The Abdus Salam International Centre for Theoretical Physics

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8th Workshop on Non-Linear Dynamics and Earthquake Prediction

3 - 15 October, 2005

Integrated Disaster Risk Management as an Innovation of Science and Technology: Issues, Methods and Challenges. Part I

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Research Division of Earthquake Disaster Prevention
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611 0011 Kyoto
Japan

Tonankai Erthquake Mitigation Initiative Project (Daidaitoku Okada Sub-project)

Entire Project Headed by Prof. Yoshiaki Kawata, DPRI, Kyoto University
Sub-project led by Norio Okada,
DPRI, Kyoto University

Lecture 1, 8th Workshop on Non-linear Dynamics and Earthquake Prediction, 11 October, 2005, Trieste in Italy

Project Period 2002-2006

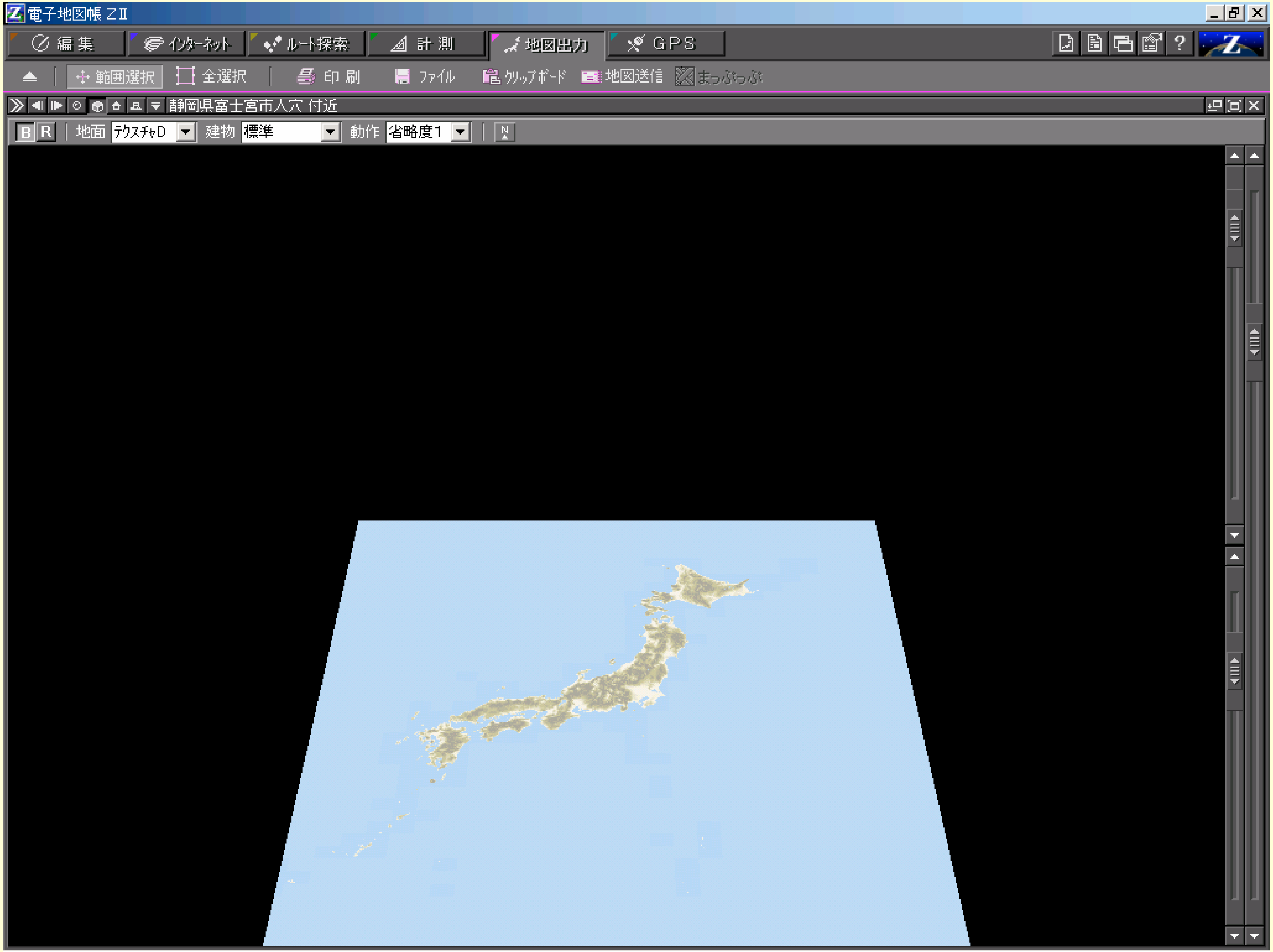
- Purpose: Implementation-oriented Research Initiative in Disaster Risk Mitigation
- Expected Outcomes:

-achievable, visible and transferable by 2006

-customers, stakeholders-available outputs

-unique and research value-added approach

-academic initiative



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インターネット
ルート探索
計測
地図出力
GPS
範囲選択
全選択
印刷
ファイル
クリップボード
地図送信
まっぷっぷ
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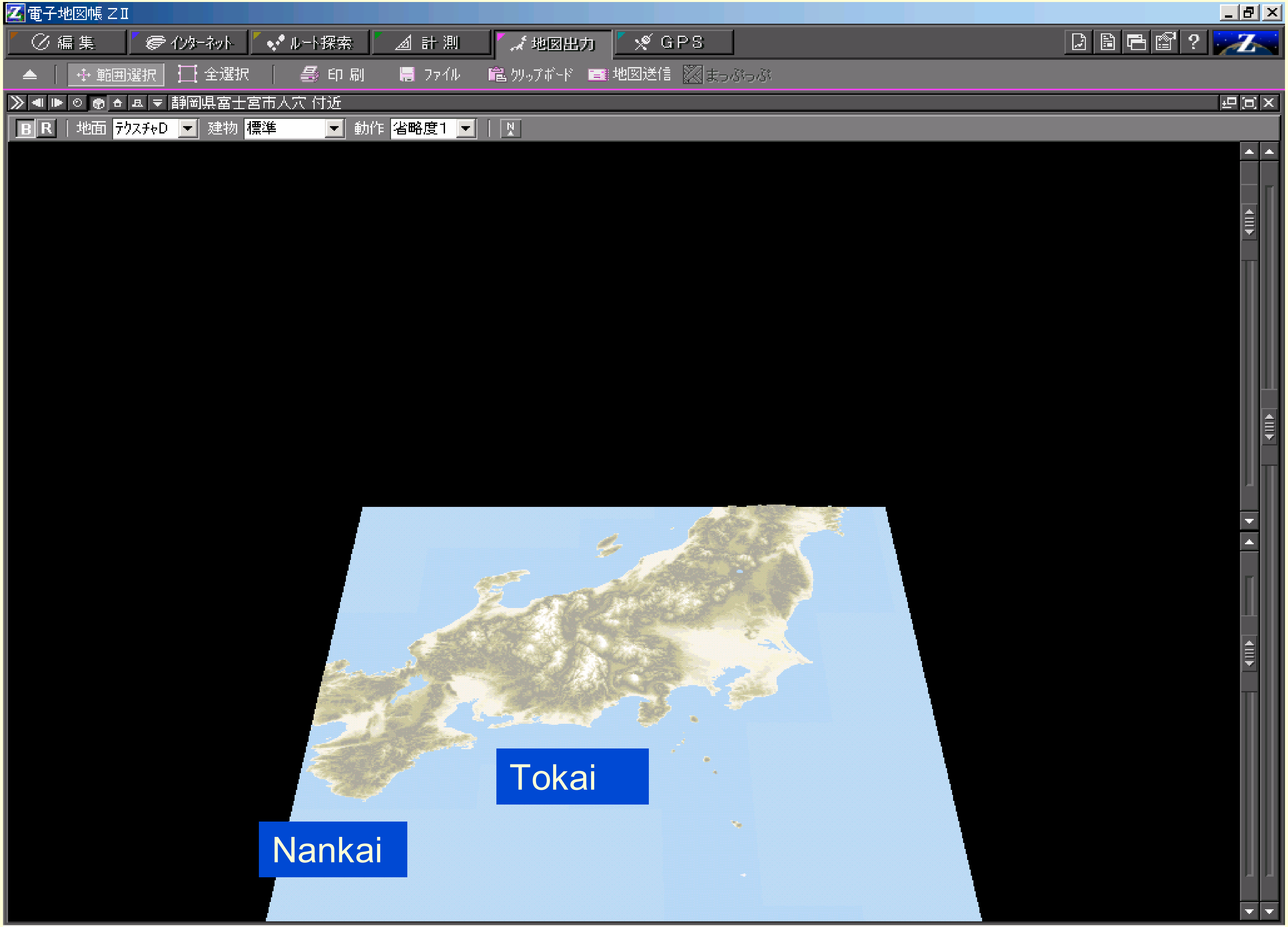
B R
地面 テクスチャD
建物 標準
動作 省略度1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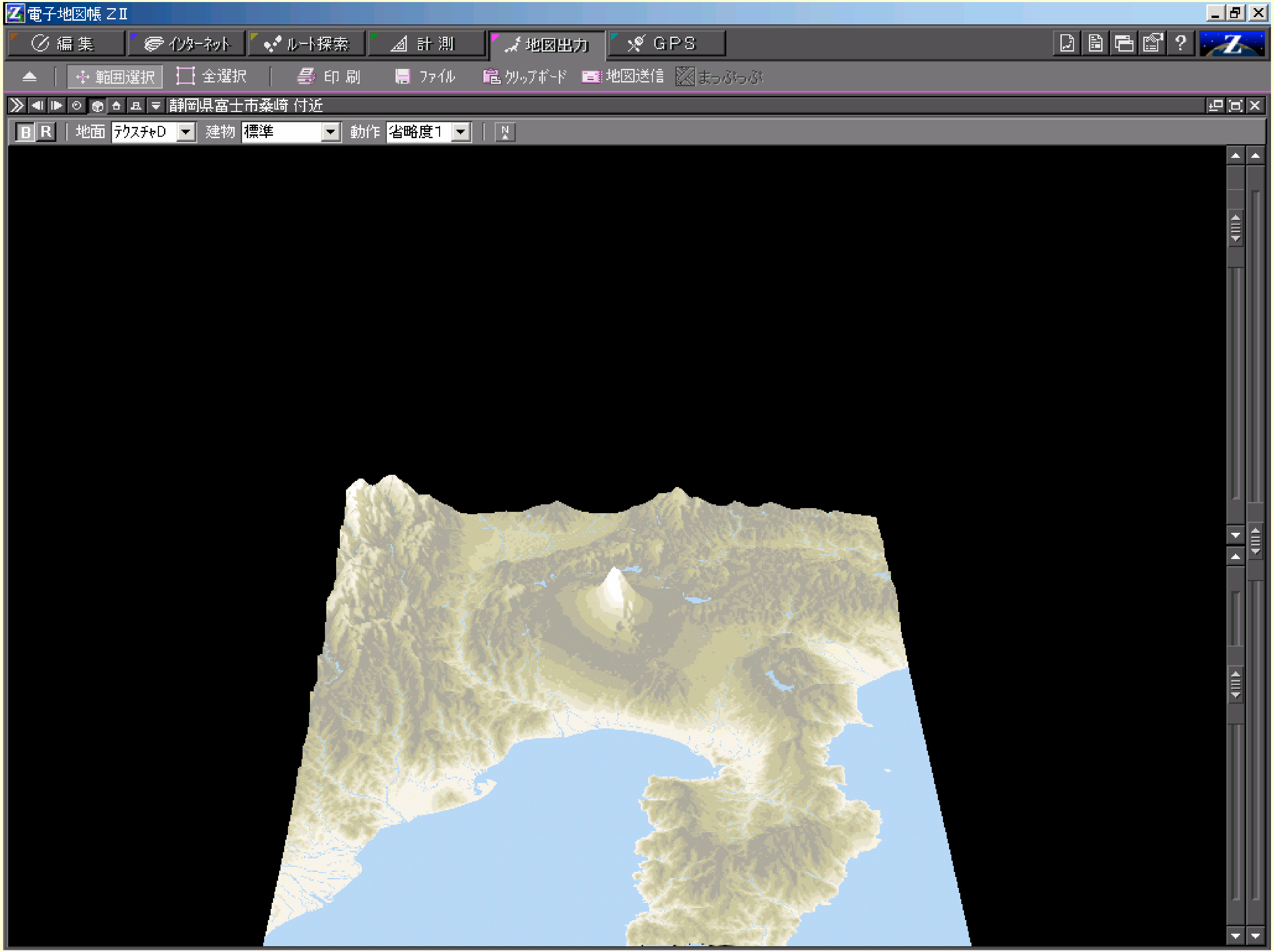
Tokai
Nankai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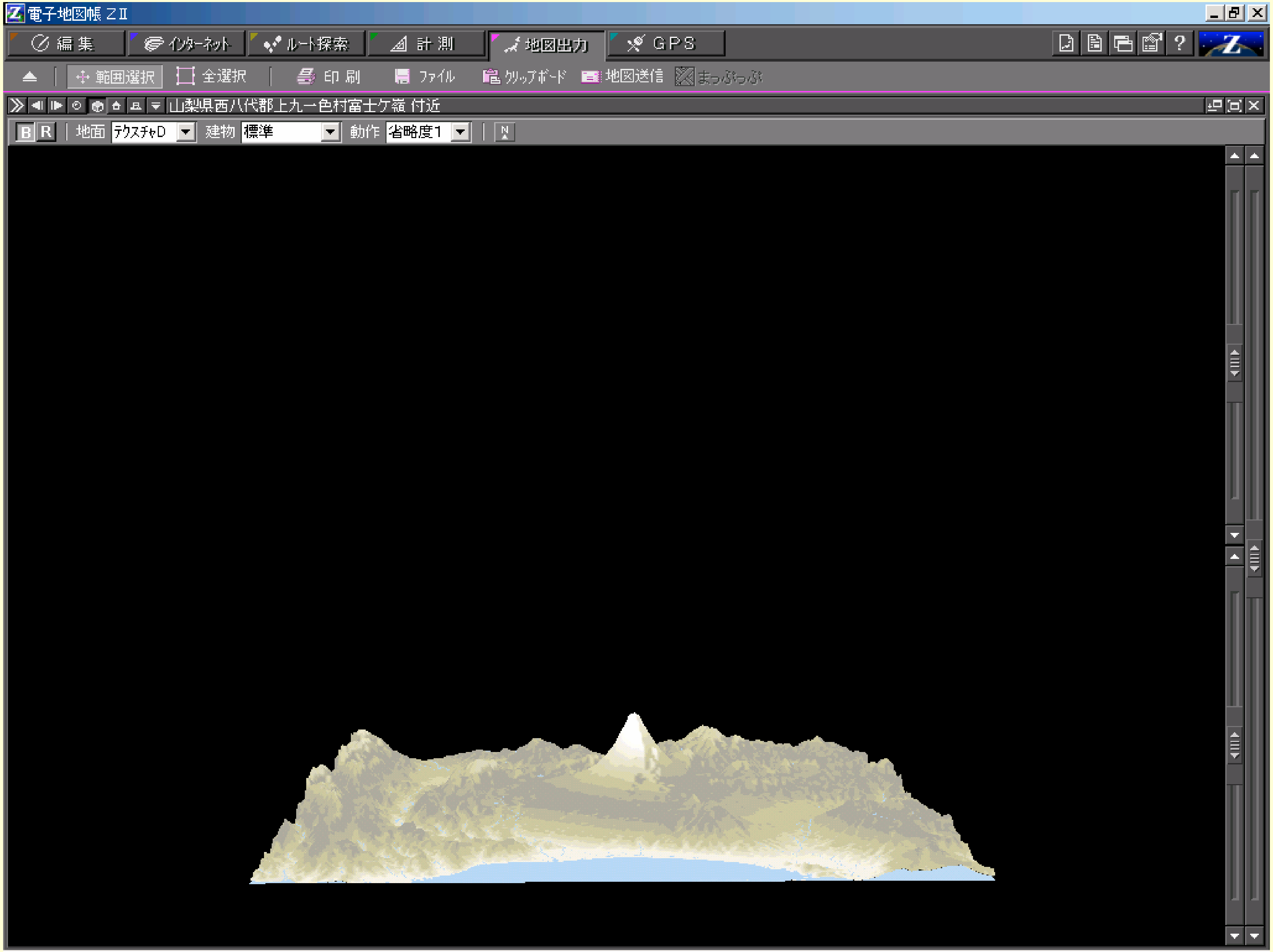

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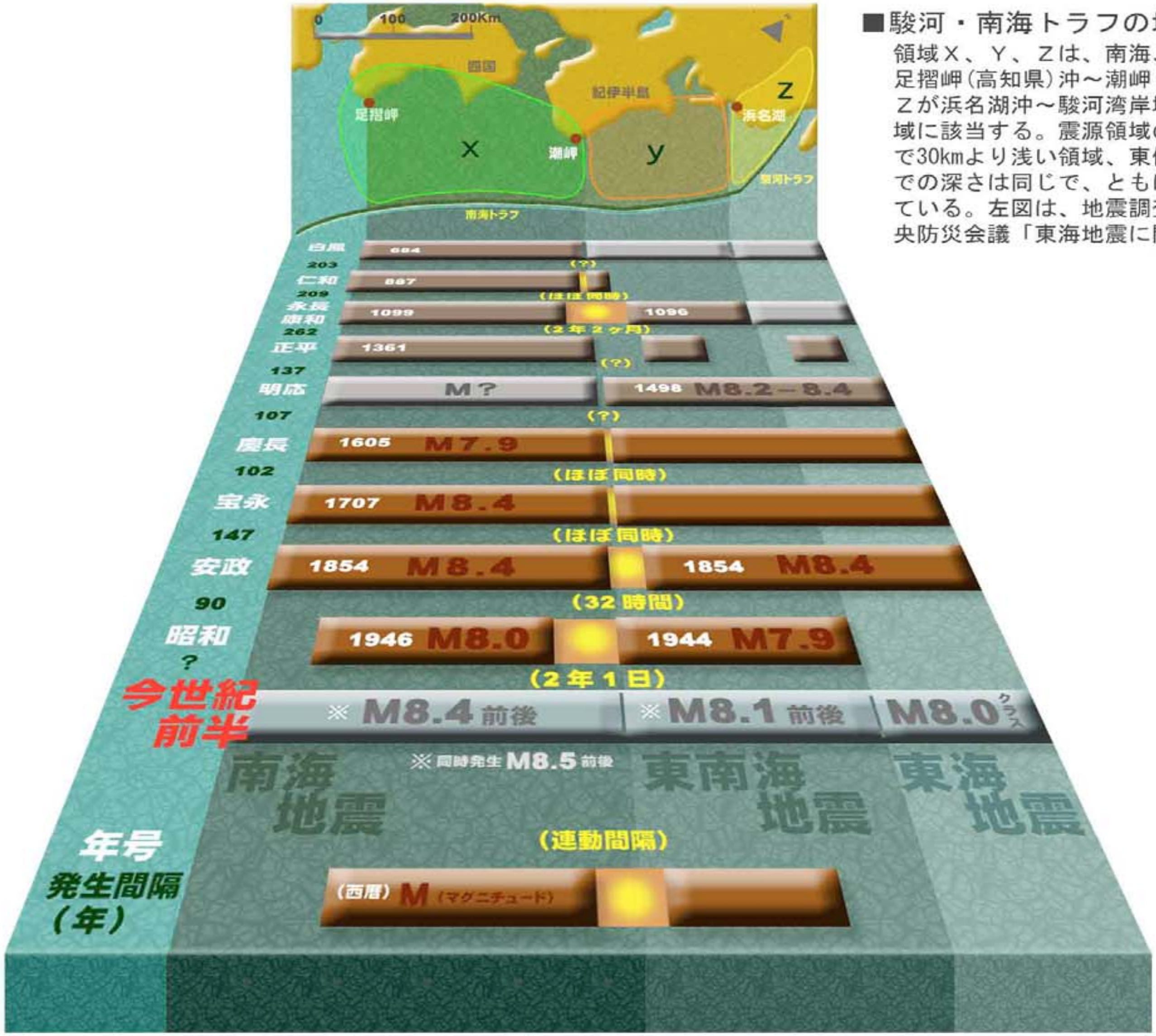
地面 ﾃｸｽﾁｬD
建物 標準
動作 省略度1


大地震火事略圖

東都珎事實録咄

Chronology of Catastrophic Earthquakes Around Suruga-Nankai Trough

(http://www.greencompass.net/)



■駿河・南海トラフの地震の震源域について

領域X、Y、Zは、南海、東南海、東海地震の想定震源域。地理的には、領域Xが足摺岬(高知県)沖～潮岬(和歌山県)沖、領域Yが潮岬沖～浜名湖(静岡県)沖、領域Zが浜名湖沖～駿河湾岸域におおむね該当する。なお領域Zは想定東海地震の震源域に該当する。震源領域の深さ(断層面の分布する深さ)は、領域Zについて北西側で30kmより浅い領域、東側で10kmより深い領域とされ、領域X、Yについて東西端での深さは同じで、ともに北端(沿岸寄り)が30km、南端(トラフ寄り)で10kmとされている。左図は、地震調査委員会「南海トラフの地震の長期評価」(2001)および中央防災会議「東海地震に関する専門調査会報告」(2001)をもとに作成。

■駿河・南海トラフの巨大地震

駿河・南海トラフ沿いに発生する地震は、ある一定の間隔で発生してきたことが知られている。しかも東海、東南海、南海という三つの巨大地震は同時もしくは近接して、東から順に発生していることがわかる。

中央防災会議「東南海・南海地震等に関する専門調査会」(2001、10～)の第一回検討資料によると、駿河・南海トラフに発生した巨大地震は西暦684年の白鳳地震から現在まで、9回の地震を挙げている。一方、同年 9月に地震調査委員会「南海トラフの」(2001)の発表によると白鳳地震から1605年より前については検討の結果、南海トラフ沿いの地震として同定にいたらなかったとして、1065 ～1946年までの期間に、4回の一連の巨大地震を挙げている。左図は両者をもとに作成。なお地震の規模を示すM(マグニチュード)は理科年表(2001)によった。

また「東南海地震」という呼称は、1944年の昭和東南海地震に対して使われてきたが、政府により先の想定震源域に基づいた検討が行われている現在は、この政府検討に基づいた呼称を用いることが多い。左図の地震もこの呼称によるものとする。

A Japan’s Challenge towards Anticipatory and Participatory Urban Disaster Risk Management: Case Study of Tonankai Earthquake Disaster Initiative

Norio Okada* and Hirokazu Tatano*

*Professor of Integrated Disaster Risk Management, Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto, 611-0011 Japan

IUEPA, Louisville, KY, 8 Sept.2004

Project Period 2002-2006

- Purpose: Implementation-oriented Research Initiative in Disaster Risk Mitigation
- Expected Outcomes:

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Major Challenges

- Anticipatory approach supported by the methodology of urban diagnosis and adaptive management
- Participatory process involving multiple stakeholders
- Integrated disaster risk management to be linked with urban and regional planning and management.

Lessons from the 1995 Hanshin-Awaji Earthquake Disaster

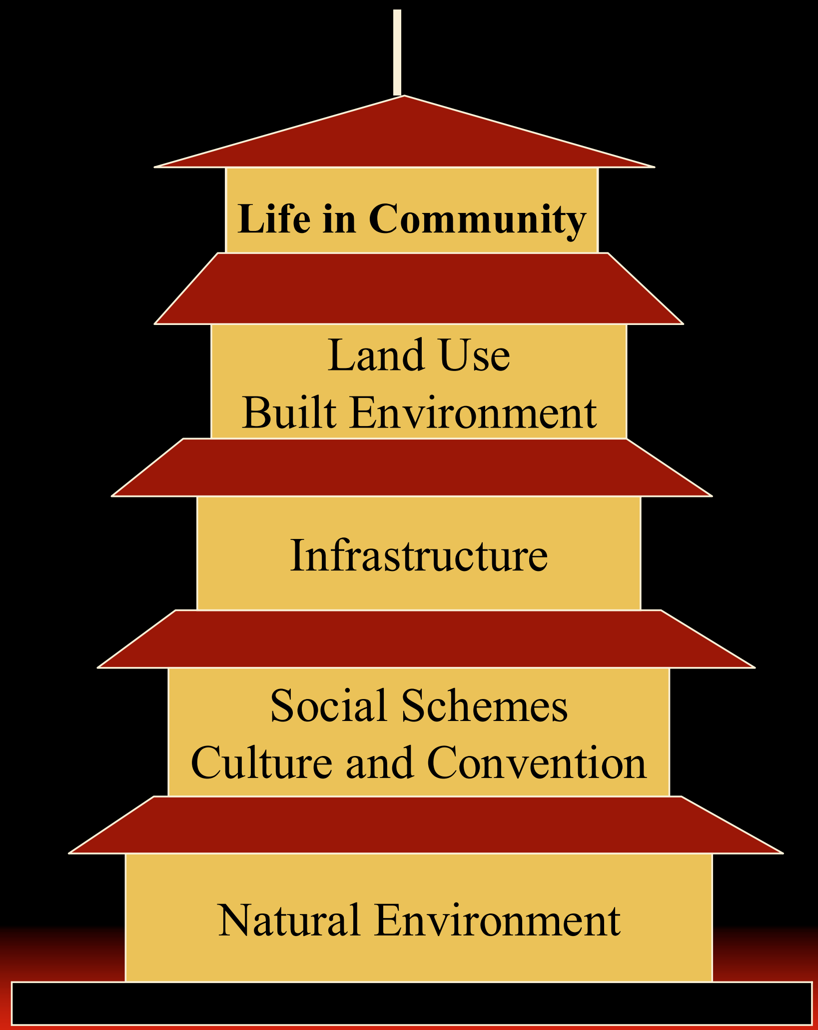
- Low-frequency, high-impact disaster (catastrophic disaster) requires a special approach different from the conventional one familiar to Japan.

- Coordinated approach to maximize the integrated capacity for the region to cope with holistic aspects of such a catastrophic disaster.
- Shift from failure-masked to fail-safe, risk management approach.
- From retroactive to proactive approach
- Link disasters to daily life concerns.

Conventional and 21st century disaster plan

Conventional disaster plan	21st century integrated disaster planning and management
reactive	proactive
emergency and crisis management	risk mitigation + preparedness
countermeasure manual approach	anticipatory/precautionary approach
predetermined planning	adaptive management
sectoral countermeasure approach	comprehensive policy-bundle approach

City/Region/Community
Viewed as a Five-storied Pagoda
(Pagoda Model)


Life in Community
Land Use
Built Environment
Infrastructure
Social Schemes
Culture and Convention
Natural Environment

Multi-level Participatory Approach

- impact of the earthquake would be immense and distribute across regions and down to local communities
- coping capacity need to be fostered on community level in anticipation of the Tonankai Earthquake.
- administrators and experts engaged in inter-regional disaster management are expected to work together and develop effective mitigation countermeasures and implement them in advance.

Table 1 Occurrence Probabilities Prediced

<Source:地震調査委員 Earthquake Investigation Committee(2001)>

next 30 years	50%	40%
next 40 years	70-80%	60%
next 50 years	80-90%	80%

Model Size

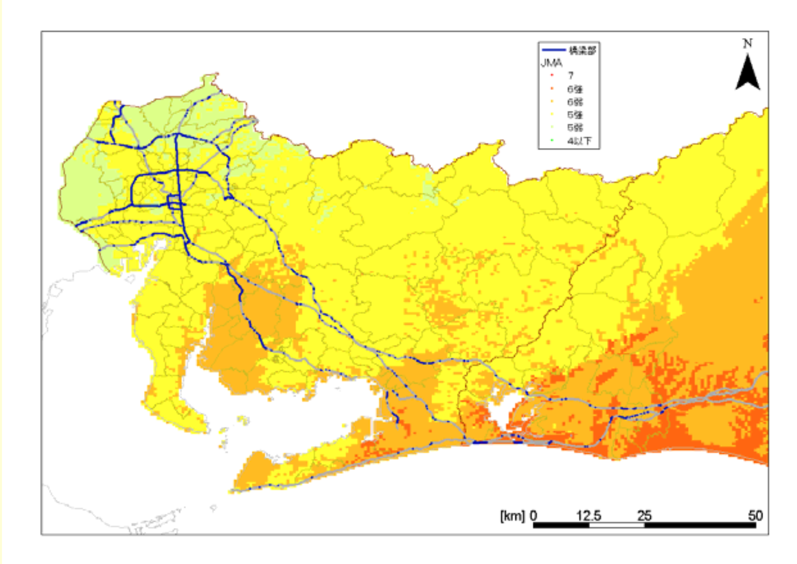
Industrial Sectors

1 : Agriculture, Forestry & Fishery

2 : Mining & Manufacturing

3 : Construction & Services

Disaster Scenario



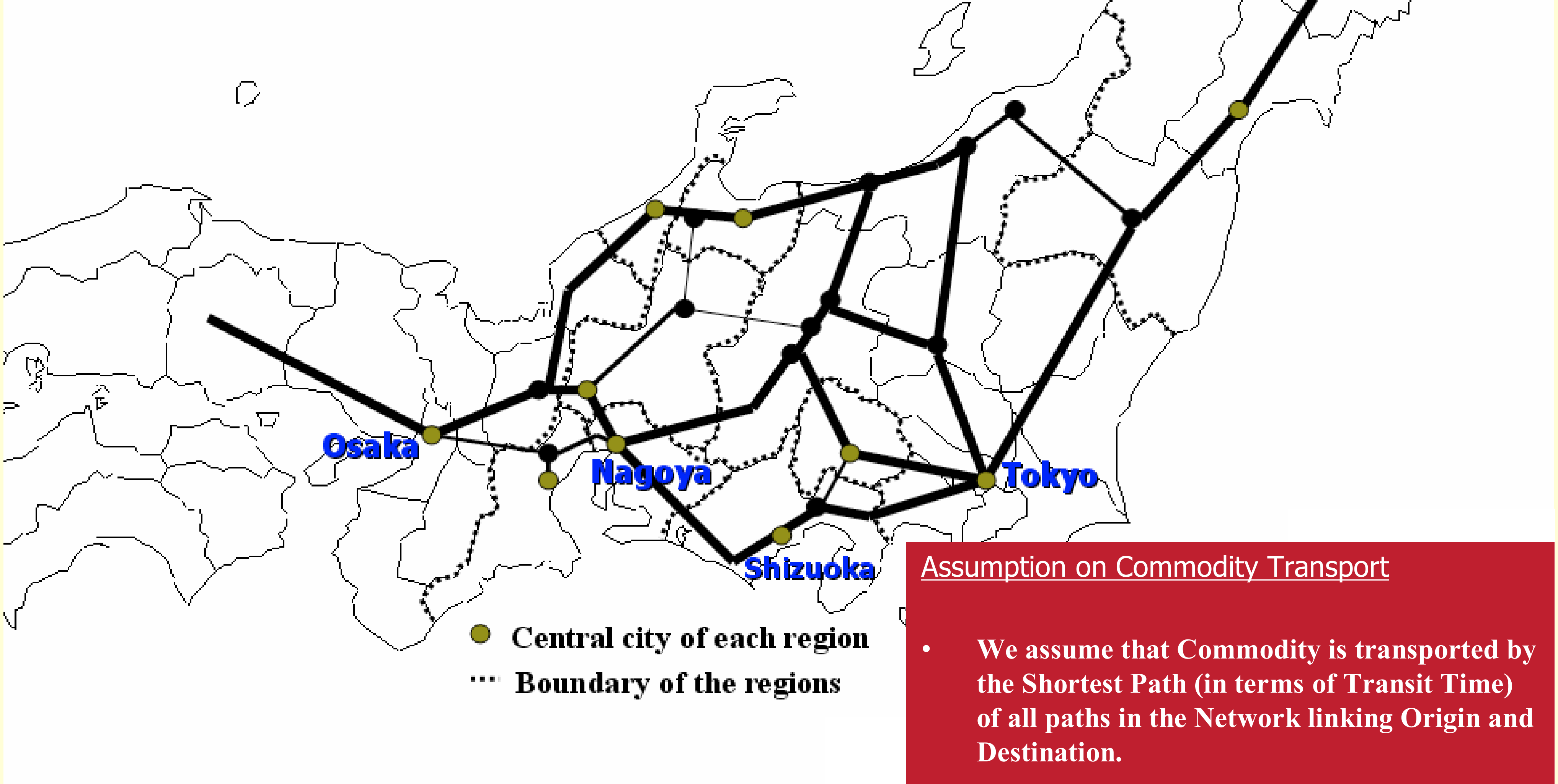
- Tokai Earthquake

  Transport infrastructure (highway, railway) is damaged, and for 3 months it is out of service due to restoration. Traffics have to go on detours.

- Congestion of the main Detour (Chuo Route)

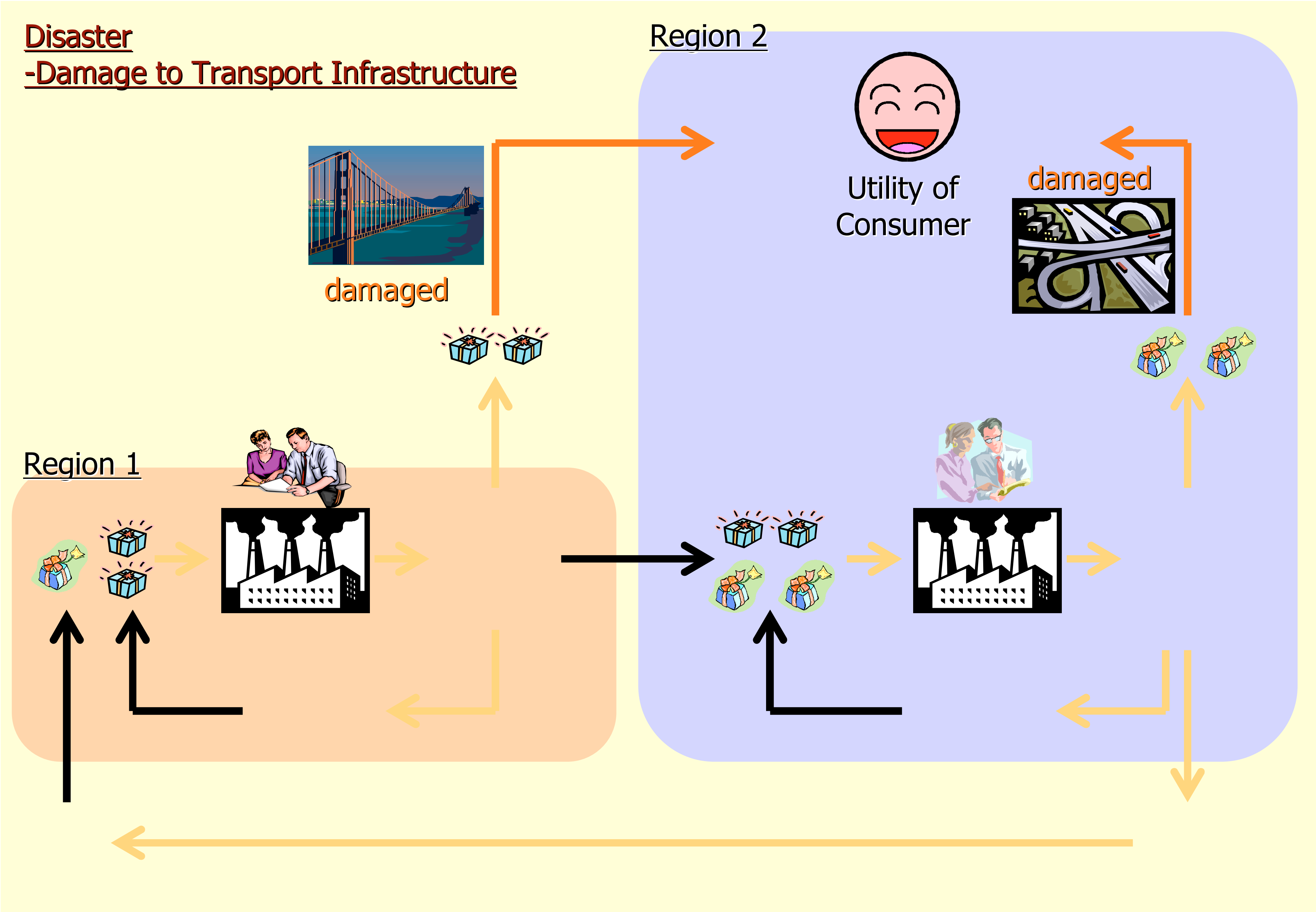
  Assuming congestion of Chuo Route, congestion effect is inserted exogenously (Scenario 2, 3).

Highway Network

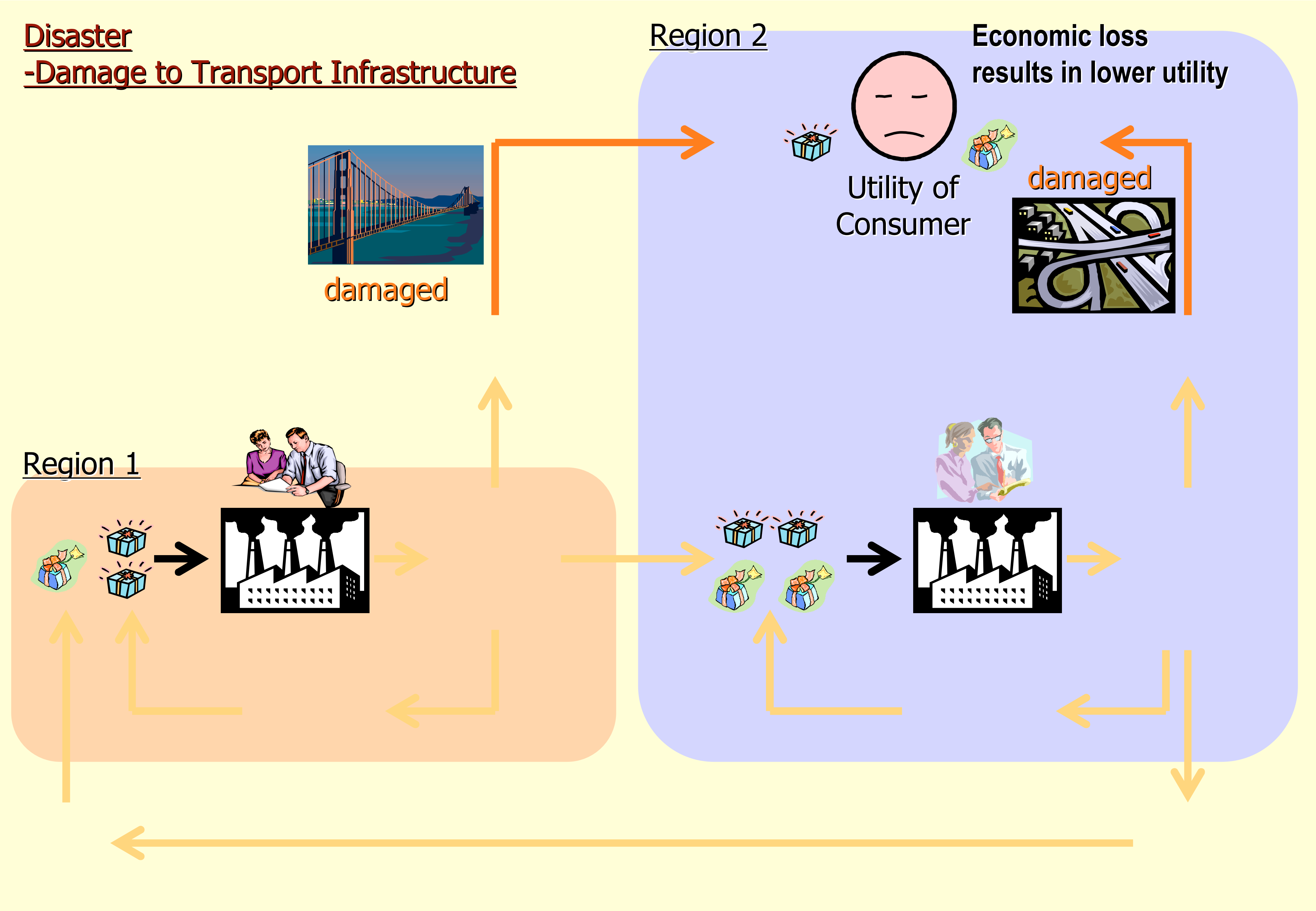


Assumption on Commodity Transport

- **We assume that Commodity is transported by the Shortest Path (in terms of Transit Time) of all paths in the Network linking Origin and Destination.**
- **This makes us possible to consider the Choice of Detour. And we reflect the change of transit time on transport cost rate (Φ) in our SCGE model.**



Disaster
-Damage to Transport Infrastructure
Region 2
Utility of
Consumer
damaged
damaged
Region 1



Disaster
-Damage to Transport Infrastructure
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Economic loss
results in lower utility
Utility of
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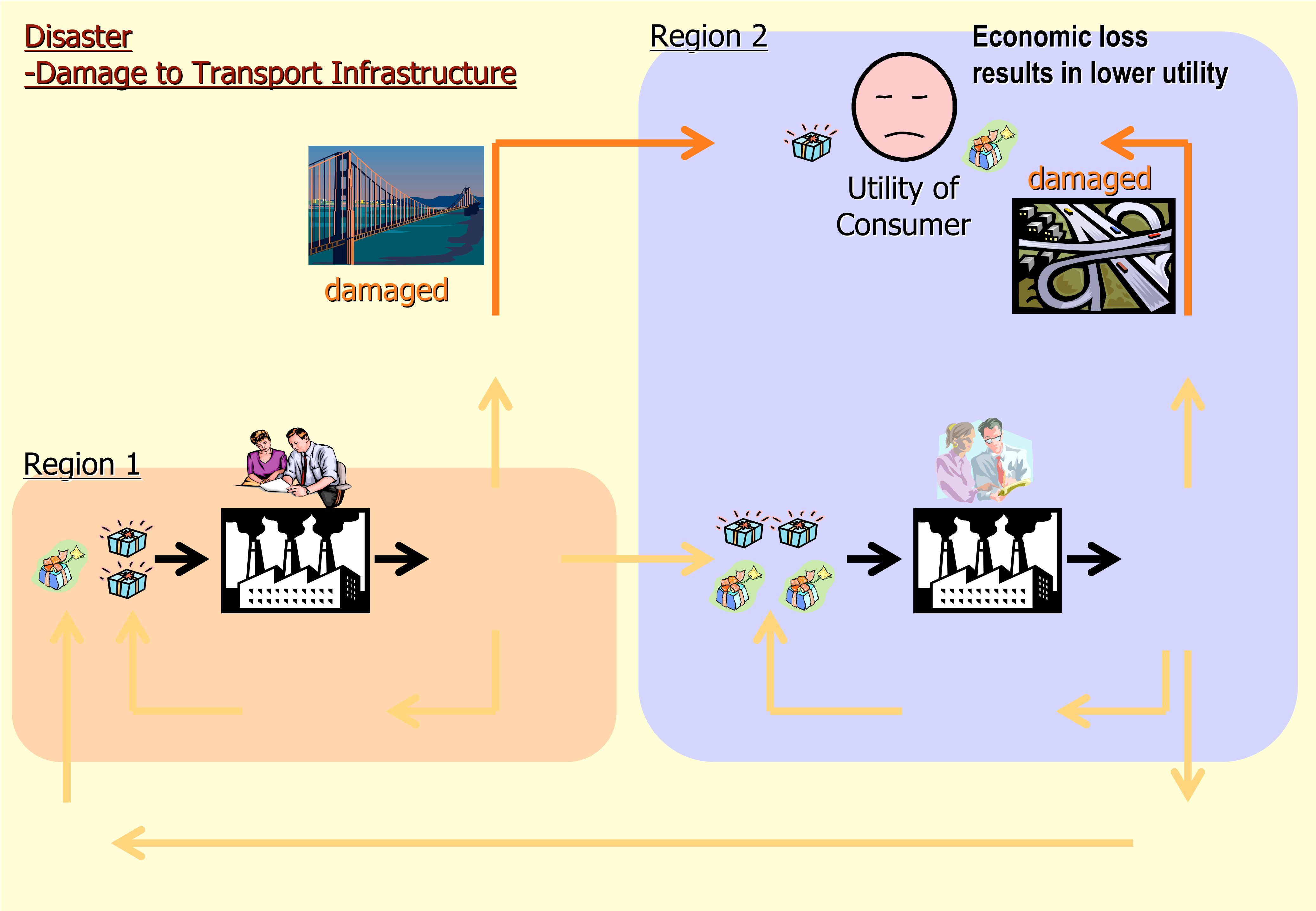
damaged
Region 1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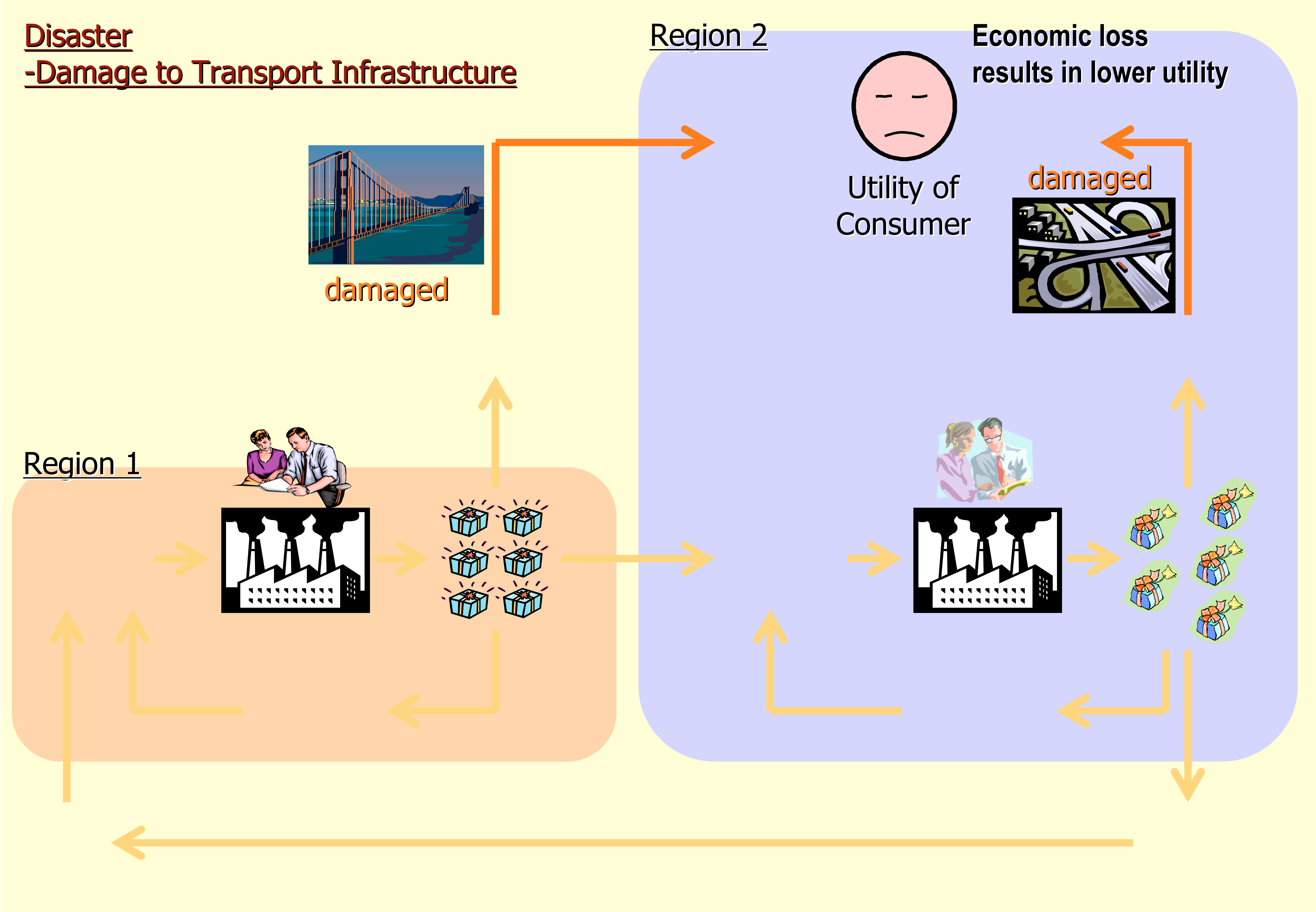
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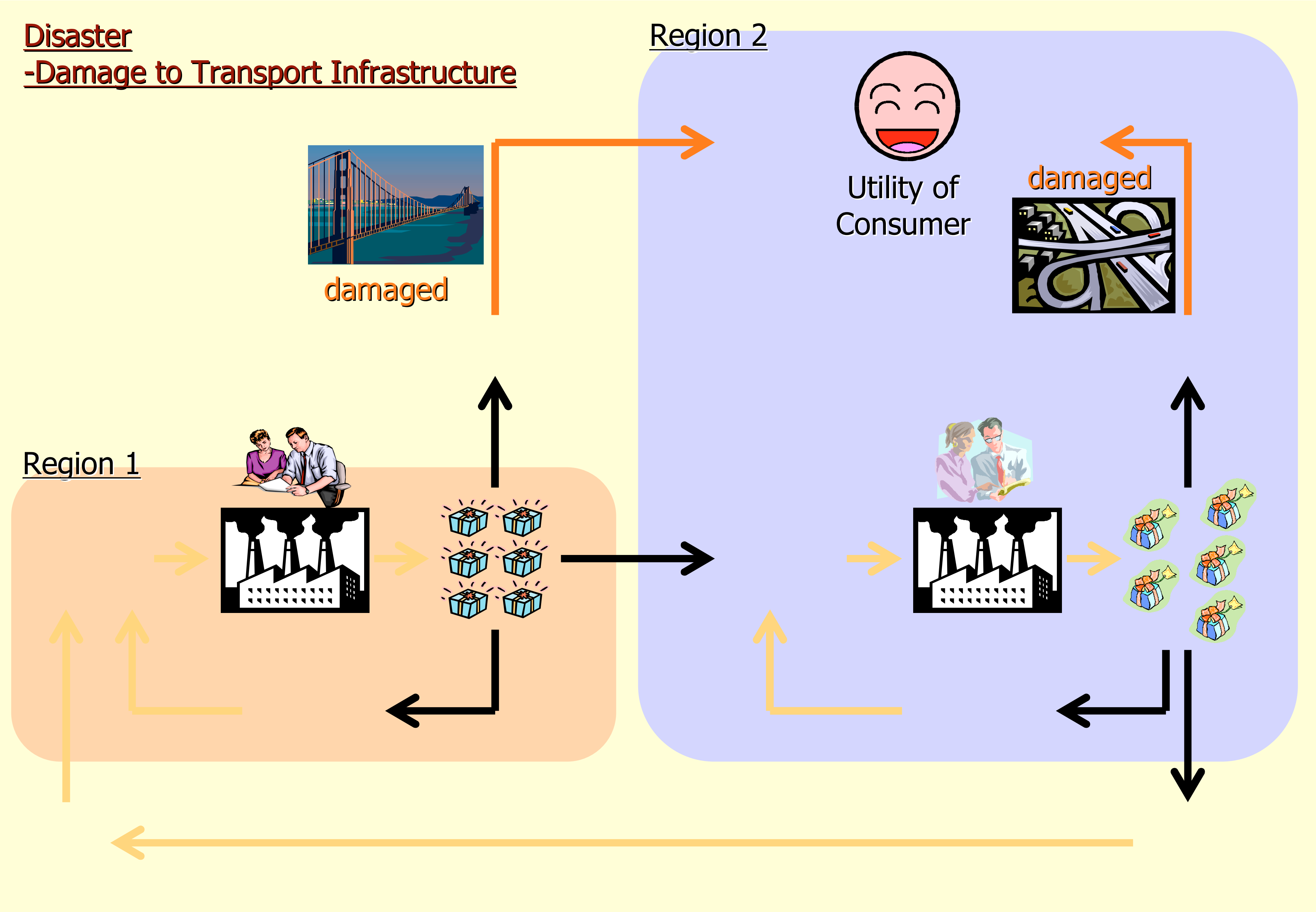
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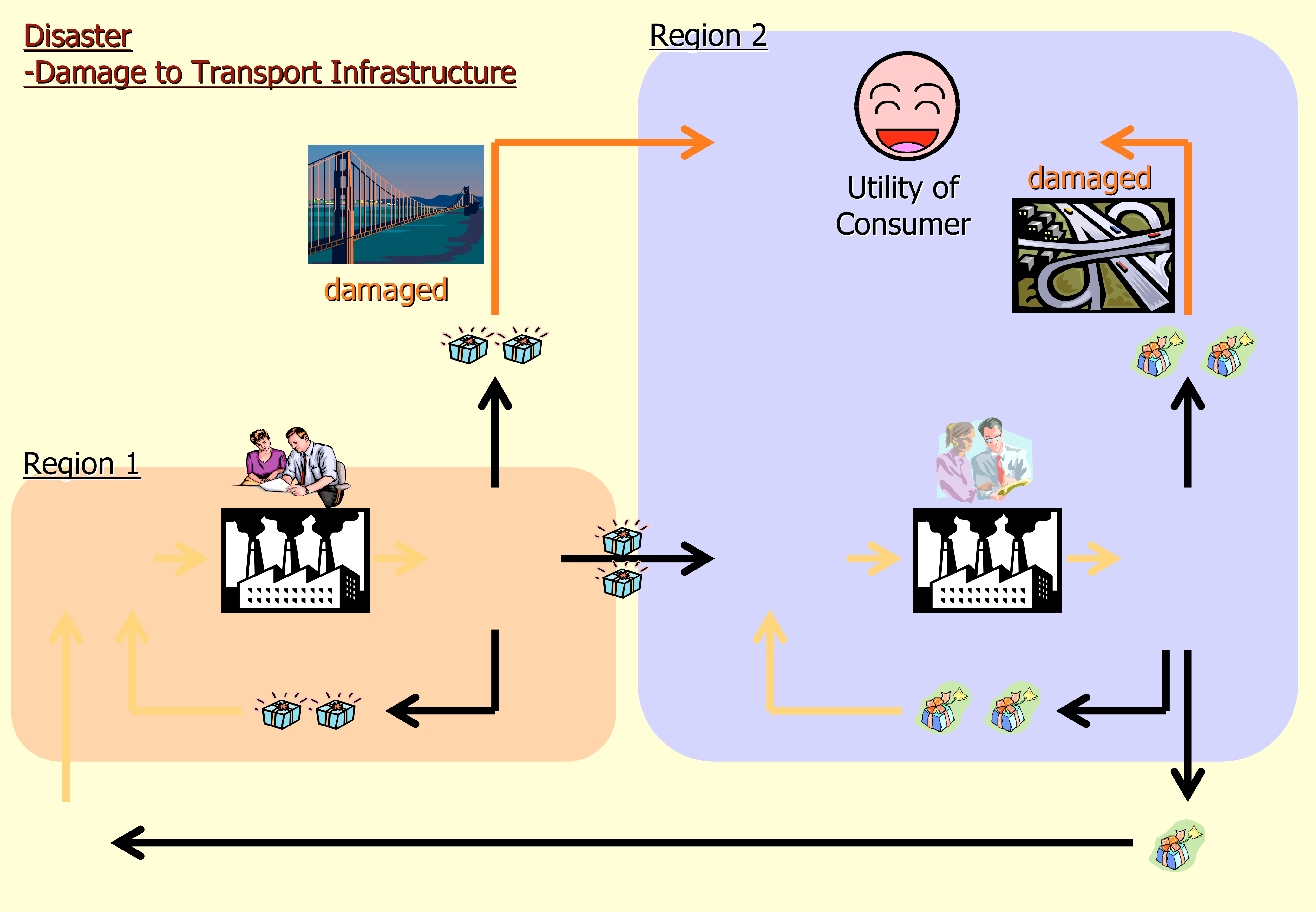
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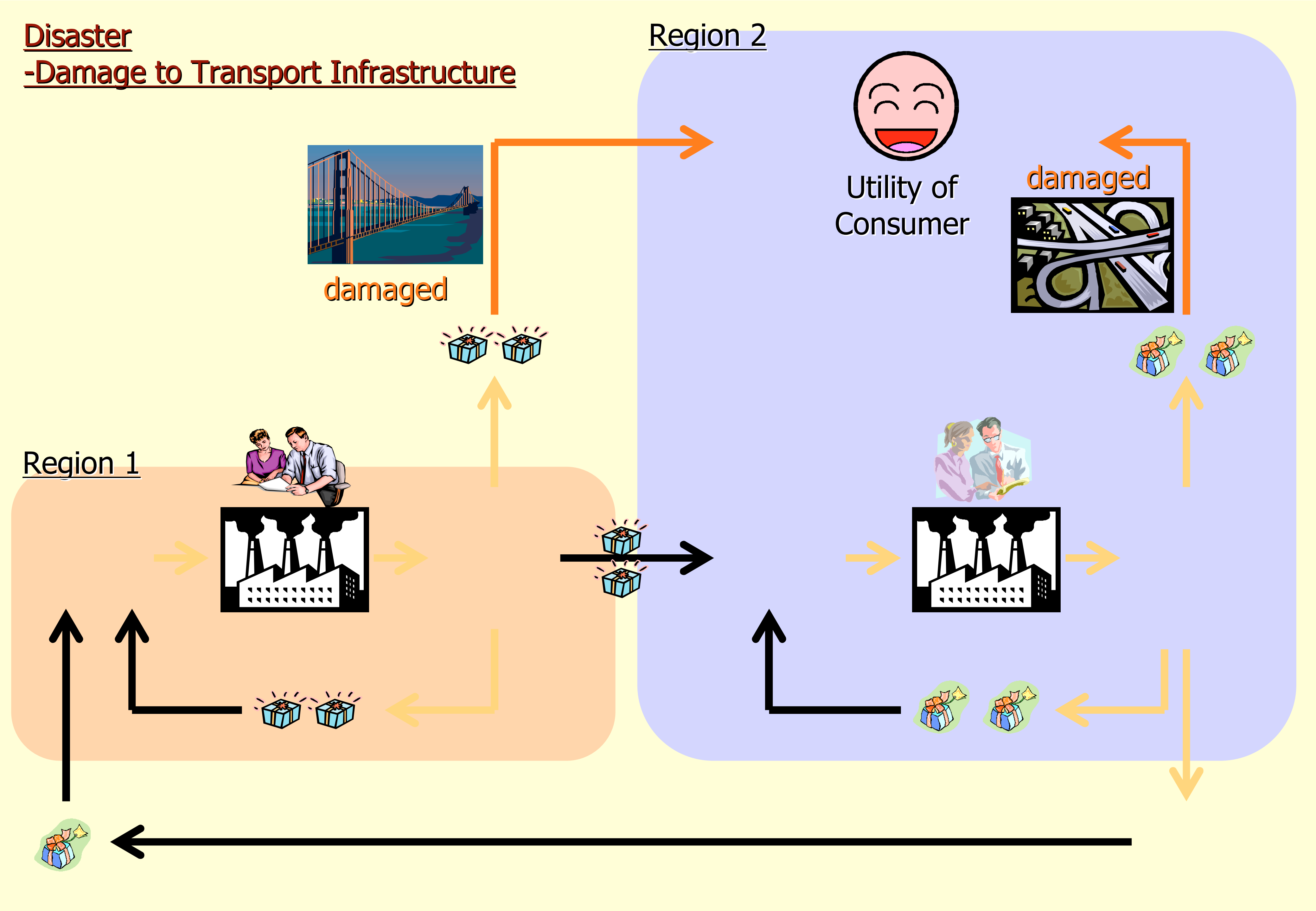
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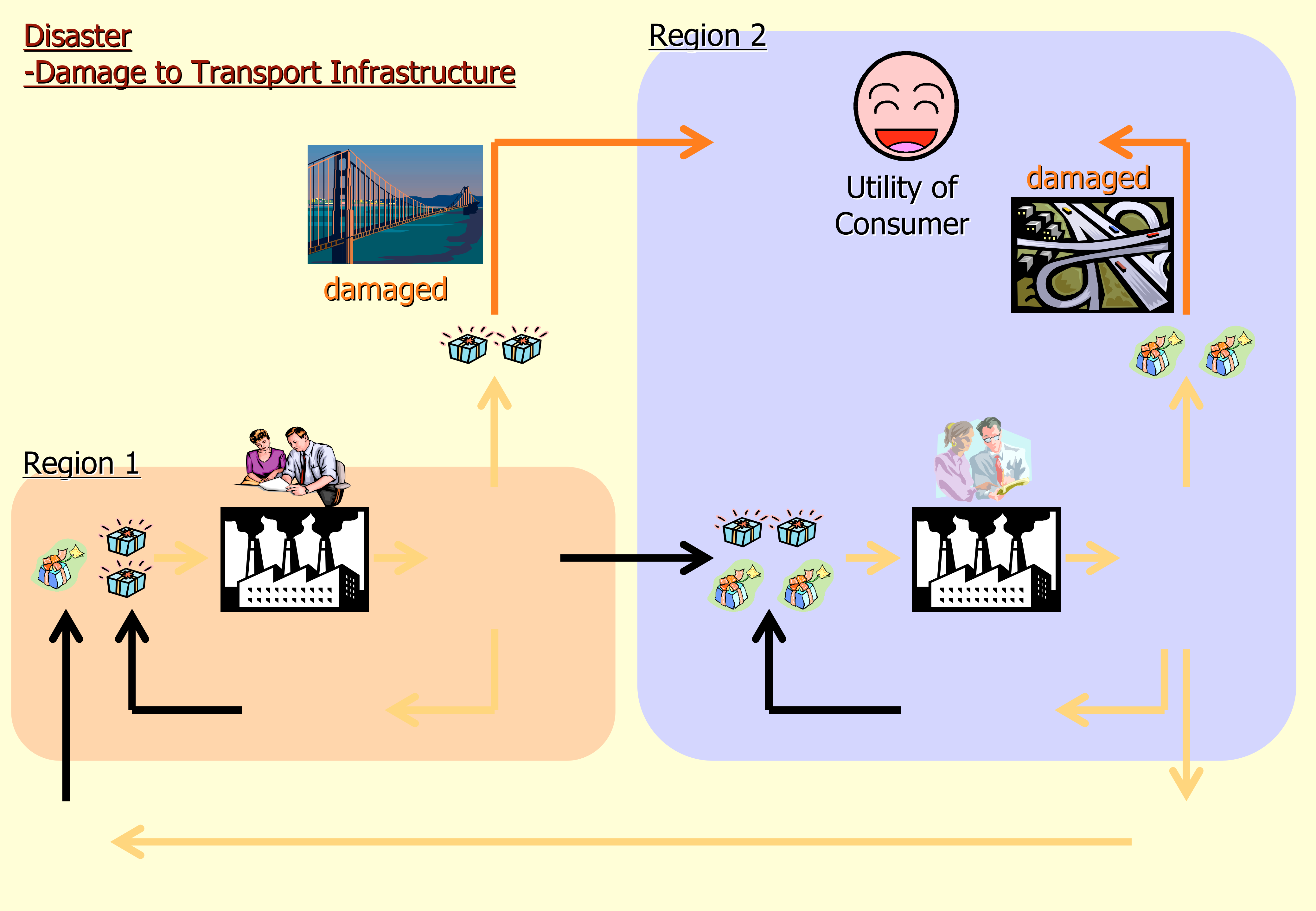
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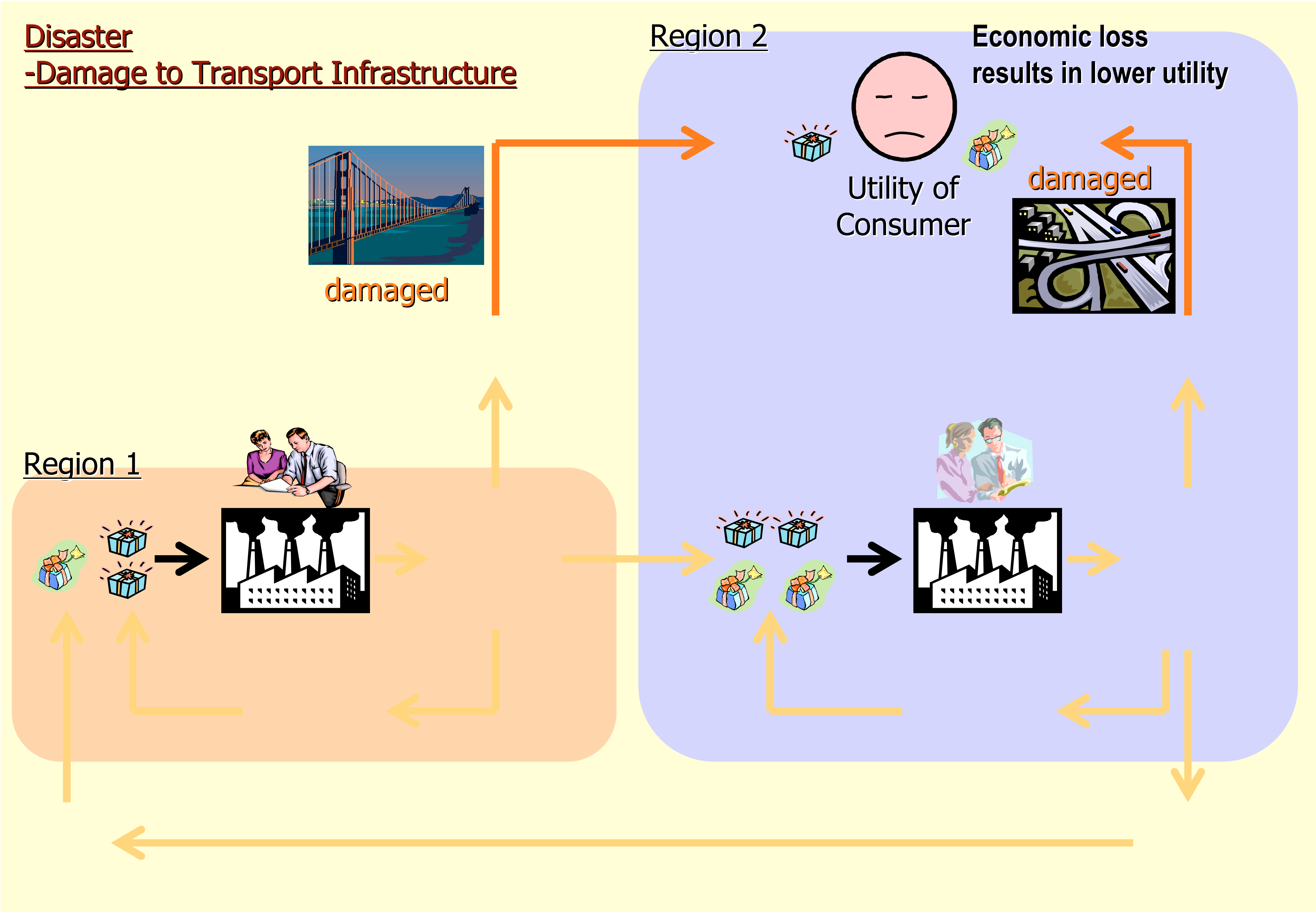
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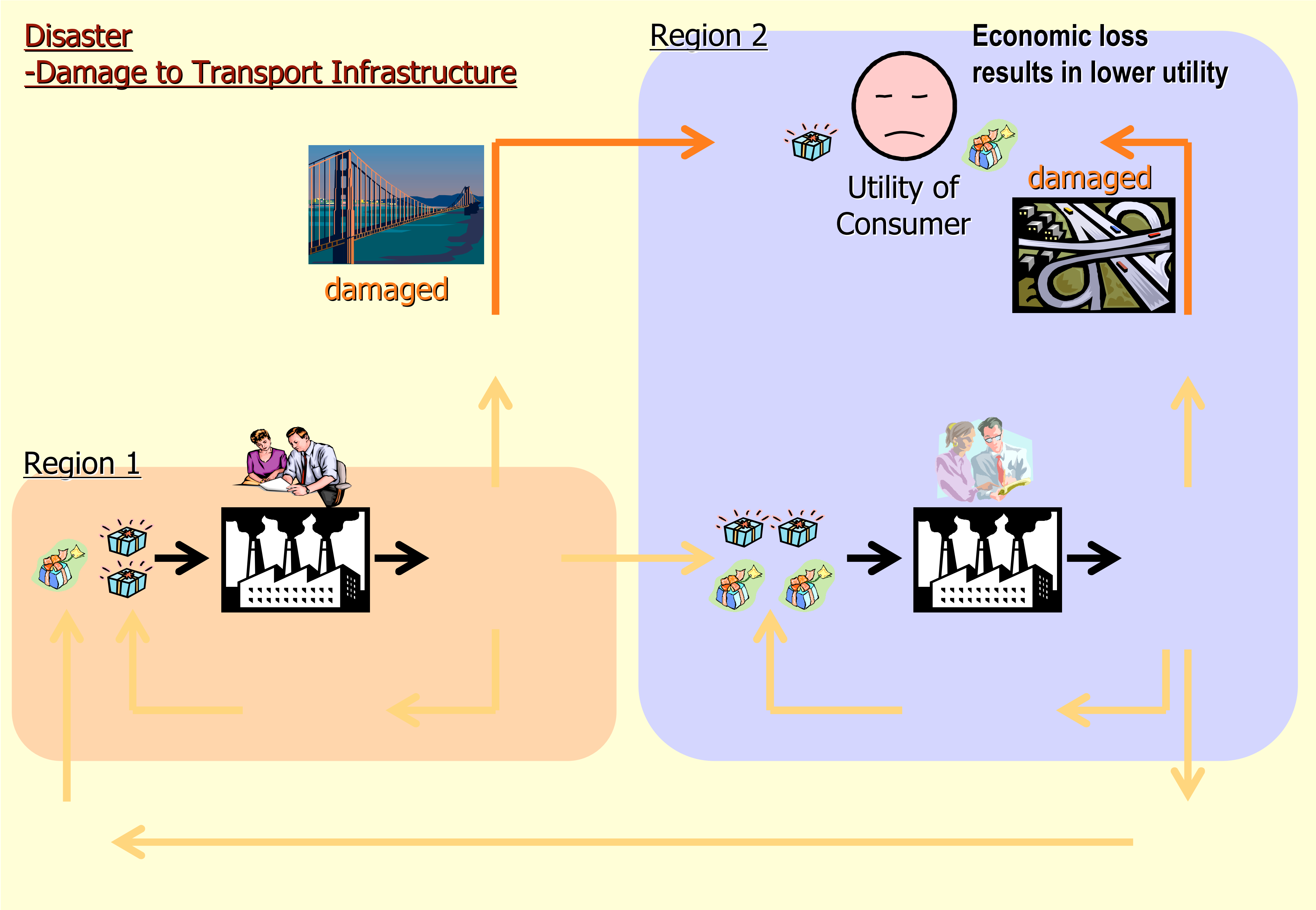
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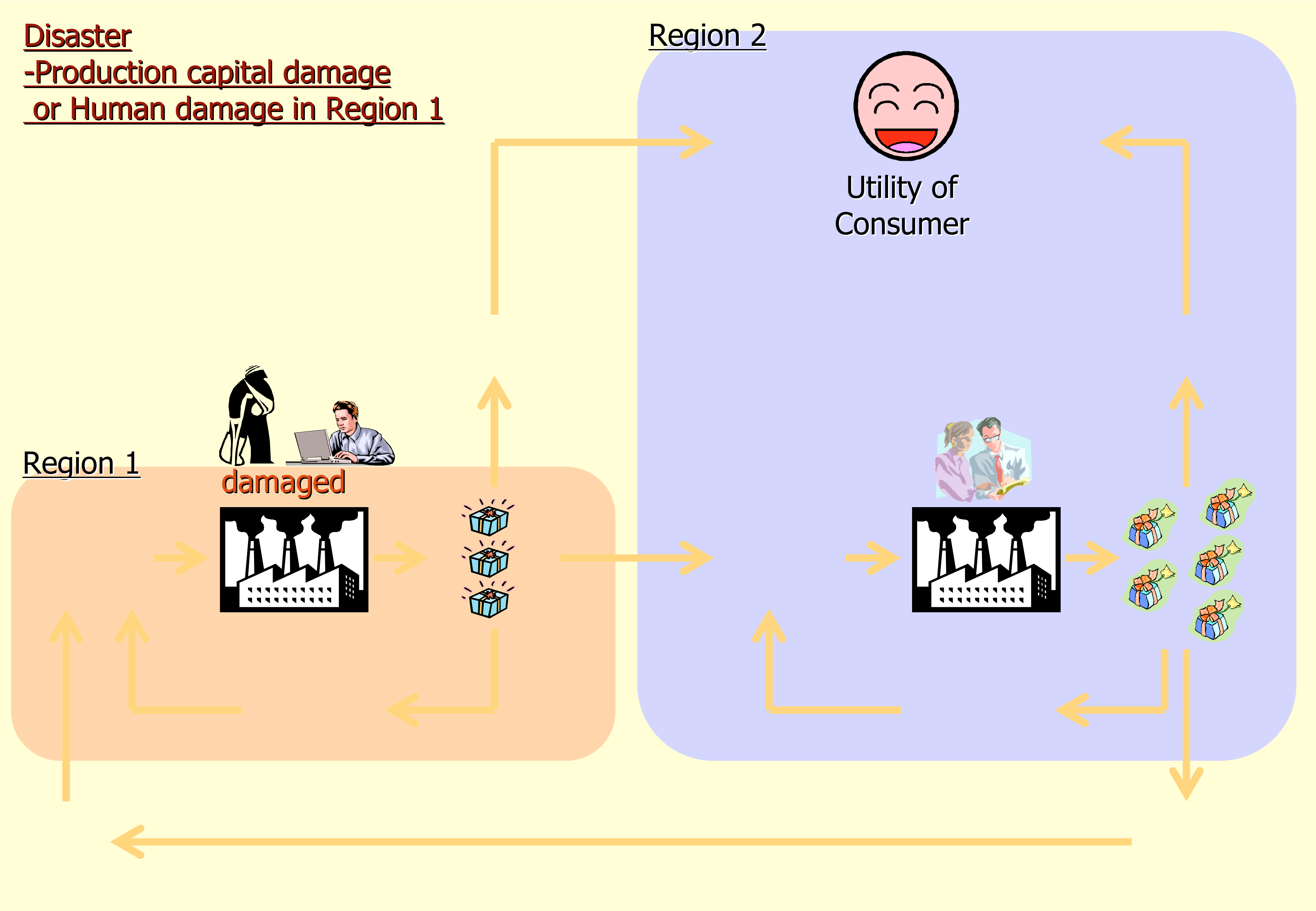
Region 1

災　害　時

(2) 人的被害・生産資本被害

in Disaster -2

Damage to People or Production Capital


Disaster
-Production capital damage
or Human damage in Region 1
Region 2
Utility of
Consumer
Region 1
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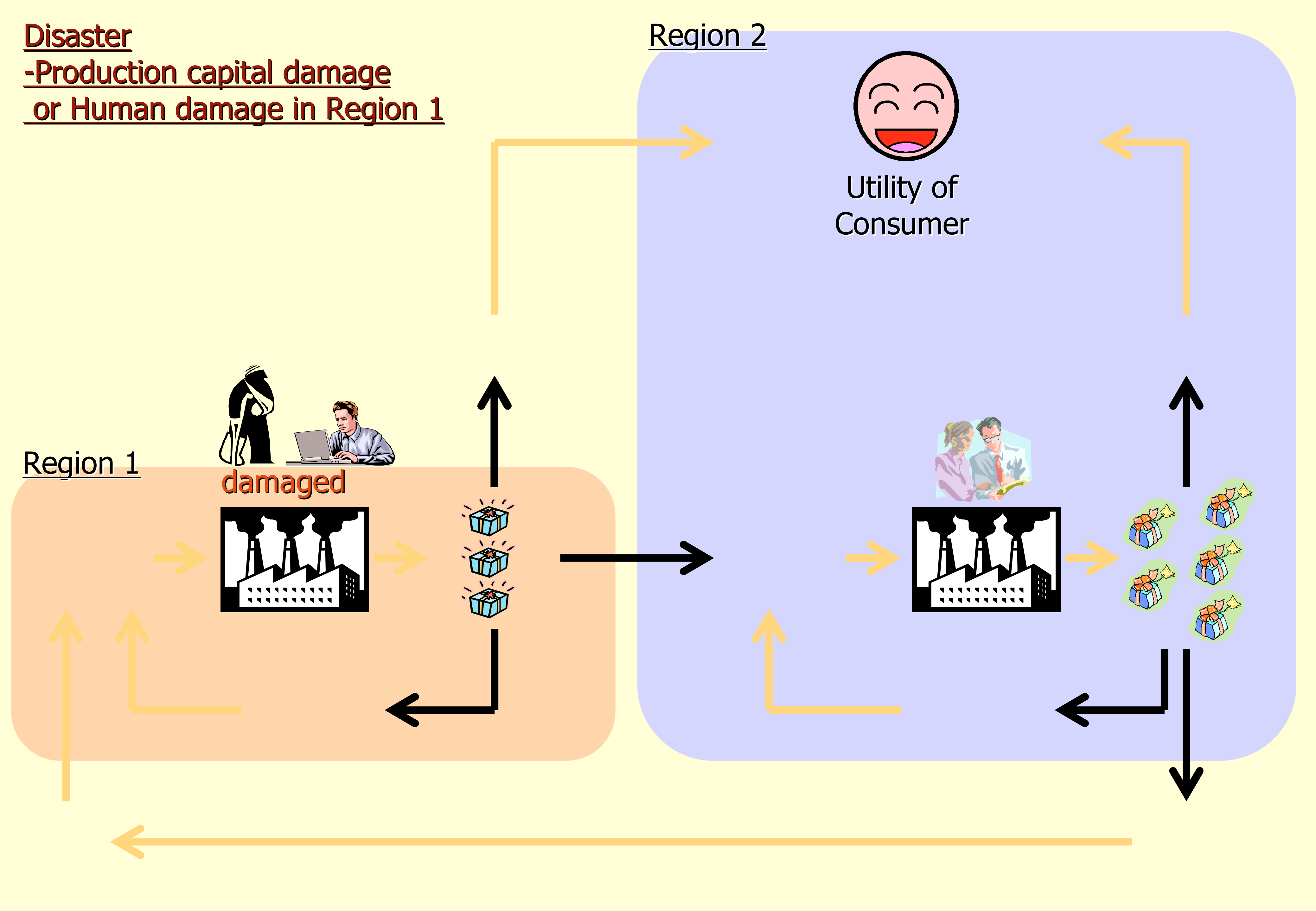

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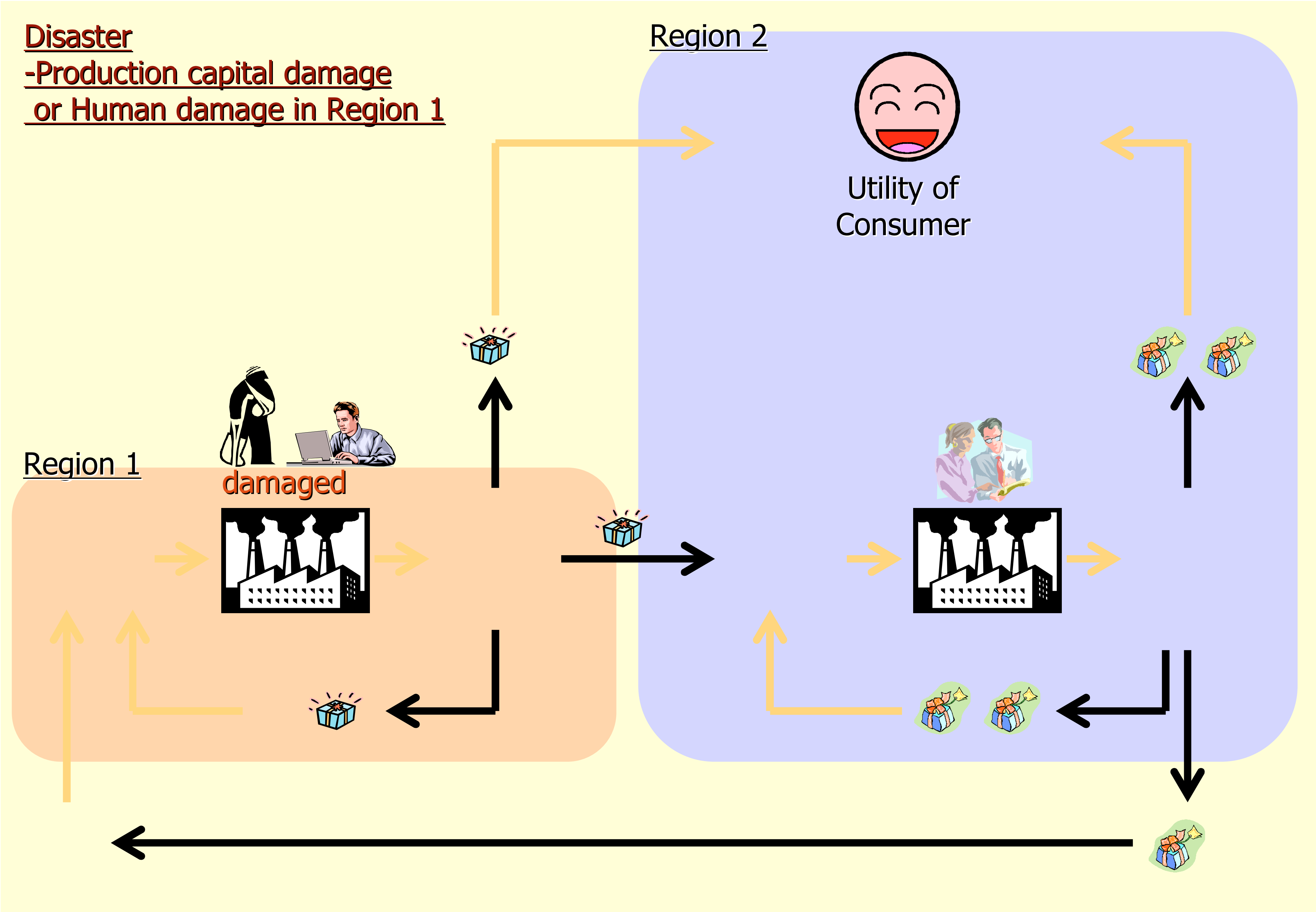
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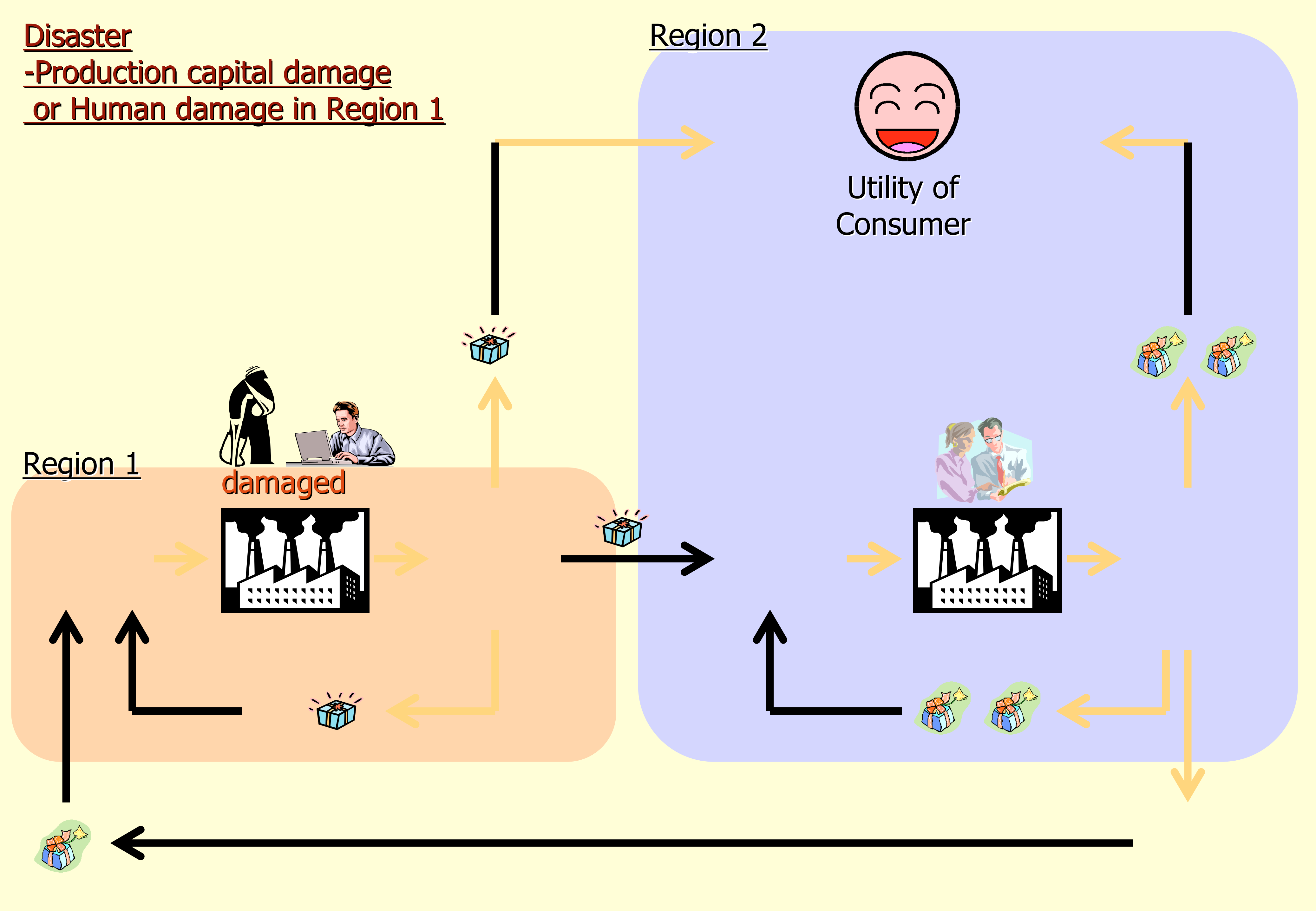
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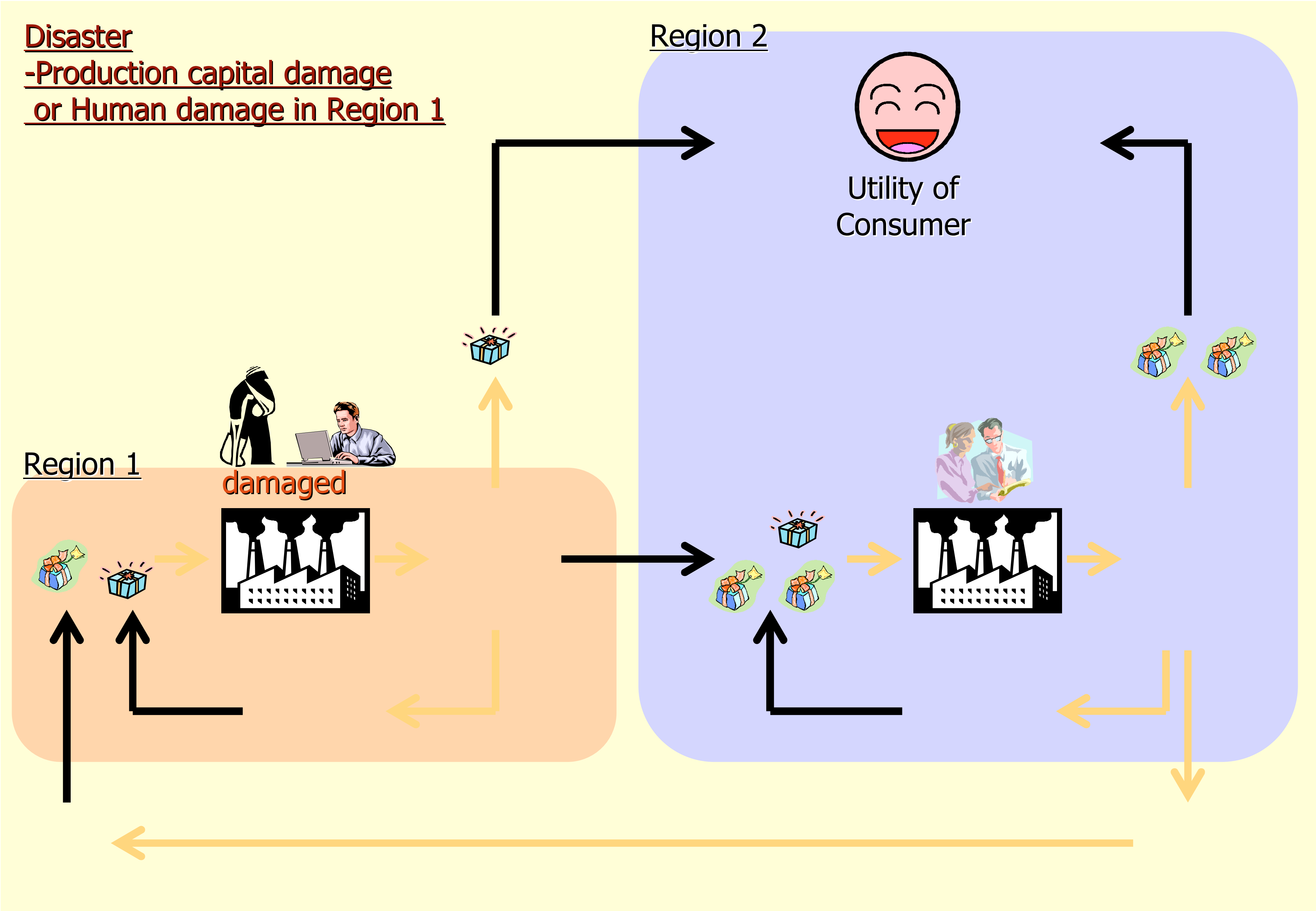
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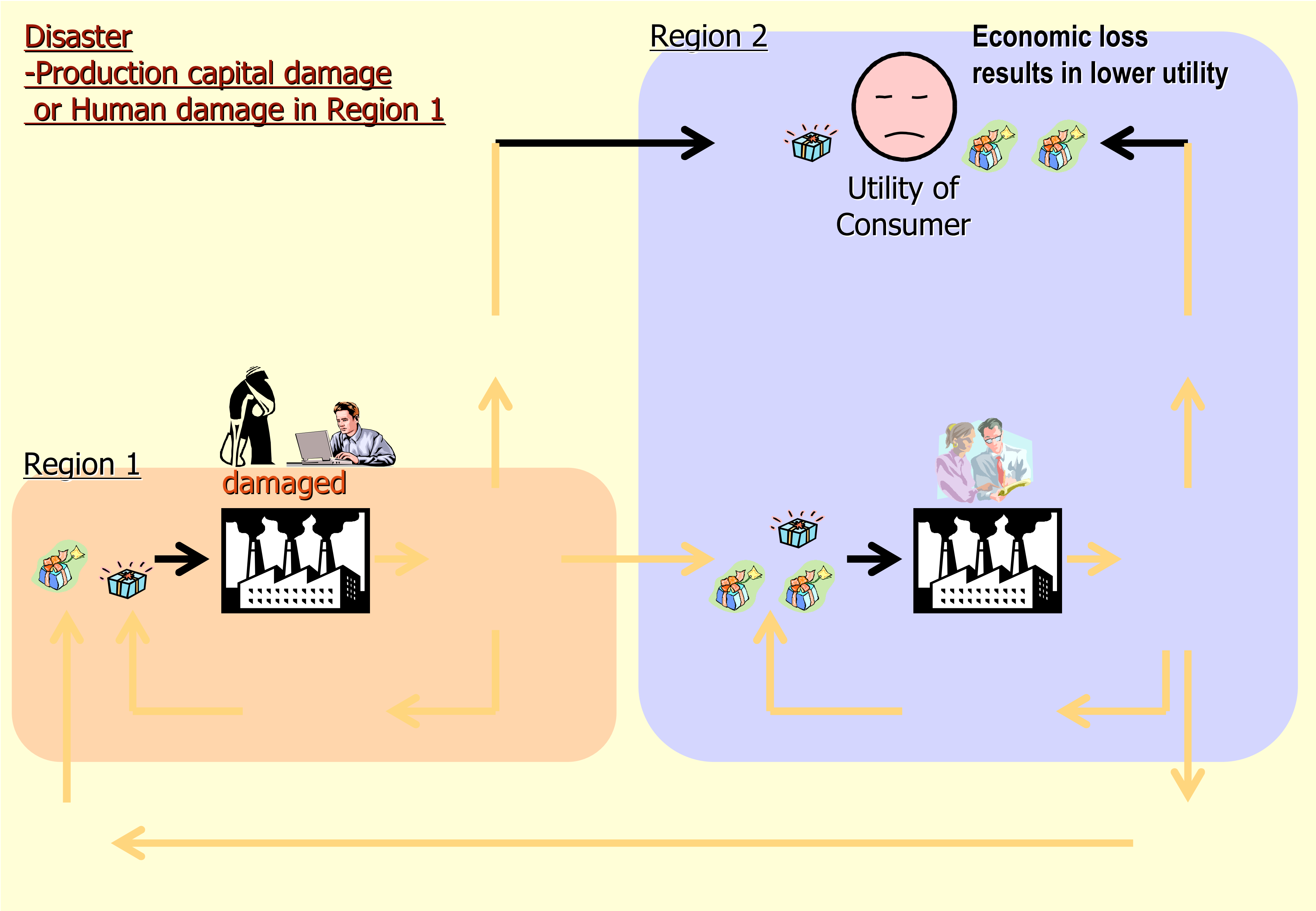
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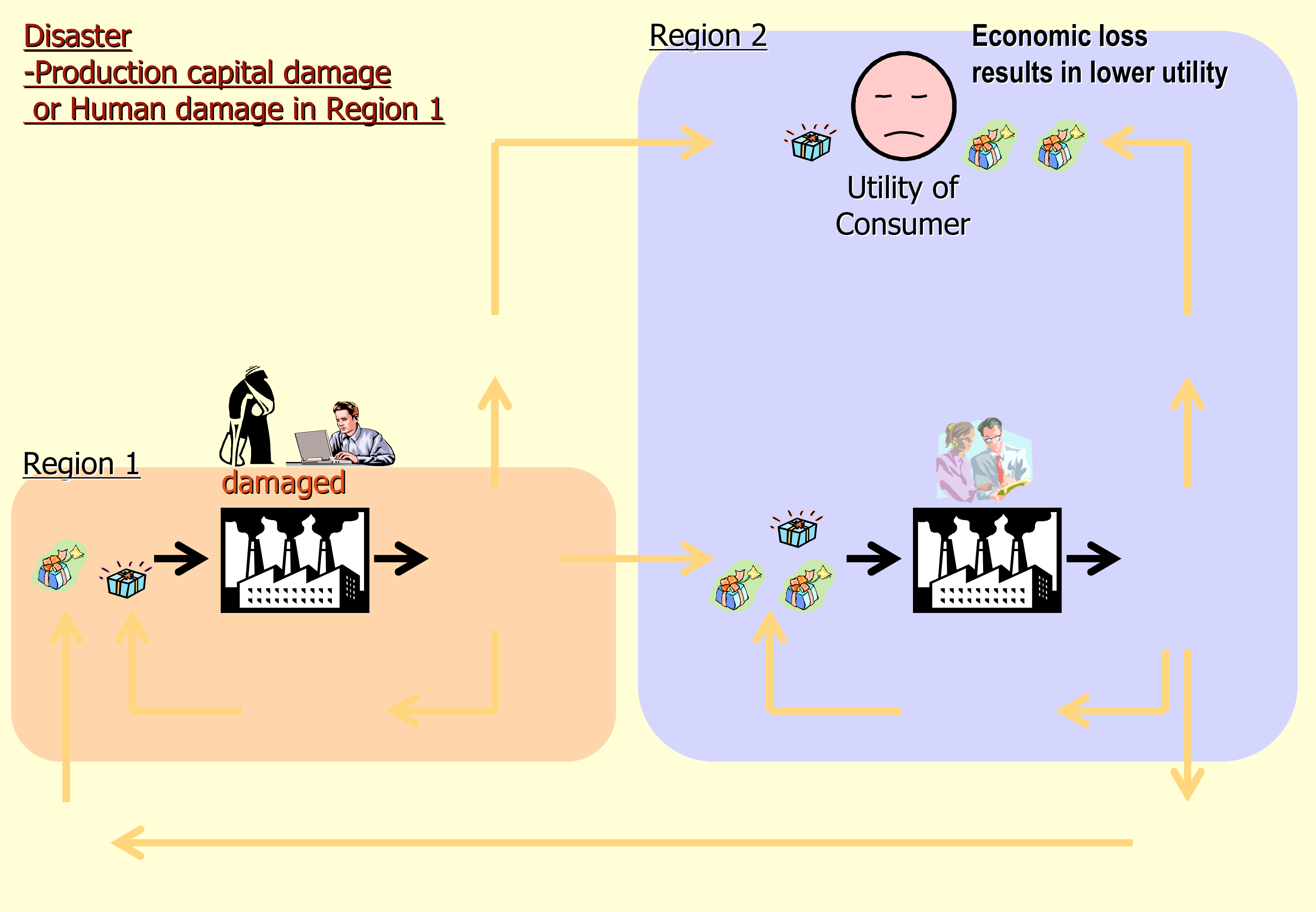
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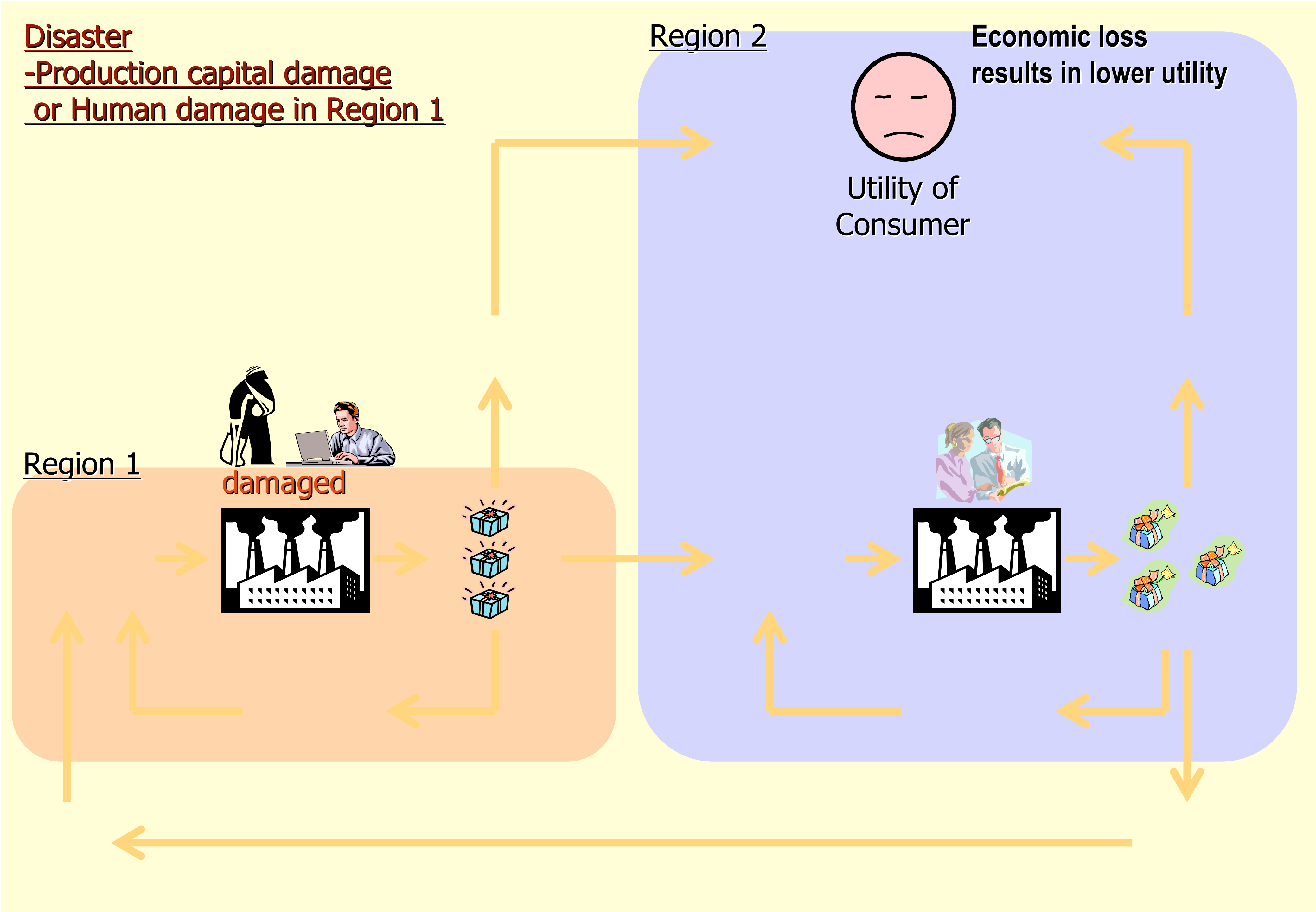
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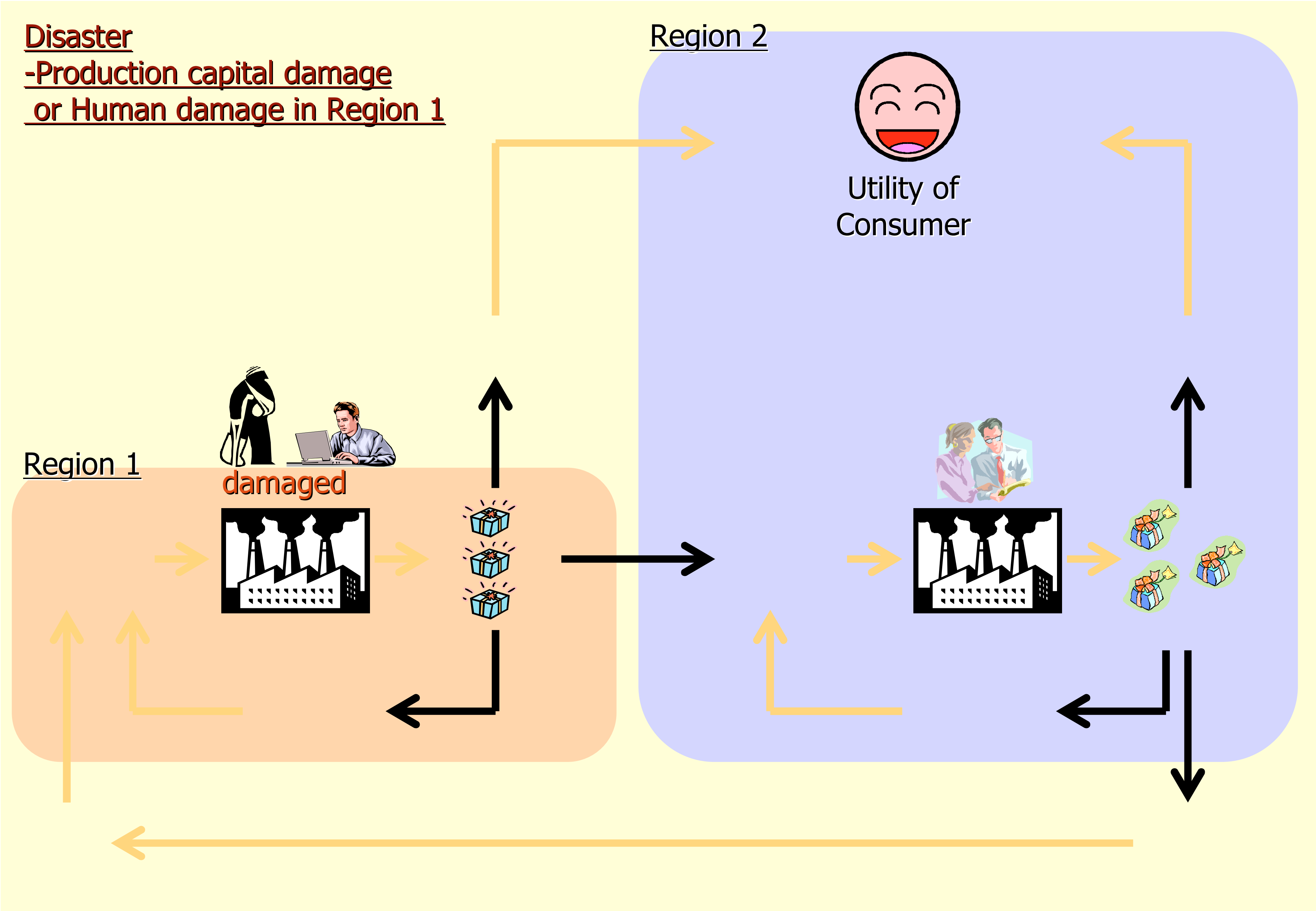
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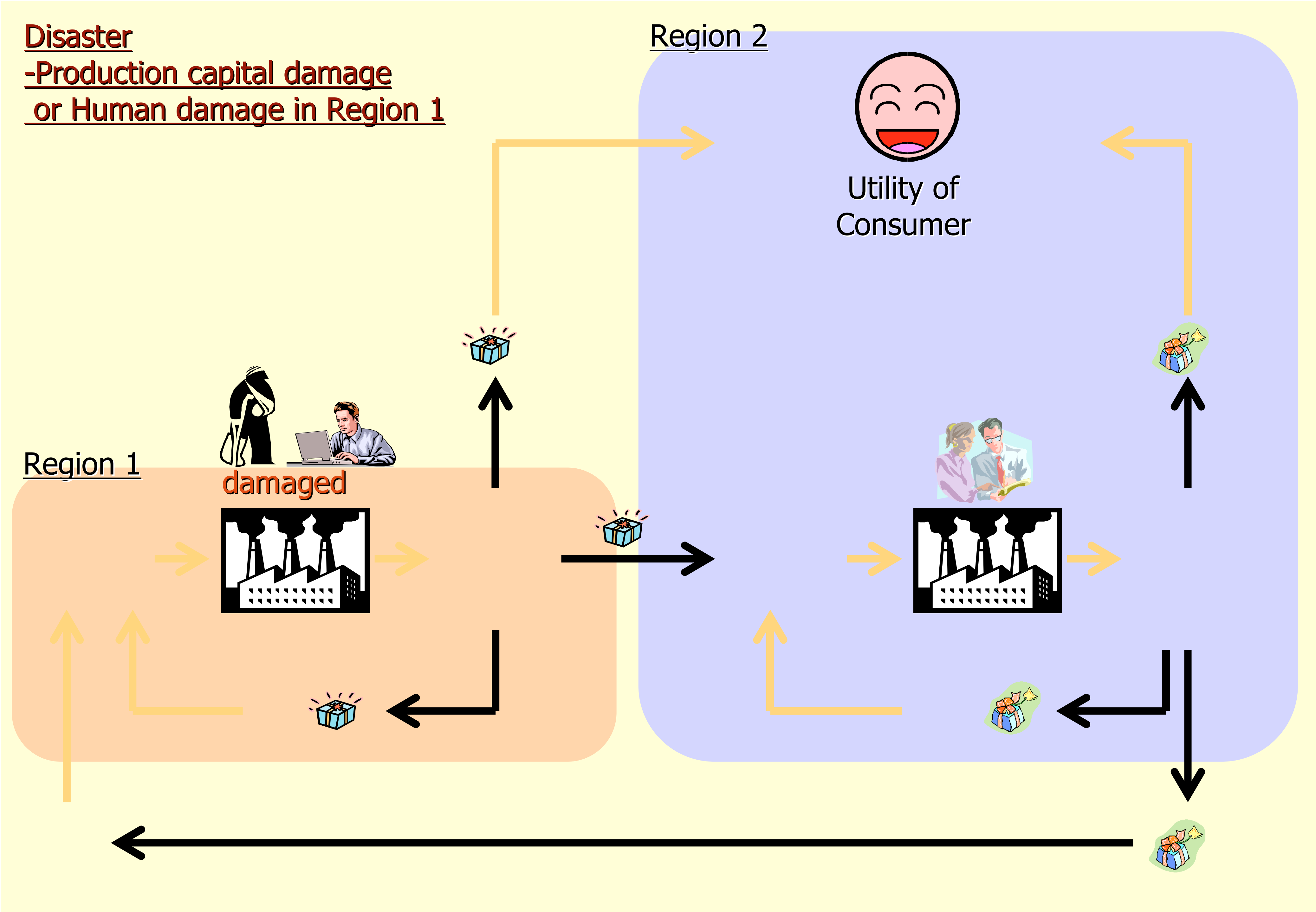
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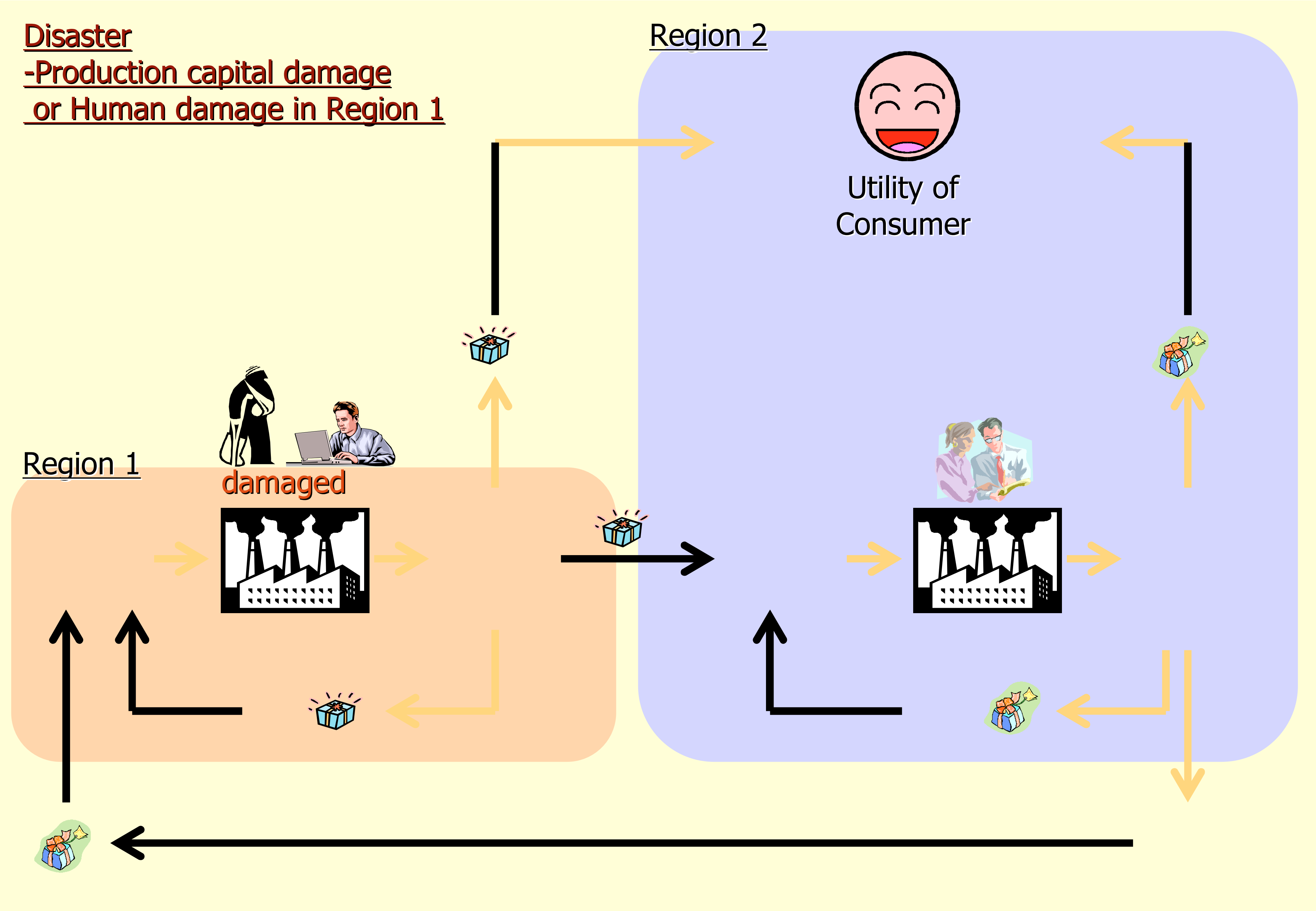
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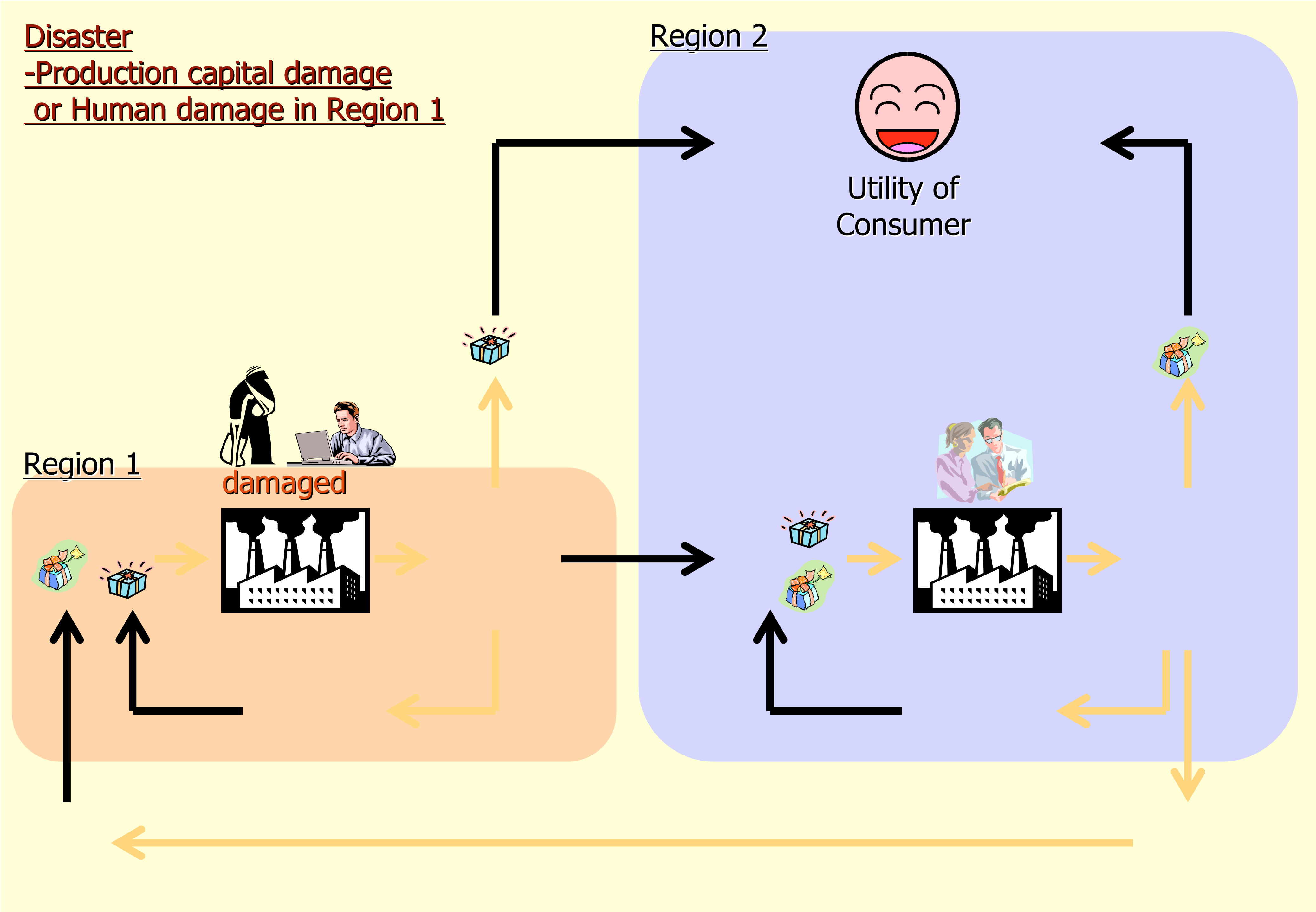
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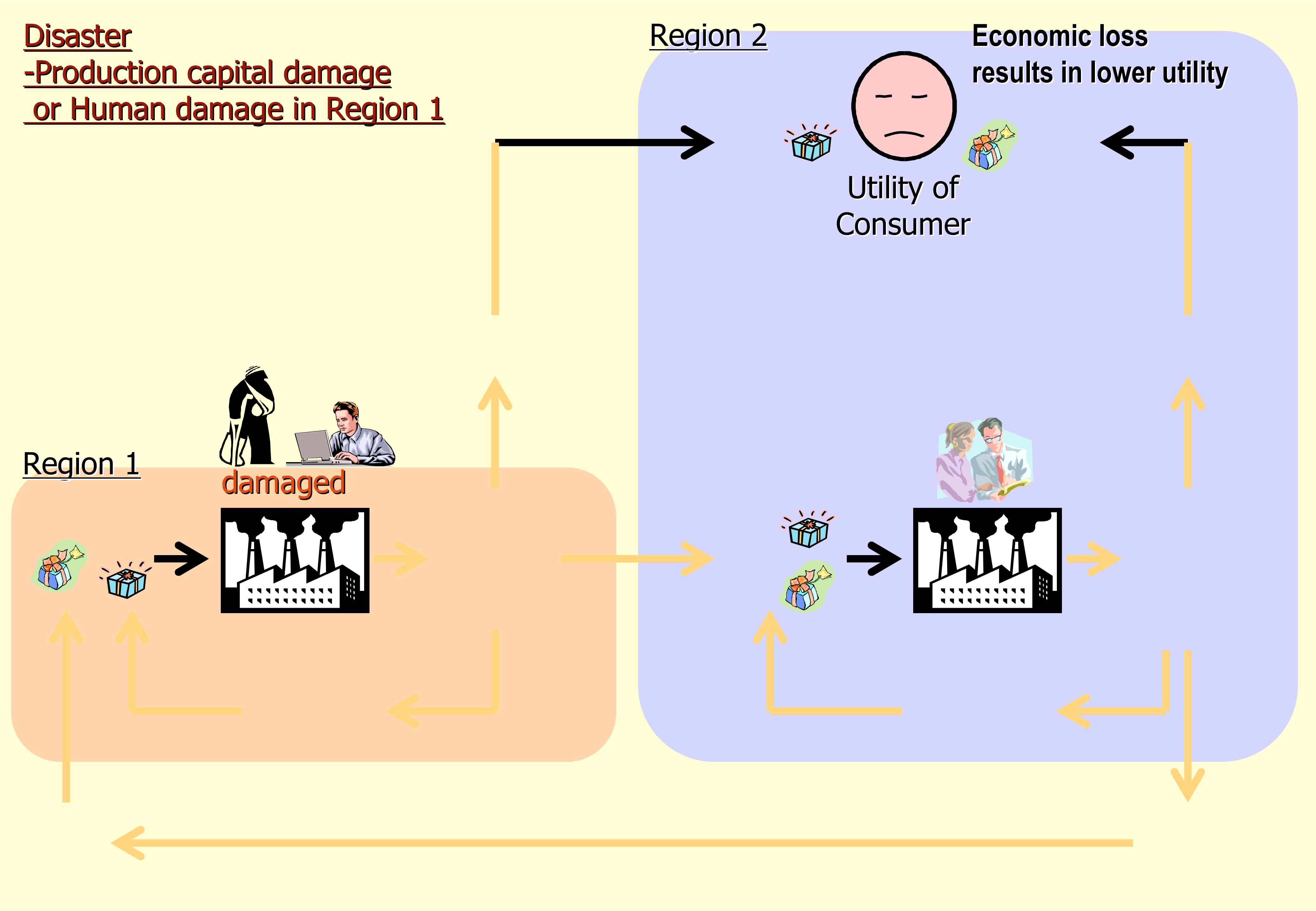
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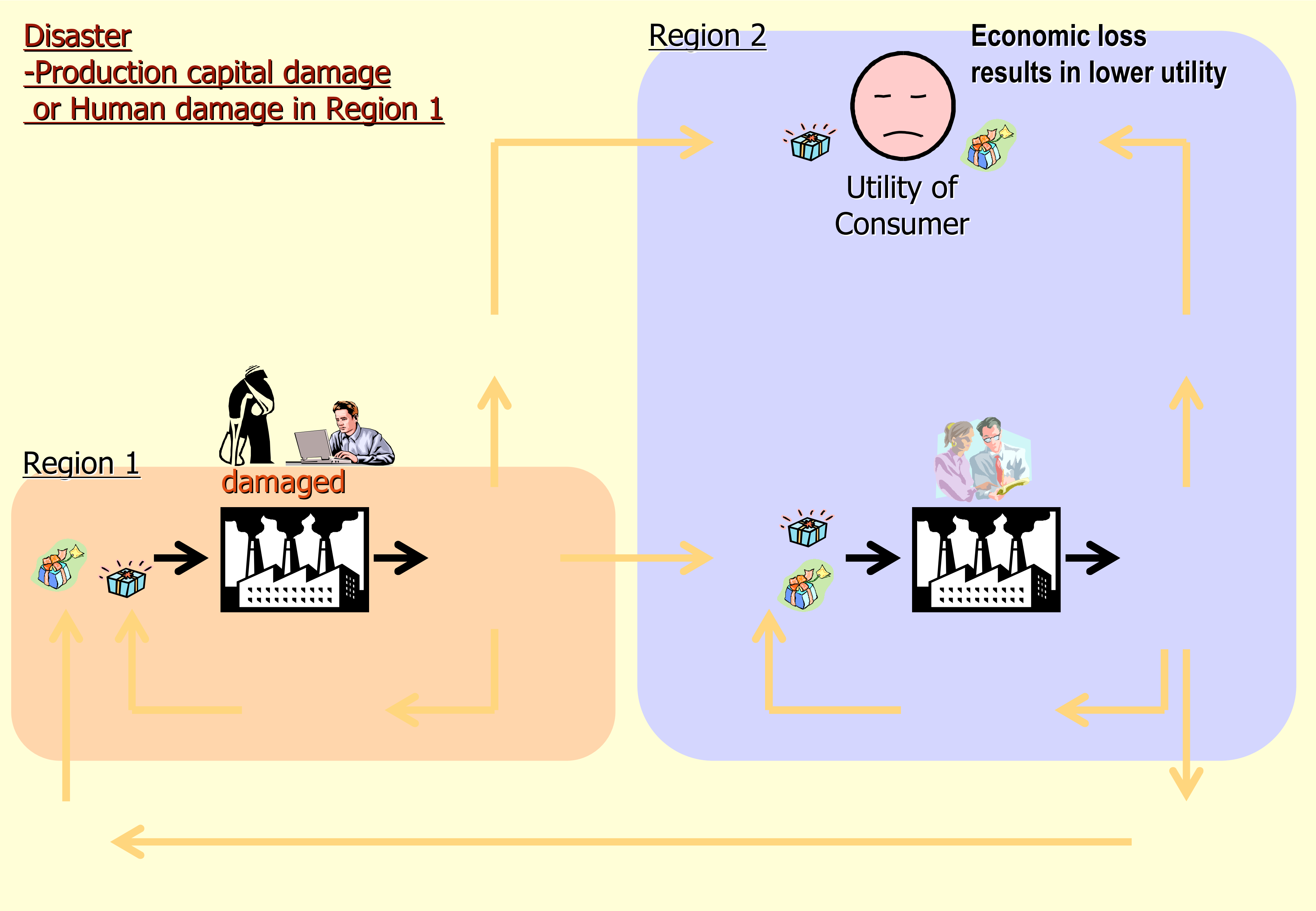
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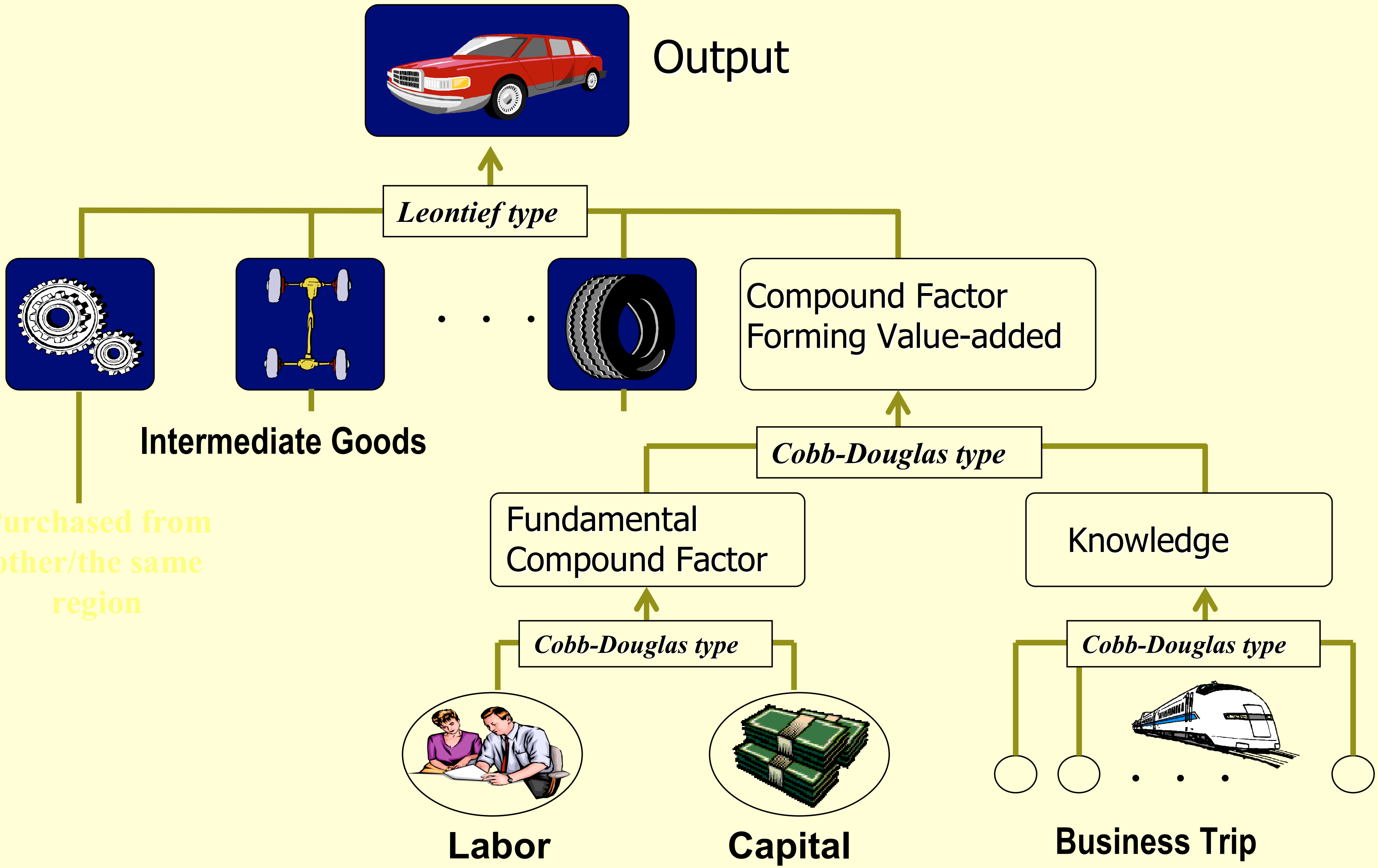
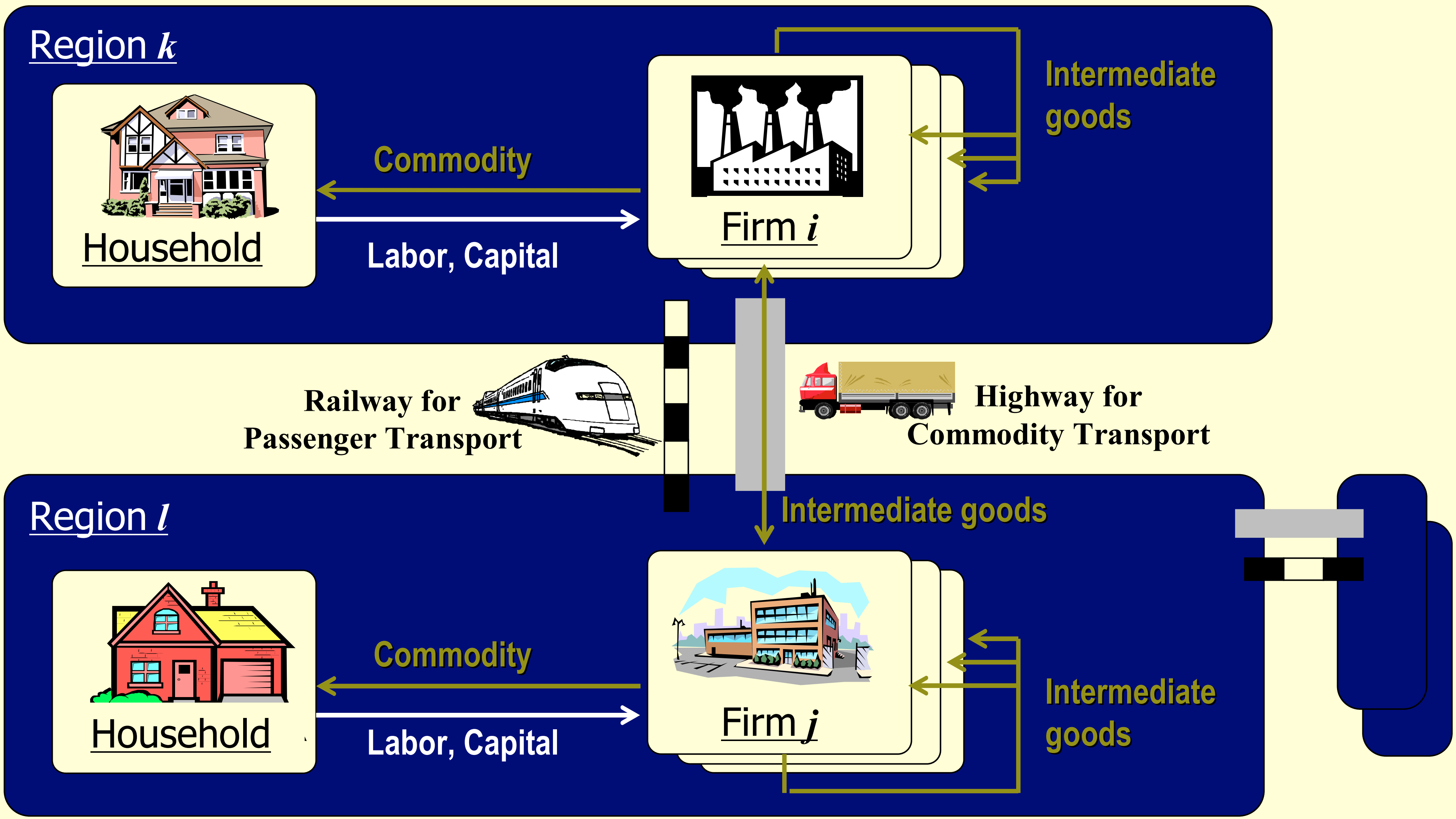
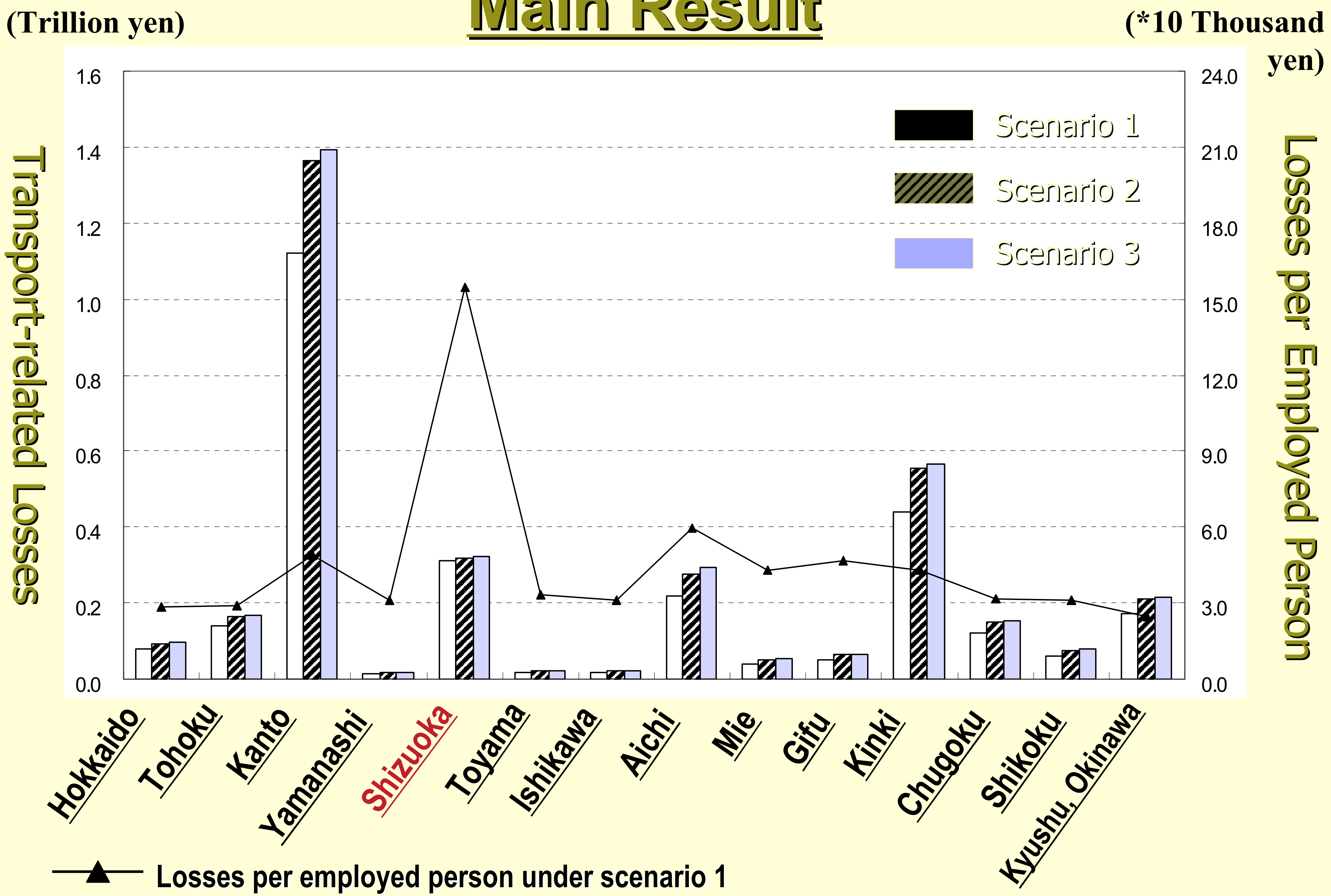
Production Structure of Firm – 1



Regional Economic System



Main Result



(Trillion yen)
(*10 Thousand yen)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
Transport-related Losses
Losses per Employed Person
Scenario 1
Scenario 2
Scenario 3
Hokkaido
Tohoku
Kanto
Yamanashi
Shizuoka
Toyama
Ishikawa
Aichi
Mie
Gifu
Kinki
Chugoku
Shikoku
Kyushu, Okinawa
Losses per employed person under scenario 1

Community-Based Approaches

Citizen-Involved

Expert Initiatives

1.Noda, Osaka (Academics-led)

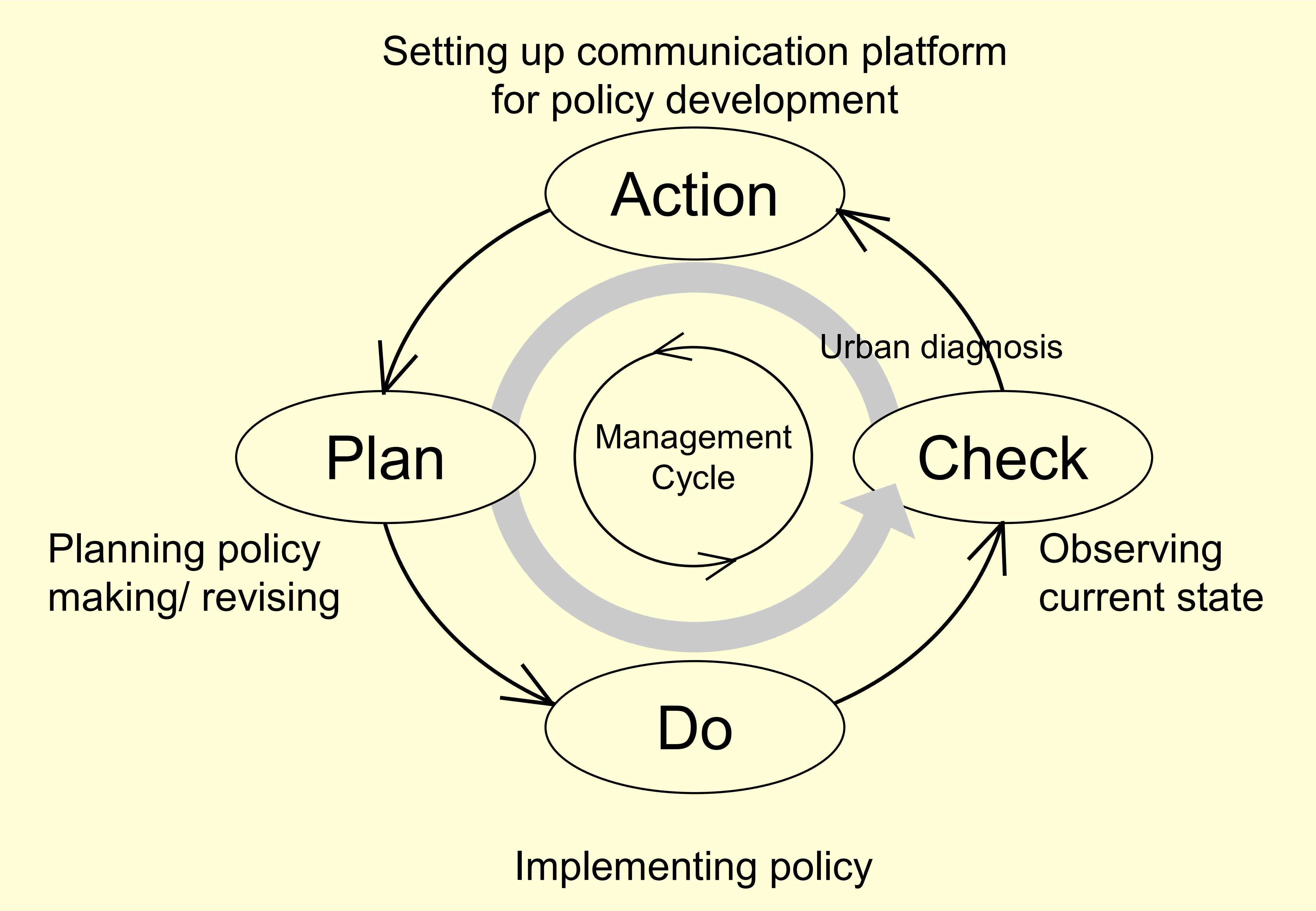
2. Noshibiwajima,Nagoya(NPO-led)

Collaborative Modeling(Regional-Professional)

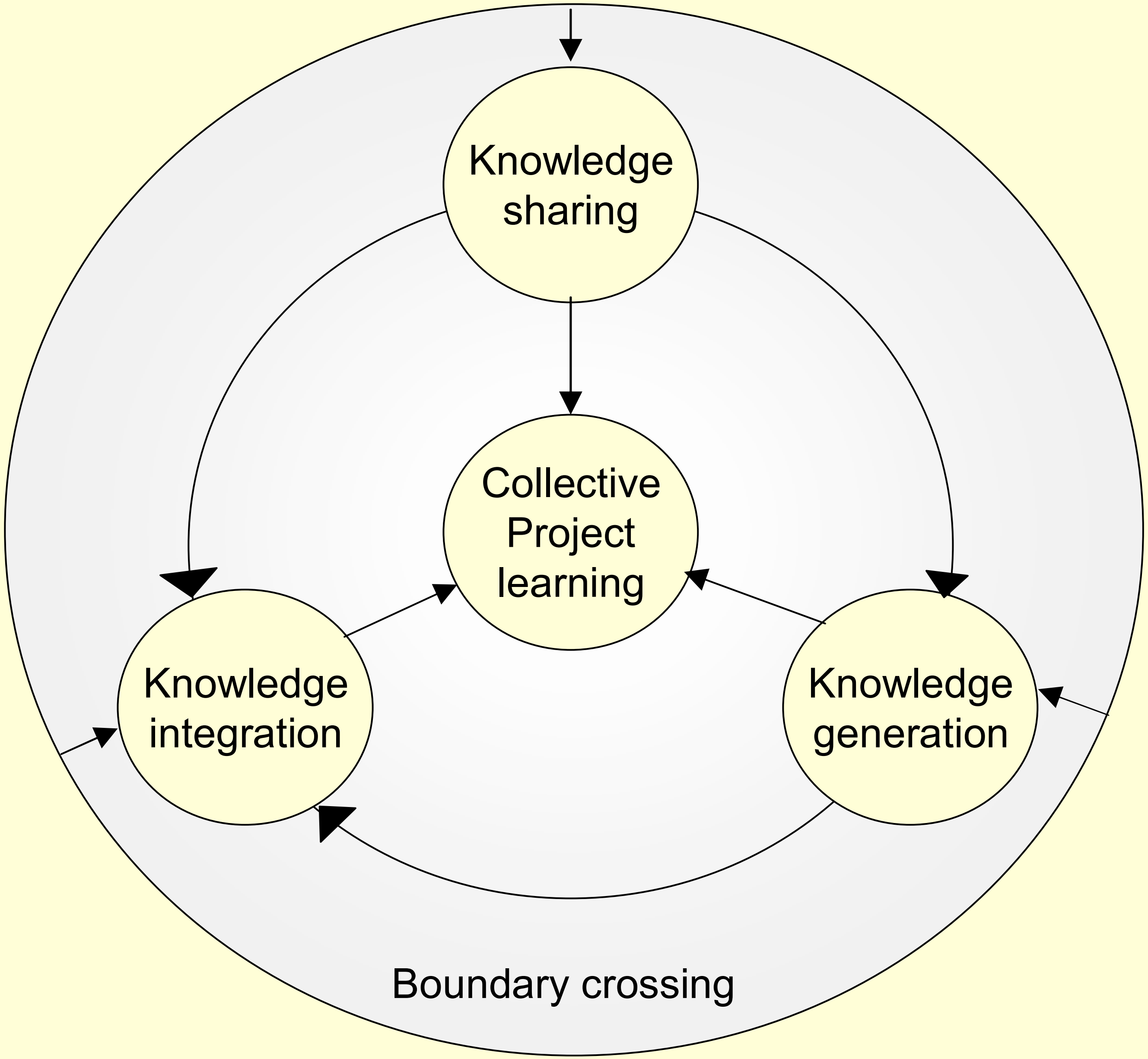
- Participatory Approach-oriented
- Alternative Policy-making Process
- Policy Prioritizing Process from among a Policy Bundle
- Scenario-based, Contingency-context
- System Engineering-endorsed
- Economically-endorsed
- Socio-culturally Tailored

防災マップの作成
～NPOによる防災教育ワークショップにて

GISツールの説明
～団地内自主日本語教室にて


Setting up communication platform
for policy development
Action
Urban diagnosis
Plan
Management
Cycle
Check
Planning policy
making/ revising
Observing
current state
Do
Implementing policy

The multidisciplinary knowledge-creation model (Fong, 2005)



Participatory community diagnosis

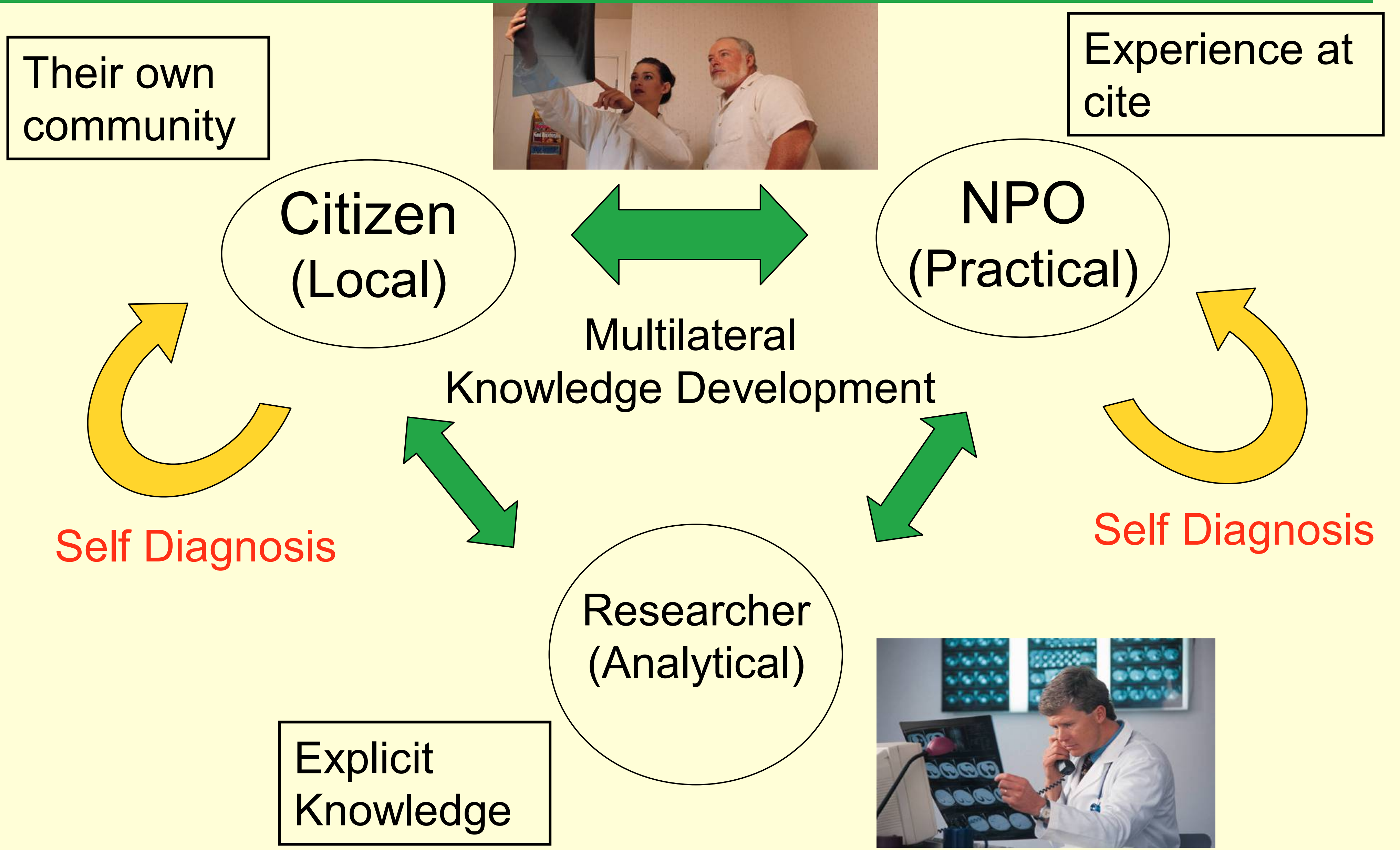
System to facilitate knowledge sharing and generation

Two phases

-Community preparedness diagnostic survey

-Policy-setting workshops

Community diagnosis



Community preparedness diagnostic sheet

43 questions are…

Selected from local people's concern which NPO has got through their workshops ⇒ Practical knowledge

Target Area	Survey Period	Valid Response
Higashiyama	Dec. 2004	3613
A Town	Nov. 2004	1155
K Town	Jan. 2005	184

Survey Sheet

学区連絡協議会長名
（地域の取り組み）

東山学区の皆様へ

各戸１部ずつ
お取りください

「地域防災力診断シート」記入のお願い

謹啓　紅葉の候、時下ますますご清祥のこととお慶び申し上げます。
平素は東山学区の諸活動にご協力とご高配を賜り、厚くお礼申し上げます。
さて、東海・東南海地震などへの警戒が叫ばれています。各ご家庭におかれましては、さまざまな備えをされているところとは存じますが、東山学区として、さらに災害に強い地域づくりを目指すために、学区ご在住の全世帯を対象として、以下のようなアンケート調査を実施することにいたしました。平常時はもとより、緊急時にも支えあい、助け合う安心・安全な東山学区を構築するため、皆様方のご協力を賜りますようよろしくお願い申し上げます。

2004 年 11 月
東山学区連絡協議会　会長　杉浦尚久

・京都大学防災研究所総合防災研究部門災害リスクマネジメント分野

１2月４（土）、５（日）、６（月）日のいずれかに組長が各戸に回収にあがります。
長宅へお持ちください。
東山学区区政協力委員会にお持ちください。

】町内会

地域防災力診断シート

近い将来、東海地震や東南海地震がおこる危険性が指摘されています。
また、愛知県は地震が起きると大きな被害が予想される地域です。
お住まいのご自宅や地域は地震に対してどのくらいの備えがあるでしょうか？

このシートはみなさんの回答を集計して地域の防災の備えを診断するものです。
質問は約 50 問あります。お答えに当たっては、できるだけご家族のかたとご相談の上、
代表の方がお答えくださるようお願いします。

まずは、ご自宅や地域の今の状況をよく思い出し、
地震に対する備えについて「十分な備えをしている」を 10 点、「全く備えていない」を０点として自己採点してみてください。

1	あなたの自宅の地震に対する備えは 10 点満点で何点ですか？	1‑2‑3‑4‑5‑6‑7‑8‑9‑10	点
2	あなたが住む地域の地震に対する備えは 10 点満点で何点ですか？	1‑2‑3‑4‑5‑6‑7‑8‑9‑10	点

では、以下の項目について当てはまる項目１つに○をつけてください。

3	震度６弱以上の地震で、自宅はどの程度の被害を受けると思いますか？	被害はないと思う 1	補修なしで住める程度の被害 2	補修が必要だが住める程度の被害 3	住めなくなるほどの被害 4
4	自宅付近の地盤のことを知っていますか？	よく知っている 1	少し知っている 2	あまり知らない 3	知らない 4
5	自宅の耐震診断をしたことがありますか？	した 1	していないが検討している 2		していない 3
6	自宅の耐震補強工事をしたことがありますか？	した 1	していないが検討している 2		していない 3
7	自宅の家具の転倒防止などをしましたか？	した 1	していないが検討している 2		していない 3
8	地域の住宅の耐震化は進んでいると思いますか？	進んでいる 1	少しは進んでいる 2	進んでいない 3	わからない 4

Self-scored
Preparedness

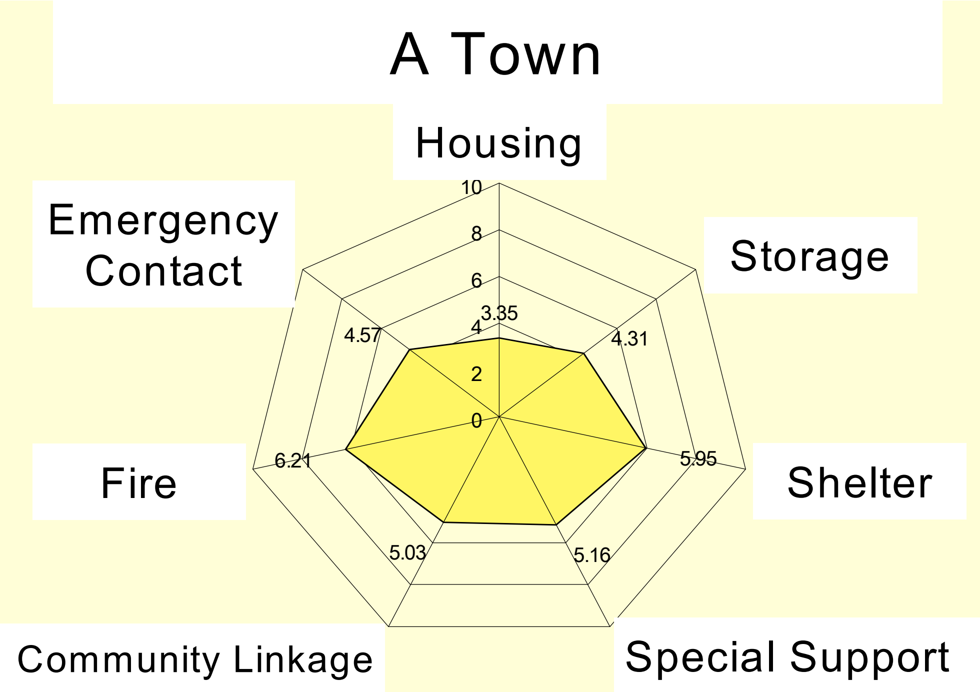
43 questions from NGO

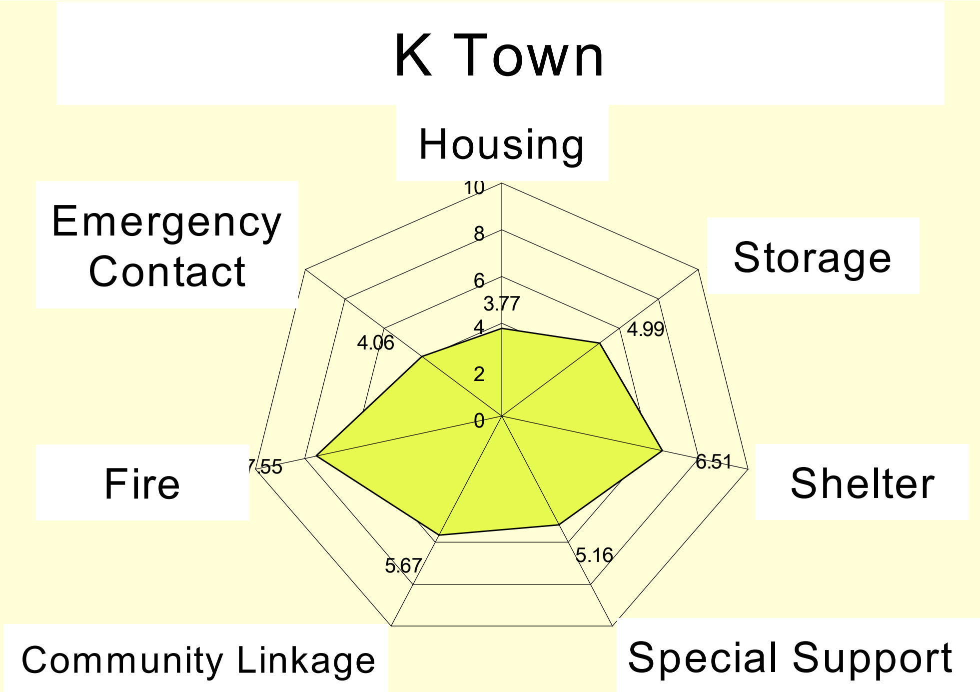
Regional Comparison (2 sample t-test)

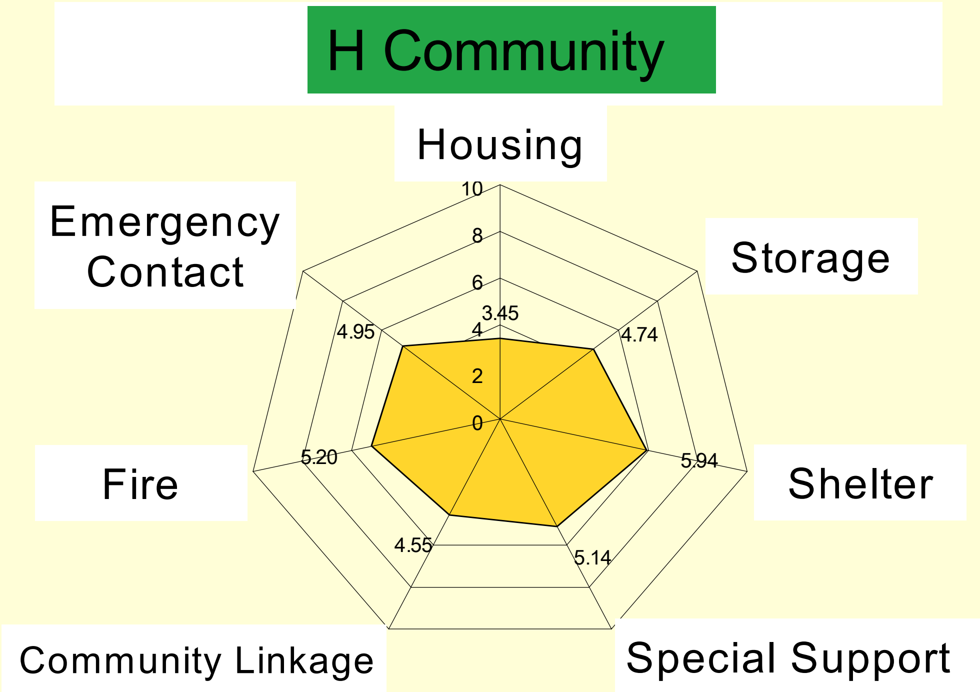
CPI	Housing	Storage	Shelter	Special Support	Community Linkage	Fire	Emergency Contact
Higashiyama	3.45	4.74	5.94	5.14	4.55	5.20	4.95
A Town	3.35	4.31	5.95	5.16	5.03	6.21	4.57
K Town	3.46	4.86	6.35	5.33	5.38	6.63	5.03

H_0 : (Avr. Higashiyama) = (Avr. Other Town)
Highlighted elements are rejected in significant level 5%) .

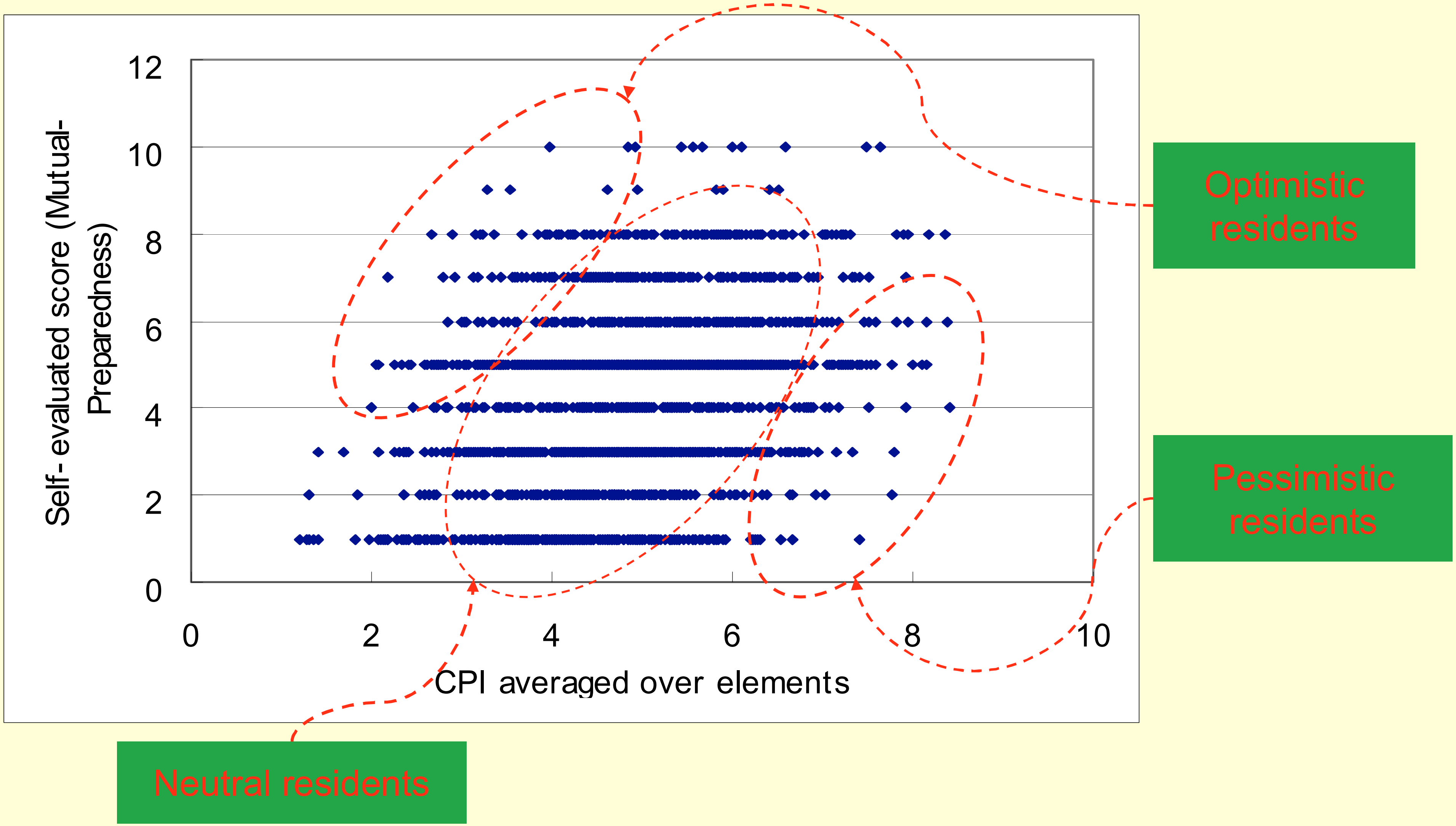
Higashiyama is significantly low score in【Community Linkage】and【Fire】


A Town
Housing
Storage
Shelter
Special Support
Community Linkage
Fire
Emergency Contact
10
8
6
4
2
0
3.35
4.31
5.95
5.16
5.03
6.21
4.57


K Town
Housing
Storage
Shelter
Special Support
Community Linkage
Fire
Emergency Contact
10
8
6
4
2
0
3.77
4.99
6.51
5.16
5.67
7.55
4.06


H Community
Housing
Storage
Shelter
Special Support
Community Linkage
Fire
Emergency Contact
10
8
6
4
2
0
3.45
4.74
5.94
5.14
4.55
5.20
4.95

Individual distribution of CPI



Prescriptive workshop (Apr. 2005)

Understanding the diagnostic survey results

List up local ideas to decrease weak points

Some of the local ideas

- <Storage> Let us know repeatedly to encourage personal storage.
- <Shelter> It is not possible for all of us to get sheltered in the school (Officially designated shelter). It's better to have an unofficial place for evacuation in our neighbourhood.
- <Shelter> We asked a neighbor church to let it open in emergency to over-80, injured handicapped as a shelter.
- <Others> We have a vague consciousness on a disaster. But it is necessary for our sense to be stimulated by posters and other printed materials to be always aware of it.
- <Others> First comes myself and my family's safety ensuring. Second comes safety for my neighbours. Community's linkage is an important factor to keep up for the purpose.

Discussions

- Citizens has been already aware of “sustainability” of disaster preparedness

- Spatial unit of disaster preparedness is 5-10 neighbouring households, not community board or other existed organization.

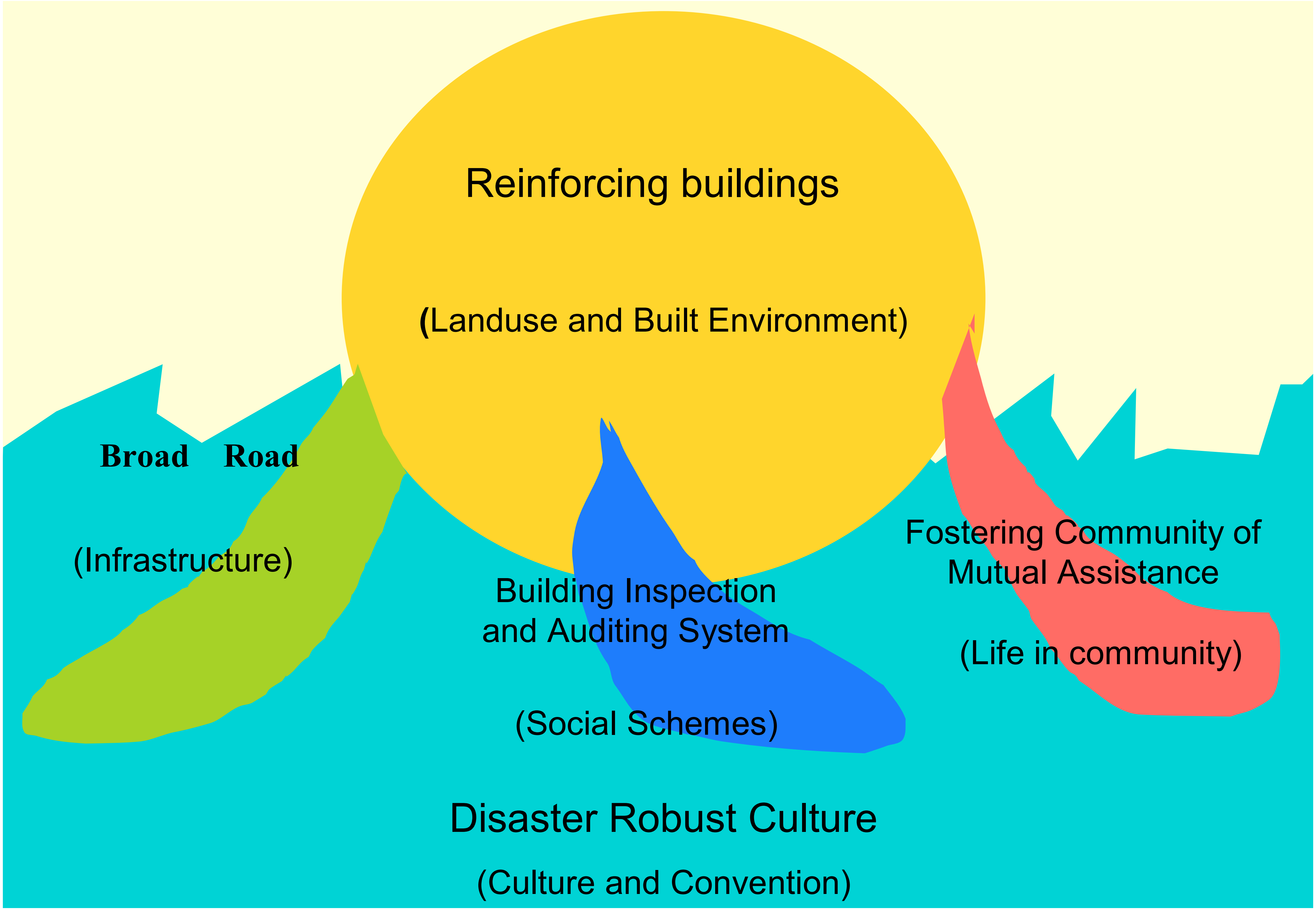
Conclusions

- Disaster preparedness in the context of
  - Sustainable community management
  - Multidisciplinary knowledge management
- Community diagnosis is introduced as its facilitating system
- Further examination is needed for
  - Plan and Action
  - Collective project learning
  - Treatment

to increase disaster preparedness

Collaborative Modeling(Community-Laymen)

- Starting with Shared Views of Status-quo
- Community Diagnosis
- Building up Evidences, Experiences and Confidences
- Fostering Coping Capacity (Plan-Do-Check-Act Cycle Repeated
- Before-During-After Disaster (Case station)


Reinforcing buildings
(Landuse and Built Environment)
Broad Road
(Infrastructure)
Building Inspection
and Auditing System
(Social Schemes)
Fostering Community of
Mutual Assistance
(Life in community)
Disaster Robust Culture
(Culture and Convention)

Fix Your Furniture to Wall or Floor

- At least in Bedroom
- Let us start Check (Status-quo) and Act!
- Plan is not enough, Do, Check and Act!
- Let experts assist, involved and mutually learn (Co-learn)
- Let other residents involved and disseminate the small and smart technology
- Let an NPO involved as catalist

We are architecting and implementing adaptive management in Research Development

More to Come in Future

Thank you!

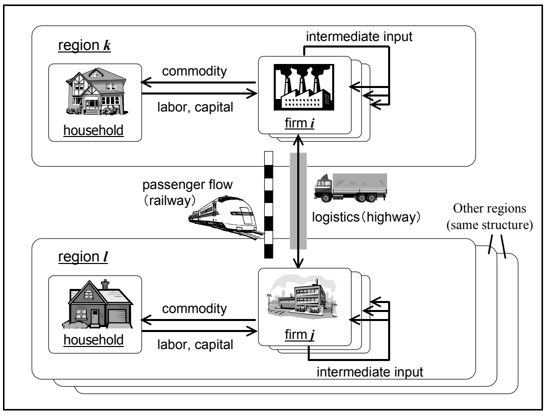


Fig. 1: Brief Picture of Regional Economy

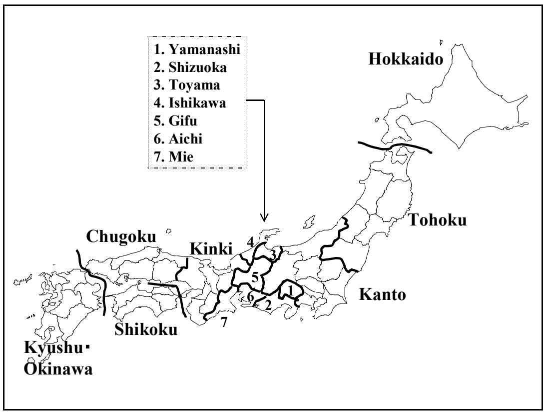


Fig. 4: 14 Zones for Loss Estimation

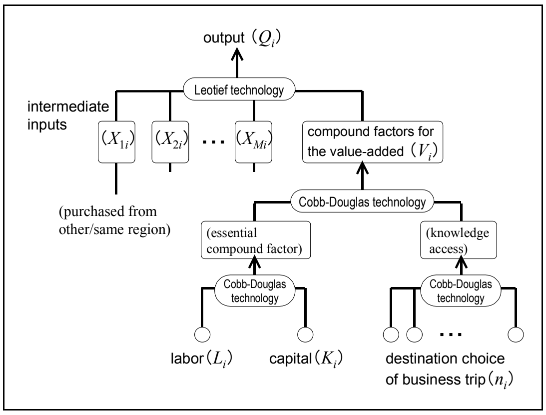


Fig. 2: Production Technology of Firms

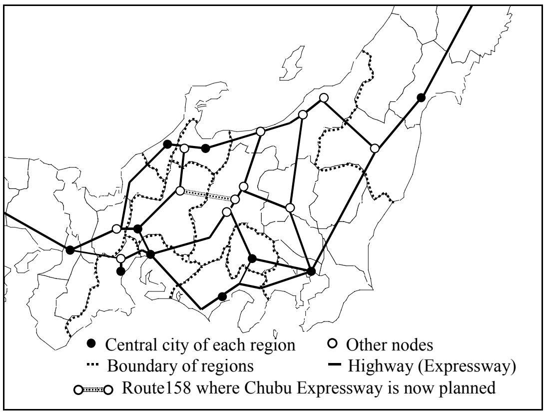


Fig. 5: Regional Highway Network

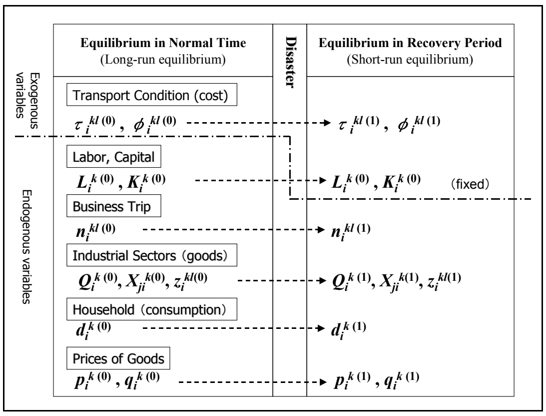


Fig. 3: Long-run/Short-run Equilibrium

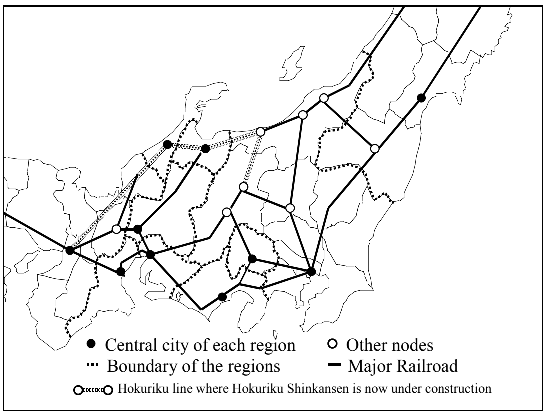


Fig. 6: Regional Railroad Network

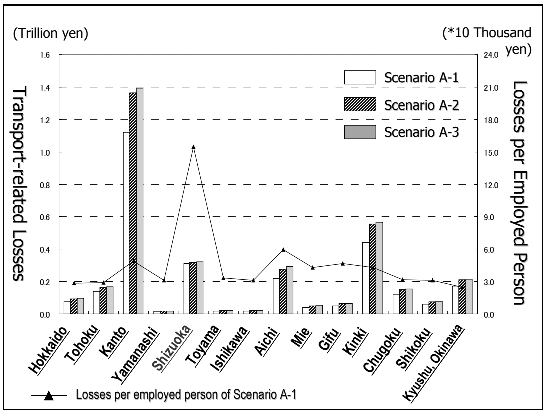


Fig. 7: The Transport-related Losses due to Transport Infrastructure Damage from the Tokai Earthquake (Accumulating Total of 3 months)

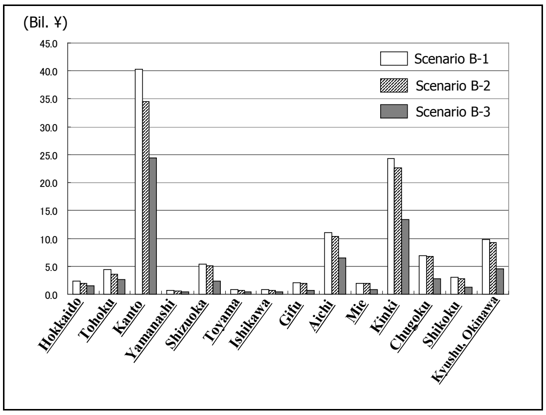


Fig. 8: The Transport-related Losses due to Traffic Restriction in the Warning of the Tokai Earthquake (per day)

A SCGE Framework of Economic Loss Assessment Caused by Transport Infrastructure Damage from Catastrophic Earthquakes

by

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Seattle, November 11-13, 2004

Abstract

This paper intends to show a process of assessing economic impacts of transport infrastructure damage from catastrophic earthquakes. A spatial computable general equilibrium (SCGE) model is employed which considers two types of inter-regional flow and transportation modes (i.e. business trip by train and commodity flow by autotruck). Next, scenario analyses for a large earthquake are conducted on condition that adjustment of labor and capital inputs is restricted in the equilibrium of the recovery period. It could then be seen how much transport-related economic losses arrive at each region through inter-industrial and inter-regional relationships of economy.

1 Introduction

Most part of Japan is exposed to the threats of natural disasters such as earthquakes and floods. The losses could be serious if catastrophic disasters hit metropolitan areas in which large population and assets are concentrated. Also, in such cases, losses would spill over into surrounding regions or whole nation.

Our daily activities are formed on transport infrastructure in terms of inter-regional trade and exchanging visits. They have increased in the last half of 20th century and, according to the white paper of transport[1)], national freight transport in 1997 became about 1.6 times as much as that of 1975 by ton kilometer, and national passenger transport became almost twice as many in the same period by man kilometer. This implies that socio-economic losses might become huge, too, if transportation service becomes unavailable in some zones. Indeed, the Great Hanshin-Awaji Earthquake (1995) and the Torrential Rain Disaster in the Tokai region (2000) showed severe impacts on transport infrastructure for both freight transport and passenger trips, as well as regional/national economy.

Traditionally damage is classified into direct and indirect effects. When a large earthquake occurs, it first hits some regions locally and causes direct losses such as human damage, production capital damage and infrastructure damage. Secondly such direct losses trigger socio-economic losses through inter-industrial and inter-regional relationships of economy. Recent findings show that such indirect effects are too big to brush off[2)]. This implies it is necessary to make countermeasures to minimizing indirect effects in addition to mitigating direct loss.

Thinking of the above background, this paper focuses on primal transportation network and aim firstly at showing a process of assessing the economic impact of transport infrastructure damage from catastrophic earthquakes. Damage to transportation network is regarded as change of inter-regional transport costs, and the effect of regional welfare level is quantified as transport-related loss, at which finally arrived at region through interdependency of economy.

Methodology of the Quantification of Economic Losses

In order to measure such losses, the following three methods might be primarily available: user disbenefit (consumer surplus), input-output (I-O) analysis and computable general equilibrium (CGE) approach. User disbenefit approach quantifies the loss at its birthplace, while the other two methods measure it at its endpoints.

There are a number of existing studies in every approach. For example, Muraki *et al*[3)] modeled a stochastic mechanism to determine an earthquake centrum and its magnitude, simulating damage pattern on transport facilities, and evaluated passengers' disruption impacts of primal railroad network of Japan. It is based on user benefit.

Meanwhile it is significant to evaluate losses at endpoints as well, since it could be measured know how moch losses finally arrive back housesold. We would then use I-O or CGE method. Moreover, if transportation network is explicitly considered in I-O or CGE model, it almost inevitably leads to multi-regional (zonal) framework. A number of studies[e.g.4),5)] has been dealing with such regional economic models and transportation in an integrated way, and applied for measuring losses due to earthquake impacts on transportation.

Unless transportation network is explicitly considered, non-spatial CGE is also promising approach to disaster impact analysis. Rose *et al*[6] some CGE applications for evaluating losses due to lifeline disruptions. In their approach, it must be emphasized that they distinguish several stages of earthquake responses along the timeframe, and that they mention the appropreate modeling approach whether, for instance, it is reasonable to think the economy could be in equilibrium in a timeframe concerned. This frame of analysis is very important in our model, too, and will be described in more details later.

Spatial Computable General Equilibrium Model

The effect of catastrophe could spill over regions and arrive at non-suffered areas, although very limited area is directly suffered. Consequently we employ CGE approach extended to multiple areas, namely a spatial computable general equilibrium (SCGE) model. SCGE requires inter-regional transport condition to link one region to another. So it is a nice tool for us to analyze how economic losses due to damaged transport infrastructure go back to both the suffered and non-suffered regions.

There are several SCGE models already developed for economic appraisal of transportation policy analysis[7], and some were applied for damage assessment of catastrophe[8].

As to transport infrastructure issues it is desirable to build a model dealing with both people and goods, since the transport-related losses from catastrophe, which are of our interest, yield due to changes of traffic condition, or transportation costs of both freight and passenger trips.

Many of SCGE studies have discussed the relationship between inter-regional commodity transport costs and regional economy, meanwhile few has considered passenger flows. Ueda *et al*[9] built a SCGE model considering inter-regional passenger trips of firms and households instead of freight transport between regions, and applied it for assessing the economic impact of catastrophe in high-speed rail network of Japan. In the meantime Bröcker[10] shows an idea to include business and private passenger travel in SCGE model in which there has been already inter-regional trade mechanism modelled.

Based on these existing study results, we build a SCGE model including both commodity flow, as transport for firm's intermediate inputs, and business trip from passenger flow, as an input factor which develops some technical knowledge through face-to-face communication.

2 The Model

2.1 Production Sector

It is assumed that a nation consists of N regions connected by transportation networks: railroads for passenger trips and highways for commodity transport, and that there are M kinds of industrial agencies in each region (Fig.1).

Each agency, or firm, aims at maximizing its profit. Firm i in region k produces commodity i by inputting the following factors: the intermediate goods j transported from region l, labor and capital inputs provided by the household in region k, and business trip input for face-to-face communication. It is assumed that the production technology has the property of constant return to scale. Fig.2 shows production technology of industrial agencies.

Maximizing the firm's profit is equivalent to the following 3-staged optimization problems.

Stage 1

$$\pi_i^k = \max_{Q_i^k, X_{ji}^k} \; p_i^k Q_i^k - \sum_{j=1}^{M} q_j^k X_{ji}^k - c_{Vi}^k(w^k, r, \tau^{k\cdot}) V_i^k \tag{1}$$

$$\text{s.t.} \quad Q_i^k = \min\left\{ \frac{X_{1i}^k}{a_{1i}^k}, \cdots \frac{X_{Mi}^k}{a_{Mi}^k}, \frac{V_i^k}{a_{Vi}^k} \right\} \tag{2}$$

Stage 2

$$c_{Vi}^k(w^k, r, \tau^{k\cdot}) V_i^k = \min_{L_i^k, K_i^k, \kappa_i^k} \; w^k L_i^k + r K_i^k + c_{Ti}^k(\tau^{k\cdot}) \kappa_i^k \tag{3}$$

$$\text{s.t.} \quad V_i^k = \alpha_{2i}^k \left\{ (L_i^k)^{\delta_{Li}^k} (K_i^k)^{\delta_{Ki}^k} \right\}^{1-\beta_i^k} (\kappa_i^k)^{\beta_i^k} \tag{4}$$

Stage 3

$$c_{Ti}^k(\tau^{k\cdot}) \kappa_i^k = \min_{n_i^{kl}} \; \sum_{l=1}^{N} \tau^{kl} n_i^{kl} \tag{5}$$

$$\text{s.t.} \quad \kappa_i^k = \alpha_{3i}^k \prod_{l=1}^{N} (n_i^{kl})^{\delta_n^{kl}} \tag{6}$$

where
π_i^k : profit of firm i,
p_i^k : producer price of commodity i,
Q_i^k : output of commodity i,
q_i^k : consumer price of commodity i,
X_{ji}^k : amount of intermediate inputs j for commodity i,
V_i^k : compound goods of input factors (labor, capital and business trip) forming value added,
c_{Vi}^k : unit cost function for V_i^k,
a_{ji}^k : input coefficient,
a_{Vi}^k : production capacity rate,
κ_i^k : knowledge obtained by business trips and face-to-face communication,
c_{Ti}^k : unit cost function for κ_i^k,
τ^{kl} : passenger transport cost for business trip from region k to l,
$\tau^{k\cdot}$: passenger transport cost for business trip from region k,
L_i^k, K_i^k : the amount of labor and capital respectively, supplied from household to firm i,
δ_{Li}^k, δ_{Ki}^k : share parameters of labor and capital inputs respectively, in firm i,
β_i^k : parameter of substitution in firm i between fundamental compound factors and knowledge,
n_i^{kl} : business trips of firm i in region k, to region l,
δ_n^{kl} : parameter of business trip on destination choice,
α_{2i}^k, α_{3i}^k : adjustment factors.
Suffix k means the variables or parameters belong to region k.

Solving (1) - (6), the following demand functions are obtained for firm i in region k.

・Demand function for business trip input

$$n_i^{kl} = \frac{\delta_n^{kl}}{\sum_{l=1}^{N} \delta_n^{kl}} \frac{\beta_i^k c_{Vi}^k(w^k, r, \tau^{k\cdot})}{\tau^{kl}} = \delta_n^{kl} \frac{\beta_i^k c_{Vi}^k}{\tau^{kl}} \tag{7}$$

N.B. $\sum_{l=1}^{N} \delta_n^{kl} = 1$

・Demand function for labor input and capital input

$$L_i^k = \frac{\delta_{Li}^k}{\delta_{Li}^k + \delta_{Ki}^k} \frac{(1-\beta_i^k) c_{Vi}^k(w^k, r, \tau^{k\cdot})}{w^k} = \delta_{Li}^k \frac{(1-\beta_i^k) c_{Vi}^k}{w^k} \tag{8}$$

$$K_i^k = \frac{\delta_{Ki}^k}{\delta_{Li}^k + \delta_{Ki}^k} \frac{(1-\beta_i^k) c_{Vi}^k(w^k, r, \tau^{k\cdot})}{r} = \delta_{Ki}^k \frac{(1-\beta_i^k) c_{Vi}^k}{r} \tag{9}$$

N.B. $\delta_{Li}^k + \delta_{Ki}^k = 1$

・Demand function for intermediate inputs

$$X_{ji}^k = a_{ji}^k Q_i^k \tag{10}$$

・Demand function for compound factor input (which composes value-added)

$$V_i^k = a_{Vi}^k Q_i^k \tag{11}$$

Production function can be described as a function of wage rate (labor price), interest and passenger transport cost:

$$c_{Vi}^k(w^k, r, \tau^{k\cdot}) = \begin{cases} (\alpha_i^k)^{-1} \left\{ \frac{\prod_{l=1}^{N} (\tau^{kl})^{\delta_n^{kl}}}{\beta_i^k} \right\}^{\beta_i^k} \left\{ \frac{(w^k)^{\delta_{Li}^k} (r)^{\delta_{Ki}^k}}{1-\beta_i^k} \right\}^{1-\beta_i^k} & \text{if } \beta_i^k \neq 0 \\ (\alpha_i^k)^{-1} (w^k)^{\delta_{Li}^k} (r)^{\delta_{Ki}^k} & \text{if } \beta_i^k = 0 \end{cases} \tag{12}$$

where $\alpha_i^k = \alpha_{2i}^k \cdot \alpha_{3i}^k$.

2.2 Household Sector

The household earns an income by supplying firms with labor and capital, and consumes commodities/services to maximize her utility. She decides how much she consumes commodities/services which are provided by firms in the region k she lives, and maximize her utility U^k under income constraint.

$$U^k(\mathbf{q}^k, y^k) = \max_{d_i^k} \left\{ \sum_{i=1}^{M} (\gamma_i^k)^{\frac{1}{\sigma}} (d_i^k)^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}} \tag{13}$$

$$\text{s.t.} \quad \sum_{i=1}^{M} q_i^k d_i^k = y^k = w^k L^k + r K^k \tag{14}$$

where
y^k : income of household,
γ_i^k : parameter,
σ : parameter of substitution,
d_i^k : the amount of consumption of commodity i,
q_i^k : consumer price of commodity i,
w : wage rate,
r : interest,

L^k, K^k : the amount of labor and capital that household possesses, respectively.
Suffix k means the variables or parameters belong to region k.

Solving (13) and (14), we obtain the following demand function of household consumption.

$$d_i^k(\mathbf{q}^k, y^k) = \frac{\gamma_i^k (q_i^k)^{1-\sigma}}{\sum_{j=1}^M \gamma_j^k (q_j^k)^{1-\sigma}} \frac{y^k}{q_i^k} \tag{15}$$

Substituting (15) into (13),

$$U^k(\mathbf{q}^k, y^k) = \left\{ \sum_{i=1}^M \gamma_i^k (q_i^k)^{1-\sigma} \right\}^{\frac{1}{\sigma-1}} y^k \ . \tag{16}$$

2.3 Inter-regional Trade

Deterministic trade theory says that inter-regional trade is specialized to either emigration or ingression, and that direction of commodity flow is one-way. In reality, however, bi-directional trade is observed. This is because commodities are actually differentiated by region or by firm, which makes difficult to deal with inter-regional trade in a deterministic way.

This paper introduces spatial price equilibrium (SPE) theory and treats inter-regional trade in a probabilistic way. Let s_i^{kl} denote a probability that industry i in region l buy goods i from region k. And we might define s_i^{kl} as

$$s_i^{kl} = \frac{Q_i^k \exp\{-\lambda_i \ p_i^k(1+\phi_i^{kl})\}}{\sum_{m=1}^N Q_i^m \exp\{-\lambda_i \ p_i^m(1+\phi_i^{ml})\}} \tag{17}$$

where
λ_i : parameter,
ϕ_i^{kl} : transport cost from region k to l, per unit commodity i.
ϕ_i^{kl} is assumed to be proportional to transit time unless transit route is changed.

The amount of commodity i carried from region k to l is s_i^{kl} times as much as total demand of region l. Therefore, using (17), we have the following equation:

$$z_i^{kl} = s_i^{kl} \left(\sum_{j=1}^M X_{ij}^l + d_i^l - IM_i^l \right) \tag{18}$$

where z_i^{kl} is the amount of commodity i transported from region k to l, and IM_i^l is the amount of commodity i imported in region l.

From a viewpoint of inter-regional commodity flow, if prices are positive, total payment of region l for a commodity i equals to the sum of sales of all possible regions, some of which will be subtracted for transport cost.

$$q_i^l \sum_k z_i^{kl} = \sum_{k=1}^N p_i^k (1+\phi_i^{kl}) z_i^{kl} \tag{19}$$

Dividing (19) by $\sum_k z_i^{kl}$, we could derive

$$\begin{aligned} q_i^l &= \frac{\sum_{k=1}^N p_i^k(1+\phi_i^{kl}) z_i^{kl}}{\sum_k z_i^{kl}} = \sum_{k=1}^N \left(\frac{z_i^{kl}}{\sum_k z_i^{kl}} \right) p_i^k (1+\phi_i^{kl}) \\ &= \sum_{k=1}^N s_i^{kl} p_i^k (1+\phi_i^{kl}) \ . \end{aligned} \tag{20}$$

The relationship of producer's and consumer's prices are also lead by (1) and (2). If a firm i in region k is competitive,

$$p_i^k Q_i^k = \sum_{j=1}^{M} q_j^k X_{ji}^k + c_{Vi}^k(w^k, r, \tau^{k\cdot}) V_{Vi}^k \tag{21}$$

since $\pi_i^k = 0$. Substituting (10) and (11) into (21),

$$p_i^k = \sum_{j=1}^{M} q_j^k \frac{X_{ji}^k}{Q_i^k} + c_{Vi}^k(w^k, r, \tau^{k\cdot}) \frac{V_i^k}{Q_i^k} = \sum_{j=1}^{M} q_j^k a_{ji}^k + c_{Vi}^k(w^k, r, \tau^{k\cdot}) a_{Vi}^k \ . \tag{22}$$

2.4 Equilibrium Condition in Normal Time

It is assuemd that the commodity market achieves equilibrium between regions with SPE, and that the labor and capital markets achieve equilibrium in each region. This is the equilibrium in normal time. And those markets are described as follows.

Labor Market and Capital Market

The balance equations of labor and capital input factors are written as follows.

$$\sum_{i=1}^{M} L_i^k = L^k \tag{23}$$

$$\sum_{i=1}^{M} K_i^k = K^k \tag{24}$$

Commodity Market

As to commodity market, the balance equations are given as follows.

$$Q_i^k - EX_i^k = \sum_{l=1}^{N} z_i^{kl}(1 + \phi_i^{kl}) \tag{25}$$

$$\sum_{k=1}^{N} z_i^{kl} = \sum_{j=1}^{M} X_{ij}^l + d_i^l - IM_i^l \tag{26}$$

where EX_i^k is the amount of commodity i exported.

(25) balances firm's supply in region k and inter-regional commodity flow from k. (26) balances inter-regional commodity flow to region l and commodity demand of l.

Markets are assumed to be perfectly competitive and in long-run equilibrium in normal time. Finally the equilibrium condition is given by a set of equations (2), (4), (6)-(12), (15), (17), (20) and (22)-(26).

2.5 Equilibrium Condition in Recovery Period

Most SCGE approach assumes long-run equilibrium scheme, or freedom of mobility for all endogenous variables. However, this assumption might not be necessarily suitable for measuring economic losses in static models. Especially, care should be attentioned to capital stock. This paper prohibits capital stock level to move between regions, even between industries located in the same region. The reason is as follows. Capital stock mobility between industries or regions implies that the economic system allows debit and credit. If so, the economic impacts would arrive back investors who might live in any regions, or even out of the nation. This would be true, to a certain extent. However, without any constraint, it might be possible to ascribe all losses to out of the suffered region ultimately. Then, lost in a maze, we would be no longer sure what we were measureing. Most of economic losses must arrive at local people. In the static framework, the amount of capital stock could drop away only when it is damaged by disaster.

This idea might be considered as a short-run equilibrium in microeconomics[11)].

Again, in our framework, equilibrium condition in recovery period is a short-run equilibrium with transport costs changed from normal time. For convenience, add suffixes $^{(0)}$ and $^{(1)}$ to variables below in order to distinguish recovery period from normal time.

With this short-run equilibrium approach, a new equilibrium could be found by solving simultaneously the set of equations where the exogenous variables $\tau^{kl(0)}$ and $\phi_i^{kl(0)}$ are replaced by $\tau^{kl(1)}$ and $\phi_i^{kl(1)}$, respectively (Fig.3).

Consequently the transport-related losses could be measured by equivalent variation (EV).

3 Numerical Study

3.1 Setup

This chapter carries out simulating the transport-related losses, by the SCGE model built in the previous chapter.

Model Size

As to industry, three sectors are assumed ($M = 3$): Agriculture, Forestry and Fishery; Mining and Manufacturing; Construction and Services.

The nation is divided into 14 zones ($N = 14$): Hokkaido, Tohoku, Kanto, Yamanashi(pref.), Shozuoka(pref.), Toyama(pref.), Ishikawa(pref.), Gifu(pref.), Aichi(pref.), Mie(pref.), Kinki, Chugoku, Shikoku and Kyushu·Okinawa (Fig.4).

Transportation Network and Transport Costs

As to transportation, we assume networks for highway (Fig.5) and railroad (Fig.6). Assuming a traffic assignment rule of the shortest path, change of transit time/travel time might be reflected on the new transport cost rate (ϕ_i^{kl}) or new τ^{kl}. This is a basic idea to connect physical damage on infrastructure with change of transport costs in our SCGE model.

Data

The benchmark data, which is regarded as the solution to the set of equations of the model in normal time, is available from inter-regional input-output table[1]. Business trip input is one

[1]Miyagi *et al*[12)] showed a framework to develop the inter-regional input-output table of Japanese 47 prefectures from the 47 intra-regional prefetural I-Os and the commodity flow survey. Or, 9 inter-regional I-O table would

feature of this model, and as to benchmark data, it could be addressed by non-household consumption expenditure (row) of the I-O table.

Two exogenous elements –freight transport cost rate ϕ_i^{kl} and passenger transport cost τ^{kl}– are prepared by using road timetable and railroad timetable, respectively.

Parameter Calibration

There are several parameters appearing in the model. Most of them can be calibrated by using benchmark data from the input-output table. A parameter of substitution σ, however, is hard to calibrate by one-shot dataset. We referred to Ichioka[13)].

3.2 Regional Economy due to Transport Infrastructure Damage from Catastrophic Earthquake

This section analyzes the economic impact of the Tokai Earthquake. According to damage anticipation to this earthquake, almost all plain area of Shizuoka prefecture is believed to have strong shakes of intensity 6+ on the richter scale[2]. Referring to this and anticipated damage to the transport infrastructure[14)], we assume transport condition scenarios in the following, in which there are several facilities damaged of To-Mei Expressway, Route 1 and some bridges of Tokaido Shinkansen (high speed railroad).

Based on the setting in the last section, the shortest path traffic assignment rule consideres detour traffic. However, it is hard to take congestion into account endogenously. Consequently we might assess the impact of transport infrastructure damage from the Tokai Earthquake with some "given" stories on traffic jam, and three scenarios are assumed as follows.

(1) Scenario A-1: new transport cost condition that can be achieved on transport infrastructure damage in Shizuoka region.

(2) Scenario A-2: a condition that, adding to scenario A-1, 10 percent congestion of Tokyo-Nagoya transport by Chuo route is taken into account. The transit time becomes longer by 10 percent than the one calculated by the shortest path traffic assignment rule. Chuo route would be the main alternative route if the east-west transportation was blocked in Shizuoka area.

(3) Scenario A-3: a condition that, adding to scenario A-2, 15 percent of intra-regional transport is considered in Aichi and Mie prefectures.

Referring to the Hanshin-Awaji Earthquake statistics, the recovery period is thought as 3 months. Fig.7 is the output of the above 3 scenarios. It shows:

(a) the impact of transport infrastructure damage spread all over the nation.

(b) the sum of regional economic losses is 2.8 (trillion JPY) on scenario A-1. Almost half of it arrives at Kanto region because of its geographical and economic scales. Also the impact for west Japan (Kinki, Chugoku, Shikoku and Kyushu · Okinawa) is not small. This implies interdependence of economy between such regions and east (Kanto region).

(c) the losses with respect to "per employed person" come back to Shizuoka area most.

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be the best alternative. We decomposite Kanto and Chubu regions of 9 inter-regional I-O, into prefectural level with intra-regional prefetural I-Os, and prepared our 14 zone table.

[2] Japanese standard.

(d) when 10 percent congestion is added to transit time by Chuo route, the losses enlarge by almost 600 (billion JPY in 3 months).

3.3 Economic Impact of the Warning on the Tokai Earthquake

This section deals with the warning announcement of the Tokai Earthquake. Japan has investigated for the past quarter century to plate-border-type earthquakes in Tokai area. And, based on the premise of earthquake prediction, the warning is announced if the committee of experts judges that crustal movement is extraordinary enough. Under the warning, there are many actions for safety taken in the regions concerned[3], most of which are restriction of daily activities. It suspends public transportation services at the closest safe places/terminals. As to private automobile, traffic is regulated on going into the concerned regions from outside, or its running speed. Consequently people living in or passing through Tokai area have to accept much inconvenience for physical security.

However, it is hard to say today that earthquake prediction has become practical art. There still remains uncertainty on occurrence of an earthquake after the warning announcement, and if it lasted for a long time, the economic losses would become serious. Who could take economic risk for the warning announcement? Unfortunately very little argument has been done so far.

Therefore, it might be worth measuring the economic impact of the warning by our SCGE framework.

The process of analysis is same as the previous one, except for one point: "recovery period" would be replaced by "the warning" or "the warning period of duration". And the transportation scenario under the warning announcement is also different. Three scenarios are assumed as follows.

(1) Scenario B-1: because of traffic (car, train) restriction in the area concerned, Hokuriku route becomes the cheapest way to move from/to Tokyo to/from Nagoya or Osaka.

(2) Scenario B-2: in addition to B-1, Hokuriku Shinkansen (high speed railroad) is supposed to be in service. Therefore passenger transport costs is less than that of B-1.

(3) Scenario B-3: in addition to B-2, Chubu Expressway is assumed to be in service, which makes freight transport costs less expensive.

The result can be seen in Fig.8. It shows the effects of transport costs change spread over regions, especially metropolitan area. The transport-related losses are calculated as about 110 (billion JPY/day), 100, 62 for scenario B-1, B-2, B-3, respectively. This implies that development of transportation network contributes a lot to mitigation in the warning announcement, or that, inversely, the impact of both To-Mei and Chuo routes shutting down seems too serious.

[3] Almost 260 municipalities are designated in the real world, but this model assumes 4 prefectures -Yamanashi, Shizuoka, Aichi and Mie- as the concerned area. Because of scale problem, the model assumption does not correspond perfectly to the reality.

3.4 Summary of This Study

The results of the above two analyses are compared in this section to infer from the viewpoint of risk management.

First, the results of scenario A-1 and B-1 are compared. The former scenario assumes the occurrence of the Tokai Earthquake, and that To-Mei route is damaged. The latter, on the other hand, assumes transportation scenario under the warning announcement, and that both To-Mei and Chuo routes are shutting down. Therefore, roughly speaking, the difference between two cases is whether or not Chuo route is travelable. And the effect of Chuo route in service when To-Mei is damaged turns out about 80 (billion JPY/day), which means the significance of Chuo route, even if we take errors from several assumptions into consideration.

Our SCGE model does not treat traffic jam endogenously. Thus, secondly, in order to see how much the losses might enlarge due to congestion, we made a scenario that Chuo route as major detour is jammed. This is the comparison of scenario A-2 to A-1. The result implies that almost 6.7 (billion JPY/day) may come out because of congestion. It amounts approximately to 20 percent or more of the transport-related losses on scenario A-1. Therefore it might be said that we need policies to cut down congestion as the next step to keeping alternative routes.

Thirdly, comparison of scenario B-2 or B-3 to B-1 could be understood as the effect of transportation network development. The results imply that a project would be meaningful if it contributed to network redundancy.

4 Concluding Remarks

In this paper, we first showed a process to assess the economic impact due to traffic infrastructure damage from catastrophic earthquakes. The spatial computable general equilibrium model employed in this paper has the following properties:

- Two types of transportation network is treated in the model: highways for freight transports and railroads for passenger trips.
- A short-run equilibrium is assumed that labor and capital inputs are fixed in the recovery period.

Simulation was next conducted. As a result, we found that the transport-related losses are spread over regions for both the earthquake scenario and the earthquake warning scenario, and that the total amount of losses could be seriously large. In addition, it would be said that, from 3.2, the losses due to congestion could be too much to ignore, and that, from 3.3, some high-speed transport projects could contribute a lot to mitigation.

Also, economic loss assessments are compared between two primary scenarios related to the Tokai Earthquake: the economic impact of transport infrastructure damage and the one in the warning announcement. From the result, we infer that it would be important to keep a primal east-west transport available in emergency.

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