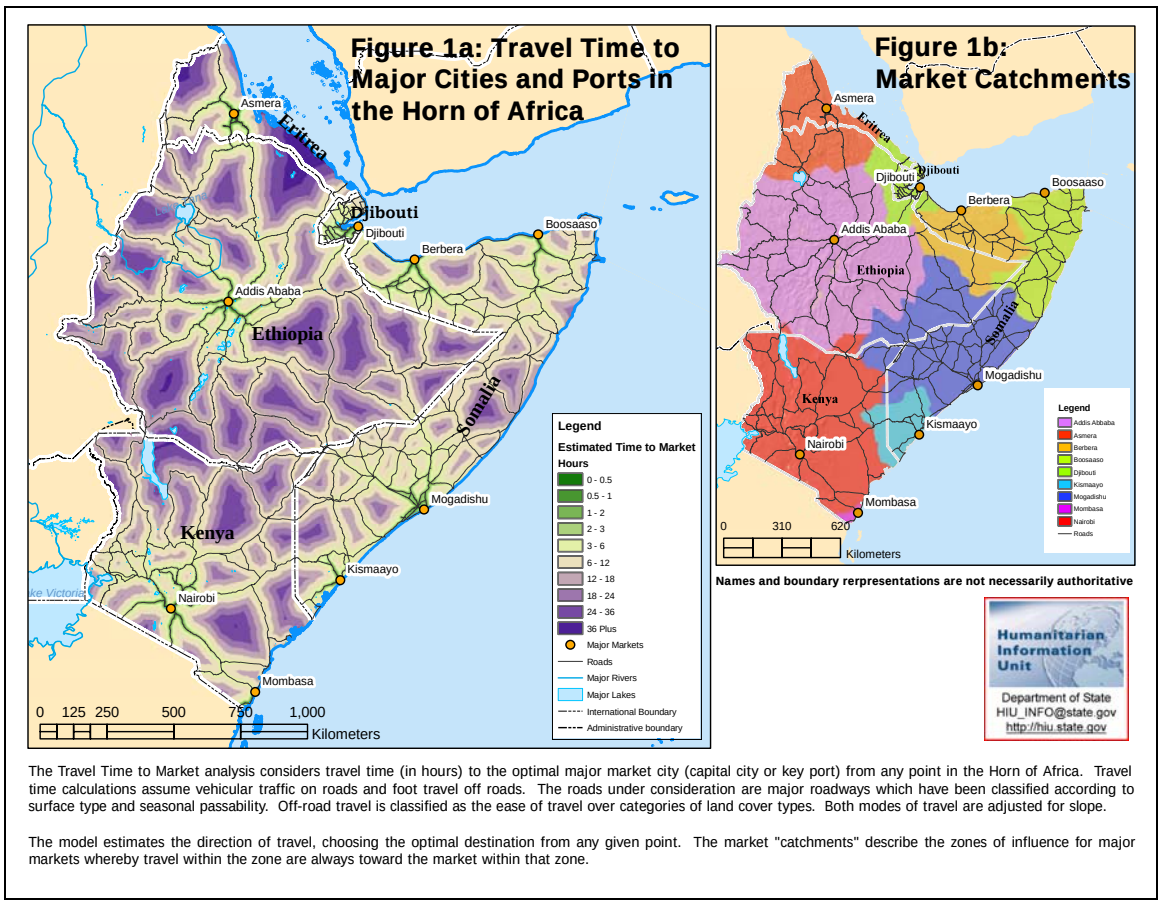


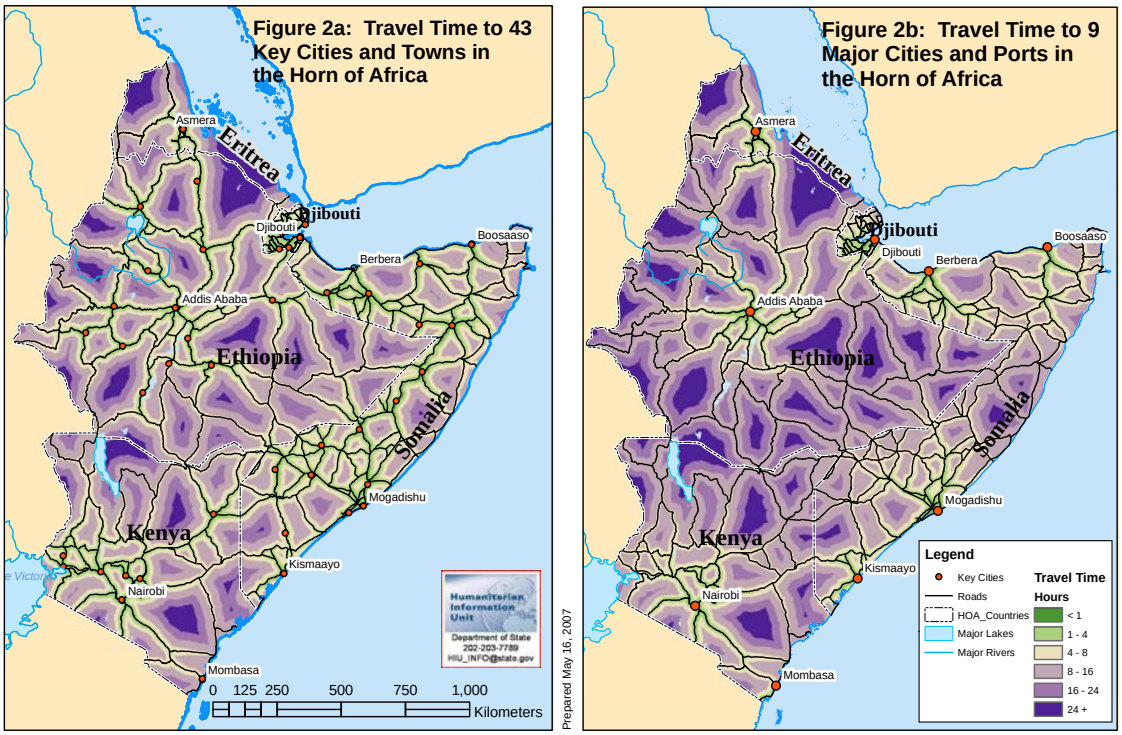

***Figure 1.*** **Travel time to capital cities and major ports in the HOA and their representative catchment areas.**

*Interpreting the maps:* The travel time to market from any point to the optimal major market city or town assumes that travel is by vehicle on roads and by foot off roads. The analysis only considered terrestrial travel to the exclusion of river and air transportation. The model assumes that an individual may consider a number of destinations, but will choose to travel to the market destination that is closest in terms of the time it takes to arrive at a given market; represented in terms of hours in this analysis (Figure 1a). Other than the population size of the city, the comparative economic strength of the pull of one particular market compared to another is not considered. Destinations close to target locations and those along major roads require considerably less travel time than areas not served by roads or distant from market towns and cities. For example, areas in the interior of Ethiopia require considerable travel time because of terrain and the quality of connecting roads. Similarly, because effective roads are absent in

southeastern Eritrea, travel times are very long. Conversely, because road data are more detailed for Djibouti, all areas are effectively reached within that country in a relatively short period of time.

A second product of the analysis determines the optimal directions of travel to target locations. The boundaries described by this product allow us to determine the broad catchment areas of key markets. In Figure 1b, we see that Addis Ababa has an extensive market catchment area for most of Ethiopia while Mogadishu and Berbera have extensive inland catchments that extend into eastern Ethiopia. The areas of these catchments would likely be affected by consideration of border crossings which delay or impede movement across borders, but this was not considered in this analysis. The effective result of our analysis shows that significant cross-border trade is possible between Ethiopia and its neighbors if regulations would allow for free transit across borders and delays due to customs control would be reduced or absent.

We developed a second model and map of travel time to a greater number of cities and towns in the region. This map depicts 43 key markets in the region. We identified these distinct towns based upon NGA unclassified map data (VMap0). Greater accuracy in depicting markets could be obtained from a more detailed set of market towns from regional market studies that identify the importance of markets based upon trade factors rather than solely by population. The effects of increasing the number of markets in the analysis can be seen by comparing the new map to the original. Both are shown below (Figures 2a and 2b).



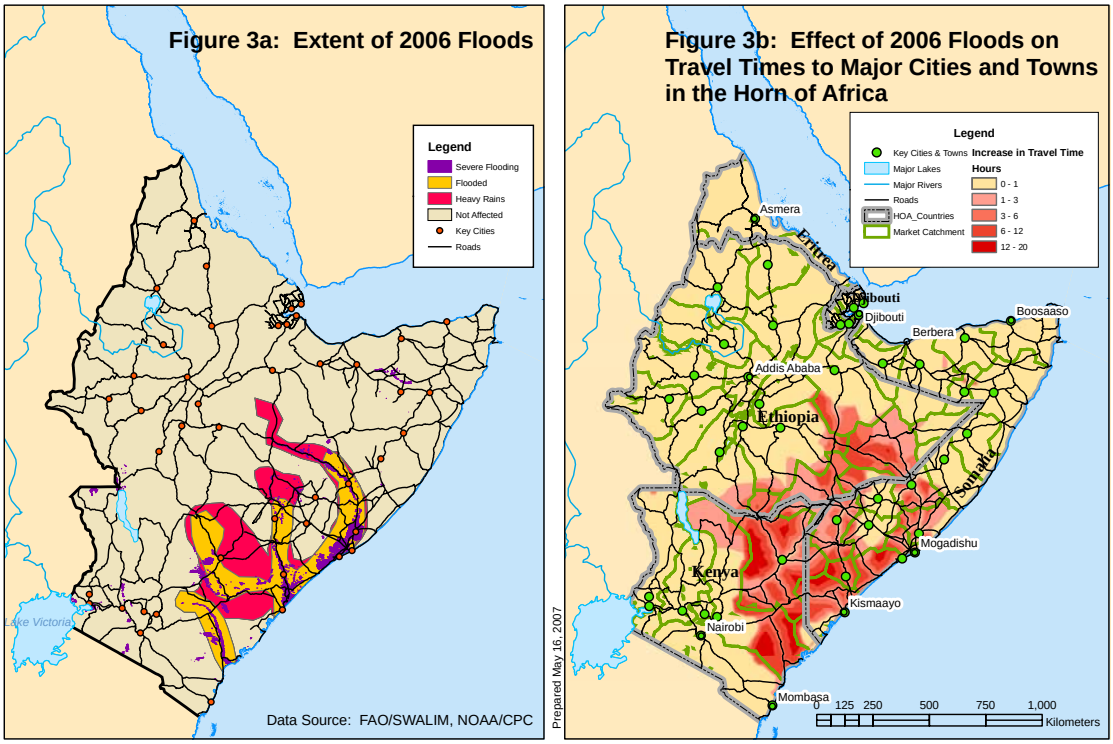

The travel time to market analysis considers travel time (in hours) from any point to the optimal major market city or town (in the left-hand map) or capital city or seaport (in the right-hand map). Travel time calculations assume vehicular traffic on roads and foot travel off roads. The roads under consideration are major roadways which have been classified according to surface type and seasonal passability. Off-road travel is classified as the ease of travel over categories of land cover types. Both modes of travel are adjusted for slope. The model estimates the direction of travel, choosing the optimal destination from any given point.

***Figure 2.*** **Representation of travel time to cities in the HOA.**

*Interpreting the map:* These maps show that overall travel time to primary markets is reduced, as expected, when a larger set of towns and cities is considered. These two maps, or a modified version thereof, may be used to identify key market chains that goods may pass through to final destination markets. Such an analysis would further refine the market catchment areas and aid in developing strategies for regional or sub-regional trade strategies. Market strategies for specific population groups that may be spatially bounded, such as clans, could be developed by considering only those areas they occupy and then identifying their optimal real or potential trading routes.

## An Applied Analysis

In the applied case, HIU used maps of areas flooded based upon data from the NOAA Climate Prediction Center (CPC) and the UN Food and Agriculture Organization Somalia Water and Land Information Management System (FAO/SWALIM). These areas are classified into three categories: areas experiencing heavy rains, areas of moderate flooding, and areas severely flooded (Figure 3a). The model was then run incorporating the flooded area classification (Figure 3a). The resulting map was compared to the previous dry-weather map (Figure 2a) resulting in a map showing differences in travel time (Figure 3b).




Travel time was calculated to 43 major cities and towns. Travel time slowed by flooded areas was also calculated. The dry season travel time was subtracted from the flood travel time to show areas in which travel was delayed as a result of floods. The principal reason for these delays was due to limited access to the normal city destinations from points normally attracted to these cities. The analysis shows that the areas with limited access from floods was much greater than the area that was physically flooded.

***Figure 3.*** **Representation of the effects of floods on travel time.**

*Interpreting the map:* When we compare the map of the inundated areas in Figure 3a to the map of areas where travel time was affected (Figure 3b), we see that the extent of the effects on accessibility was considerably greater than the actual geographic extent of flooding. There are several reasons for this, compounding the problem of travel within isolated inundated areas being already difficult, if not impossible, because of standing water and washed out roads. Residents outside of the inundated areas may have been forced to choose a market that took longer to reach because their normal destination was unreachable due to flooding. Furthermore, travel along non-flooded roads may have been slowed due to congestion, resulting in longer travel times to market. From this we can see that floods have an immediate physical effect from inundation as well as a more extensive effect on lengthened travel times even though flooding may not have occurred in the particular location where a population resides.

The most severe floods in recent history had a significant impact on many portions of southeastern Ethiopia, southern Somalia, and eastern Kenya as heavy rains in November and December of 2006 produced floods that killed nearly 200 people and placed the livelihoods of nearly 1 million people at risk. The floods severely damaged infrastructure and destroyed household assets across the affected region. Nearly a dozen administrative districts experienced flooding in the three countries. Relief was hampered by washed out roads and bridges, particularly those providing access to refugees and displaced persons in camps near the Somali border in Kenya and Ethiopia.

The impacts of flooding were greatest in eastern Kenya, southern Somalia, and southeastern Ethiopia. The highest reductions in accessibility are associated with poor roads in flooded areas, many of which are seasonal roads and impassible during heavy rains. The disruption of travel in flood-affected areas had a two-fold impact: areas were isolated from their usual market destinations and people were unable to move or transport goods. Further, overland relief to the region was delayed or impossible due to flooded roads. The World Food Program's Vulnerability Assessment Methodology Unit (VAM) produced an update on road conditions as they existed in November 2006 which corresponds to the impacts as predicted from the model for Kenya.

**Further Applications:**

This model is highly flexible in its application and variants of the model have been applied in a range of cases, including determining access to health care services, the relationship of market access to poverty, and identifying development planning priorities. Several direct applications of the model would prove useful in addressing development and relief efforts in the Horn of Africa: modeling market linkages in livestock trade within the region, analysis of the impacts of ethnic conflict on trade, and looking at the impacts of drought on herd movements. All of these would require some level of modification of the model and would depend upon expert knowledge of conditions in the field.

HIU will be able to apply this model in other regional and national settings as well. Since the model is not designed for any one specific area or scale – i.e. it can be applied on a regional, national, or local level – the analyses can be combined with other factors in looking at impacts and trends in the evolution of complex humanitarian emergencies. Such analytical capabilities may be applied by other relief and development organizations as well.

The model can be enhanced by including the use of cross-border delays at customs posts, improved consistent and detailed roads data, and the use of higher-level land classification systems such as those employed by the FAO-funded Global Land Cover Network.

An appendix is attached to this report that describes the process of calculating time to travel. The appendix provides step-by-step instructions on how to develop such an analysis, which may be applied in any geographic setting. The overall model, which is available as a file operating in ArcGIS v. 9, is presented as a summary.

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**Bibliographic Resources:**

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Juliano, R.P., (1996). Measuring accessibility using GIS. New University of Lisbon.

Kam, S.P. et al. (2002). "Analyzing and mapping accessibility in Cho Don District, Bac Kan Province, Vietnam." Paper presented at GIS Day 2002, Manila, Phillippines.

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**Technical Appendix on Methodology**

The following discussion of Market Access is a measure of the ease of access to key markets, usually in terms of travel time to market (TTM). It may also be measured in terms of travel costs when such cost structures are known. The Centro Internacional de Agricultura Tropical (CIAT), IFPRI and the Humanitarian Information Unit have used a common model for determining market access based upon TTM. This model is geospatially based and uses the following geo-spatial data:

- Slope derived from elevation
- Road speeds based upon a road network classified according to their characteristics
- Land cover
- Administrative boundaries
- Other natural barriers such as rivers

The model used in the access analysis is based upon a model developed by the Centro Internacional de Agricultura Tropical (CIAT), which has been applied in Central America and adapted for use at the national level by the International Food Policy Research Institute in Ethiopia and Uganda. This model is based upon the use of friction layers that determine travel speed attenuated by slope. The result of the model describes the time it takes to reach key locations along optimal paths. Computations have a spatial resolution of one kilometer.

The ModelBuilder tool in ArcInfo version 9 Spatial Analyst provides a robust format for developing models of the complexity that access analysis requires. It provides a graphic interface that allows the analyst to "map" out the processes involved and to create documentation as well as providing a platform from which to run the model. Models developed in ModelBuilder are saved as tools in the ArcInfo Toolbox and can be used for other applications elsewhere (assuming the user has the proper licenses to run the various tools incorporated in the model).

The analysis is composed of seven steps, with the input of geo-spatial data describing land cover, road characteristics, slope, and key locations. A generalized scheme of the process is shown in Figure 1.

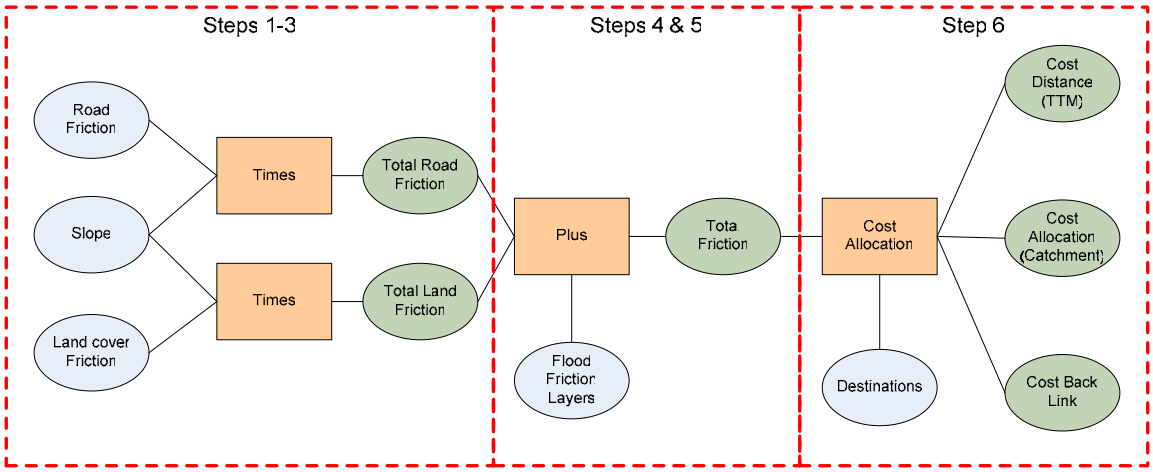


***Figure 1.*** **Generalized model of the Travel Time Model.**

*Step 1: Slope Layer Creation*

The Slope Layer is derived from a topographic model based upon Shuttle Radar Telemetry Mission (SRTM) elevation data. Slope for the region was calculated in degrees and then converted to radians providing slope values between zero and one.

The effect of slope on travel time is exponential rather than linear. Thus, the friction (*f* in the diagram below) is attenuated by the exponentially increasing "drag" as slope values increase. In order to demonstrate this, the radian slope value is increased to a power of pi (3.1416). The total slope factor is then given as

(1) $$S = 1 + \theta^{\pi}.$$

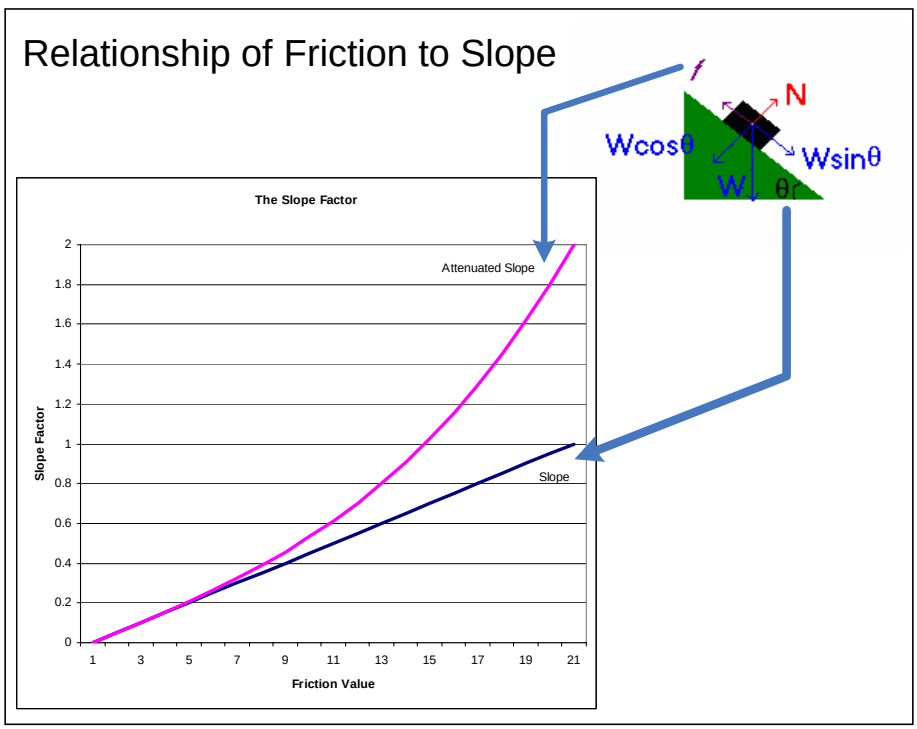


***Figure 2.*** **Graphical representation of attenuated slope effect on travel speed.**

*Step 2: Road Friction Layer Creation*

Road friction is based upon classifications of road types in the region. Three road classes are defined according to whether or not the road is paved and whether or not it is an all weather or fair weather road. Travel speeds (specified in kilometers per hour) for these three classes were

assigned based upon previous applications of the model and from experience in traveling in the region. The model assumes that for roads, travel will always be in a vehicle and truck speeds were applied. In the raster representation, a value of zero is applied to rasters off roads in order to eliminate duplications in the calculation of off-road speeds.

**Table1.** ***Road quality classification scheme.***

| Road class | Speed (Km/h) |
|---|---|
| Paved/All Weather/Primary Road | 100 |
| Unpaved/All Weather (Secondary) | 75 |
| Unpaved/All or Fair Weather | 50 |
| Unpaved/Fair Weather | 25 |
| Off-road | 0 |

Friction calculations require that larger values indicate higher levels of friction. Road speed is therefore converted into the number of minutes required to cross one kilometer of road.

*Step 3: Land Cover Friction Layer Creation*

Travel speed off roadways depends upon the nature of the land cover found in the region. We use a land-cover map developed by the University of Maryland and based upon an Africa-wide land cover map developed by the US Geological Survey was used. This map has 13 classes of land cover, twelve of which occur in the Horn of Africa. Each class was assigned a walking speed based upon the estimated ease of passing through each class, essentially based upon vegetation density. Two walking speeds were determined: 4 km/h for open areas and 3 km/h for densely vegetated areas or swamps. Additionally, roads were depicted on the map with a value of zero, assuming that no foot travel occurred on roadways (all road travel speeds are determined by the roads layer). The friction values were converted to minutes per kilometer as in the case of the Road Friction Layer.

*Step 4: Total Friction Calculation*

Having separately defined friction values for roads and land cover types, the two layers were combined to represent travel time based upon walking speeds off roads and truck travel speeds on roadways. A Total Friction Layer was then created as the product of the attenuated slope layer and this combined friction layer. In this way, travel time was reduced (or increased) as roads and land cover crossed varying degrees of slope.

The mathematical calculation is straightforward, where total friction (*TF*) is the product of travel time and slope:

(2) $$TF = S*(F_{roads}+F_{land\ cover})$$

*Step 5: Optional Addition of Other Friction Layers*

Other friction layers may be applied to the model in order to incorporate effects specific to the type of analysis under consideration. Such barriers may include delays at border crossings, areas isolated due to conflict incidents, or ethnic and socio-economic factors.

As an application, we considered the impacts of floods that occurred in November and December 2006 in Kenya, Somalia and Ethiopia. Flood extents were determined from data provided by NOAA/CPS and FAO/SWALIM. These were classified into three levels of friction, where areas experiencing heavy rain doubled travel time, moderately flooded areas quadrupled travel time and areas of extreme flooding made areas impassable.

Functionally, these values were iteratively multiplied to the Total Friction layer (TF), so that

(3) $TF_{(floods)} = TF * Flood_1 * Flood_2 * Flood_3$

The baseline analysis makes use of a depiction of travel time during the dry season with no barriers. Travel time attenuated further by a depiction of the slowing effects of flooded areas, as was used in this analysis. This depiction is then subtracted from a second depiction of travel time affected by flooded areas as described by the NOAA Climate Prediction Center and the FAO Somalia Water and Land Information System (SWALIM). The SWALIM data are derived from satellite imagery, portions of which are from NGA provided by the HIU. The resulting map depicts areas that have experienced a slowing of travel time to key cities and towns.

*Step 6: Definition of Destination Targets for Travel*

Total travel time requires the specification of destinations, or sources of attraction for travel. The model was run separately for two sets of sources: key markets (43 major cities and towns) and for a smaller set of 9 primary markets (capital cities and key ports).

*Step 7: Accessibility Calculation*

Accessibility is defined as the cost (in terms of time to travel) between any destination (*i*) an any point within the area of analysis (*j*):

(4) $$TC_i = \sum_{j=1}^{k} d_{ij} / k ,$$

Where $TC_i$ is the travel cost index, $d_{ij}$ is the travel cost and the number of points of origin the number of destinations is represented by *k*.

The model uses the Cost Allocation tool in ArcGIS. ArcGIS determines the cost for a path to pass through cells to reach a destination (source in the ESRI lexicon). The total cost to travel horizontally or vertically through a particular cell is the cost assigned to the cell times the resolution, in this case 1,000 meters ($TC=COST*1000$). The diagonal travel cost is the square root of two times cost times resolution ($TC= \sqrt{2} * COST*1000$).

To determine the cost for a path to pass through cells to reach a destination, the cost surface functions are based on the note/link cell representation used in graph theory. Every link has an associated impedance, based upon the friction cost (*TF*) from the friction and slope layers, and the direction of movement through the cells. If the movement is from a cell to one of the four directly connected neighbors, the cost to move across these links to the neighboring node is:

(5) $$TC_1 = \frac{cst_1 + cst_2}{2}.$$

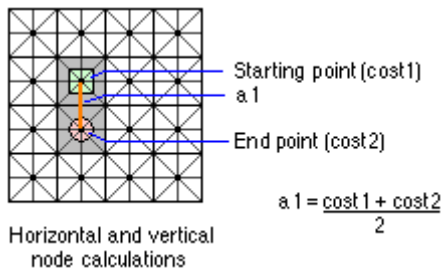


***Figure 3.*** **Initial cost calculation.**

The cumulative cost to move from cell 1 to any destination is determined by

(6) $$TC_i = \sum_{j=1}^{k} cst_{ij} / k$$ **, following** from (4).

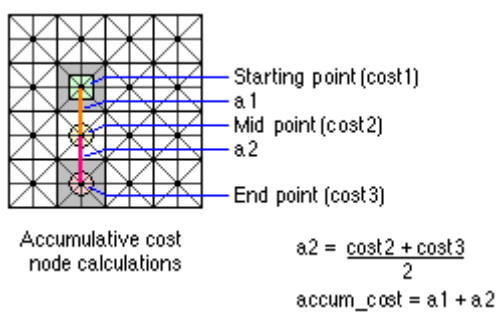


***Figure 4.*** **Iterative cost calculation.**

The Cost Allocation tool provides three outputs: Cost Distance, Cost Allocation and Cost Back Link. The Cost Distance is the travel time to the least costly destination, which is the primary objective of the model. The Cost Allocation is useful in that the market catchment areas of the various destination markets. The Cost Back Link output describes the direction of travel within particular catchment areas and may prove useful in three-dimensional representations of the model.

Since the Cost Distance output is presented in terms of minutes to destination, the result must be converted into hours through a simple mathematical calculation applied to each cell in the area of analysis.

The following is a representation of the full model (Figure 5):

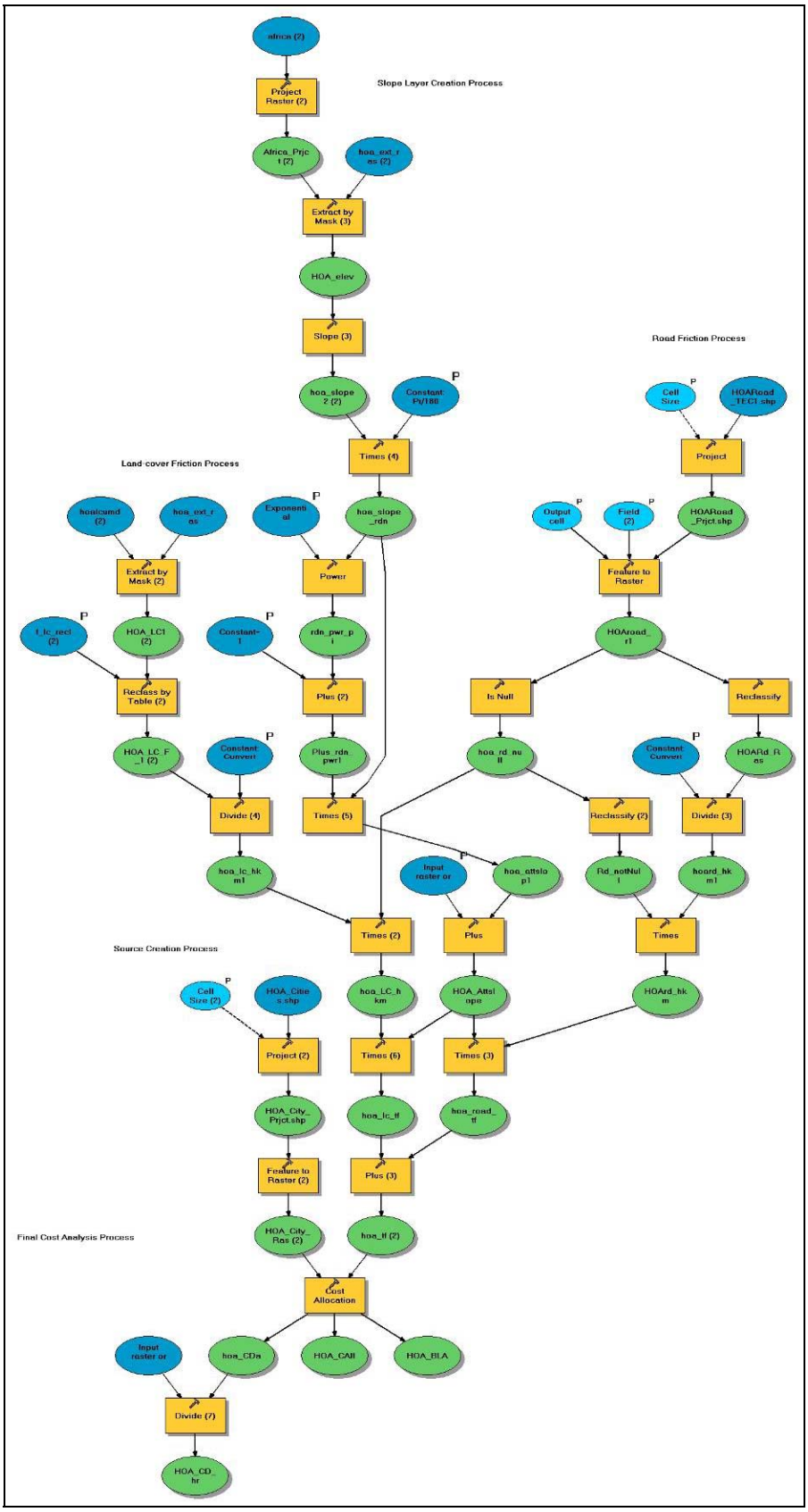


***Figure 5.*** **The general accessibility modeling process.**