The Corridor: Using GIS to Propose Satisfactory Transportation Paths between the West Bank and the Gaza Strip

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Connection between the West Bank and the Gaza Strip is a critical factor in the success of the prospective Palestinian state. Such a connection cannot be guaranteed without providing Palestinians with a transportation path or "corridor" through Israel that includes roads, a rail link, and infrastructure. The Palestinian Ministry of Planning needs a flexible process-modelling tool to propose a range of acceptable ground-based transportation paths between the two territories. The tool's flexibility will be used in the future to modify the weight of each criterion so as to adapt to the terms of negotiations with the Israeli side. This article describes how to use multi-criteria evaluation (MCE) with weighted linear combination (WLC) to create a map of suitability and then shows how this map can be used as friction surface of cost to calculate the least-cost pathways between Gaza's main crossing points and the West Bank's major roads. The article reflects Palestinian-recommended criteria that take into account (1) Israeli city centres that limit where pathways can run, (2) topographical realities for environmental and technical considerations, (3) the existing network of Palestinian main roads for financial considerations, and (4) existing and planned Israeli routes (in order to minimize the number of intersections with such routes). Results present four possible solutions that satisfy all the criteria; the lowest-cost solution is a path that runs south-east from the Erez crossing point of Gaza to Beit Awwa village near Hebron City in the south-west West Bank.

Key words: West Bank, Gaza Strip, the Corridor, multi-criteria evaluation (MCE), suitability map, weighted linear combination (WLC)

Relier la Cisjordanie et la Bande de Gaza est un facteur critique pour le succès du futur État palestinien. Cette connexion ne peut être garantie sans accorder aux Palestiniens un couloir de transport ou un « corridor » à travers Israël, comprenant des routes, une liaison ferroviaire et des infrastructures. Le Ministère du Plan palestinien a besoin d'un outil flexible pour pouvoir proposer une série de couloirs de transport terrestre entre ces deux territoires. La flexibilité de cet outil pourra être utilisée dans le futur pour modifier le poids de chaque critère afin d'adapter le tracé lors des négociations avec les Israéliens. Cet article décrit comment utiliser une évaluation multicritère à l'aide de combinaisons linéaires pondérées pour produire une carte d'aptitude et montre comment une telle carte peut être employée comme une surface de friction de coût, pour calculer le corridor le moins onéreux entre les principaux postes-frontières de Gaza et les routes principales de la Cisjordanie. L'article expose les critères recommandés par les Palestiniens qui prennent en compte 1) la présence des centres urbains israéliens qui limitent les tracés possibles, 2) les réalités topographiques, pour des raisons environnementales et techniques, 3) le réseau existant de routes palestiniennes principales, pour des raisons financières, et 4) les routes israéliennes existantes et programmées, afin de minimiser les intersections avec celles-ci. Quatre solutions satisfaisant tous ces critères sont présentées ; la moins coûteuse est un tracé qui se dirige vers le sud-est depuis le poste-frontière d'Erez à Gaza vers le village de Beit Awwa

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près de la ville de Hébron, dans le sud-ouest de la Cisjordanie.

Mots clés : Cisjordanie ; Bande de Gaza, corridor, évaluation multicritère, carte d'aptitude, combinaison linéaire pondérée

1. Introduction

The Palestinian Ministry of Planning (MOP) is concerned about the lack of a territorial link between the West Bank and the Gaza Strip and is therefore striving to propose a range of acceptable ground-based transportation paths. This article proposes a flexible approach to finding possible solutions by creating a GIS model that is more than a layout tool for analytical sequences. This model can be updated to take into consideration emerging challenges, existing changes, and differing priorities and needs. This analysis is based on the following assumptions:

1 The prospective Palestinian state would be based on the 1967 borders.
2 This work is based on what Palestinian developers have deemed essential criteria for a transportation path.
3 The suitable passage will include a traffic route, a train line, and other lines necessary for electricity, natural gas, telecommunications, water, and so on, as recommended by the Palestinian Ministry of Transportation.
4 The preferred way to construct the passage is by paving a new surface road. Intersections with Israeli routes can occur via interchanges on overhead or underground sections, so that the road does not come into contact with Israeli traffic (Arbel et al. 2001).

Background

The Palestinian Authority, Israel, and the quartet composed of the United States, the European Union, Russia, and the United Nations all support the establishment of an independent Palestinian state on two territories: the West Bank and the Gaza Strip (Agha et al. 2001; Simon et al. 2005). From the Palestinian perspective, many considerations emphasize that the geographic (land) connection between the West Bank and Gaza is the cornerstone of any future Palestinian state's territorial continuity (Sheqaqi et al. 1999; Edwan 2005).

Strategic considerations: The West Bank and the Gaza Strip each has its own distinct importance; at the same time, they complement each other. The Gaza Strip has the only seaports and airports in Palestine; in addition, Gaza borders Egypt and, thus, with the western part of the Arab world and North Africa. The West Bank derives its strategic importance from its borders with the eastern part of the Arab world. Therefore, the geographic connection serves not only Palestinian needs but also the whole region's need to connect east and west (Sheqaqi et al. 1999; Suisman et al. 2005).

Security considerations: The Israeli proposal of open borders is important for economic development, but this proposal contradicts Israeli security policy and will significantly complicate the situation in an unstable political and security situation. On the other hand, full separation between Palestinians and Israelis, with contiguity of Palestinian land, has been proposed as a solution that would minimize Palestinian–Israeli contact (Sheqaqi et al. 1999) and improve the level of security in the region.

Political considerations: The separation between the West Bank and Gaza has created two separate entities with different economic (Kershner 1999), legal, and administrative characteristics (Brown 2005; Simon et al. 2005). For example, the Gaza Strip is influenced by the Egyptian legal system, while the West Bank is more influenced by the Jordanian legal system (Sheqaqi et al. 1999). A geographic connection would contribute to a smooth and rapid integration of the two entities.

Demographic considerations: In May 2006, according to the Palestinian Central Bureau of Statistics, there were about 2.5 million Palestinians living in the West Bank and about 1.5 million living in Gaza Strip,

totalling 40 % of the world's Palestinian population. Another 50 % live in the four neighbouring states (Jordan, Lebanon, Syria, and Egypt), and about 10 % live farther abroad (Simon et al. 2005; Suisman et al. 2005). Considering the Green Line (the 1967 borders) as the borders of the future Palestinian state, the population density of the Gaza Strip is 4 300 persons per square kilometre, more than 10 times as the density in the West Bank (420/km^2). Furthermore, it is expected that the population in the West Bank and Gaza will double in the next 15 years as a result of the combination of natality and immigration (i.e., refugee return; Simon et al. 2005). The high population density in the Gaza Strip highlights the importance of a geographic connection with the West Bank to promote natural immigration from the former to the latter.

Social considerations: There are psychological barriers between the residents of the West Bank and those of the Gaza Strip (Sheqaqi et al. 1999). West Bankers perceive Gazans as poor and less educated, while Gazans believe that they are subject to discrimination and that West Bankers dominate the political, economical, and social spheres (Sheqaqi et al. 1999; Kershner 1999).

Economic concerns: Palestinian economic viability depends in large measure on territorial contiguity (Sontag 1999, A1); it requires that movement of goods among Palestinian territories be as free as possible, so that domestic employment can grow. Furthermore, the link between the Gaza Strip and the West Bank would provide a transportation backbone between the Arab capitals, and especially between Cairo and Amman. Such a scenario would significantly encourage economic development and growth (Simon et al. 2005).

Examining Proposed Solutions

The Israeli-proposed solutions of open borders (Prusher 1999) and safe passages using existing Israeli routes cannot be adopted as a permanent and viable solution in the Permanent Status Negotiations (Arbel et al. 2001). Past experience with the "Safe Passage" of the Oslo II agreement has proved that any Israeli jurisdiction over the passage puts Palestinians under the control of Israelis ("Safe Passage" 2006).

According to article X of the Oslo II Agreement, Israel instituted safe passages between the West Bank and Gaza Strip in 1999. Palestinians using the safe passage had to obtain, in addition to personal and vehicle documentation, a safe-passage card and a vehicle safe-passage permit; they were given a set amount of time to make the journey by bus, by taxi, or in their own vehicles. Palestinians prohibited from entering Israel were able to make the trip in an Israeli-escorted bus operated for seven hours on two days per week ("Framework for Peace" 1995). Palestinians using the safe passage remained subject to strict Israeli control. In 2000 Israel closed the safe passage route, effectively separating the Gaza Strip from the West Bank.

"The Arc: A Formal Structure for a Palestinian State," a project that won an international award in regional and urban design, proposes a model for an integrated physical infrastructure plan for a future Palestinian state (Perman 2006; Suisman et al. 2005; Brown 2005). Its route would go along the eastern outskirts of the main West Bank cities, then south into the Naqab, eventually linking to Gaza. As a concept, the Arc may be useful to highlight Palestinian interests and needs, and to garner international support for more extensive development projects; unfortunately, however, this concept is impractical and would be extremely difficult to implement (NSU 2005).

Representatives of the Negotiation Support Unit (NSU) and the Palestinian MOP met in March 2005 to discuss the Arc concept. Many concerns were raised about this project. Because the project is complicated and fairly detailed, those present at the meeting recommend doing a more extensive study before

making any assessment; they are concerned, however, that the Arc concept as proposed has many weaknesses. In particular, it does not adequately consider development plans for the West Bank and Gaza Strip already created by the Palestinians; the placement of the Arc does not adequately take into account topographical realities; and work on such a large project might divert funding from other Palestinian needs (NSU 2005). This project would take approximately 10 years to build and cost $8.3 billion (Suisman et al. 2005); thus there is a risk that it would be begun and not completed, leaving Palestinians with some sort of partial Arc (NSU 2005).

Developing New Techniques

Because ensuring free and continuous movement between the West Bank and the Gaza Strip is a top priority for Palestinians, this study uses new techniques to make the possibility of negotiating the corridor concept more realistic. The use of geographic information science (GIS) tools is proposed in order to further Palestinian development plans. The attractiveness of the GIS concepts may help Palestinians to gain more support to make the land connection a reality.

This article suggests a flexible process-modelling tool to propose a range of acceptable ground based transportation paths between the two territories through Israel. The MOP and the Negotiation Support Unit (NSU) have specified the following criteria:

1 No path should be within 1 000 m of any Israeli city centre.
2 The farther the transportation paths are from Israeli cities, the better.
3 The location should be on fairly level ground with slopes less than 15 %.
4 The existing Palestinian network of main roads should be used to reduce traffic-related environmental and economic drawbacks.
5 Intersections with Israeli traffic should be minimized.
6 The actual distance travelled should be minimized.
7 The GIS tool should be flexible, so that it can be used in the future to modify the weights of the various criteria so as to adapt to the requirements of negotiation with the Israeli side.

This paper describes how to use appropriate GIS tools for decision-strategy analysis to create a base map of suitability. The non-Boolean standardization technique, which gives each location a value representing its degree of suitability, and the weighted linear combination (WLC) technique of multi-criteria evaluation (MCE), which allows factors to trade off with one another, are applied to create the map (Jiang and Eastman 2000; Bolstad 2005); then the Cost-Grow algorithm of the Cost Distance operator is used, assuming the major existing roads of the West Bank as the features from which cost distances are calculated. The output map of the MCE is a friction surface that indicates the relative cost of moving through each cell. In order to calculate the least-cost pathways from Gaza's main crossing points to the existing major roads of the West Bank, the pathway modeller is supplied with the resulting continuous image of the Cost-Grow algorithm and a raster representation of the main four existing border-crossing points between the Gaza Strip and Israel. The final result is the most satisfactory path that the Corridor should follow in order to incur the least cost (highest suitability), according to parameter values reflecting Palestinian interests and needs. Furthermore, each border-crossing point between Gaza and Israel is separately examined to compare the most desirable ground-based paths. A macro-modeller and a WLC are constructed and saved in IDRISI,[1] to be altered and run instantly with any new values given by Palestinian or Israeli developers.

The data and the Corridor model are presented in section 2 below. Section 3 gives the results of the model for examining Palestinian-recommended parameters, comparing the

output of the acceptable paths with previously suggested solutions, and testing the sensitivity of the factors considered. Section 4 interprets the results and discusses essential modules used in creating the model; section 5 concludes, giving the most important points.

2. Methods

Data Sources

The data used in this study are the best the author could obtain by visiting Ramallah, in the West Bank, in 2006. The Palestinian Ministry of Planning (MOP) and the Central Elections Commission (CEC) supplied vector data of the study area. These data sets contain boundaries (West Bank, Gaza Strip, Israel, and neighbours), bodies of water, Israeli towns, Palestinian roads, Israeli roads, and 5-metre contour lines.

As well, essential criteria and recommendations were collected through background research and via 10 face-to-face interviews and three telephone interviews with Palestinian officials, GIS specialists, and political analysts. It is important to keep in mind that the recommendations used here come from the Palestinian side only. Other important factors, such as land use and highly agricultural areas, are not considered in the analysis, but they could alter the results.

Data Analyses

The 5-metre contour shape file is converted to raster format using ArcGIS tools before being exported to IDRISI as an elevation image. IDRISI offers efficient modules that help create the intended model of acceptable paths. The other sets of spatial data are defined by two different coordinate systems, UTM Zone 36 North and Palestine 1927, that do not have same bounding rectangle. Therefore, they are imported in IDRISI and re-georeferenced to UTM36N, their coordinate positions are redefined to match layers, and then they are converted to raster images of 90-metre resolution to begin the three major steps of the analysis: (1) creating the constraint and factor maps, (2) weighting and evaluating the factors, and (3) calculating the least-cost pathways.

Creating the Constraint and Factor Maps

The recommendations of Palestinian developers and officials are incorporated into the decision-making process. Since the parameters of these recommendations are subject to change, Macro Modeler is used to construct and run the criteria maps. Once the model is saved, it can be altered and run instantly. The first level of Figure 1 illustrates the cartographic model for creating the different constraint and factor maps.

Constraint maps are created to exclude areas that must be avoided in locating the proposed paths. These Boolean images are (1) neighbours other than Israel, (2) bodies of water, (3) steep gradients, and (4) Israeli city centres. They are created by assigning 1 to the codes for Israel, the West Bank, and the Gaza Strip (and 0 to all neighbour codes), reclassing water bodies as 0, reclassing all slopes greater than 15 % as 0, and creating a 1 000-m buffer zone around Israeli city centres.

The major factors affecting suitability for the location are (1) slope, (2) Israeli cities, (3) major Israeli roads, (4) local Israeli roads, (5) internal Israeli roads, and (6) planned Israeli roads. The first factor image is created from the elevation map using IDRISI's surface module, the second from Israeli cities using the distance module, and the rest from Israeli roads using the distance module.

Weighting and Evaluating the Factors

The factors are standardized to a byte-level range of 0–255 using a fuzzy set membership function inversely (0 is the highest suitable, 255 the lowest suitable), as the map of suitability will be used as a friction surface that indicates the relative cost of moving through each cell to calculate the least-cost pathways.

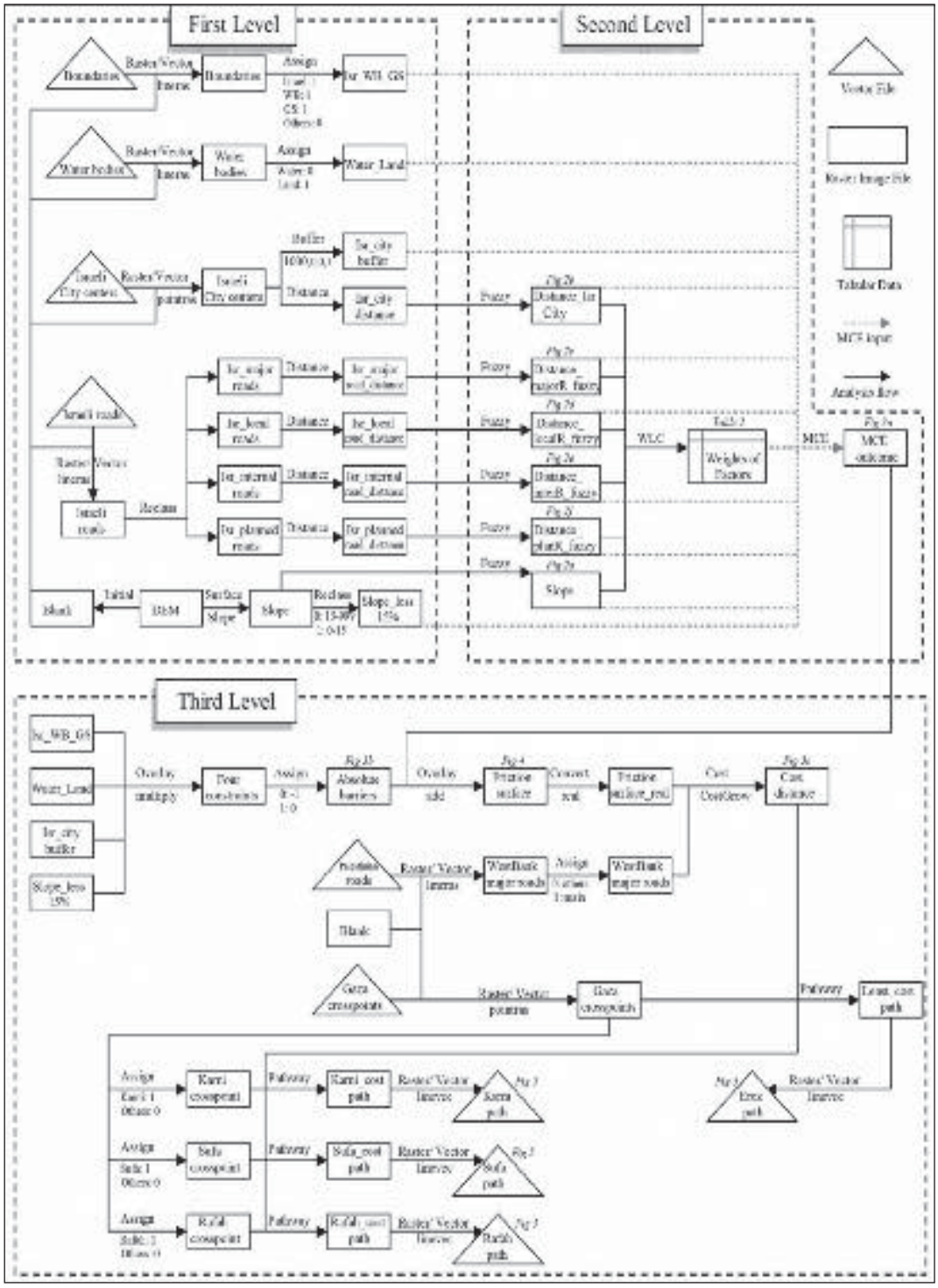

FIGURE 1
The methodological flow of the analysis

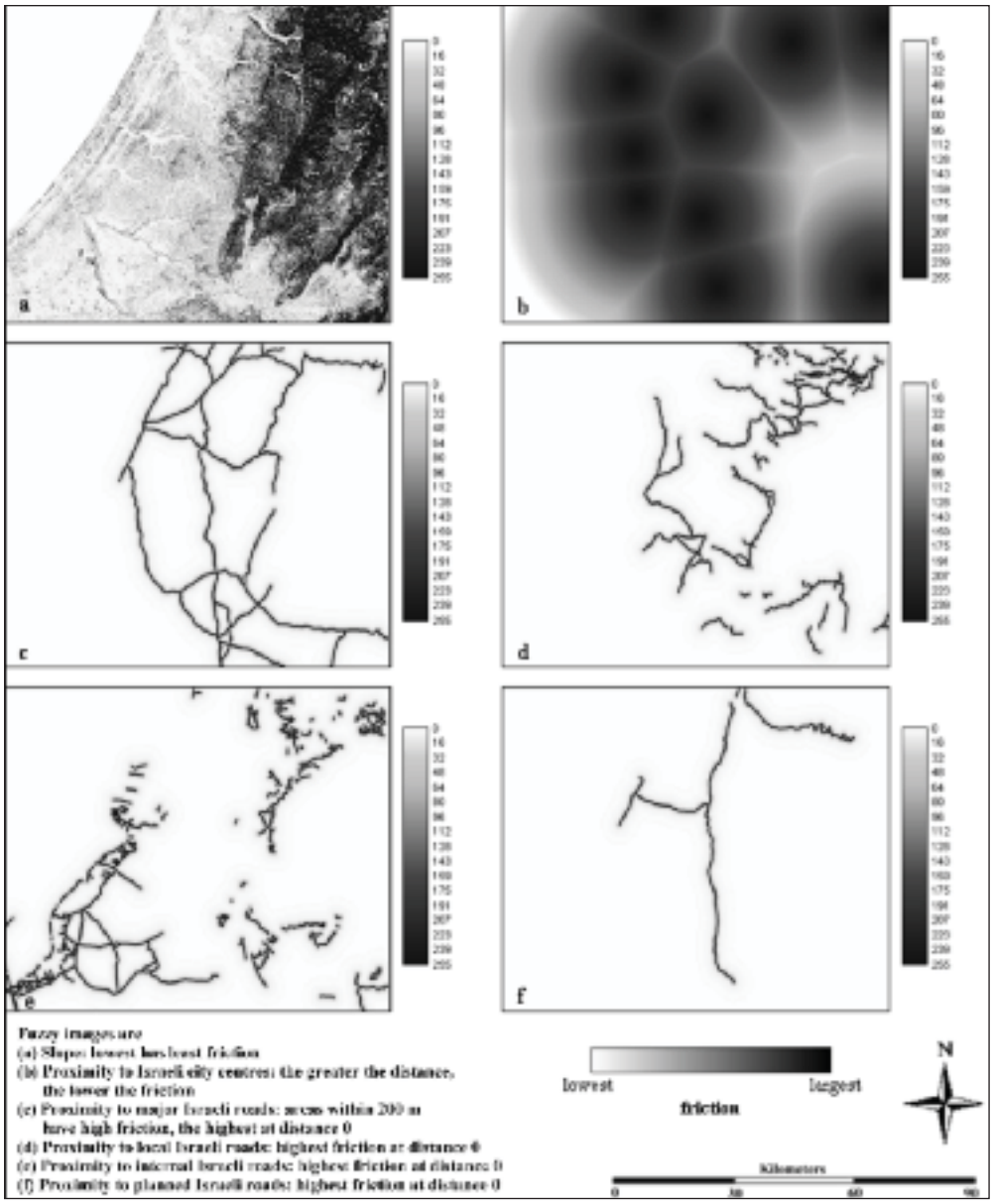

FIGURE 2
Six fuzzy maps are created in order to give each location a value representing its degree of friction in a byte-level range.

The monotonically increasing sigmoidal function is used to rescale slopes to the 0–255 range; the lowest slope creates the least friction, with a score of 0, and any slope above 15 % is highly unsuitable (see Figure 2a).

Measures of relative distance from Israeli town centres are rescaled by choosing the monotonically decreasing linear function to a range of suitability where the greatest-cost distance (Israeli city centres) has the largest friction score (255) and the least-cost distance has the lowest friction score (0), as illustrated in Figure 2b.

To propose paths with a minimum

TABLE 1
A pairwise comparison matrix using the Analytical Hierarchy Process (AHP) 9-point rating in IDRISI

	Distance _Isr_City	Slope	Distance _MajorRoad	Distance _LocalRoad	Distance _InterRoad	Distance _PlanRoad
Distance_Isr_City	1					
Slope	3	1				
Distance_MajorRoad	1/3	1/3	1			
Distance_LocalRoad	1/5	1/5	1/3	1		
Distance_InterRoad	1/7	1/7	1/5	1/5	1	
Distance_PlanRoad	1/3	1/3	1/3	3	5	1

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	equally	moderately	strongly	very strongly	extremely
← less important						more important →		

number of intersections with Israeli routes, areas within 200 m of Israeli routes are identified as having a continuously decreasing suitability that approaches but never reaches 0. This function is described by a decreasing J-shaped curve. The second control point (d) is set at 200 in rescaling the remaining factors: distance from major, local, internal, and planned roads. The fuzzy maps are showed in Figure 2 (c–f).

Another aggregation method, the weighted linear combination (WLC), is used so that the factors can trade off with one another. The weighting procedure is based on the Analytical Hierarchy Process (AHP), the first step of which is to make a judgement on the relative importance of pairwise combinations of the factors involved. In making these judgements, in accordance with the Palestinian recommendations, the AHP-9 point rating scale is used. To provide a systematic procedure for comparison, a pairwise comparison matrix is created by allocating one row and one column for each factor. Rating is then carried out for each cell in the matrix (see Table 1). For example, crossing a local Israeli road is strongly less important than crossing an Israeli city centre. Thus the rating scale used is 1/5. The outcome weights of the factors are given in Table 2.

TABLE 2
Outcome weights of factors from the AHP matrix.

Factor	Eigenvector of weights
Distance_Isr_City	0.3794
Slope	0.2610
Distance_MajorRoad	0.1578
Distance_LocalRoad	0.0647
Distance_InterRoad	0.0284
Distance_PlanRoad	0.1086

Finally, the MCE is performed to combine the constraint maps, the fuzzy factor maps, and the weights to produce the map shown in Figure 3a, which illustrates the friction of each pixel and can be used as a friction surface in the following step.

Calculating the Least-Cost Pathways

Pathway Modeler is used to calculate the least-cost pathways from the existing major roads of the West Bank to Gaza's main crossing points. To use this modeller, two continuous images are prepared by constructing another Macro Modeler, as illustrated in the third level of Figure 1. Cost Modeler calculates distance in terms of suitability cost; the CostGrow algorithm is used because it can work with a complex friction surface, including absolute barriers to movement. To apply this concept of absolute barriers, all constraint maps are combined; then a value of -1 is assigned to all cells of forbidden locations and a value of 0 to the rest, as illustrated in Figure 3b. The combined map is then overlaid on the map

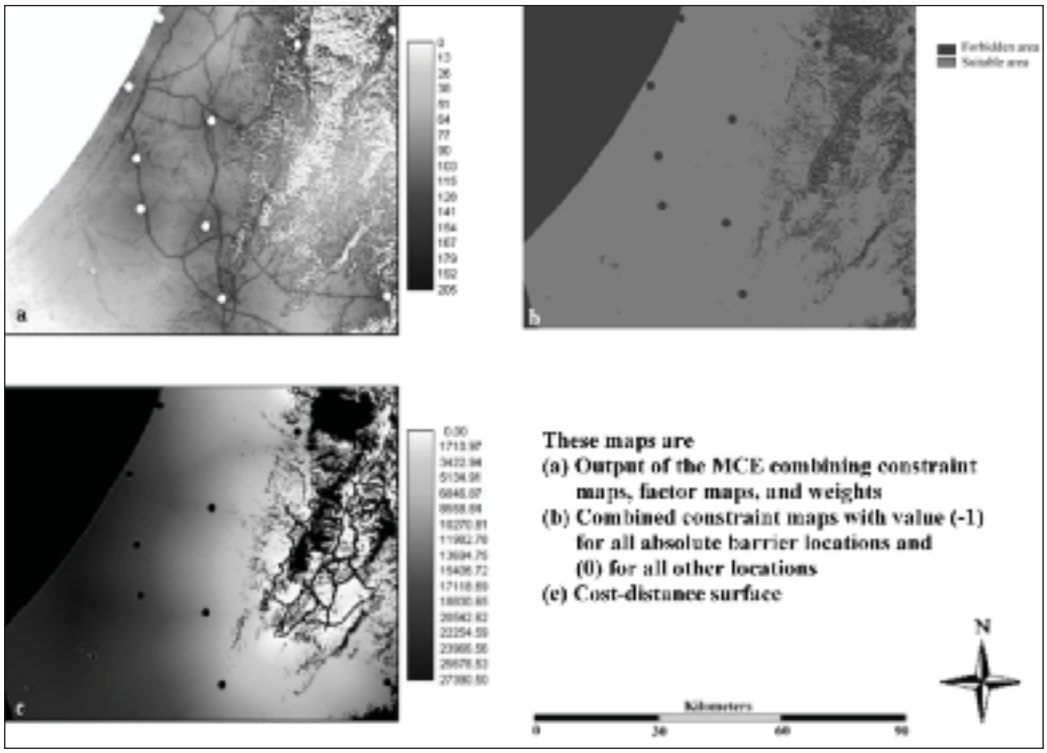

FIGURE 3
Outcome maps of running modules in Macro Modeler

created in the previous step and supplied to Cost Modeler as a friction surface that indicates the relative suitability of moving through each cell (see Figure 4). The raster image of major West Bank roads is supplied to Cost Modeler as a feature image from which cost distances are calculated. The resulting cost-distance image incorporates both the actual distance travelled and the friction effects encountered along the way. Figure 3c illustrates this Cost-Distance surface.

Once the cost-distance surface has been created and the intersections of major Palestinian roads with the Gaza boundary have been created as vector points and rasterized, the Pathway module is used to determine the least-cost routes between Gaza's four crossing points and the nearest major road of the West Bank, from which cost distances are calculated. Since the output of the least-cost pathway is always one path that runs through the pixels with the lowest values, this does not mean that other solutions are not satisfactory. For this reason the other crossing points between the Gaza Strip and Israel are examined, one at a time time, through the Pathway module, using the same cost-distance surface. The full model, combining all these steps to find the most suitable paths, is illustrated in Figure 1. Figure 5 presents these most satisfactory transportation paths, including the least-cost path (Path 1).

Comparison of Path Options

Each outcome of the model is examined to compare the top acceptable ground-based paths. In addition, previous options—the Safe Passage and the Arc—are examined on the same friction surface to make them comparable to the proposed paths. Boolean maps are created for each route and then multiplied by the friction surface. The outcome maps are reclassed such that off-route cells have the

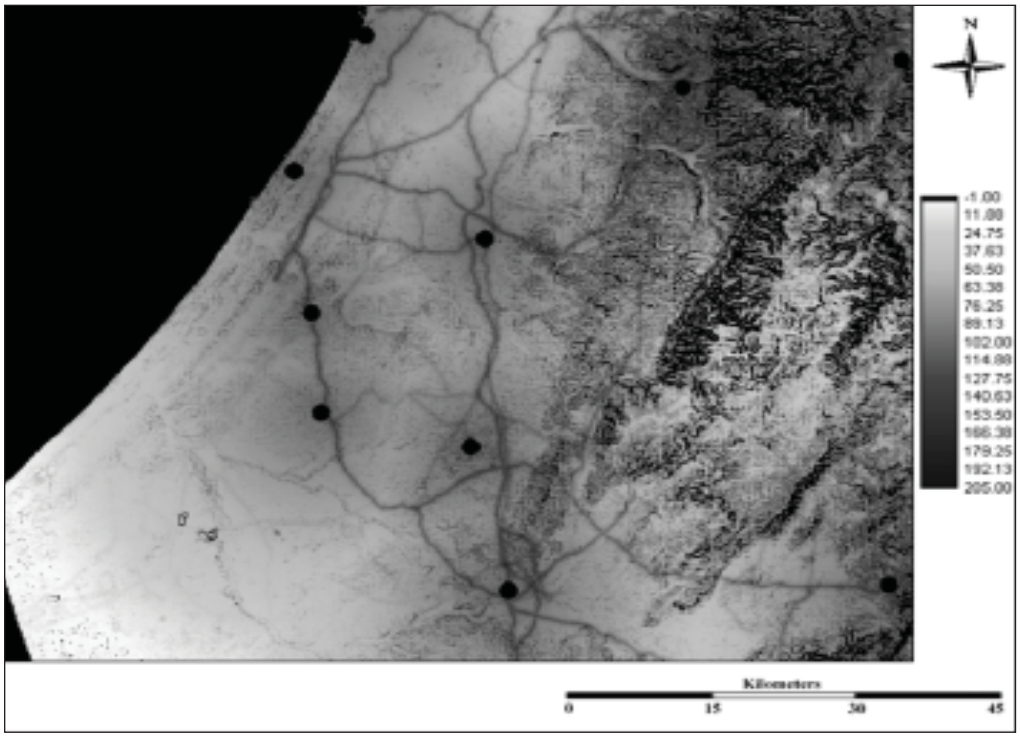

FIGURE 4
Friction surface with "absolute barrier" values

flag value -1. The CostGrow module is used with each route's friction surface to calculate the cost distance of each route and make it comparable to the outcome of the Corridor model.

The proposed paths are compared in terms of length, highest slope, relative difficulty, and number of major, local, internal, and planned Israeli routes crossed. In order to calculate linear distance along all path options, the proposed paths are converted from raster to vector layers and their length calculated. To calculate the maximum slope each path reaches, a Boolean map of each option is multiplied by the slope surface; the maximum slope along each path is then detected. The relative difficulty of each option is the cost distance of that route, calculated by running the CostGrow module using that route's friction surface. The number of roads crossed is determined in ArcGIS by selecting each type of Israeli route that intersects the proposed paths. The results of these comparison are given in Table 3.

Testing the Method for Sensitivity to the Many Subjective Criteria

The Corridor model is tested for sensitivity to the many subjective criteria. The effects of the four highest-weighted factors (distance from Israeli cities, slope, distance from major roads, and distance from planned roads) are examined by running the model four times, excluding one factor each time; Figures 6, 7, 8, and 9 illustrate the results. These runs determine which of the four factor maps is the most sensitive to the model and show whether the judgement of the relative importance of pairwise combinations of the factors in Table 1 corresponds with the sensitivity-test results.

TABLE 3
Comparison of path options

	Length (km)	Slope (%)	Relative difficulty	Linking points from GS to WB		Number of routes intersected				Comments
						Major	Local	Internal	Planned	
Path 1	43	13.8	22240	Eariz –	Beit Awwa	3	2	3	1	The least cost route
Path 2	46	14.7	23872	Karni –	Beit Awwa	3	2	4	1	
Path 3	63	12.9	24567	Sufs –	Adahria	3	0	6	1	
Path 4	85	11.8	22626	Rafah –	Adahria	3	0	6	1	
1st SP	57	12.3	30615	Rafah –	Beituniya	3	6	7	2	Paving parallel route
2nd SP	54	22.1	29502	Rafah –	Idnah	3	5	5	2	Paving parallel route
Arc	76	19.6	×	Rafah –	Adahria	4	2	6	1	

3. Results

There is one path that can be considered the most suitable (lowest-cost) transportation option; this route runs south-east from the Erez crossing point into Gaza to Beit Awwa village near Hebron in the West Bank. By examining each crossing point separately, the method finds three other acceptable solutions that satisfy all the criteria, as illustrated in Figure 5. Thus, the Corridor could follow any one of these. Determining which one to pursue depends on Palestinian and Israeli developers' evaluations of the strengths and weaknesses of each solution.

Comparison of path options shows that the lowest travel distance is 43 km for Path 1, the least-cost pathway. The minimum highest slope is 11.8 % reached through Path 4, which connects the Rafah crossing point with Adahria village in the West Bank. All path options cross three major Israeli routes, but the Arc crosses four. The Cost module refuses to run with the Arc option because the Arc passes through the buffer area of the fifth-largest Israeli city, Be'er Sheva, which is considered an absolute barrier.

Testing the method for sensitivity shows that the most sensitive factor map is the distance from Israeli city centres; next are slope and crossing major roads. Crossing planned roads is not a sensitive factor because there is only one planned road that runs from north to south, and any proposed path must cross it.

4. Discussion

This study builds upon concepts discussed with Palestinian developers and policy makers. In order to bring the Palestinian and Israeli sides closer regarding the Corridor, flexibility in appraising the passage's criteria should be allowed. GIS concepts, as described above, can be helpful in creating a model for proposing a range of satisfactory transportation paths between the West Bank and the Gaza Strip, a model whereby the weight of each criterion can be modified to adapt to the requirements of negotiations.

Because of disagreements between Palestinian and Israeli developers over the evaluation of the criteria, there are no fixed qualitative or quantative characteristics for the proposed passage. Therefore, Macro-Modeler was configured to run all conceptual criteria. Once the model has been saved, the modules' parameters can be changed and run instantly. The hard Boolean decision of defining any particular location as absolutely suitable or not suitable for each criterion is avoided by using decision support tools, since this problem fits well into an MCE scenario. A soft "fuzzy" concept is used to give each

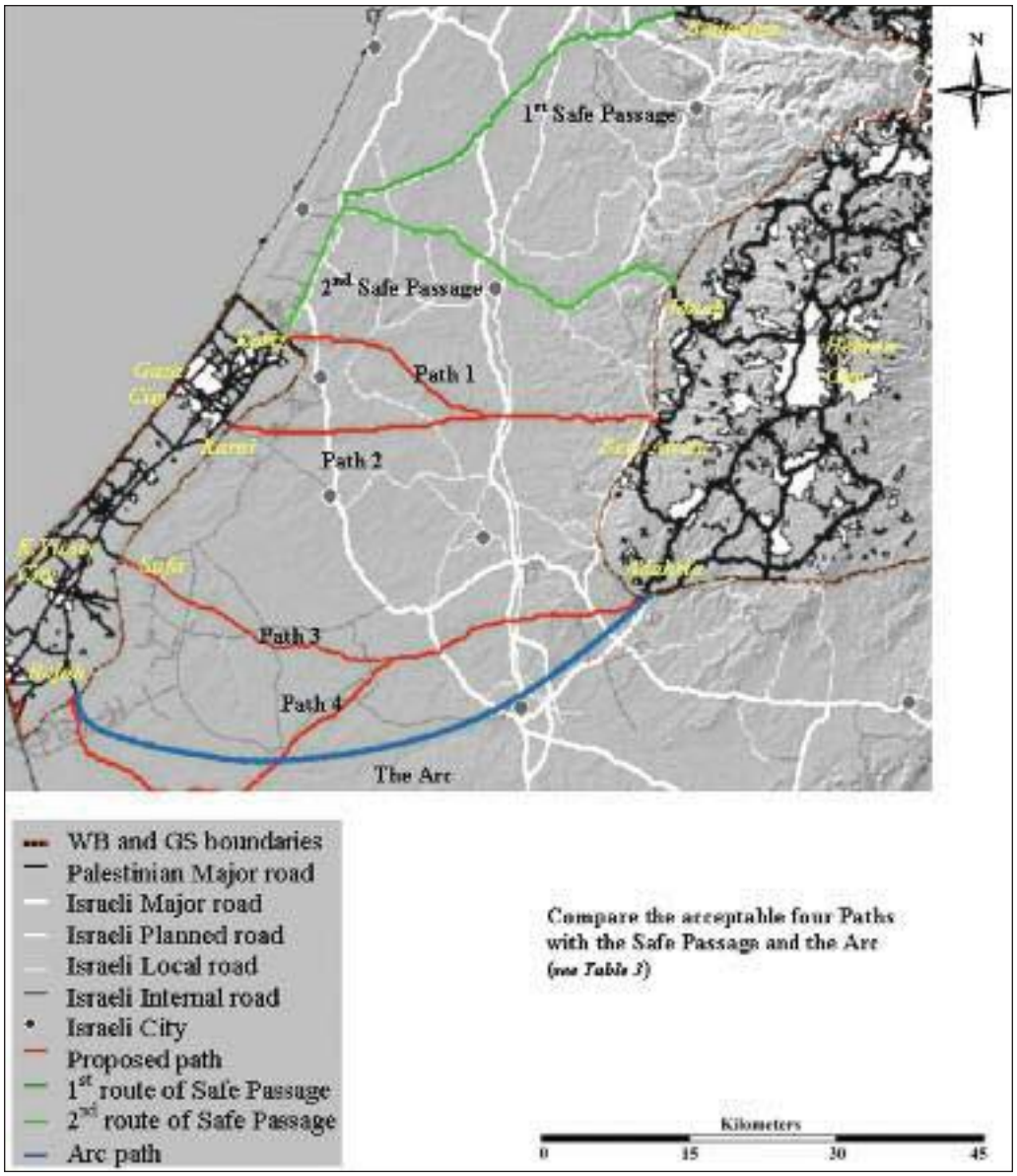

FIGURE 5
The comprehensive map shows the most satisfactory transportation paths of the Corridor model and previously suggested paths: the Safe Passage (www.state.gov/p/nea/rls/22697.htm) and the Arc (www.rand.org).

location a value representing its degree of friction. As the output image is used as a friction surface of the Cost module, fuzzy functions and parameters are signed inversely: value 0 is the most suitable, with the lowest cost, and value 255 is the least suitable, with the highest cost of movement. Therefore, the relative cost of moving through each cell to calculate the least-cost pathways goes through the most suitable pixels.

Another aggregation method, the weighted linear combination (WLC), is also used. This procedure retains the variability from the continuous factors; it also allows for

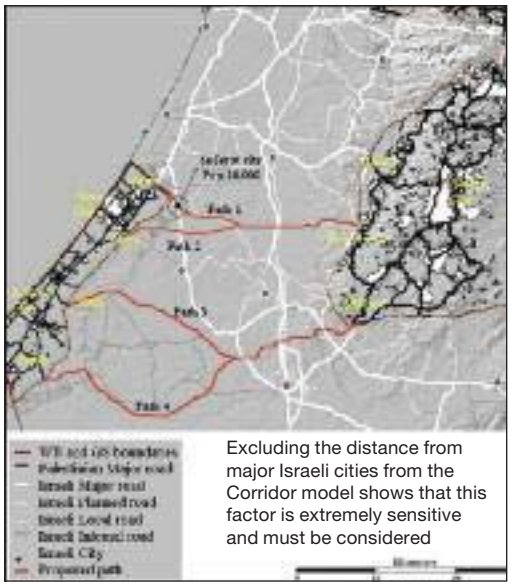

FIGURE 6
Testing the sensitivity of the factor "distance from Israeli city centres"

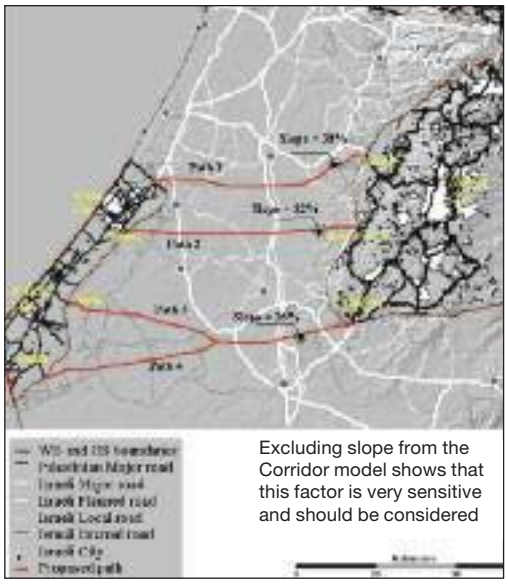

FIGURE 7
Testing the sensitivity of the factor "slope"

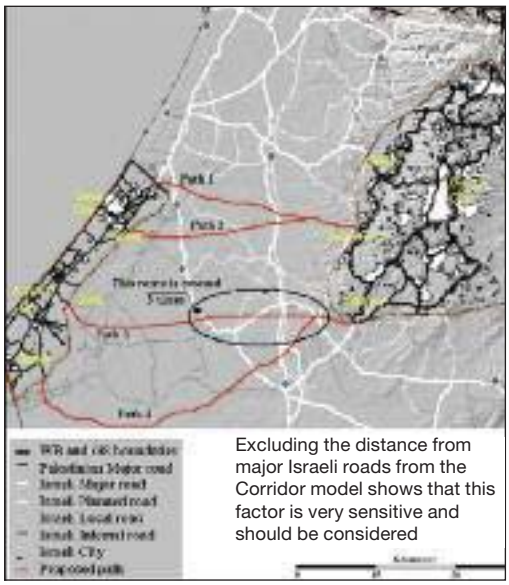

FIGURE 8
Testing the sensitivity of the factor "distance from major Israeli roads"

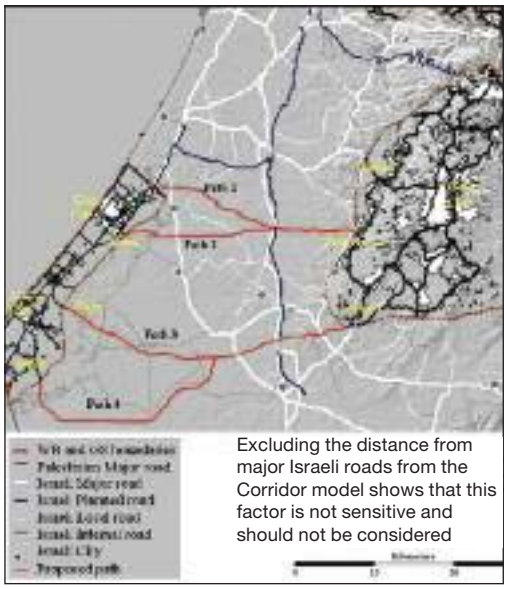

FIGURE 9
Testing the sensitivity of the factor "distance from planned Israeli roads"

the factors to trade off with one another. How factors trade off with one another is determined by a set of weights indicating the relative importance of each factor. The output image presents the cost of each pixel; the highest suitability should have the lowest value, so the path can run through that pixel.

The Cost Distance operator is used to

calculate distance from major Palestinian roads in the West Bank in terms of the measure of suitability calculated above. These friction values, in this case, represent the number of criteria a route would satisfy while crossing areas with certain attributes. Because these friction values are always calculated relative to some fixed base amount, which is given a value of 1, all values between 0 and 1 are reclassed to 1, representing the most suitable location to run through. Besides this, the "absolute barrier" concept of the CostGrow algorithm is applied by assigning -1 to all cells of 0 value. The resulting cost-distance image incorporates both the actual distance travelled and the frictional effects encountered along the way. This cost surface is entered into the Pathway module to determine the least-cost route between Gaza's main crossing points and West Bank routes.

Running the Corridor model shows that only one path is the most suitable, but it also shows that each of the other paths examined has its own distinct importance. As a result, an argument could be made for any of the four proposed routes. The differences lie in the number of roads crossed, the length of the route, and the maximum slope reached. The ranking process is rather subjective, and arguments could be made for other routes, depending on which criterion is deemed to be most significant. At this stage of analysis, testing the method for sensitivity to the many subjective parameters shows that the method is extremely sensitive to the distance of the path from Israeli city centres.

The Corridor model, as presented in this study, could provide a first step in the process of negotiation, helping both Palestinians and Israelis to see the many considerations to be taken into account and making the concept of a link between the West Bank and the Gaza Strip more realistic. If it is to be pursued as a formal model and used to develop a solution to the problem of linking the West Bank with the Gaza Strip, the Negotiation Support Unit should then work on incorporating Israeli recommendations. As well, this flexible model could be improved to consider land use in routing the path, and to route it away from the most productive agricultural areas, by adding other constraints and factors, weighting and evaluating these factors, and then re-running the model to create a more acceptable linkage route.

5. Conclusions

The GIS approach outlined in this article, using multi-criteria evaluation and least-cost pathway analysis, has proved successful in creating and running a model to propose a range of acceptable ground-based transportation paths between the West Bank and the Gaza Strip. Running the Corridor model produces different results (paths) depending on the parameters applied each time.

In this study, the two previously suggested routes—the Safe Passage and the Arc path—are compared with the results of the Corridor GIS model. This comparison indicates that the routes designed by applying GIS modules are more acceptable than these others. Based on the results of this examination, applying GIS technology and including the views of both Palestinian and Israeli developers are recommended to help provide a platform for both sides to present their own development plans, using GIS as a base.

Furthermore, the approach developed in this study allows the method to be tested for sensitivity to many subjective criteria. Proximity to Israeli city centres, slope, and intersection with major Israeli roads are factors that affect the outcome paths. The present study shows that the most influential factor is proximity to Israeli city centres.

The model developed in this study could be helpful to further endeavours in considering the use of GIS technology for planning transportation paths.

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Note

1 See www.clarklabs.org.

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