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Chapter 3
Economic Impacts of Terrorist Attacks and Natural Disasters: Case Studies of Los Angeles and Houston

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Abstract Large metropolitan regions are vulnerable to terrorist attacks and natural disasters. Ports and downtown business districts could be targets of terrorist attacks and are also prone to substantial losses from natural disasters like earthquakes or hurricanes. It is important for stakeholders and decision makers to be aware of the spatial distribution of these losses and recognize the potential economic losses from various hypothetical terrorist attacks and natural disasters on these crucial facilities and core sites. The Southern California Planning Model (SCPM), a GIS-based regional planning model developed initially for the five-county Los Angeles metropolitan area, is capable of endogenizing freight and passenger flows and allocating impacts spatially via unexpected impedances to trips and shipments through the regional highway network. This chapter presents the SCPM model and describes several applications via three case studies of hypothetical events: (1) A radiological bomb or so-called "dirty bomb" attack and conventional bomb attacks on the twin ports of Los Angeles and Long Beach; (2) A radiological bomb attack on a large office building in Downtown Los Angeles Financial District; and (3) A hurricane striking the Houston-Galveston-Brazoria (HGB) region. The results show that the model can allocate the losses to various types of impact analysis zones or political jurisdictions. The methods used in this study are adaptable to almost any kind of terrorist and natural disaster attacks and also transferable to other large metropolitan areas.

Keywords Economic impacts, terrorist attacks, natural disasters, GIS, Los Angeles, Houston

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3.1 Introduction

The 9/11 attacks on the New York World Trade Center in 2001 have raised concerns over the safety of downtowns and similar sites and the socio-economic effects of terrorist attacks on such facilities. The Government Accounting Office (2002) reports that the September 11 attacks on the two World Trade Center buildings cost about $83 billion. Similarly, hurricanes Katrina and Rita of 2005 caused significant economic losses in the Gulf Coast states and indirectly throughout much of the United States. The total number of fatalities directly and indirectly related to Hurricane Katrina is 1,833 and a preliminary estimate of total damage is about $81.2 billion (Knabb et al. 2006a). Though Hurricane Rita spared the heavily populated Houston-Galveston Area and made landfall on the Texas-Louisiana border, it claimed 120 direct and indirect deaths and total damages of about $10 billion (Knabb et al. 2006b). Catastrophes such as these illustrate why it is necessary to investigate the potential losses of earthquakes in California, tornados in the mid-east region, and other types of natural disasters in the rest of America, to consider mitigation steps, arrange emergency response efforts, and allocate manpower and resources for disaster planning more cautiously and efficiently.

This chapter summarizes our economic impact research in three case studies. Two of them are from studies we completed for the Economic Modeling Group at the Center for Risk and Economic Analysis for Terrorism Events (CREATE) at the University of Southern California. One explores possible radiological bomb attacks at the Ports of Los Angles and Long Beach combined with conventional bomb attacks on access bridges. The other examines a radiological bomb attack on a major downtown office building in Los Angeles. The third case study estimates the economic losses of a hypothetical hurricane event in the Houston-Galveston Area.

We apply a well-established model to measure economic impacts, called the Southern California Planning Model (SCPM). This is a metropolitan input–output model in the Garin-Lowry tradition that is spatially disaggregated (with more than 3,000 Traffic Analysis Zones (TAZs) in the 2005 version of the model), to which we add a highway network with endogenously determined loadings, including freight and passenger flows. SCPM enables us to estimate spatially detailed output and job impacts of a variety of exogenous shocks, including policies, projects, and plans. In this case, the exogenous shock is a terrorist attack or a natural disaster.

3.2 Methodology

It is important for federal, state, and local policy makers to address disaster preparation and response questions by utilizing plausible loss estimates of terrorist attacks and natural disasters at fine levels of spatial detail. The Southern California Planning Model (SCPM) provides useful tools and functions to estimate total economic impacts and allocate the impacts spatially over a large metropolitan area.

It is capable of allocating the losses to various types of impact analysis zones or political jurisdictions. Multiple versions of SCPM offer flexibility to determine the geographical location of indirect and induced economic losses through a simple Garin-Lowry style approach or a complex integrated spatial interaction model with an endogenized transportation network.

3.2.1 The Southern California Planning Model Version 1 (SCPM1)

The Southern California Planning Model version 1 (SCPM1) was developed for the five-county Los Angeles metropolitan region, and has the unique capability to allocate all impacts, in terms of jobs or the dollar value of output, to 308 sub-regional zones, mainly individual municipalities defined by the Census Bureau. This is the result of an integrated modeling approach that incorporates two fundamental components: input–output and spatial allocation. The approach allows the representation of estimated spatial and sectoral impacts corresponding to any vector of changes in final demand. Exogenous shocks treated as changes in final demand are fed through an input–output model to generate sectoral impacts that are then introduced into the spatial allocation model to determine their spatial distribution.

The first model component is built upon the well-known IMPLAN input–output model, which has a high degree of sectoral disaggregation (509 sectors). The second basic model component is used for allocating sectoral impacts across the 308 geographic zones in Southern California. The key is to adapt a Garin-Lowry style model for spatially allocating the induced impacts generated by the input-output model. The building blocks of the SCPM1 are the metropolitan input–output model, a journey-to-work matrix, and a journey-to-nonwork-destinations matrix. This is a journey-to-services matrix that is more restrictively described as a 'journey-to-shop' matrix in the Garin-Lowry model.

The journey-to-services matrix includes any trip associated with a home-based transaction other than the sale of labor to an employer. This includes retail trips and other transaction trips, but excludes non-transaction-based trips such as trips to visit friends and relatives. Data for the journey-to-services matrix include all trips classified by the Southern California Association of Governments (SCAG) as home-to-shop trips, and a subset of the trips classified as home-to-other and other-to-other trips.

The key innovation associated with SCPM1 is to incorporate the full range of multipliers obtained via input–output techniques to obtain detailed economic impacts by sector and by submetropolitan zone. The SCPM1 follows the principles of the Garin-Lowry model by allocating sectoral output (or employment) to zones via a loop that relies on the trip matrices. Induced consumption expenditures are traced back from the workplace to the residential site via a journey-to-work matrix and from the residential site to the place of purchase and/or consumption via a journey-to-services matrix. See Richardson et al. (1993) for a further summary of SCPM1.

3.2.2 The Southern California Planning Model Version 2 (SCPM2)

Incorporating the Garin-Lowry approach into spatial allocation makes the transportation flows in SCPM1 exogenous. These flows are also relatively aggregated compared with transportation models, defined primarily at the level of political jurisdictions. Most transportation models use TAZs, which are much smaller. However, with no explicit representation of the transportation network, SCPM1 has no means to account for the economic impact of changes in transportation capacity. Terrorist attacks and natural disasters, especially against the transportation system, may induce such changes, including capacity losses that will contribute to reductions in network level service and increases in travel delays. SCPM1 does not account for such changes in transportation costs, underestimating the costs of any exogenous shock. Treating the transportation network explicitly endogenizes otherwise exogenous Garin-Lowry style matrices describing the travel behavior of households, achieving consistency across network costs and origin-destination requirements. SCPM2 makes distance decay and congestion functions explicit. This allows us to endogenize the spatial allocation of indirect and induced economic losses by endogenizing choices of route and destination. This better allocates indirect and induced economic losses over zones in response to direct losses in trade, employment, and transportation accessibility (Fig. 3.1). See Cho et al. (2001) for a more detailed summary of SCPM2.

3.2.3 The Southern California Planning Model Version 2005 (SCPM 2005)

The most recent version of the model is more sectorally disaggregated with 47 industrial sectors. We call these the USC (University of Southern California) Sectors because they have been constructed to reconcile various databases and to integrate SCPM with a national model, NIEMO (National Interstate Economic Model). See Park et al. (2007) for a detailed description. The updated transportation network follows the definition in the SCAG's 2001 regional transportation model with 3,217 TAZs and 89,356 network links. This disaggregation is an important feature of a major update of SCPM, called SCPM05.

SCPM05 includes more up-to-date data and other refinements beyond SCPM2. Also, the model makes use of 2005 Freight Model estimates. In general, freight flows are more difficult to estimate than passenger flows, so it is quite important to obtain external validation for the accuracy of these estimates. To test this, our 2005 estimates were compared with the SCAG 2003 Annual Average Weekday Truck Traffic Counts (SCAG/LAMTA 2004). Under a variety of assumptions about PCEs (Passenger Car Equivalents), we plotted estimated against actual freight flows, and obtained R^2s in the 0.67–0.80 range.

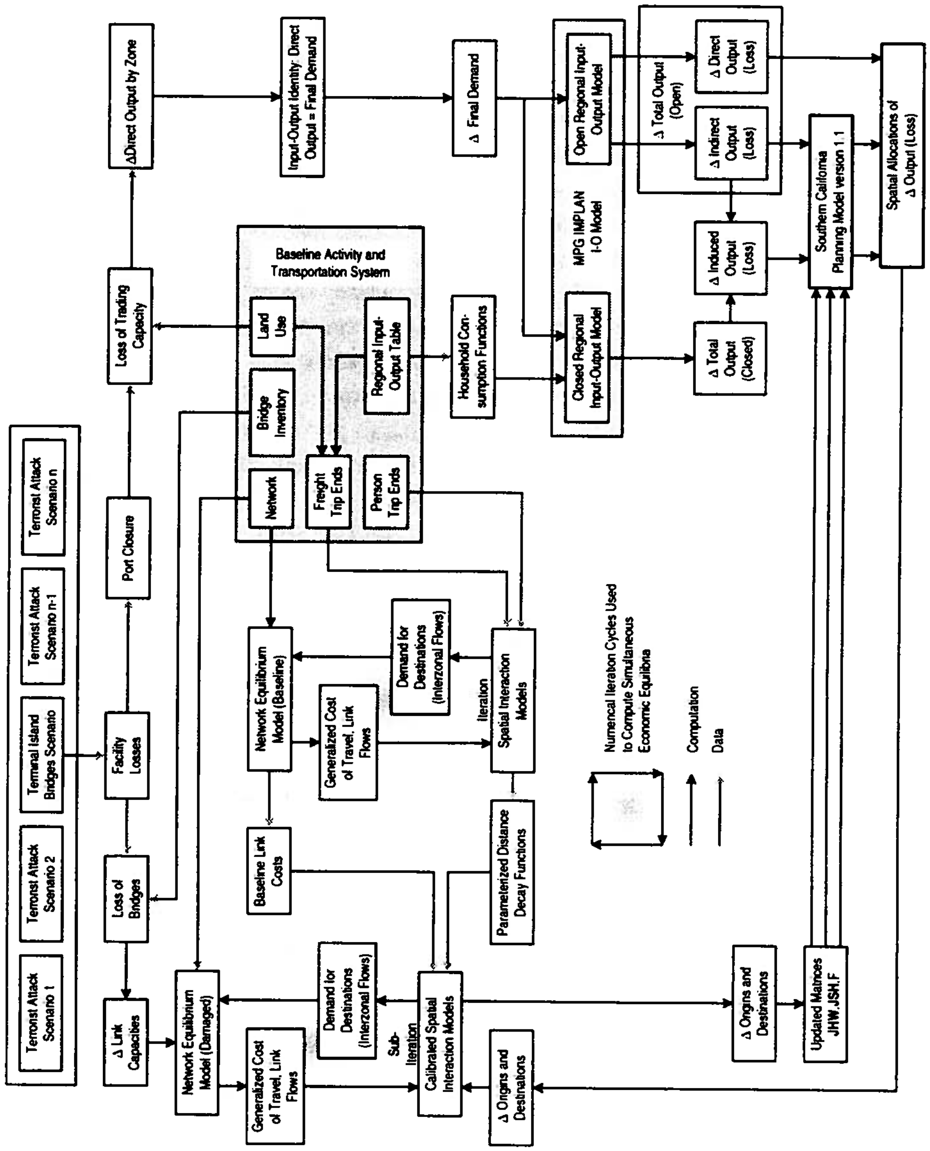

Fig. 3.1 SCPM2 data flows and calculations

3.3 Case study I: The Cost of a Terrorist Attack on Terminal Island in Los Angeles[1]

The twin ports of Los Angeles and Long Beach have played a significant role in the local and national economy. They are the third largest port complex in the world. They rank first and second nationally in terms of containerized traffic and accounted for 135 million tons of seaborne trade in 2005 (USACE 2005). There are half a million workers, about seven percent of the region's labor force, working directly or indirectly for freight traffic that goes through these two ports. The combined import and export trade flows of more than $218 billion through these two ports in 2003 (USDOT 2004) is equivalent to about 26 percent of the greater Los Angeles gross regional product. Reflecting trends in the national economy, imports are much more important than exports ($184 billion compared with $34 billion). About one-half of the imports and two-thirds of the exports originate outside the region. In other words, the ports fulfill a national function, even more than a regional function.

In this case study, we hypothesized a possible radiological bomb attack on Terminal Island and proposed three scenarios to examine the impacts of port closure on regional economics and transportation system performance: 15-day closure with no bridge damage, 120-day closure with bridge damage, and one-year closure with bridge damage called Terminal Island scenario. One of our previous research (Gordon et al. 2006) estimated that the closure of the Los Angeles and Long Beach Ports for anywhere from 15–120 days would cost the US economy in a range of $4 to $34 billion—or 26,000 to 212,000 person-years of employment (see Table 3.1

Table 3.1 Output and employment losses of a 15-day, 120-day and one-year closure of Terminal Island (Authors' calculations in Gordon et al. 2006a)

	Output ($1,000s)			Jobs (Person-Years)		
	15-Day	120-Day	One-Year	15-Day	120-Day	One-Year
City of Los Angeles	423,152	3,385,384	4,537,531	2,639	21,111	28,503
City of Long Beach	87,787	700,310	815,517	657	5,249	5,787
County of Los Angeles	1,034,070	8,271,386	10,914,814	6,513	52,097	68,535
County of Orange	262,434	2,100,029	2,796,342	1,669	13,352	17,791
County of Ventura	72,609	580,860	774,623	435	3,482	4,641
County of Riverside	64,052	512,697	680,566	421	3,371	4,475
County of San Bernardino	89,270	714,515	949,071	568	4,548	6,044
Sum of Five Counties	1,522,436	12,179,488	16,115,416	9,606	76,850	101,485
Regional Leakages	2,736,487	21,891,893	28,754,513	16,914	135,316	178,482
Total	4,258,923	34,071,381	44,869,929	26,521	212,165	279,967

[1] This part of the paper draws upon research results originally reported in the 'The Costs of a Terrorist Attack on Terminal Island at the Twin Ports of Los Angeles and Long Beach' by Peter Gordon, James E. Moore II, Harry W. Richardson and Qisheng Pan, Chapter 3 in John D. Haveman and Howard J. Shatz (eds.) *Protecting the Nation's Seaports: Balancing Security and Cost*. San Francisco: Public Policy Institute. 2006.

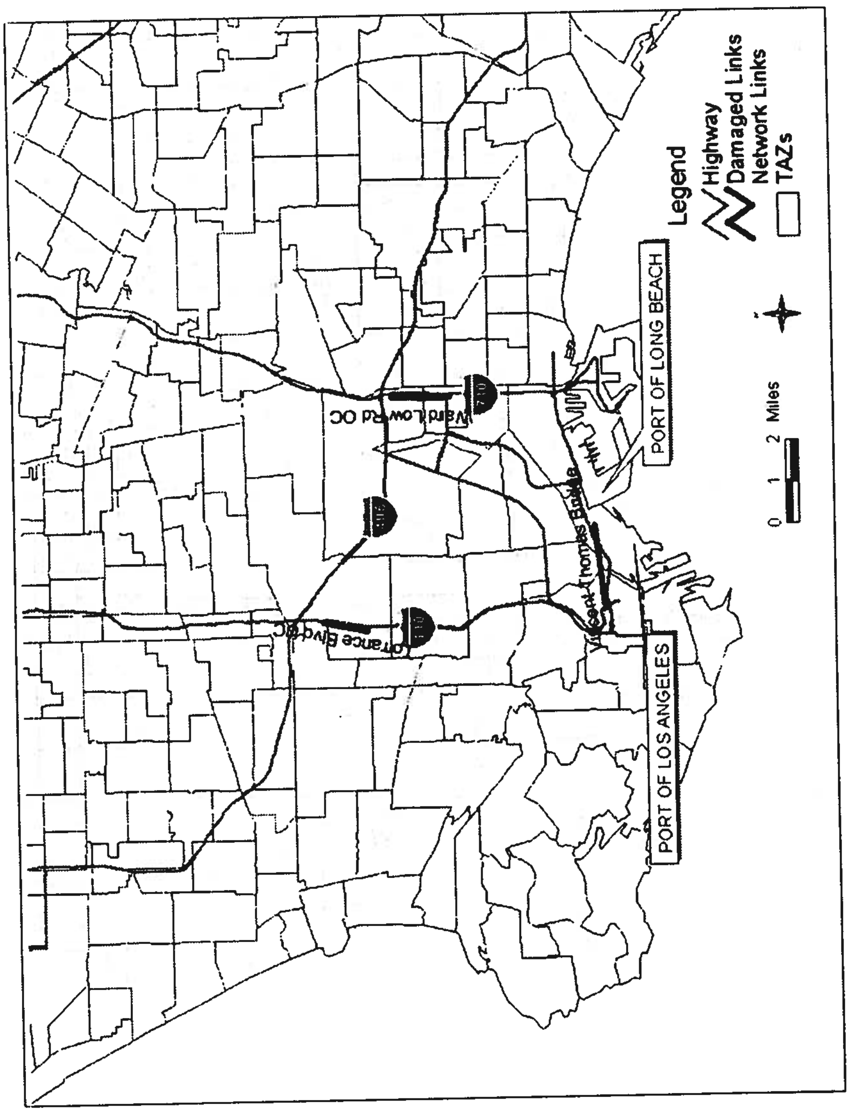

Fig. 3.2 Geographic locations of the network links where the damaged bridges are located

for aggregate results and county-level details). SCPM2 provided economic results in much greater spatial detail, to the level of counties, cities, census tracts, or TAZs if required. This preliminary work established the ground for the 15-day closure and 120-day closure scenarios.

This study also determined that many of the ports' vulnerabilities arise from restricted highway access to most of the docks. Therefore, we decided to further study the implications of bridge attacks intended to isolate all or part of the ports complex. In particular, freight going to and from Terminal Island accounts for a significant portion of combined port activities. The best estimate is 55 percent of total trade dollars although Port authorities were unable to provide exact figures.

The Terminal Island docks are accessed by four major bridges: the Vincent Thomas Bridge, the Gerald Desmond Bridge and the Commodore Schuyler F. Heim Lift Bridge, and a rail bridge (Badger Bridge) parallel to the Heim Bridge, which handles 21 percent of Terminal Island trade. These bridges are elevated facilities that permit ship traffic in the waters between the coast and Terminal Island. The Desmond Bridge, for example, is 250 feet above the water. In addition to these bridges, we also identify the critical facilities on the Interstate Highway 110 and 710 (two major highways connecting the Ports of Los Angeles and Long Beach), including the Torrance Boulevard Underpass and Willow Street Overpass, as the most vulnerable locations (Fig. 3.2). After the bridges break down, the network links where the bridges are located become inaccessible.

The 15-day scenario assumes no bridge damage so that Terminal Island is still accessible through the bridges. However, the 120-day estimates are based on scenarios that involve destruction of various access bridges, which significantly multiplies the downtime of the ports. The ports could reopen and shippers could resort to congested surface streets, but at a substantial efficiency cost. Thus, an additional $90 million dollars in transportation network delay costs are incurred in the 120-day scenario. This scenario includes a loss of network capacity in this period because of bridge damage and a reduction in transportation demand because of port closures. The model estimates the associated changes in network flows and costs.

SCPM2 simulations also revealed that an attack that incapacitates these bridges for twelve months would create economic losses of almost $45 billion per year, accounting for job losses of nearly 280,000 person-years. Thirty-five percent of these losses impact the local five-county area, and the remaining 65 percent are spread throughout the US (see Table 3.1 for county-level results and Fig. 3.3 for detailed spatial results for the region).

Tables 3.2a, b compare changes in transportation costs across all three scenarios. In the case of the Terminal Island scenario, network costs increase by $58 million per year. This value is lower than the increase in delay costs associated with the 120-day scenario in the radiological bomb plus bridge access study because the Terminal Island scenario represents only a partial elimination of port capacity. It is important to note that these are delay costs; we have not made precise estimates of bridge repair costs.

We do not know how quickly access to Terminal Island could or would be restored. If under normal circumstances bridge repairs on this scale take up to two years, then our approach can be used to approximate the benefits of speedier

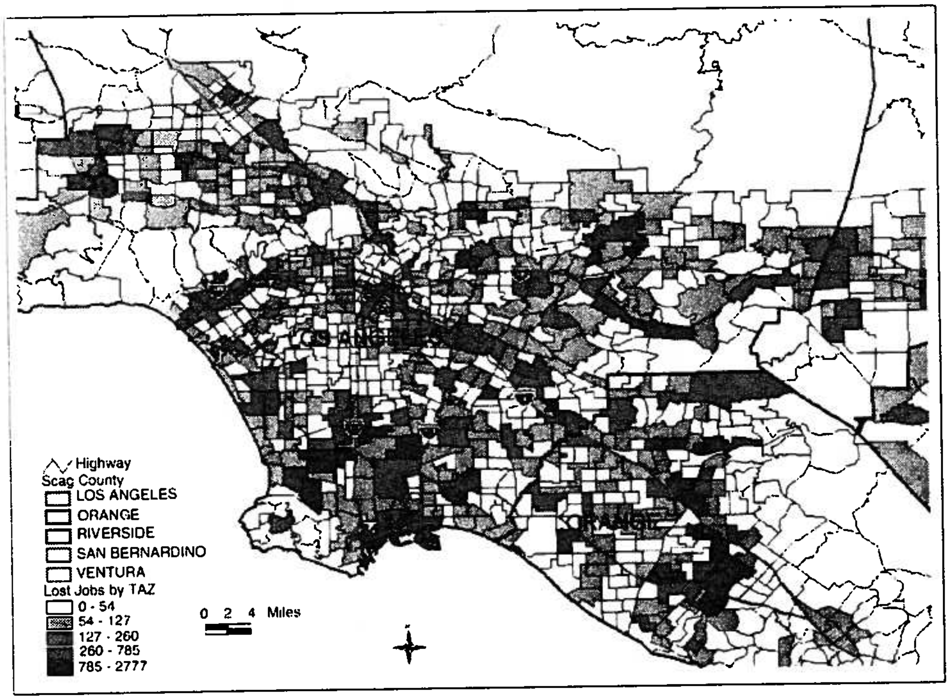

Fig. 3.3 Spatial distribution of job losses, one year closure of Terminal Island

Table 3.2a Network performance for multiple impact scenarios (total travel costs in $million)

	Freight travel costs[a]	Personal travel costs[b]	Total costs[d]	Personal travel cost[c]	Total costs
Baseline–15 day	1,031.88	2,507.11	3,539.00	5,014.23	6,046.11
Baseline–120 day	8,255.07	20,056.91	28,311.98	40,113.82	48,368.89
Baseline–one year	25,109.18	61,006.43	86,115.62	122,012.87	147,122.05
15 Day Radiological Scenario	1,007.18	2,494.93	3,502.11	4,989.85	5,997.03
120-Day Radiological Scenario	8,137.61	20,160.48	28,298.09	40,320.95	48,458.56
Terminal Island Scenario	24,771.72	61,204.11	85,975.82	122,408.21	147,179.93

[a]Freight trip cost is assumed to be $35.00 per PCE per hour
[b]Personal trip cost is assumed as $6.50 per PCE per hour
[c]Personal trip cost is assumed as $13.00 per PCE per hour
[d]Total trip cost is the sum of freight trip cost and personal trip cost
It should be noted that the model does not yet explicitly include the rail network. The highway network cost estimates do not accommodate the truck traffic accessing the rail

repairs, including the installation of temporary facilities. Temporary high capacity bridges might be constructed relatively quickly, but these low-design facilities would block ship traffic in the channels separating Terminal Island from the remainder to the port complex.

Table 3.2b Change in total travel costs for multiple impact scenarios ($million) (Authors' calculations)

	Freight Travel Costs	Personal Travel Costs	Total Costs	Personal Travel Cost	Total Costs
15 Day Radiological Scenario	−24.70	−12.18	−36.89	−24.38	−49.08
120-Day Radiological Scenario	−117.46	103.57	−13.89	207.13	89.67
Terminal Island Scenario	−337.46	197.68	−139.80	395.34	57.88

Table 3.3 Total output and highway network losses for alternate bridge reconstruction periods (Authors' calculations)

	Output Loss	Network Loss	Total Loss
24 Month Bridge Loss	$89.74 billion	$115.8 million	$89.856 billion
18 Month Bridge Loss	$67.31 billion	$86.9 million	$67.392 billion
12 Month Bridge Loss	$44.87 billion	$57.9 million	$44.928 billion
6 Month Bridge Loss	$22.44 billion	$29.9 million	$22.464 billion

Table 3.3 shows the total losses for the Terminal Island scenario by six-month increments up to two years. The estimated benefits of accelerated repairs are approximated by the differences between Row 1 of Table 3.3 and the row corresponding to the actual repair period. The differences are significant, and the implications are obvious: it is highly cost-effective to analyze emergency bridge reconstruction options and formulate plans for the protection of the Terminal Island access routes or their speedy replacement.

Recent estimates from the California Department of Transportation are that the costs of the replacement span for the Oakland Bay Bridge are in the range of $5.1 billion. This span carries 275,000 passenger-car equivalents each day, approximating the scale of the Vincent Thomas Bridge. The other two bridges now serving Terminal Island are comparatively smaller, and would be cheaper to replace. A $12 billion total reconstruction cost for all bridges is a reasonable estimate, but it is unknown to what extent these costs might arise if construction is accelerated. Accepting the linearity assumptions associated with our alternative loss estimates, accelerating access to all the bridges would have an economic benefit of $3.75 billion per month.

Planning now to protect these facilities or for reconstruction or rapid temporary replacement of these critical bridges is easily justified. The costs of accelerated repairs to the Santa Monica Freeway bridges following the Northridge Earthquake were easily justified. Our modeling approach makes it possible to be specific *ex ante* about the efficiency gains of accelerated repairs.

3.4 Case study II: The Economic Impacts of a Terrorist Attack on Downtown Los Angeles Financial District

This case examines a representative terrorist attack on the financial district in downtown Los Angeles, aimed at an unspecified major office building. It mimics the 9/11 World Trade Center attack in some respects in that it is an attack on a major downtown office building in Los Angeles. The mechanism, however, is different by incorporating a radiological bomb rather than airplanes. We choose to simulate a radiological rather than a conventional bomb attack because we are interested in examining non-localized attacks. This chapter focuses on business interruption effects only. We do not attempt to estimate accurately the number of deaths and injuries and their costs. Also, we do not estimate the costs of physical damage to the attacked building and other nearby buildings.

Hypothetically, we assumed the explosion of a 50-lb bomb, the maximum portable without requiring a vehicle as the delivery instrument. Blast damage would be quite limited, with deaths and serious injuries within a range of perhaps 50 meters and with moderate damage to physical infrastructure, except at ground zero. The outer evacuation zone would include all areas with exposure >1 REM (Roentgen Equivalent Man), a unit of radiation dose. We assume a hypothetical radiation plume, a long narrow rectangle four kilometers long and more than 200 meters wide with an inner and more contaminated zone of about 100 meters radius (an area of 0.03 km^2), an oversimplification of plume representations that are not open source. The critical early phase of exposure lasts about four days (EPA guidelines); the time frame for intermediate and later phases is variable and subjective (weeks, months, even years). We assume a one-year evacuation in the Inner Zone, and a one-month evacuation in the Outer Zone. With respect to the Outer Zone, this may be conservative because some firms may trickle back with a lag after being given permission to return. Health factors will dictate an immediate evacuation, but because the health effects are long-term, the decision to allow a return will be determined by political rather than scientific considerations.

By dividing the Inner and Outer Zone in the plume area in terms of the variation of damage levels and evacuation times, we examine three limiting cases: first, an exit scenario where firms disappear (either close down or move out of town); second, a relocation scenario where all the evacuating firms relocate to other subcenters within the five-county metropolitan region; and third, a hybrid scenario where the Inner Zone firms exit and the Outer Zone firms relocate. These are just three of an almost limitless set of scenarios, and they are all based on the assumptions of a one-year evacuation of the Inner Zone and a one-month evacuation of the Outer Zone. These time periods are based on discussions with experts on radiological contamination, but alternative time periods are easily substitutable.

Our field of research does not focus on deaths and/or injuries but on business interruption. The health costs of a radiological attack stretch out over a long time, but a blind guess of the immediate toll might be 20 deaths and 200 hospital-related injuries. The duration of the disruption determines the length of time for which firms throughout the region will be non-operational or operating below normal levels of service. This allows the calculation of exogenously prompted reductions in demand by these businesses. These are introduced into the interindustry model as declines in final demand. The I/O model translates this production shock into direct, indirect, and induced costs. The indirect and induced costs are spatially allocated over the 3,000-plus zones in terms consistent with the endogenous transportation behavior of firms and household.

Although our study takes transportation networks into account, the transportation repercussions of a downtown closure are relatively modest. First, there are no freeways in the inner zone. Second, as a major service center, downtown attracts fewer deliveries and pick-ups than the rest of the metropolitan region. Our data show only a two percent PCE (passenger cars equivalent) truck flow rather than the seven percent region wide. Third, only 8,620 jobs are affected, a drop in the bucket compared with the nine million jobs in the region. Fourth, and more important, most trips to the downtown area are through traffic rather than traffic with origins and/or destinations in the downtown area. Our analysis assumes that if motorists roll up their windows and keep the air conditioning off that they can pass through the plume area in relative safety. If the authorities mandate a different and more coercive procedure, the transportation impacts would be magnified. As it is, the network effects in this particular case study are so small that they are not worth reporting.

We utilized the latest version of the Southern California Planning Model, called SCPM 2005, to measure economic impacts. Similar to its previous versions, it is also a metropolitan input–output model in the Garin-Lowry tradition, but it utilizes more industrial sectors (47 USC Sectors) and is more spatially disaggregated (with more than 3,000 TAZs), to which we add an up-to-date highway network with endogenously determined loadings, including freight and passenger flows in 2001. The SCPM 2005 includes 2005 Freight Model estimates, which has better validation results in comparison to the Southern California Association of Governments 2003 Annual Average Weekday Truck Traffic Counts. It enables us to estimate the geographical output and job impacts of a variety of recent exogenous shocks, including policies, projects and plans. In this case, of course, the exogenous shock was a terrorist attack.

The estimates for jobs and households impacted by the radioactive plume after the bomb attack are based on the 1997 SCAG Employment Data and the Census 2000 Summary File. There are 7,843 jobs and no households affected in the Inner Zone for a one-year evacuation period. There are more than 8,500 jobs and 60,000 people in the Outer Zone, but because the evacuation period is only one month and the model is run as an annual model, the model input is 710 jobs and 2,424 households. Despite the absence of households, the economic impacts of evacuation in the Inner Zone are much larger than those in the Outer Zone (the economic impact from a lost job is greater than that from a lost household, by a factor of more than three).

The Exit Scenario assumes that firms and households exit from the region for the evacuation periods. The true regional economic impact is the discounted value of the stream of future output and job losses because the firms and households may be gone forever. Thus, the Exit Scenario is merely a measure of the losses during the evacuation period under the assumption that there are no regional offsets in the form of positive relocation impacts.

Table 3.4 shows the results of the Exit Scenario. Although impacts that distinguish between the Inner and the Outer Zones have been estimated for all scenarios, we report such results only for the Exit Scenario. The Inner Zone impacts were much larger ($5.624 billion of output and 38,000 jobs) than those in the Outer Zone ($0.278 billion of output and 2,391 jobs) for a total of $5.901 billion of output and 40,391 jobs (Table 3.4). As a generalization, one-half of the overall impacts (indirect and induced as well as direct) occur in the City of Los Angeles (of course, all the direct impacts are in the City), and about two-thirds occur in Los Angeles County. Regional leakages (i.e. spillovers in the indirect and induced effects) are small ($0.726 billion of output and 5,408 jobs); this reflects the fact that the local component of the financial and office sectors is very high, with minimal reliance on imports from outside the region (such as computing, other information technology equipment, materials and supplies). Overall, however, the indirect and induced effects are larger than the direct effects, implying a sizeable output multiplier (2.25) and an even larger employment multiplier (4.82), reflecting highly paid workers in the Financial District that generate above-average consumption (and induced jobs in the retail and service sectors).

Table 3.4 Economic impact of a terrorist attack on downtown Los Angeles, exit scenario, for all businesses and households moving out of the Inner and Outer Zones (Authors' calculations)

	Output ($1,000s)				Jobs			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
City of Los Angeles	2,304,493	136,563	499,580	2,940,636	7,257	961	5,171	13,389
County of Los Angeles	2,304,493	362,308	1,301,283	3,968,084	7,257	2,412	13,472	23,141
County of Orange	0	116,622	459,508	576,130	0	863	4,758	5,622
County of Ventura	0	24,227	107,274	131,501	0	172	1,110	1,282
County of Riverside	0	36,558	202,202	238,761	0	276	2,101	2,376
County of San Bernardino	0	44,422	216,455	260,877	0	313	2,248	2,562
Sum of Five Counties	2,304,493	584,137	2,286,722	5,175,352	7,257	4,037	23,689	34,983
Regional Leakages	312,733	80,190	332,954	725,878	1,363	623	3,425	5,408
Total	2,617,225	664,327	2,619,676	5,901,229	8,620	4,660	27,114	40,391

The Relocation Scenario is more complex than the Exit Scenario because it requires a procedure for relocating both firms and households out of downtown and the outer zone, which stretches northeast of downtown. Households were relocated using an empirically estimated distance-decay function with a negative exponential formula. According to a study by Clark et al. (2002) on the association between residential changes and commuting behavior in the Greater Seattle area, the mean move distance was 6.28 miles. Using this as a template, the probability distribution function (PDF) for household relocation is as follows:

$$F_X(x) = 1 - e^{-x/6.28}, x \geq 0. \quad (1)$$

where x is moving distance.

This function is used to randomly generate moving distances for the households. The final destinations of a relocating household are locations close to the estimated moving distance with similar median housing rents/prices to the origin locations. The Census 2000 (Summary File) data on household income and house price data (combined with the relocation distance assumptions) are employed to identify the probable destinations.

There were no households living in the inner zone in the year when the database was constructed based on the Census 2000 data at block level, but there were 2,424 households in the outer areas. All these 2,424 households are relocated over the Five-County Los Angeles region. Of these, all but 31 relocated within Los Angeles County, with most of the rest in Orange County. Finally, Census 2000 blocks with the moving-in households are further aggregated into the SCAG 1999 TAZs for modeling purposes. Household consumption at the new locations is calculated by using the average propensity to consume from the Consumer Expenditure Survey for Los Angeles.

Businesses moving out from the inner and outer impact zones of downtown Los Angeles are relocated in the region based on the job vacancy and job distribution by sector in the business submarkets. Based on the second quarter office vacancy report in MarketBeat Mid-Year 2005 by Cushman and Wakefield (2005), there are over 50 submarkets with an average 14 percent of vacancy rate in Los Angeles North, Southern, Central, West, and the Tri-Cities Offices sub-regions. After the development of a correspondence table between submarkets and TAZs, the office vacancy rates are recalculated from submarkets to TAZs.

SCAG 1999 TAZs with the 3191 internal zones are used as a base for business relocation. SCAG 1997 employment by business establishment by SIC code is translated into employment by USC Sector and finally aggregated into SCAG TAZs. The jobs moving out of the inner and outer impact areas are relocated into these TAZs based on the vacancy rate and the job distribution by sector in the TAZs. Most, but not all, of the jobs relocate within Los Angeles County. The move-in jobs are converted into dollar values of output by applying the dollars per job ratio obtained from the regional input–output model.

Overall, the Relocation Scenario is a 'wash' with minimal changes at the County level (a decline of $77 million of output and 217 jobs in Los Angeles County relocated to Ventura County; Tables 3.5a, b). The major impacts take place at the city level, especially in Los Angeles (a net loss of $1.567 billion with an outward movement of $2.941 billion and an inward movement of $1.373 billion and 5,099 jobs with 13,389 jobs out and 8,289 in). The major gainers were Torrance, Industry, El Monte, Glendale and Pasadena in terms of output and Torrance, El Segundo, Pasadena, Glendale, Beverly Hills, and Santa Monica in terms of jobs. All of the top 25 gainers (in terms of output and job gains) were in Los Angeles County with the exception of Thousand Oaks (in Ventura County) (Tables 3.6a, b). Figure 3.4 shows the spatial distribution of the relocated jobs throughout the region; it illustrates their wide geographical dispersion, with concentrations at subcenters derived from the submarket analysis.

The Exit Scenario does not seem plausible for activities in the Outer Zone if the evacuation lasted for only a few weeks. So we developed the Hybrid Scenario where Inner Zone firms exited while Outer Zone firms and households temporarily relocated. The numbers in the Hybrid Scenario are a modified version of the Exit Scenario, reflecting the dominance of Inner Zone impacts. They total $5.624 billion of output and 38,000 jobs (Table 3.7). One half of the output losses and almost three-fifths of the job losses occur in Los Angeles County. The City of Los Angeles experiences a modest output loss of $57.826 million and a job loss of 413 jobs. The main cities gaining from relocation are El Segundo, Torrance, Glendale, Pasadena, Beverly Hills, Commerce, and Santa Monica in that order.

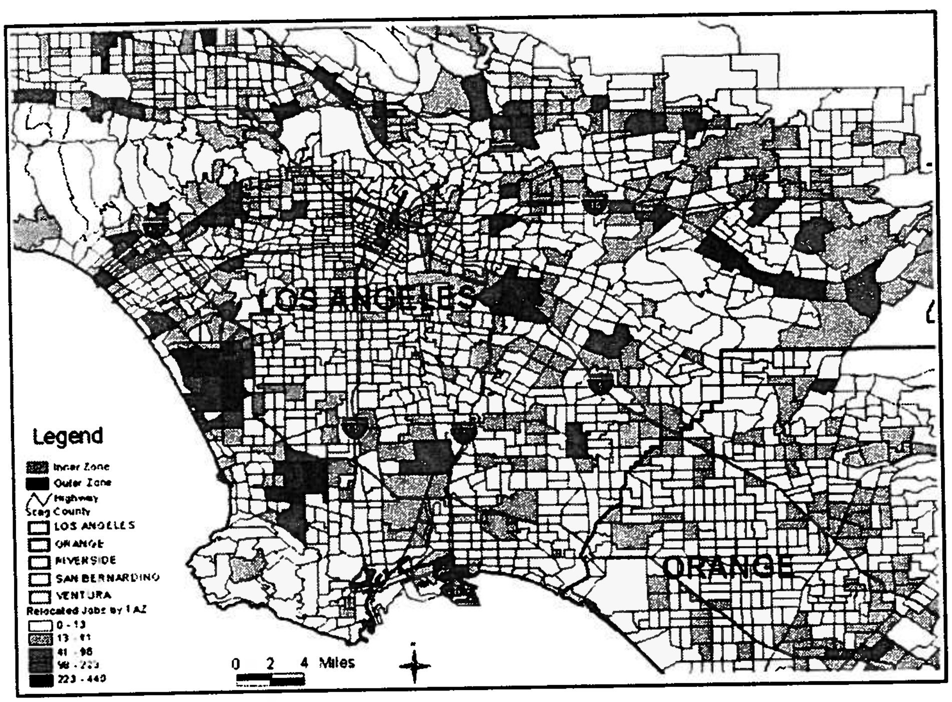

Fig. 3.4 Relocated jobs from a terrorist attack on downtown Los Angeles (relocation scenario) for all businesses and households moving out of the Inner and Outer Zones, five-county region, 2000

Table 3.5a Economic impacts of all businesses and households from the Inner and Outer Zones: Relocation scenario (output, $1,000s, 2001) (Authors' calculations)

	Positive				Negative				Net			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
City of Los Angeles	737,221	136,563	499,581	1,373,365	2,304,493	136,563	499,580	2,940,636	−1,567,272	0	1	−1,567,271
County of Los Angeles	2,227,433	362,308	1,301,284	3,891,024	2,304,493	362,308	1,301,283	3,968,084	−77,060	0	1	−77,059
County of Orange	56	116,622	459,507	576,185	0	116,622	459,508	576,130	56	0	−1	55
County of Ventura	76,996	24,227	107,274	208,496	0	24,227	107,274	131,501	76,996	0	0	76,995
County of Riverside	0	36,558	202,202	238,761	0	36,558	202,202	238,761	0	0	0	0
County of San Bernardino	9	44,422	216,455	260,886	0	44,422	216,455	260,877	9	0	0	9
Sum of Five Counties	2,304,493	584,137	2,286,722	5,175,352	2,304,493	584,137	2,286,722	5,175,352	0	0	0	0
Regional Leakages	312,733	80,190	332,954	725,878	312,733	80,190	332,954	725,878	0	0	0	0
Total	2,617,225	664,327	2,619,676	5,901,229	2,617,225	664,327	2,619,676	5,901,229	0	0	0	0

Table 3.5b Economic impacts of all businesses and households from the Inner and Outer Zones: Relocation scenario (jobs 2001) (Authors' calculations)

	Positive				Negative				Net			
	Direct	Indirect	Induced	Total[a]	Direct	Indirect	Induced	Total[a]	Direct	Indirect	Induced	Total[a]
City of Los Angeles	2,157	961	5,171	8,289	7,257	961	5,171	13,389	−5,099	0	0	−5,099
County of Los Angeles	7,039	2,412	13,472	22,924	7,257	2,412	13,472	23,141	−217	0	0	−217
County of Orange	1	863	4,758	5,622	0	863	4,758	5,622	1	0	0	1
County of Ventura	217	172	1,110	1,499	0	172	1,110	1,282	217	0	0	217
County of Riverside	0	276	2,101	2,376	0	276	2,101	2,376	0	0	0	0
County of San Bernardino	0	313	2,248	2,562	0	313	2,248	2,562	0	0	0	0
Sum of Five Counties	7,257	4,037	23,689	34,983	7,257	4,037	23,689	34,983	0	0	0	0
Regional Leakages	1,363	623	3,425	5,408	1,363	623	3,425	5,408	0	0	0	0
Total	8,620	4,660	27,114	40,391	8,620	4,660	27,114	40,391	0	0	0	0

[a] Total impact is the sum of direct, indirect, and induced effects

Table 3.6a Relocation scenario: Impacts of businesses and households from Inner and Outer Zones (2001, $1,000s)

			Positive[a]			Negative[a]			
Rank	**County**	**Place**	Households	Businesses	Total	Households	Businesses	Total	**Net**
1	LOS ANGELES	Los Angeles	5,577	1,367,788	1,373,365	6,732	2,933,904	2,940,636	−1,567,271
2	LOS ANGELES	Torrance	128	353,697	353,825	115	38,661	38,775	315,050
3	LOS ANGELES	Industry	59	166,563	166,622	56	21,550	21,606	145,016
4	LOS ANGELES	El Monte	60	124,233	124,293	40	15,124	15,163	109,129
5	LOS ANGELES	Glendale	134	135,522	135,657	101	37,034	37,135	98,521
6	LOS ANGELES	Pasadena	273	124,371	124,644	96	34,476	34,572	90,072
7	LOS ANGELES	Monterey Park	28	79,094	79,123	26	9,217	9,243	69,880
8	VENTURA	Thousand Oaks	79	96,838	96,917	79	28,269	28,348	68,570
9	LOS ANGELES	UNCOR-LOS ANGELES	182	113,487	113,669	131	53,103	53,234	60,434
10	LOS ANGELES	West Covina	55	71,297	71,351	37	13,573	13,609	57,742
11	LOS ANGELES	El Segundo	38	70,759	70,797	37	14,314	14,351	56,446
12	LOS ANGELES	Santa Clarita	48	71,765	71,812	46	19,154	19,200	52,613
13	LOS ANGELES	Commerce	40	65,517	65,557	39	15,541	15,580	49,976
14	LOS ANGELES	Santa Monica	128	78,251	78,379	77	28,432	28,509	49,869
15	LOS ANGELES	Avocado Heights	12	42,168	42,180	7	2,794	2,801	39,379
16	LOS ANGELES	Alhambra	89	47,496	47,584	37	13,944	13,981	33,603
17	LOS ANGELES	Beverly Hills	121	52,467	52,587	63	22,236	22,299	30,289
18	LOS ANGELES	Arcadia	31	36,536	36,566	29	10,682	10,712	25,854
19	LOS ANGELES	Cerritos	35	37,596	37,631	35	13,032	13,066	24,564
20	LOS ANGELES	West Hollywood	33	34,186	34,219	33	12,105	12,138	22,081
21	LOS ANGELES	Monrovia	23	30,022	30,045	22	8,624	8,646	21,399
22	LOS ANGELES	Manhattan Beach	40	25,878	25,918	20	7,291	7,311	18,608
23	LOS ANGELES	Agoura Hills	7	20,652	20,659	7	2,567	2,575	18,085
24	LOS ANGELES	Burbank	73	42,148	42,221	70	25,326	25,396	16,825
25	LOS ANGELES	Culver City	43	27,403	27,447	43	15,902	15,945	11,502

[a] Direct + Indirect + Induced

Table 3.6b Relocation scenario: Impacts of businesses and households from Inner and Outer Area (2001, jobs)

			Positive[a]			Negative[a]			
Rank	County	Place	Households	Businesses	Total	Households	Businesses	Total	Net
1	LOS ANGELES	Los Angeles	62	8,228	8,289	75	13,314	13,389	−5,099
2	LOS ANGELES	Torrance	1	1,037	1,038	1	356	357	681
3	LOS ANGELES	El Segundo	0	616	616	0	125	125	491
4	LOS ANGELES	Pasadena	3	830	833	1	345	346	487
5	LOS ANGELES	Glendale	1	765	766	1	361	362	404
6	LOS ANGELES	Beverly Hills	1	482	483	1	206	207	276
7	LOS ANGELES	Santa Monica	1	545	547	1	280	281	266
8	LOS ANGELES	Industry	1	430	430	1	203	204	226
9	VENTURA	Thousand Oaks	1	475	476	1	281	282	194
10	LOS ANGELES	El Monte	1	324	325	0	148	148	177
11	LOS ANGELES	Manhattan Beach	0	236	236	0	73	73	163
12	LOS ANGELES	UNCOR-LOS ANGELES	2	636	638	1	476	477	161
13	LOS ANGELES	Commerce	0	288	288	0	137	137	151
14	LOS ANGELES	West Covina	1	274	274	0	138	138	136
15	LOS ANGELES	Burbank	1	371	371	1	239	240	132
16	LOS ANGELES	Monterey Park	0	219	219	0	91	91	128
17	LOS ANGELES	Arcadia	0	231	231	0	106	107	125
18	LOS ANGELES	Alhambra	1	238	239	0	127	128	112
19	LOS ANGELES	Cerritos	0	217	218	0	125	126	92
20	LOS ANGELES	West Hollywood	0	206	207	0	122	123	84
21	LOS ANGELES	Monrovia	0	161	161	0	82	82	79
22	LOS ANGELES	Santa Clarita	0	248	249	0	171	172	77
23	LOS ANGELES	Culver City	0	230	231	0	158	159	72
24	LOS ANGELES	Avocado Heights	0	83	83	0	26	27	56
25	LOS ANGELES	Agoura Hills	0	72	72	0	24	24	48

[a] Direct + Indirect + Induced

Table 3.7 Economic impacts from businesses and firms of a terrorist attack on downtown Los Angeles: Hybrid scenario (Authors' calculations)

	Output ($1,000s)				Jobs			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
City of Los Angeles	2,162,218	130,270	478,036	2,770,525	6,643	907	4,953	12,503
County of Los Angeles	2,216,711	347,420	1,245,170	3,809,300	6,643	2,283	12,906	21,832
County of Orange	56	111,077	439,692	550,825	0	814	4,559	5,373
County of Ventura	3,269	23,138	102,648	129,054	0	162	1,063	1,226
County of Riverside	0	35,045	193,485	228,531	0	262	2,012	2,274
County of San Bernardino	9	42,746	207,124	249,878	0	298	2,154	2,452
Sum of Five Counties	2,220,044	559,426	2,188,119	4,967,589	6,643	3,820	22,694	33,157
Regional Leakages	284,059	70,813	301,237	656,109	1,200	544	3,101	4,843
Total	2,504,103	630,239	2,489,356	5,623,698	7,843	4,363	25,795	38,000

In summary, we examined three scenarios (Exit, Relocation, and Hybrid) in this case study. The aggregate impacts in the Exit Scenario are $5.901 billion of output and 40,391 jobs, somewhat less in the Hybrid Scenario ($5.624 billion and 38,000 jobs). The Relocation Scenario is neutral from a regional perspective, although direct losses in the impacted zones are 7,257 jobs and $2.617 billion of output. The City of Los Angeles is the main loser, with a net output loss of $1.567 billion and a net job loss of 5,099 jobs. The County-level changes are insignificant with a small loss in Los Angeles County balancing an equivalent increase in Ventura County (the City of Thousand Oaks). Otherwise, jobs decentralize to major subcenters in Los Angeles County.

3.5 Case study III: The business Interruption Losses of a Hypothetical Hurricane event in the Greater Houston Area

In this case, the exogenous shock was a natural disaster. The analysis utilizes an SCPM-style model to capture the business interruption losses of a hypothetical hurricane event in the Houston-Galveston Area. The hypothetical hurricane strike is designated by adopting the storm parameters of Hurricane Rita at its landfall hour from the HURREVAC 2000 database and shifting the storm track of Hurricane Rita to the southwest by about 85 miles, which causes the hurricane to make landfall at

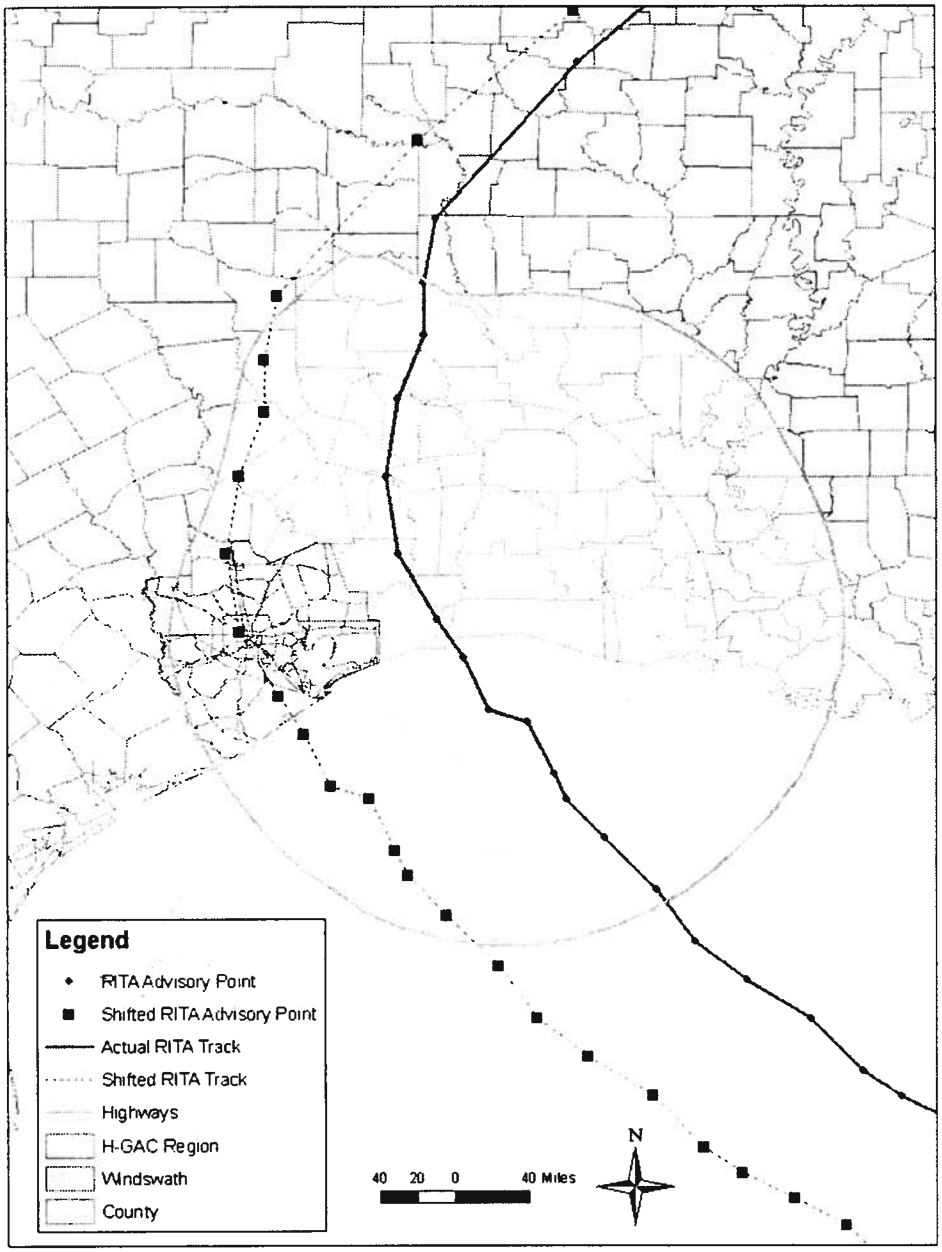

Fig. 3.5 Storm track and advisory points for the hypothetical hurricane

the coast of Galveston and then follow Interstate 45 north to downtown Houston. This scenario is considered the worst case scenario for a hypothetical hurricane event for the Houston-Galveston region (Fig. 3.5).

HURREVAC 2000 is a Windows-based hurricane decision assistance tool for government emergency managements developed by the Sea Island Software Incorporation for the FEMA and the Army Corps of Engineers. It provides historical storm data in various formats. Furthermore, it offers various analysis tools for real time hurricane forecast data from the National Weather Service (NWS) and the Tropical Prediction Center/National Hurricane Center (NHC) to assist local evacuation efforts (Sea Island Software Inc. 2006).

Similar to the losses reported for earlier natural disasters like the Northridge earthquake in 1994, Hurricane Andrew in 1992, and the flooding of the Mississippi River in 1993, the property damage and economic losses estimated for Hurricanes Katrina and Rita vary widely. The economic losses are also interpreted differently among various agencies and researchers. Some refer to property (replacement) damage only and others include business interruption losses. Different perceptions and inconsistent estimation of economic losses have made it difficult to compare efficient mitigation plans and allocate appropriate relief funding. The economic impacts in this case study focus on the business interruption losses, defined by the losses of output and employment related to the economic activities in the region. They are further categorized as direct, indirect, and induced impacts and allocated to small impact analysis zones.

To estimate direct economic losses of a hurricane in a region, it is necessary to inventory the damage of building structures in different residential types and industrial sectors. Building damages and their recovery time can be employed to calculate the relevant business interruption losses. FEMA's Hurricane Modeling Package, the so-called HAZUS package, includes a large database to store a nationwide inventory of building blocks, facilities, transportation systems, utility systems, and hazard material facilities (Schneider and Schauer 2006). The HAZUS model incorporates a series of engineering-based physical damage functions to estimate the damage states for different types of residential and commercial buildings in a hurricane event. It also employs empirical loss estimation techniques to determine repair costs and recovery times for different buildings.

The limitation of the HAZUS Hurricane Model is that there is no module to calculate indirect and induced impacts of hurricanes on industry purchases and household consumption (FEMA 2006a). Indirect impacts represent the ripple effects from direct final demand changes on related industrial purchases, while induced impacts reflect the effects on regional industries caused by the changes of household consumption due to the effects of direct final demand changes. Unlike the Earthquake Model and the Flood Model (FEMA 2006b), the Hurricane Model in the recently released HAZUS (HAZUS MH-MR2) does not have a module to estimate either indirect or induced economic losses related to business interruption.

In addition, the direct and total losses of output estimated by the HAZUS Hurricane Model for a high-intensity hurricane are usually less than 5 percent of structure damage losses or 0.5 percent of total regional output, which are far less than the ratios found in other studies. For instance, Burrus et al. (2002) found that total business interruption impacts, including direct, indirect, and induced impacts, in a low-intensity hurricane are equivalent to between 0.8 and 1.23 percent of total regional output.

In this hypothetical hurricane scenario, HAZUS reports a total of $48.5 billion building-related economic losses, which includes $40.9 billion of property damage losses and \$7.6 billion of income-related business interruption losses (See Table 3.8). The HAZUS Hurricane Model also estimates output and employment losses at a total of \$1.6 billion and 9,293 jobs. The total of \$1.6 billion direct output losses is only 0.4 percent of \$402.3 billion output in the region, which is much lower than the ratios for low-intensity hurricanes estimated by Burrus et al. in 2002.

This study proposes an approach to calculate direct impacts related to business interruptions systematically. First, it utilizes building damage state probabilities for each specific occupancy class in each census tract estimated by the HAZUS Hurricane Model, and building recovery times for different damage states for different occupancy classes (borrowed from the technical documents of the HAZUS Earthquake Model) to calculate the building and service interruption times by occupancy class by census tract. Second, it links the estimated commercial building and service interruption times to small area employment data to calculate the lost jobs in terms of business and service interruptions. Finally, it converts the job losses to dollar values of output losses using dollar per job ratios. The calculation of job losses in a census tract or a loss analysis zone is:

$$L_{z,s} = J_{z,s} * (\sum_{d} (DS_{z,s,d} * BRT_{s,d} * F_{s,d})), \qquad (2)$$

where

$L_{z,s}$ = the total losses of job*day in industrial sector s in zone z,

$J_{z,s}$ = the jobs in industrial sector s in zone z,

$DS_{z,s,d}$ = the probabilities of damage states in damage state d, occupancy class (or sector) s, and zone z,

$BRT_{s,d}$ = the building recovery times (including both construction and clean-up time) measured in days for buildings in damage state d and occupancy class (or sector) s, and

$F_{s,d}$ = the building and service interruption time multiplier for buildings in damage state d and occupancy class (or sector) s.

Equation (2) associates employment data with the corresponding building damage status to estimate the total losses of jobs by time, which are further converted to annual losses of jobs to be consistent with the regular time span for data analysis in input–output models.

After we determine the direct impacts, it is standard procedure in SCPM to calculate total indirect and induced effects from the direct final demand changes. In this case study, we develop a simple version of SCPM that is an analogue of the SCPM 1.

This SCPM1-style model transfers the methodology initially developed for the Southern California to the Houston-Galveston area. First, it constructs an IMPLAN input–output model for the H-GAC region. Second, it calculates indirect and induced impacts from direct impacts from this IMPLAN input–output model and aggregates the impacts in hundreds of industrial sectors calculated to a small number of sectors, i.e. 17 sectors. Third, it allocates the indirect effects spatially to 886 census tracts in the H-GAC region using employment-weighted attractions and

Table 3.8 Building-related economic losses by county ($1000) (Authors' calculations using HAZUS)

County	Property Damage				Income-Related Business Interruption				Total
	Building	Content	Inventory	Subtotal	Relocation	Capital	Wage	Rental Income	
Brazoria	3,301,559	1,539,740	21,539	4,862,838	475,645	43,497	54,400	164,644	5,601,024
Chambers	17,399	3,248	76	20,723	1,737	251	391	641	23,742
Fort Bend	841,619	269,285	3,581	1,114,485	126,332	6,413	7,852	42,156	1,297,238
Galveston	6,695,523	3,064,312	24,897	9,784,732	928,544	138,856	153,676	357,382	11,363,190
Harris	17,928,184	6,907,206	128,498	24,963,888	2,934,520	370,001	454,083	1,304,565	30,027,055
Liberty	8,680	1,670	14	10,364	576	35	60	229	11,265
Montgomery	155,311	41,604	164	197,079	10,071	1,546	1,512	5,174	215,381
Waller	1,276	116	0	1,392	15	0	0	8	1,415
Total	28,949,551	11,827,181	178,768	40,955,500	4,477,440	560,598	671,973	1,874,798	48,540,310

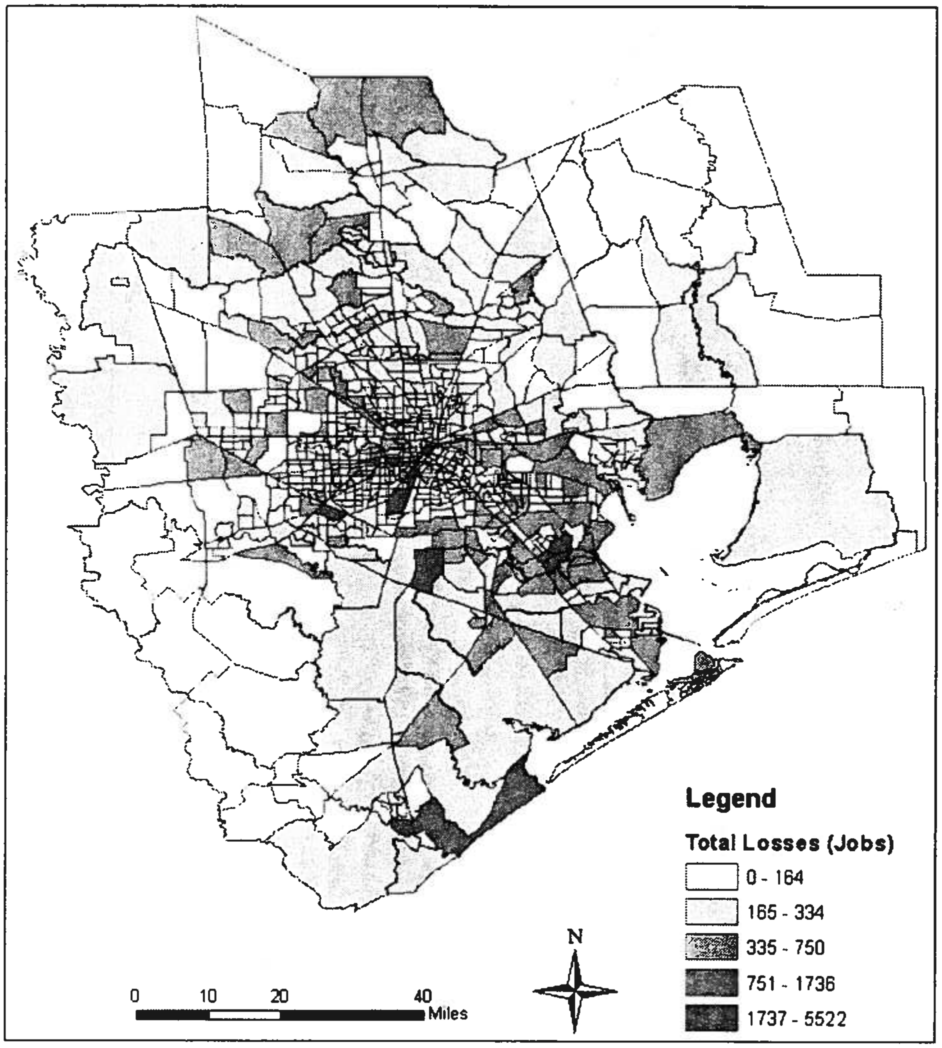

Fig. 3.6 Total losses of jobs from the hypothetical hurricane event

productions. Finally, it distributes induced impacts using a Garin-Lowry style model with two trip origin-destination (O-D) matrices, a journey home-to-work matrix, and a journey home-to-shop matrix. The journey home-to-work O-D matrix traces wages from workplace back to home and the journey home-to-shop matrix traces housing expenditures from the home to the retail stores or service establishments. The results of output and job losses in this hypothetical hurricane event are summarized in Table 3.9. Total impacts including direct, indirect, and induced impacts measured by job by census tract are shown in Fig. 3.6.

Table 3.9 Output and job losses from the hypothetical hurricane event (Authors' calculations)

	Output ($1,000s)				Jobs			
	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
City of Houston	5,188,013	2,377,868	2,926,709	10,492,589	40,201	15,490	30,918	86,610
Brazoria County	790,277	154,107	491,683	1,436,066	5,577	964	5,457	11,998
Chambers County	7,827	24,375	60,699	92,901	56	153	659	869
Fort Bend County	238,171	300,781	822,678	1,361,630	1,334	1,669	8,724	11,727
Galveston County	962,184	134,033	457,894	1,554,110	8,218	894	5,164	14,277
Harris County	7,209,271	3,340,298	5,707,274	16,256,843	54,365	21,629	60,380	136,375
Liberty County	456	28,450	128,895	157,800	3	164	1,436	1,603
Montgomery County	17,225	257,194	733,068	1,007,487	117	1,457	7,794	9,368
Waller County	44	17,479	63,023	80,546	0	108	676	784
Sum of Eight Counties	9,225,454	4,256,717	8,465,213	21,947,383	69,671	27,039	90,290	187,000
Regional Leakages	3,724,930	1,529,657	3,104,553	8,359,140	25,302	10,236	32,981	68,519
Regional Total	12,950,384	5,786,373	11,569,766	30,306,523	94,973	37,275	123,271	255,518

Table 3.10 The 20 cities with the highest losses of output in the hypothetical Hurricane Rita event (Authors' calculations)

		Output ($1,000s)				Jobs			
Index	City Name	Direct	Indirect	Induced	Total	Direct	Indirect	Induced	Total
1	Houston	5,188,013	2,377,868	2,926,709	10,492,589	40,201	15,490	30,918	86,610
2	Pasadena	448,527	99,425	230,836	778,788	3,200	550	2,479	6,229
3	Galveston	260,244	42,583	81,588	384,415	2,669	306	942	3,918
4	Texas City	265,844	32,478	81,645	379,967	1,888	194	918	3,000
5	Sugar Land	50,268	105,509	133,564	289,341	301	504	1,394	2,199
6	The Woodlands	9,493	109,493	127,498	246,485	54	484	1,314	1,852
7	Pearland	139,341	21,016	84,221	244,578	1,179	147	911	2,236
8	League City	123,143	16,469	99,276	238,887	1,515	142	1,121	2,778
9	Webster	175,369	13,813	18,326	207,508	1,994	108	206	2,308
10	Stafford	105,282	77,498	19,815	202,595	406	357	206	970
11	Missouri City	46,421	25,888	118,238	190,547	350	172	1,241	1,763
12	Deer Park	105,656	21,733	57,644	185,033	651	139	616	1,406
13	La Porte	95,386	21,874	61,067	178,327	559	141	653	1,352
14	Alvin	130,112	15,480	27,862	173,454	1,012	95	302	1,410
15	La Marque	93,233	12,011	29,635	134,879	374	59	330	763
16	Channelview	64,023	23,588	45,671	133,281	282	125	480	888
17	Baytown	27,240	23,779	81,164	132,184	231	173	883	1,287
18	Friendswood	68,162	7,825	49,104	125,092	794	63	546	1,403
19	Aldine	35,833	18,675	26,501	81,010	271	135	280	687
20	Conroe	871	31,299	48,720	80,890	8	210	531	749
Total		7,432,459	3,098,305	4,349,084	14,879,849	57,940	19,596	46,272	123,809

Table 3.9 shows that total output losses in the region would be over $30.3 billion, including about $13.0 billion direct losses, $5.8 indirect losses, and $11.6 billion induced losses. The region as whole also loses over 255,518 employment person-years, among which 94,973 person-years are direct losses, 37,275 are indirect losses, and 123,271 are induced losses.

There are also about $8.4 billion output losses and 68,519 job losses as regional leakages, which account for about 27 percent of total regional losses of output and employment. This high percent of losses in areas outside of the H-GAC region indicates the important role of the region in the national economy.

In the eight-county metropolitan area, Harris County accounts for about half of the total losses in output and employment. Galveston County ranks second by loss among all the counties. Brazoria County ranks third, mostly due to its geographic location along the Gulf Coast.

Table 3.10 lists the top 20 cities ranked by losses of output in dollars after the hypothetical Hurricane Rita event. The City of Houston, the one suffering the greatest impacts on the list, loses over 86,000 jobs, which accounts for about one-quarter of the total job losses in the region. The output losses in the City are $10 billion, which is about one-third of the regional losses. The total losses in the top 20 area cities are $16.9 billion output and 146,000 jobs, which is slightly higher than the losses in Harris County.

3.6 Conclusions

This chapter has examined three case studies on the economic impacts of terrorist attacks and natural disasters, including a terrorist attack on Terminal Island at the Los Angeles-Long Beach ports complex, a plausible radiological bomb attack on Los Angeles' Downtown Financial District, and a hypothetical hurricane event in the Houston-Galveston area.

The Terminal Island case study utilized a more detailed version of the Southern California Planning Model, i.e. SCPM2, to estimate spatial and sectoral impacts corresponding to the exogenous shocks of exploding a radiological bomb in the port area and the destruction of bridges accessing Terminal Island. The results demonstrated that a relatively simple terrorist attack could inflict massive damage not only to the Southern Californian local economy but also to the national economy. This study also suggests a high *ex ante* payoff to accelerate restoration in the event of a successful attack.

In the second case study, a hypothetical radiological bomb attack on Downtown Los Angeles Financial District, an up-to-date version of SCPM called SCPM 2005 was employed to simulate household and firm relocation in three scenarios: an exit scenario where households and firms in both the inner and the outer zone disappear; a relocation scenario where households and firms in the inner and the outer zone relocate to somewhere else within the five-county metropolitan region; and a hybrid scenario where the households and firms in the inner zone disappear while those in the outer zone relocate. This case study finds that the effects on the inner zone play a dominant role because of its long evacuation period. The exit scenario has an aggregate impact of $5.9 billion of output losses and 40,391 job losses. The relocation scenario has neutral effects from a regional perspective but direct losses in the impacted zones are 7,257 jobs and $2.617 billion of output. The hybrid scenario may be the most realistic, but its impacts are marginally lower than the exit scenario because of the dominance of the inner zone impacts.

In the hurricane case study, the SCPM 1 approach initially established for the Southern California region was transferred to the Houston-Galveston area. This study designs a hypothetical hurricane by adopting the storm parameters of Hurricane Rita but shifting the storm's tracks to make landfall at the Galveston Coast and then follow Interstate 45 to strike downtown Houston. First, it utilizes the Hurricane Model in FEMA's HAZUS-MH package to estimate damage states of buildings in the area. Second, it calculates direct impacts using building damage states estimated by the HAZUS Hurricane Model, building recovery time from HAZUS technical documents, and employment data from local planning agencies. Third, it utilizes a regional input–output model to calculate indirect and induced effects from direct final demand changes. Finally, it uses SCPM 1 to allocate these predicted effects to small impact analysis zones and highlight the most vulnerable geographic areas in the region. All three case studies show that the economic impacts of terrorist attacks and natural disasters on a large metropolitan area would extend to the whole nation rather than be limited to the local area. The large economic impact costs justify considerable resource expenditures on prevention.

The SCPM model is adaptable to almost any kind of terrorist attack or natural disaster on major urban infrastructures and attractions, such as ports, airports, downtowns, and theme parks, etc. The Houston case study demonstrates that the SCPM model initially constructed for Southern California is transferable to another large metropolitan area where suitable data are available.

A noticeable advantage of SCPM models is the scalable functionality and flexible data requirements. SCPM 1 has minimum data requirements on model construction. It uses the regional input–output table, small area employment data, a journey home-to-work matrix, and a journey home-to-shop matrix to develop the base model. In addition to the data used by SCPM 1, SCPM 2, and SCPM 2005 need network link files to develop sophisticated network routing functions to analyze the change of network performance under different situations. SCPM 2005 can handle a large number of economic sectors, TAZs, and network links. The scalable model structures of SCPM enhance adaptability of the model to different scenarios with different data availability, which is demonstrated in the three case studies in this chapter.

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